NASA Student Launch

Centennial Challenge MAV Project

2015-2016 CDR

January 15, 2015

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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 will be pursuing a career in the aerospace industry after graduation, working with Raytheon Missile Systems.

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) CDR 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)	30.13
Loaded mass (lb)	37.88
Motor selection	CTI 3660-L1720-WT-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 37.88 lbs. In order to safely launch the vehicle and provide a margin of error for mass assumptions of various components, a CTI 3660-L1720-WT-P solid Ammonium Perchlorate motor was chose. Exact details for size, weight, and motor selection are outlined further in Section 5.

Recovery

The recovery system consists of several components that include a custom built 20.89 ft. diameter polyconical parachute, four 5/16 inch quick links, one ball bearing swivel, reefing ring system, and shock cord. The parachute design was verified through a successful sub-scale launch. Testing was accomplished for the electronics of the reefing system. One test in particular, the black powder ejection charge test, mitigated the concern of a pe-mature main. Calculations shown below in Table 2 and Table 3 to ensure the launch vehicle will land at a safe kinetic energy.

Section of rocket	**Area (ft^2)**	**Diameter (ft)**	**Velocity (ft/s)**
Reefed (Drogue)	9	3.39	60.74
De-Reefed (Main)	342.86	20.89	11.76

Table 2: Reefed and de-reefed characteristics.

Section of Rocket	Mass (lbs)	KE (ft-lb_f)
Nose Cone	6.20	60
Rest of Rocket	28.37	60

Table 3: Mass and kinetic energy of individual sections of rocket.

Payload: 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	CDR

Vehicle Properties	
Total Length (in)	108
Diameter (in)	6.11
Gross Lift Off Weight (lb)	37.88
Airframe Material	Carbon Fiber
Fin Material	Fiberglass
Drag	Drag coefficient: 0.34

Motor Properties	
Motor Manufacturer(s)	Cesaroni
Motor Designation(s)	L1720-WT
Max/Average Thrust (lb)	437/398
Total Impulse (lbf-sec)	822.8
Mass (before, after burn)	7.36/3.49
Liftoff Thrust (lb)	425.73

Stability Analysis	
Center of Pressure (in from nose)	81.32
Center of Gravity (in from nose)	62.81
Static Stability Margin	3.09
Thrust-to-Weight Ratio	10.51
Rail Size (in)/ Length (in)	96
Rail Exit Velocity (ft/s)	59.9

Ascent Analysis		
Maximum Velocity (ft/s)	659	
Maximum Mach Number	0.59	
Maximum Acceleration (ft/s^2)	350	
Target Apogee (1st Stage if Multiple Stages)	5277	
Stable Velocity (ft/s)	50	
Distance to Stable Velocity (ft)	4.25	

Recovery System Properties				
Reefed Parachute				
Manufacturer/Model	Polyconical - custom made			
Size	9 ft^2			
Altitude at Deployment (ft)	Apogee			
Velocity at Deployment (ft/s)	0			
Terminal Velocity (ft/s)	60.74			
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	342 ft^2			
Altitude at Deployment (ft)	800			
Velocity at Deployment (ft/s)	60.74			
Terminal Velocity (ft/s)	11.76			
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
	60	60		

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)	5.4

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	CDR

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	CDR

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

7) Changes since PDR

Vehicle

The launch vehicle has undergone only major changes since PDR. This has been to increase the motor diameter from a 54mm motor to a 75mm motor. This choice was made in order to facilitate growth in vehicle weight due to manufacturing.

During preliminary designs, weights of the recovery system were underestimated, essentially eliminating all planned ballast and manufacturing weight growth. This was deemed unacceptable and thus a higher impulse motor was necessary. In order to select a higher impulse motor, the motor tube diameter was increased. The team settled upon a CTI 3660-L1720-WT-P. This motor selection will provide ample room for growth during manufacturing as well as any unplanned or unforeseen growth in weight of the recovery electronics and hardware.

Recovery

The original design of the reefing ring posed several issues with transitioning the parachute from a drogue to main state. The first concern that raised issues was the tangling of the shroud lines before de-reefing occurs. If tangling got too severe the opening force of the inflation of the main wouldn't be strong enough to push the reefing ring downward. With this realization, the configuration of shroud line rings allowed for a claw type actuation

The second concern was our redundant system of a tender descender because if the primary ejection pin were to be successful, a pulling force would occur from the electric match that would be connected to the tender descender. To mitigate this problem, a disconnect device was implemented to allow power to be armed to the stratologgerCF.

AGSE

The primary change that has been made to the AGSE is with regards to the ignition station. The original plan to 3D print the belts required machinery that has been down for several weeks. The design was changed to avoid using this specific machine. Additionally further detailing was completed on the payload capture device including motor mounts, feedback device mounting, and power transmission details. The sub-frame also saw improvements including addition of a launch platform rest to relieve load from the vehicle actuation system while in a horizontal orientation.

Project Plan

The project plan is very much in line with where it was a PDR. 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.

8) PDR Feedback

Numbered below are the questions and concerns that were provided on River City Rocketry's PDR feedback form. In order to make the answers to the questions easily accessible, they have been consolidated to this section. However, some of the questions were addressed in length, so the section of the report where the concern is addressed is linked here.

1. How did you calculate the stability margin with the transition unit in your rocket?

The Barroman equations were utilized to calculate the stability margin of the rocket as shown in Table 1.

$$L_N := 30\ in \quad X_p := 76\ in \quad X_B := 96\ in$$

$$d_r := 4\ in \quad L_T := 12\ in \quad N := 3 \quad X_R := 7\ in$$

$$L_F := 7.5\ in \quad C_{NN} := 2$$

$$d_f := 6\ in \quad R := 2\ in \quad C_R := 10\ in$$

$$d := 6\ in \quad C_T := 5\ in \quad S := 6\ in$$

$$X_N := \frac{2}{3} \cdot L_N$$

$$X_T := X_p + \frac{L_T}{3} \left(1 + \frac{1 - \frac{d_f}{d_r}}{1 - \left(\frac{d_f}{d_r} \right)^2} \right)$$

$$C_{NT} := 2 \cdot \left(\frac{d_r}{d} \right)^2 - \left(\frac{d_f}{d} \right)^2$$

$$C_{NF} := \left(1 + \frac{R}{S+R} \right) \left(\frac{4 \cdot N \cdot \left(\frac{S}{d} \right)^2}{1 + \sqrt{1 + \left(\frac{2 \cdot L_F}{C_R + C_T} \right)^2}} \right)$$

$$X_F := X_B + \frac{X_R \cdot (C_R + 2 \cdot C_T)}{3 \cdot (C_R + C_T)} + \frac{1}{6} \cdot \left((C_R + C_T) - \frac{C_R \cdot C_T}{C_R + C_T} \right)$$

$$CP := \frac{C_{NN} \cdot X_N + C_{NT} \cdot X_T + C_{NF} \cdot X_F}{C_{NN} + C_{NT} + C_{NF}} = 81.314\ in$$

Figure 1: Stability margin calculations for transition.

These calculations build off of the equations that are outlined in applicable formulas from Section 5, Technical Design: Vehicle.

2. Can you elaborate on the reefing system?

See Section 6, Technical Design: Recovery, for a detailed description of the system. The reefing system has become significantly more defined since PDR. Both electrical and mechanical details are located in this section.

3. Will the ring chafe the lines?

No. Subscale testing has been completed with a reefing ring. Through an extensive series of tests, there are still no signs of chafing. Additionally, the ring is made out of ABS and has rounded edges, reducing the risk of chafing.

4. Is there a line running from the ring to the chute?

Yes, the top of the reefing ring will be attached to the top of the parachute.

5. How does the transition section affect airflow over the fins?

The fins have been sized up enough from a standard rocket that they see an appropriate amount of airflow to ensure a stable flight.

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 2: 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 3: River City Rocketry cage.

FirstBuild

Figure 4: 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 5: 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 newly designed website:

- Keep public up to date on the project with project updates.
- Maintain a historical archive of team documents.
- Inform educators of available educational outreach programs.
- Allow educators to request events.
- Provide a bank of articles, pictures, and videos from the team.
- Link to social media outlets.
- Ability to request for a media event.
- Team member pictures and bios.
- Alumni bios.
- Connect with team members over LinkedIn.

- Accessible interest form for potential team members.
- Recognition of team sponsors.

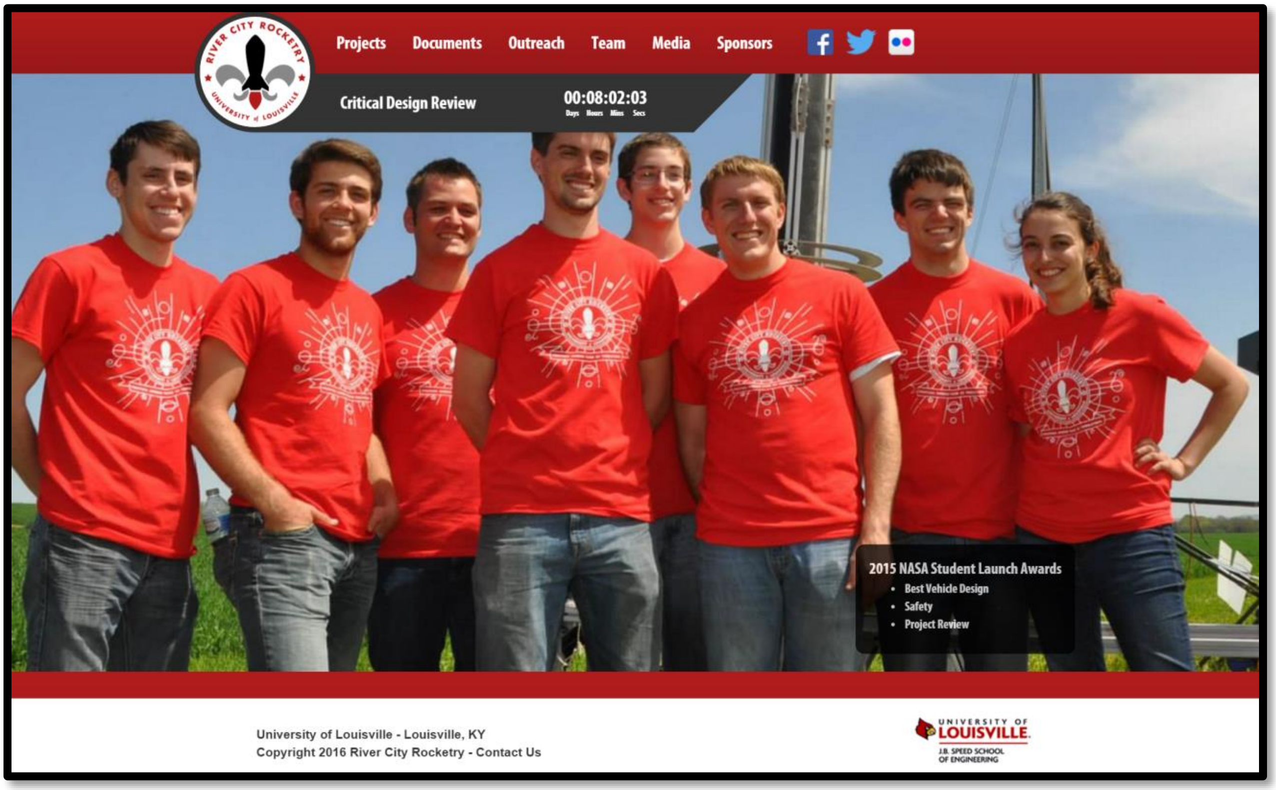


Figure 6: RiverCityRocketry.org home page.

In addition to being able to view the website on a computer, the active mobile site makes it easily accessible for any viewers on mobile devices. 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

1) 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 6 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 4.

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 4: 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 5.

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 5: 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 6. 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 6: 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 due to the fact that all systems have not been tested. While preliminary testing has been completed for some systems and analysis has been completed, the risk level will not be reduced until the full scale system has been built and tested. Justification and mitigation techniques are listed in the assessment for each hazard regarding why it is as low as it is. This may include analysis, safety precautions, and/or testing. In the event that any physical tests have been completed, the test report will be referenced in the assessment.

Lab and Machine Shop Risk Assessment

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus labs. The hazards assessed in Table 100 are risks present from working with machinery, tools, and chemicals in the lab.

AGSE Launch Platform Risk Assessment

The hazards outlined in Table 101 are risks linked to the launch platform 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 Table 102 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 Table 103 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.

Sub Frame Risk Assessment

The hazards outlined in Table 104 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 Table 105 discuss the risks associated with the payload capture device. The payload capture device interfaces with multiple systems, making it prone to hazards.

Stability and Propulsion Risk Assessment

The hazards outlined in Table 108 are risks associated with stability and propulsion. The team has multiple members of the team with certifications supporting that they can safely handle motors and design stable rockets of the size that the team will be working with. This area is considered a low risk for the team, but it is still important to address any potential problems that the team may face throughout the project.

Recovery Risk Assessment

The hazards outlined in Table 109 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 in Table 110 are risks that could potentially be encountered throughout the assembly phase and during launch preparation.

Environmental Hazards to Rocket Risk Assessment

The hazards outlined in Table 111 are risks from the environment that could affect the rocket or a component of the rocket. Several of these hazards resulted in a moderate risk level and will remain that way for the remainder of the season. These hazards are the exception for needing to achieve a low risk level. This is because several of these hazards are out of the team's control, such as the weather. In the case that environmental hazards present themselves on launch day, putting the team at a moderate risk, the launch will be delayed until a low risk level can be achieved. The hazards that the team can control will be mitigated to attain a low risk level.

Hazards to Environment Risk Assessment

The hazards outlined in Table 112 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.

2) NAR/TRA Procedures

NAR Safety Code

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

NAR Code	Compliance
1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only Darryl, the team mentor, and certified team members are permitted to handle the rocket motors.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The Mechanical Engineering team will be responsible for selecting the appropriate materials for construction of the rocket.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Motors will be purchased through Wildman Rocketry and will only be handled by certified members of the team who are responsible for understanding how to properly store and handle the motors. Additionally there is a portion on motor safety in the team lab manual that the entire team is responsible for understanding.

4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its batter and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before	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 any allowable wind condition, the rocket will be able to attain a rail exit velocity that will ensure a stable flight. The AGSE will

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

11. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The Recovery team will be responsible for designing and constructing a safe recovery system for the rocket. A safety checklist will be used on launch day to ensure that all critical steps in preparing and packing the recovery system and all necessary components into the rocket are completed.
12. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

Table 7: NAR safety code compliance.

3) 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

If a violation to the contract occurs, 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.

4) 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.

5) 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.

6) 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

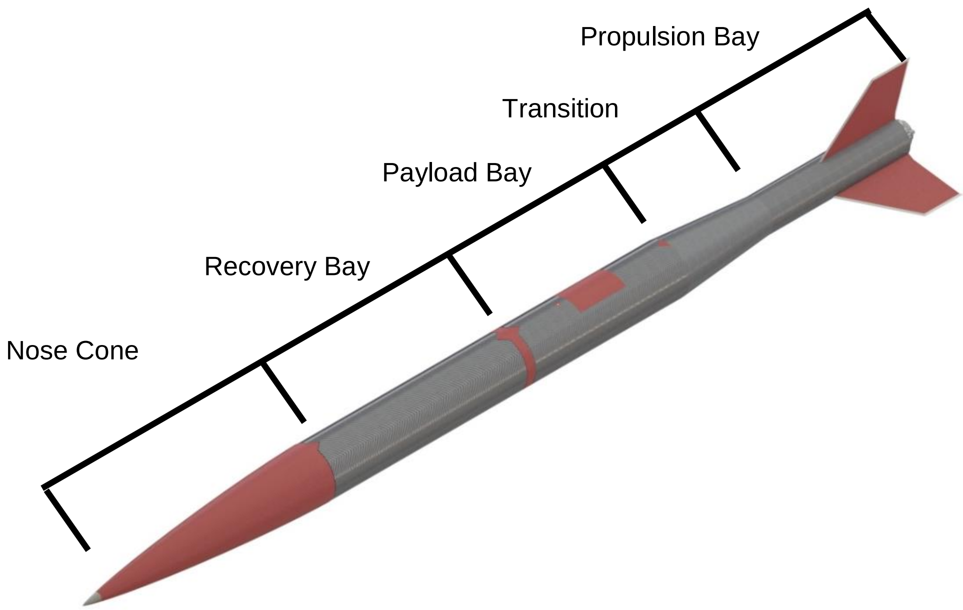


Figure 7: Full scale launch vehicle.

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 revamping 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 7 shows the basic layout of all launch vehicle subsections: nose cone bay, recovery bay, payload bay, transition, and propulsion bay.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

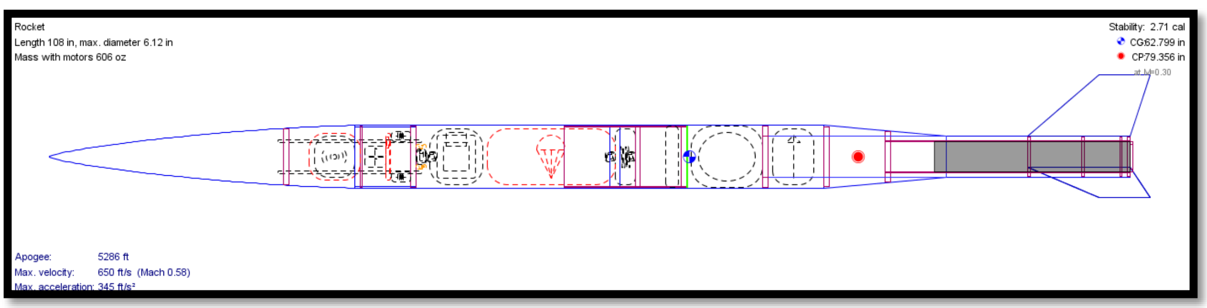


Figure 8: OpenRocket simulation of 2015-2016 launch vehicle.

Figure 8 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: Technical Design: Recovery.

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. The tip and root chord lengths are 5 inches and 10 inches respectively, providing a stability margin of 2.75 with the motor installed. This value was calculated using the Barrowman equations outlined in the applicable formulae section above and compared to the value provided by OpenRocket. 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 while retaining sufficient stability during the duration of the flight.

Airframe

The launch vehicle airframe will be constructed from 6.0 inch diameter filament wound carbon fiber airframe, a 6.0 inch to 4.0 inch filament wound carbon fiber transition, and 4.0 inch diameter filament wound carbon fiber airframe. Using a 4-axis X-winder composite winder, 6k carbon fiber tow will be wound to obtain a maximum wall thickness of 0.055 inches. Because the airframe will be 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. Additional wraps may be required to obtain desired structural properties, thus resulting in planned manufacturing weight growth.

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-2A 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 8.

Glenmarc's G5000 Epoxy	
Tensile strength	7,600 psi
Compression strength	14,800 psi
Shore "D" Hardness	85
Elongation at break %	6.30%

Table 8: G500 epoxy material properties.

Nose Cone Design

The Von Karman Nosecone, seen in Figure 9, was chosen due to its performance and efficiency at subsonic speeds.

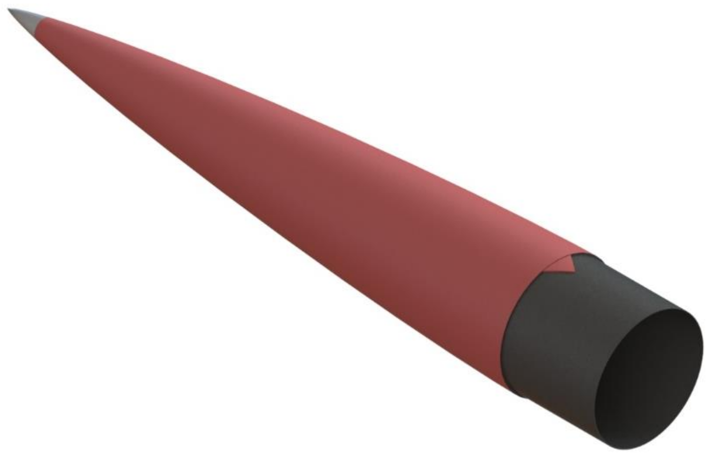


Figure 9: Von Karman nosecone.

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.

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 606 oz. was selected. Current predictions for the weight of the launch vehicle prior to ballast are 496 oz., allowing for a growth of 110 oz. in overall weight of the launch vehicle. This allows for the addition of expected manufacturing weight of 48 oz. 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 606 oz.

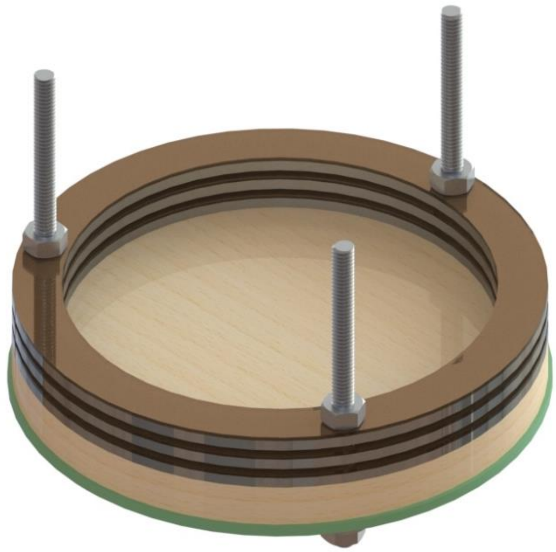


Figure 10: Rendered image of the payload bay ballast system.

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-2A threaded rod

Figure 11 shows the detailed drawing for the weighted rings to be used in the ballast system.

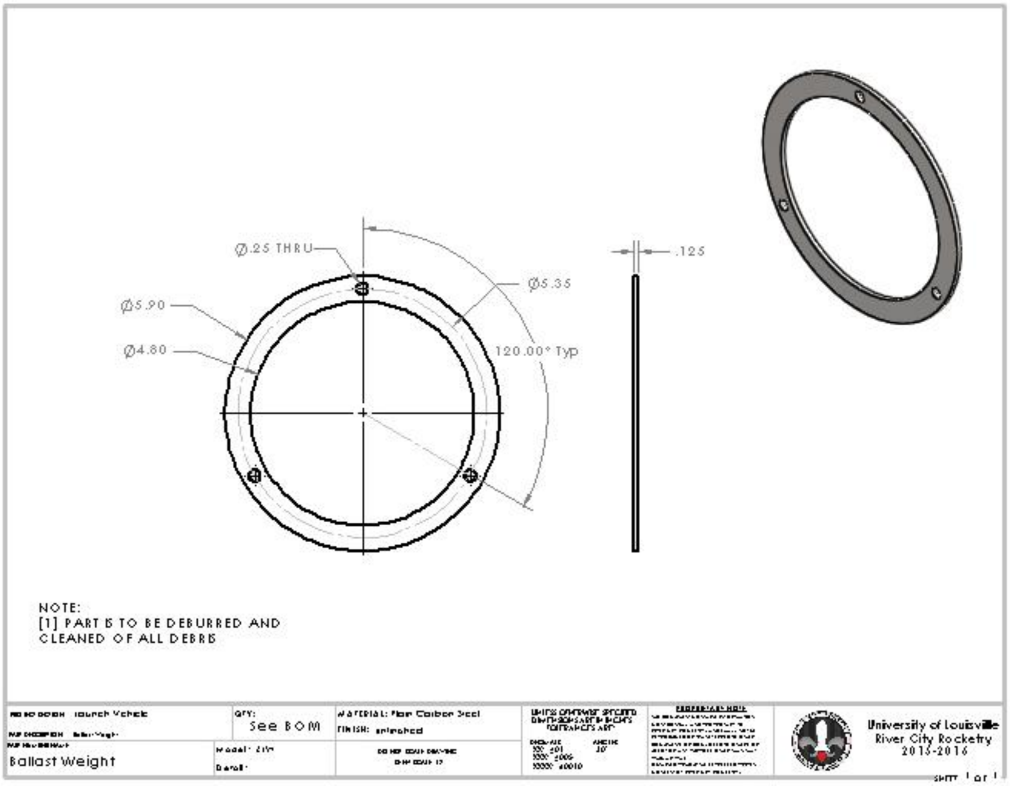


Figure 11: Detailed drawing of ballast weighted ring.

Figure **12** shows the detailed drawing of silicone rubber ballast spacer and dampener.

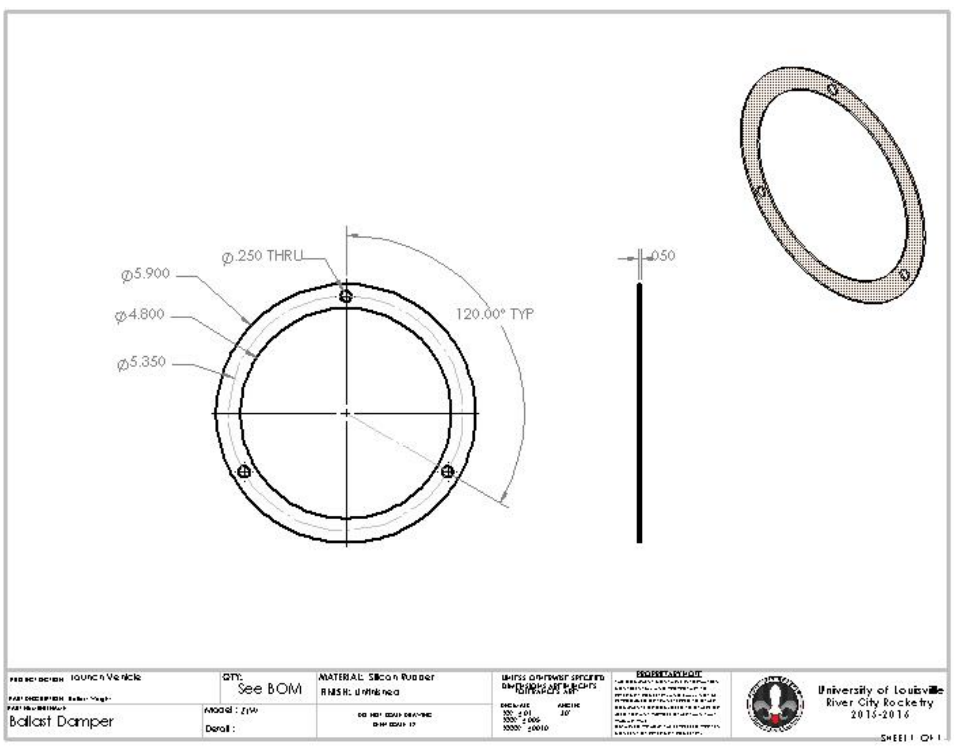


Figure 12: Detailed drawing of ballast spacer/dampener.

The inclusion of the ballast spacer/damper was to reduce any and all vibrations that may 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 606 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 9: 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 606 oz.

Propulsion Bay Design

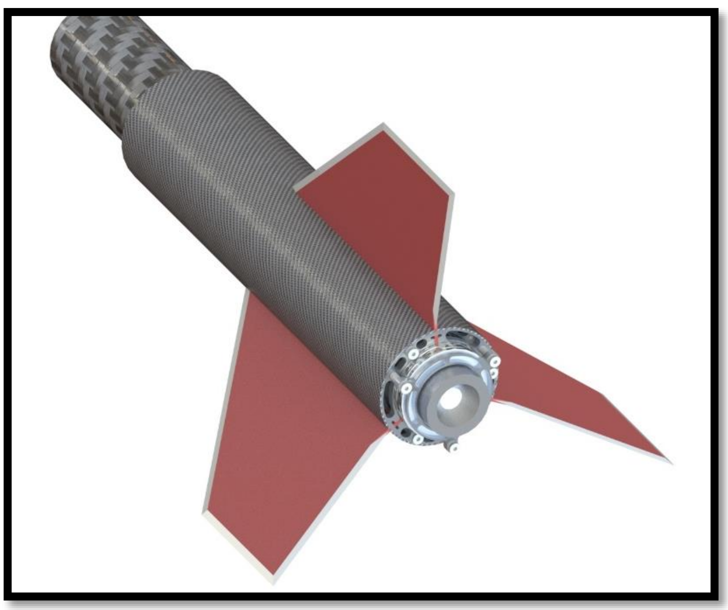


Figure 13: Propulsion bay assembly.

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 4.0 inch diameter filament wound carbon fiber tubing. The fin slots shall 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.

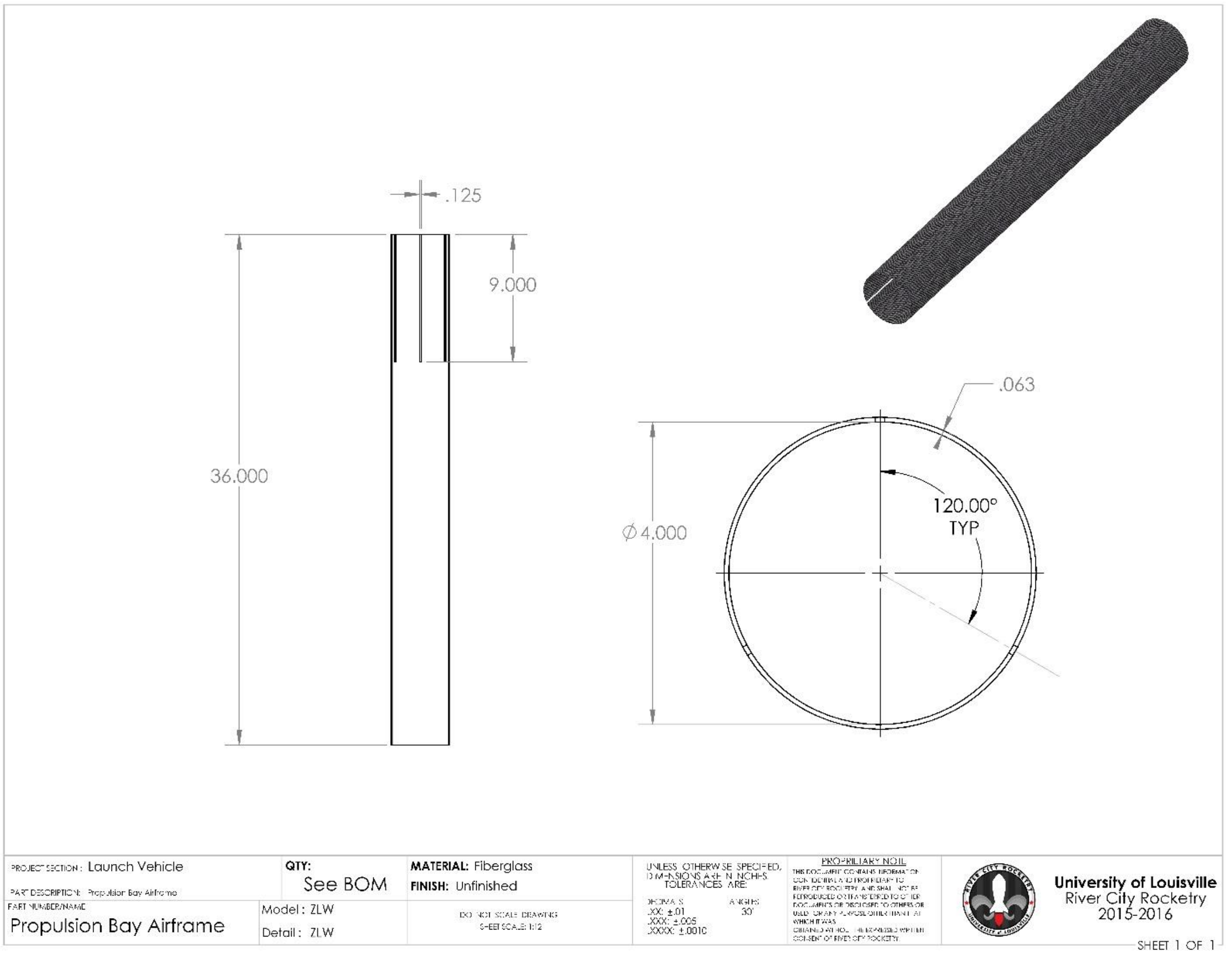


Figure 14: Detailed drawing of propulsion bay airframe

Motor Tube

The motor tube will be constructed from 3.0 inch diameter filament wound carbon fiber tubing. The motor tube will be cut to a length of 24 inches, allowing for motor tube to exceed the motor casing by 4.75 inches.

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, resulting 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.

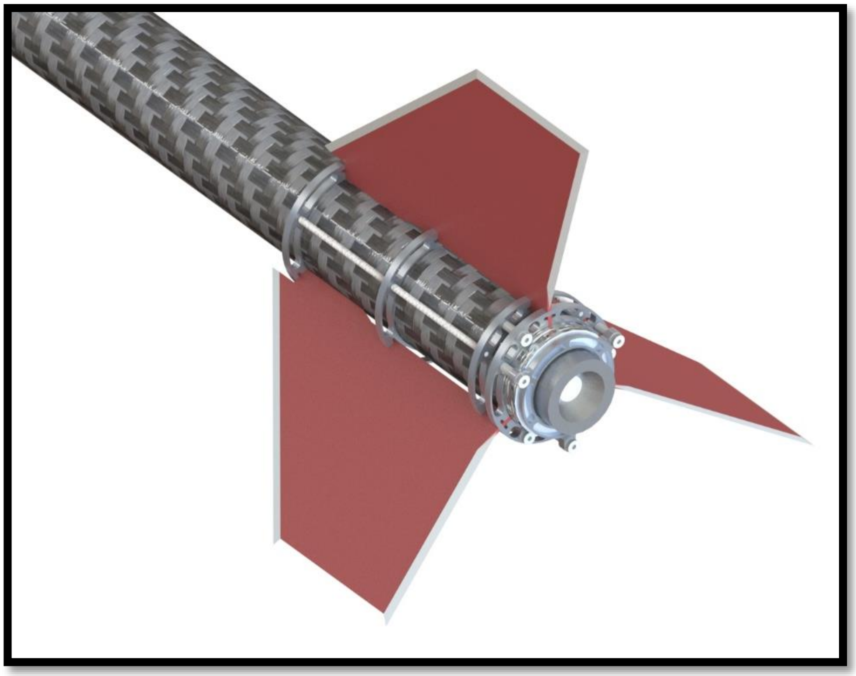


Figure 15: Removable fin system assembly.

Figure 15 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 two the mid and fore centering rings during powered ascent.

The fin retainer will mount to the aft centering ring via three #10-32 UNF-3A 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 1 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 16.

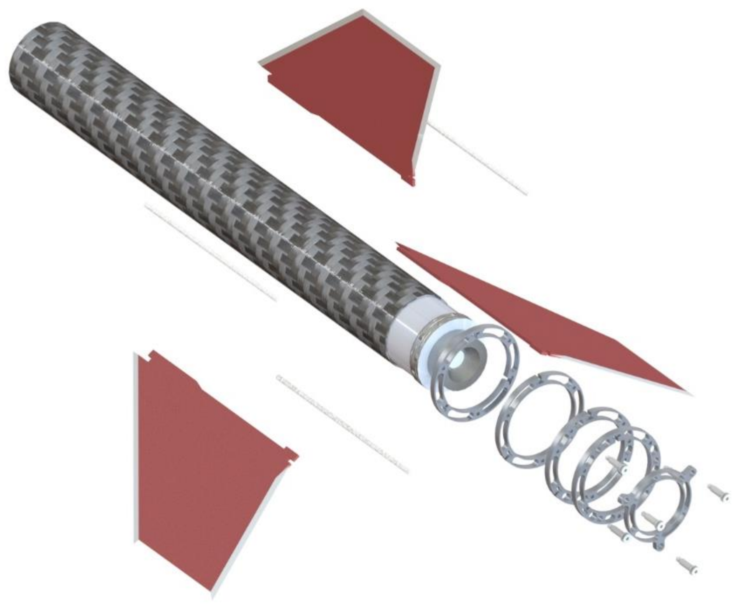


Figure 16: Exploded view of propulsion bay assembly.

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.

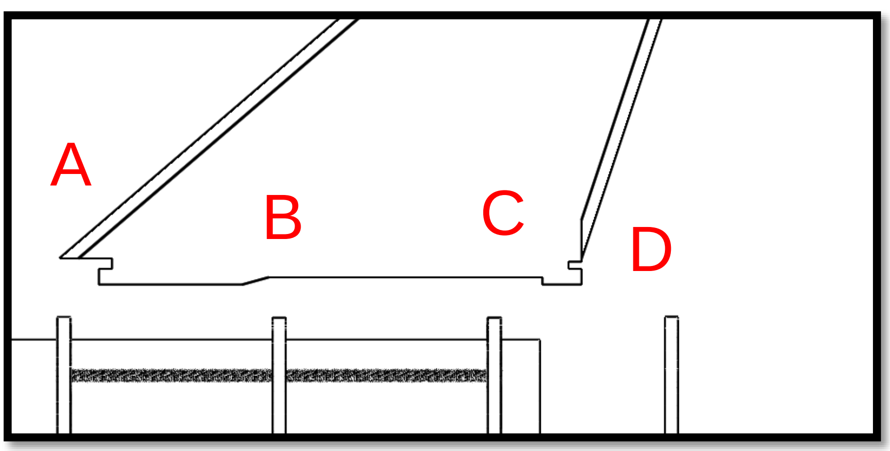


Figure 17: Highlight of 4 contact points of removable fin system.

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 as illustrated below Figure 18.

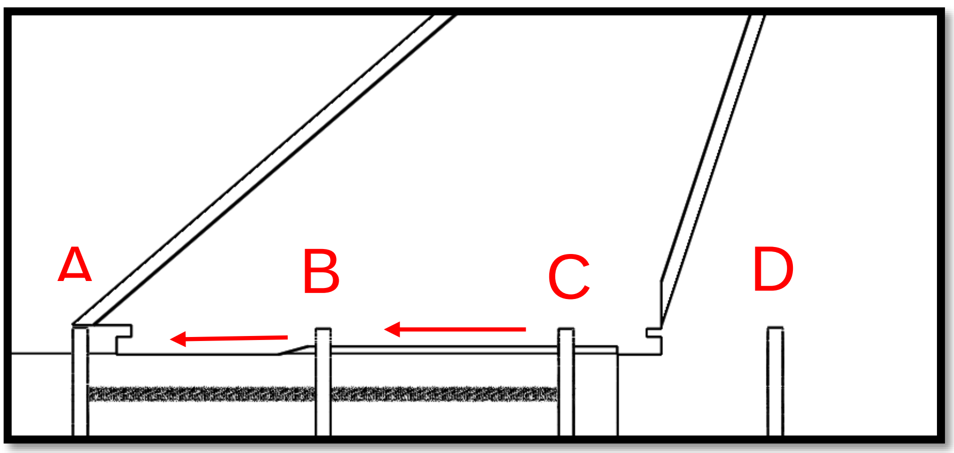


Figure 18: Fin installation step 2.

The fin retainer is then assembled unto the rear fin tab and attached via the threaded fasteners. This is illustrated bellow in Figure 19. Once installed, the threaded fastener will hold the fin retainer rigidly in place, thus fully containing the fins for launch.

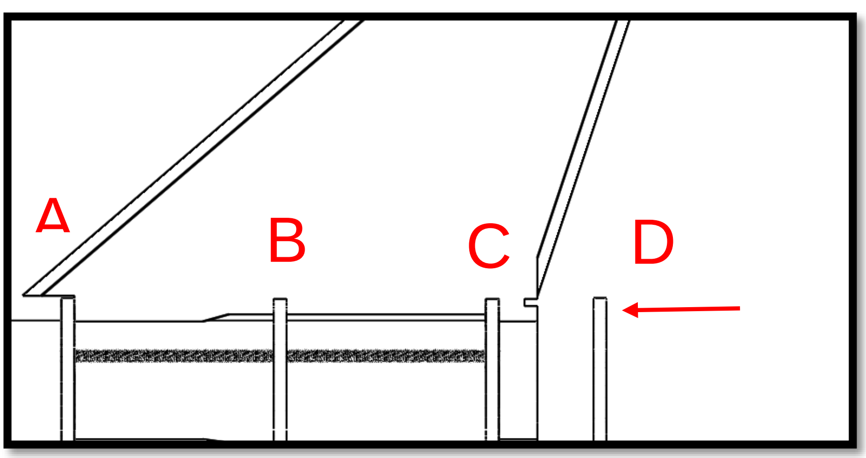


Figure 19: Fin retainer installation.

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 fin and centering ring, creating a single, ridged body. To reduce overall weight of the centering rings, each ring was subject to a design study and optimization. Figure 20 , below, shows a rendering of the fore centering ring.

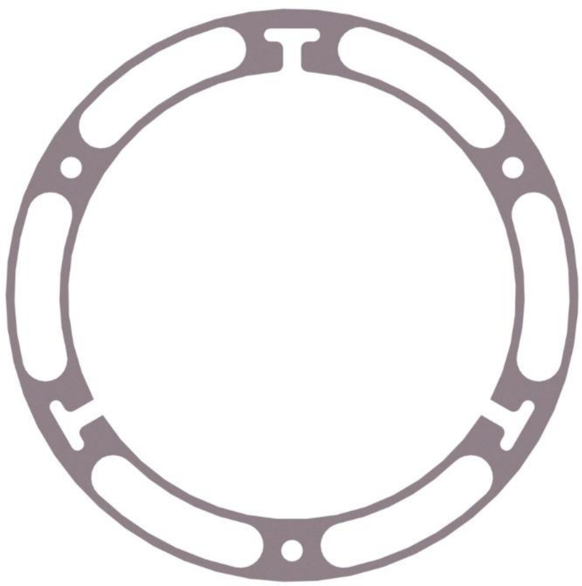


Figure 20: Front view of fore centering ring.

The fore centering ring has through slots for the insertion of the fins. Each slot is spaced 120^{o} radial, to equally space the launch vehicle fins. A detailed drawing of the fore centering ring is show in Figure 21 below.

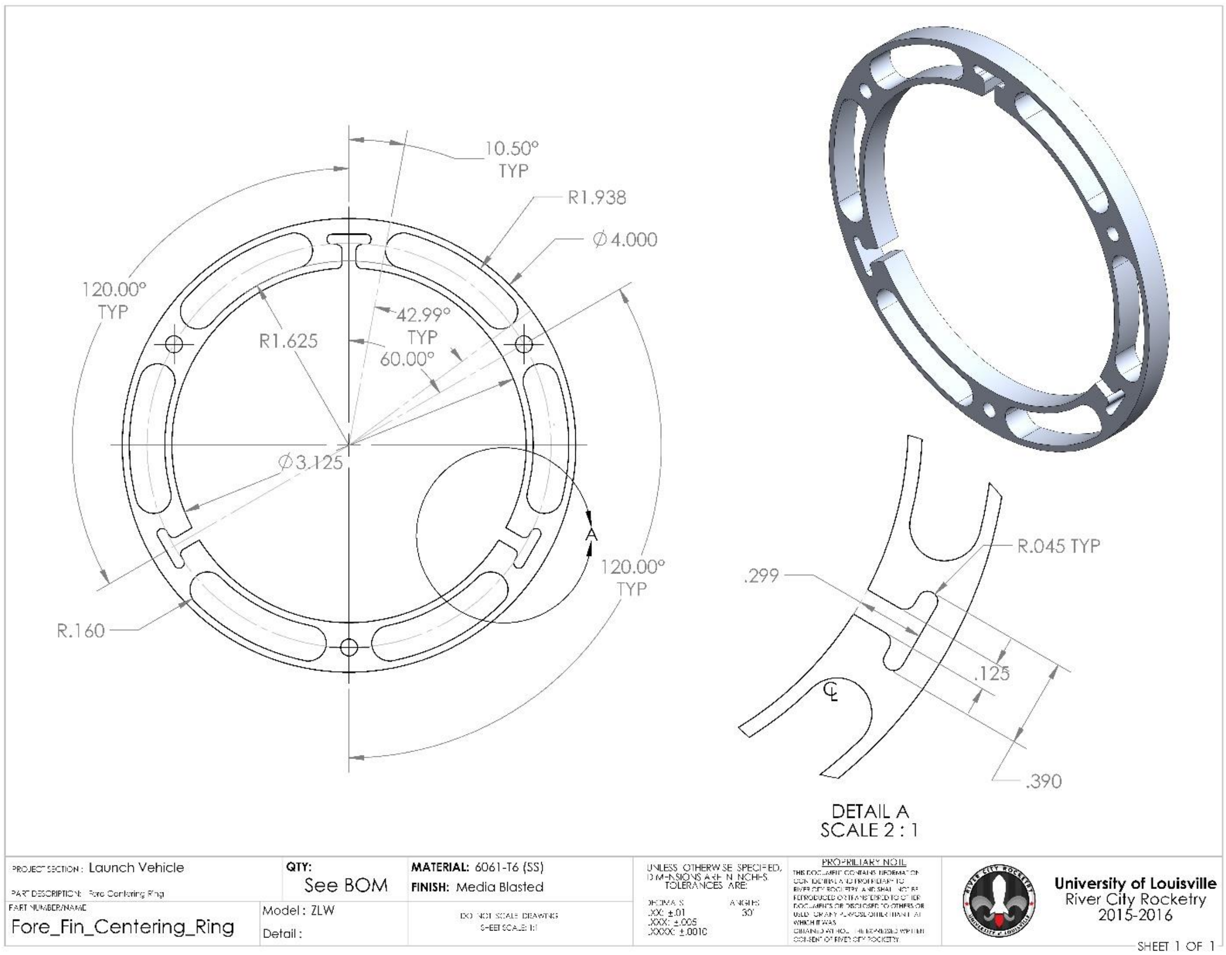


Figure 21: Detailed drawing of fore centering ring.

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 with the following parameters:

Component	Load applied	% of Motor force
Fore centering ring	649 N	33%
Mid centering ring	649 N	33%
Aft centering ring	1947 N	100%

Table 10: FEA parameters.

With the parameters outlined above, the fins were optimized to have an isolated factor of safety greater than 2.0. A sample displacement plot generated from the FEA static model is shown below in Figure 22.

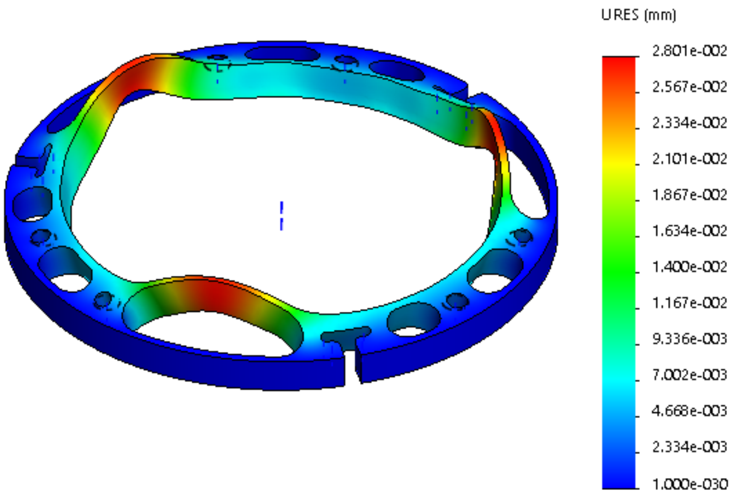


Figure 22: Finite element analysis displacement plot.

The design optimization yielded the following parameters for each centering ring:

	Maximum stress	**Maximum displacement**	**Minimum factor of safety**
Fore centering ring	2.944×10^7 N/m^2	0.010 mm	9.34
Mid centering ring	2.385×10^7 N/m^2	0.009 mm	11.15
Aft centering ring	6.858×10^7 N/m^2	0.028 mm	4.01

Table 11: 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. Although the Factor of Safety is significantly higher than the chosen optimization value, the current design was deemed acceptable to in both weight and strength characteristics.

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 23 shows a detailed drawing of the motor retainer.

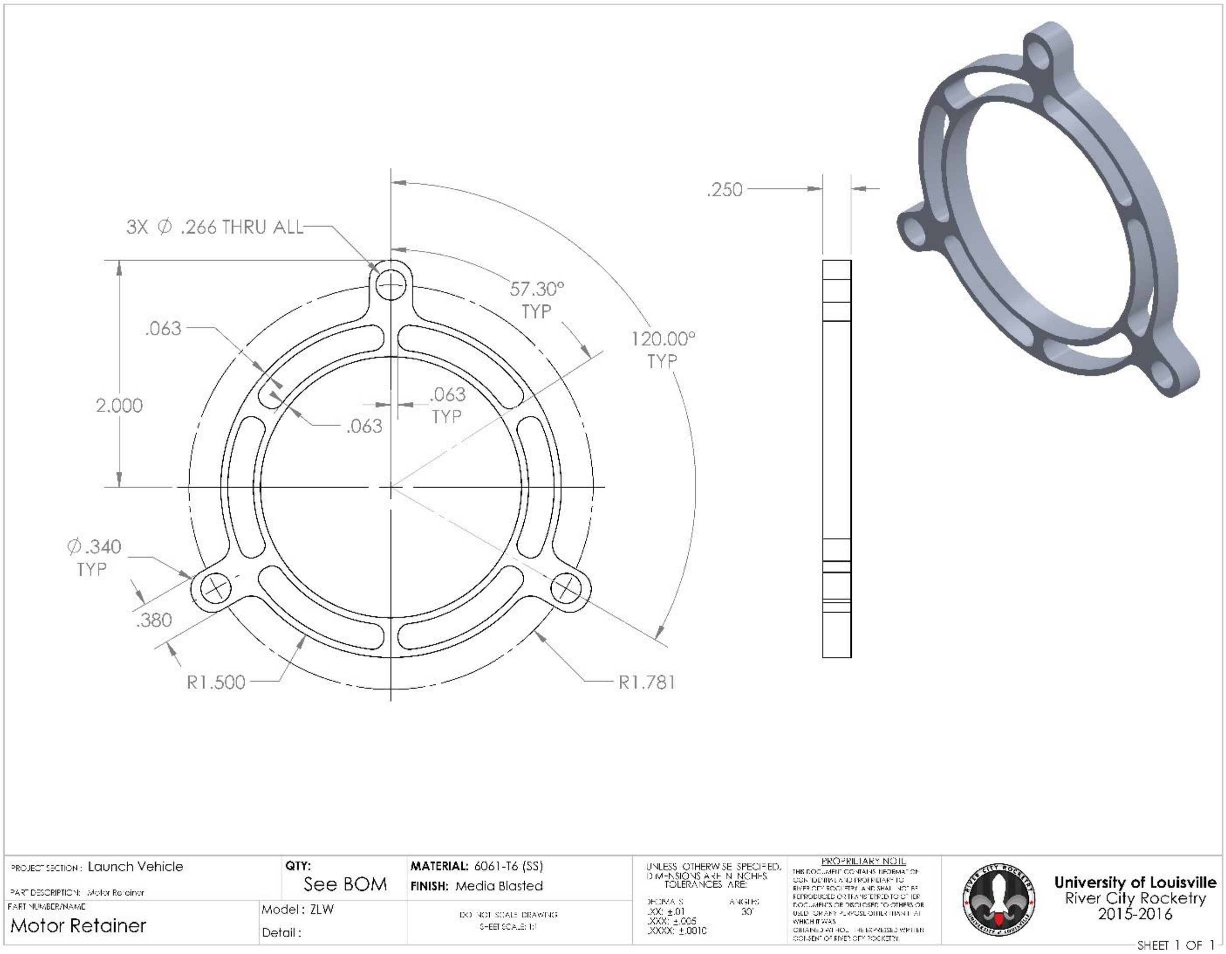


Figure 23: Detailed drawing of motor retainer.

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 1 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 24 shows a detailed drawing of the launch vehicle fins.

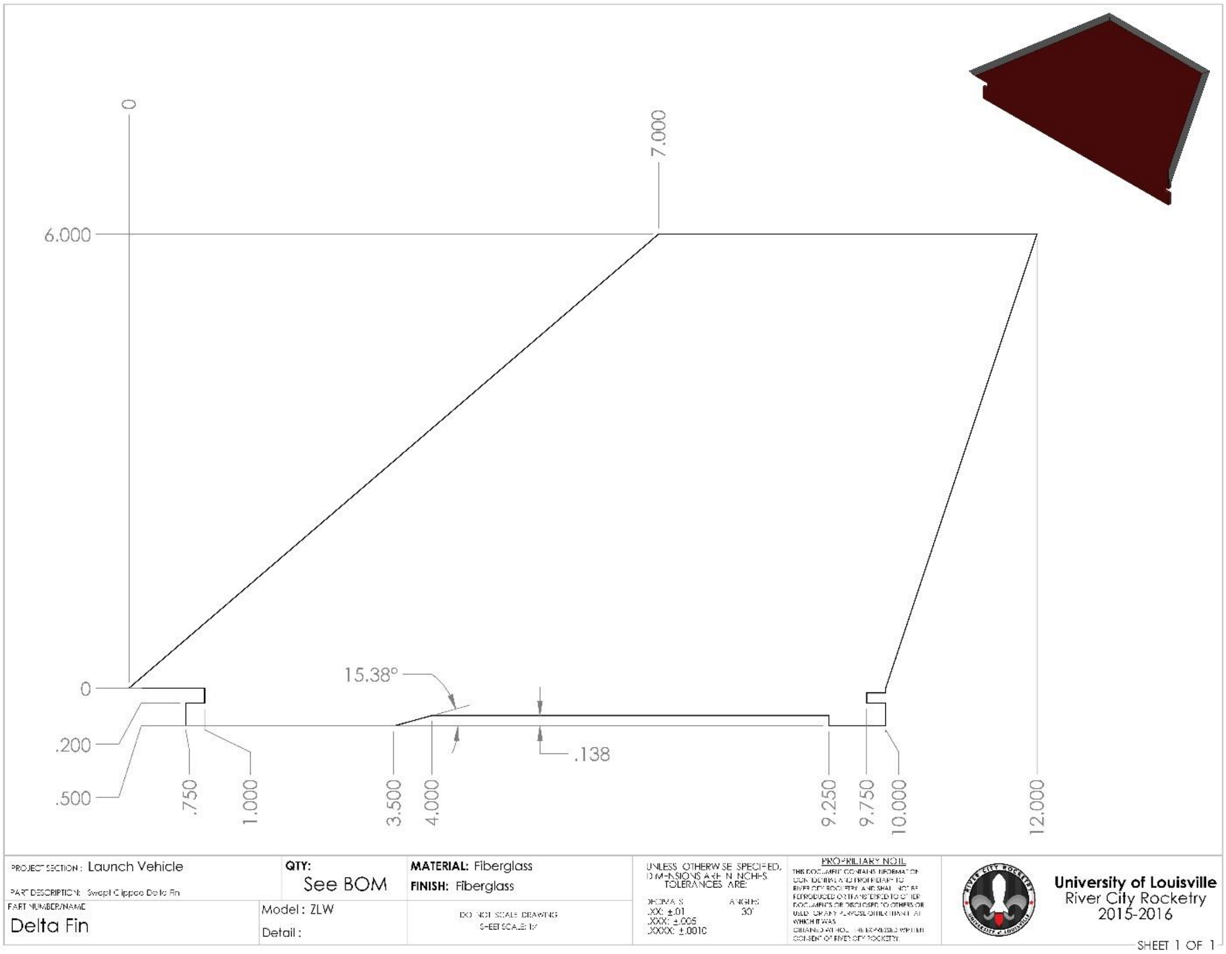


Figure 24: Detailed drawing of launch vehicle fins.

Table 12, 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 12: Component material of propulsion bay.

Subscale Testing Plan

In order to test the design and aerodynamic characteristics of the launch vehicle, a one half scale model was constructed. To facilitate a standard dual deployment recovery configuration, the cache containment bay featured in the full scale model was replaced with an altimeter bay and drogue parachute bay. Additionally, recovery bay sizes were adjusted to allow adequate room for all recovery equipment. The final subscale launch configuration is shown in Figure 25 below.

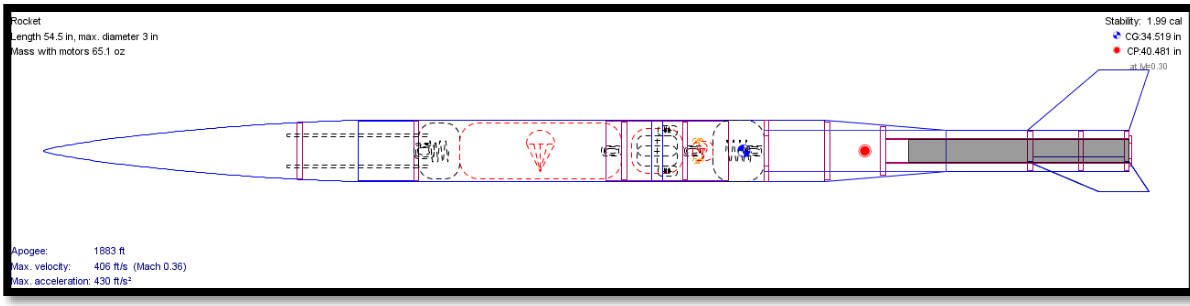


Figure 25: Subscale launch vehicle configuration.

Extensive effort was made to keep launch characteristic of the subscale model similar to the full scale vehicle to ensure adequate vehicle design testing. A comparison of the full scale and subscale flight characteristics are shown in **Table 13** below.

Property	Subscale	Full scale	Comparison (% difference)
Center of Gravity: Length (%)	63.33	58.15	8.53
Center of Pressure: Length (%)	74.28	75.31	1.38
Rail Exit Velocity (ft/s)	79.5	62.3	24.26
Max. Acceleration (ft/s^2)	456	652	35.38
Max. Velocity	405	346	15.71

Table 13: Comparison of vehicle launch characteristics.

The similarity of launch vehicle characteristics shown in Table 13 verified that the overall vehicle design is adequate for a safe launch as well as an acceptable scale test.

Subscale Flight Test Results

Due to the size of the subscale launch vehicle, only the overall vehicle characteristics and parachute design were able to be tested. Although the reefing parachute system was tested, it was not used during the subscale flight due to the size required to adequately test the system. The results of the reefing parachute system are discussed in their entirety in the Recovery section, Technical Design: Recovery.

The rocket was launched to an altitude of 1359 feet with the main parachute deploying at 700 feet. At 500 feet, a secondary, redundant altimeter was set to fire a black powder ejection charge to prevent recovery ejection failure. The results from the onboard primary and secondary altimeter are included in Figure 26 and Figure 27 below.

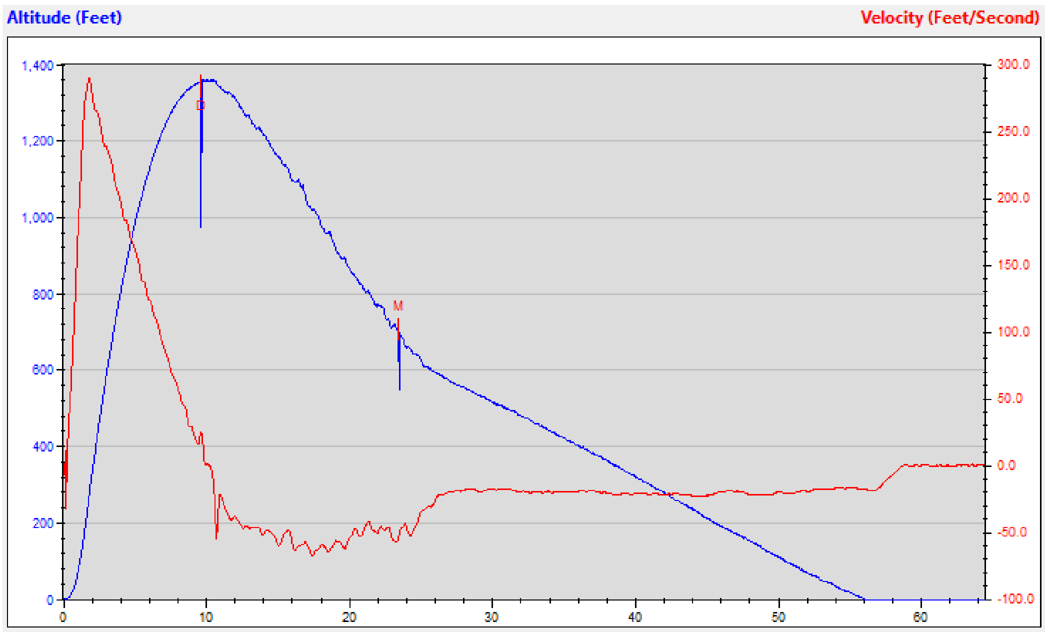


Figure 26: Primary altimeter flight results.

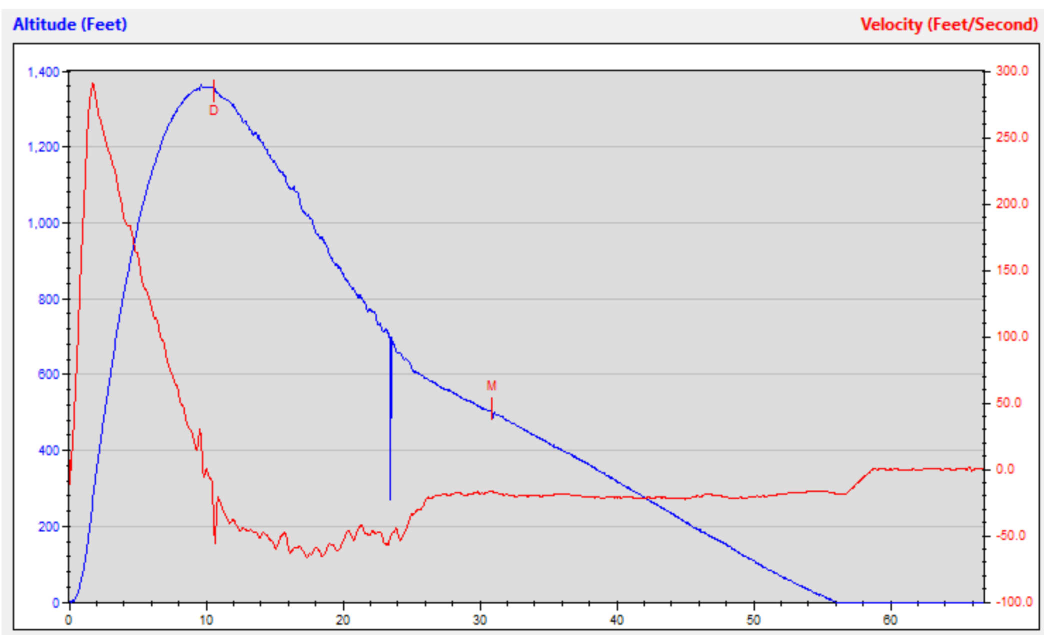


Figure 27: Secondary altimeter flight results.

The simulated flight of the subscale model predicted an altitude of 1883 feet using launch day weather characteristics. A comparison of the altitude prediction from the simulation to the actual recorded the team produced an error of 26.4%. After further analysis, it was found that the surface finish and weights of internal components were not adequately accounted for in the simulation, resulting in poor model accuracy.

The two primary lessons were learned from the subscale launch; proper sizing of the ejection charges, and the necessity of ground testing. Both primary and secondary charges were ground tested in order to assure proper separation during recovery. Miscalculations in the charge sized caused the vehicle to not separate when fired. Without proper ground testing, the vehicle would not have separated during flight and thus would have resulted in a failed recovery and failed flight.

For more detail of the subscale test setup and criterion, see Test Plan: (Subscale Launch Vehicle).

Preflight Testing

In order ensure the success of the launch vehicle, each applicable subsection shall be tested independently before being integrated into the completed assembly. The following subsections shall be tested:

1. Payload bay door actuation
2. Breakaway connector release force
3. Black powder ejection charge sizing
4. Airframe structural integrity

Payload Bay Door Actuation

The actuation of the payload door is integral to the automatization of the AGSE and vehicle assembly. In order to ensure the success of the payload door section, testing shall be performed. The testing shall verify that the payload bay door is able to actuate to the closed position, forming a near seamless body in conjunction with the payload bay airframe. In order to be deemed successful, the payload door shall be able to actuate into the closed position five sequential times. After each test, the door shall be reset to allow the actuation to occur a following time.

Breakaway Connector Release Force

The breakaway connection is required in order to connect the payload bay of the launch vehicle to the AGSE master controller. While no minimum or maximum separation force has been determined, the separation force must be greater than the downward force of the connector, while being low enough to successfully separate during actuation of the launch vehicle into launch configuration. The expected separation force due to the magnetic attraction between the N52 neodymium magnets is 1.09 lb_f. This force shall be verified using a digital force gauge upon manufacture of the connector. The connector shall also be tested within AGSE to verify that the force is sufficient to remain connected during payload bay actuation while allowing the connection to release upon actuation of the AGSE.

Black Powder Ejection Charge Sizing

Ejection charge sizing is paramount to the successful recovery of the launch vehicle. Similarly to subscale testing, the full scale launch vehicle shall undergo ejection charge ground testing to verify separation occurs as expected. This specific charge testing is outlined in Test Plan: (Subscale Ejection Charge Testing)

Airframe Structural Integrity

Due to the nature of custom manufactured airframe, the structural integrity is unknown. In order to classify the launch vehicle as structurally sound, structural compression testing of the airframe shall be performed. A control group of both fiberglass and phenolic tubing shall be used. The results of the custom wound tubing shall be compared with that of the control groups. To quantify the testing as successful, the compression yield strength shall be greater than that of the phenolic tubing. Additionally, the tubing shall poses a factor of safety of 10.0 or greater when compared to the thrust of the launch vehicle motor selected. This will provide sufficient strength to the launch vehicle while remaining similar in nature to the factor of safety of the fore centering ring of 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-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: 37.88 lbs
- Stability Margin: 3.01 caliber (From tip: CG - 62.80 inches, CP – 81.32 inches)

Figure 28, below, shows the design of the full scale launch vehicle.

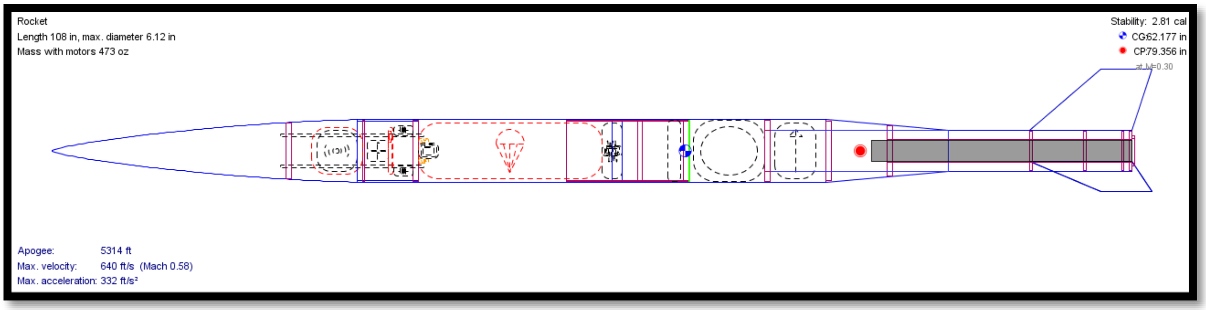


Figure 28: OpenRocket simulation of full scale launch vehicle design.

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 14 below, lists the weights of each section of the launch vehicle.

Section of launch vehicle	Length of section (in)	Mass (lbs)
Nose cone	30	6.20
Recovery bay	26	7.89
Payload bay	20	11.54
Transition	12	0.98
Propulsion bay	20	3.93
Motor	N/A	7.38
	Total mass	**37.9**

Table 14: 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 23% growth in launch vehicle weight due to additional fasteners, epoxy joints, and miscalculated component masses. The team has deemed that 23% growth is an acceptable margin.

Motor Selection

The full scale launch vehicle will utilize a Cesaroni L1720-WT solid Ammonium Perchlorate rocket motor. Based on the familiarity with motors from this manufacturer, Cesaroni was the sole choice for motor selection. Cesaroni motors are known for their ease of use, reliability, and performance characteristics. A detailed thrust curve of the L1720-WT's thrust versus time is shown below in Figure 29.

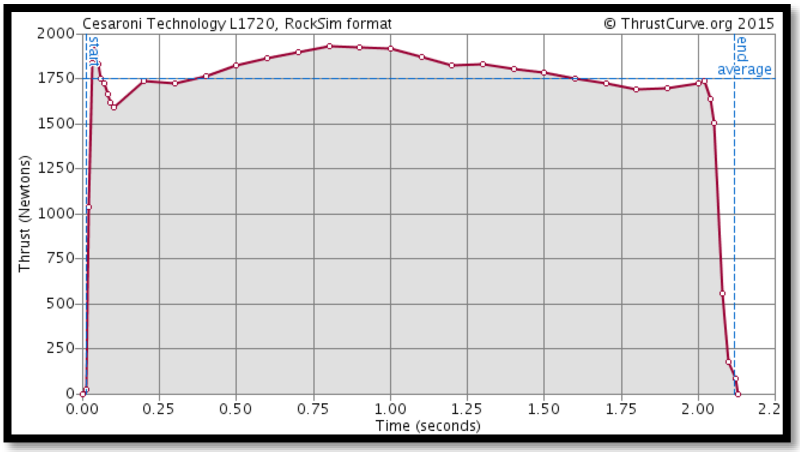


Figure 29: Thrust curve of CTI L1720-WT

The motor was chosen to allow the launch vehicle to reach a simulated apogee of 6533 feet without ballast. By installing ballast weight and induced manufacturing weight, the launch vehicle apogee can be dialed to exactly 5280 feet. Table 15 lists the simulated vehicle information and motor details as a justification for the motor selection.

Thrust-to-weight ratio	10.51
Rail exit velocity	62.3 ft/s
Project altitude	5279 ft
Maximum acceleration	350 ft/s2
Motor burn time	2.0 sec
Maximum motor thrust	1946.0 N
Average motor thrust	1771.0 N
Total motor impulse	3660.0 N-sec

Table 15: Simulated launch vehicle motor details.

The following plots shown in Figure 30 and Figure 32 display various simulation results, justifying proper motor selection, CG and CP location.

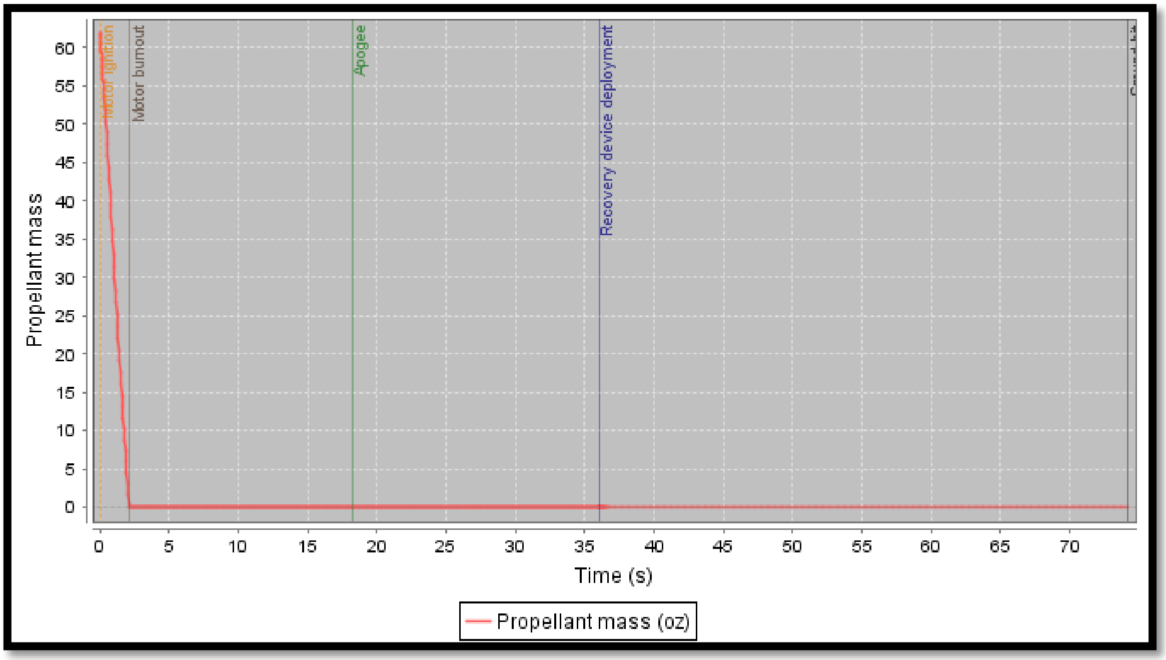


Figure 30: Propellant mass vs. flight time.

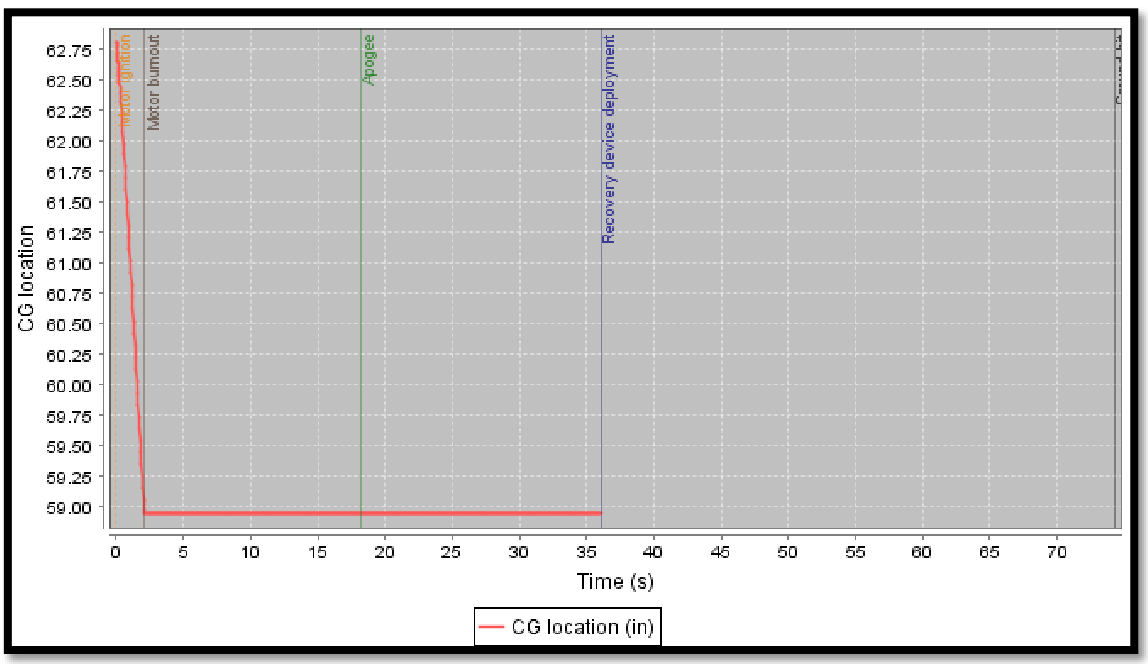


Figure 31: CG location vs. flight time.

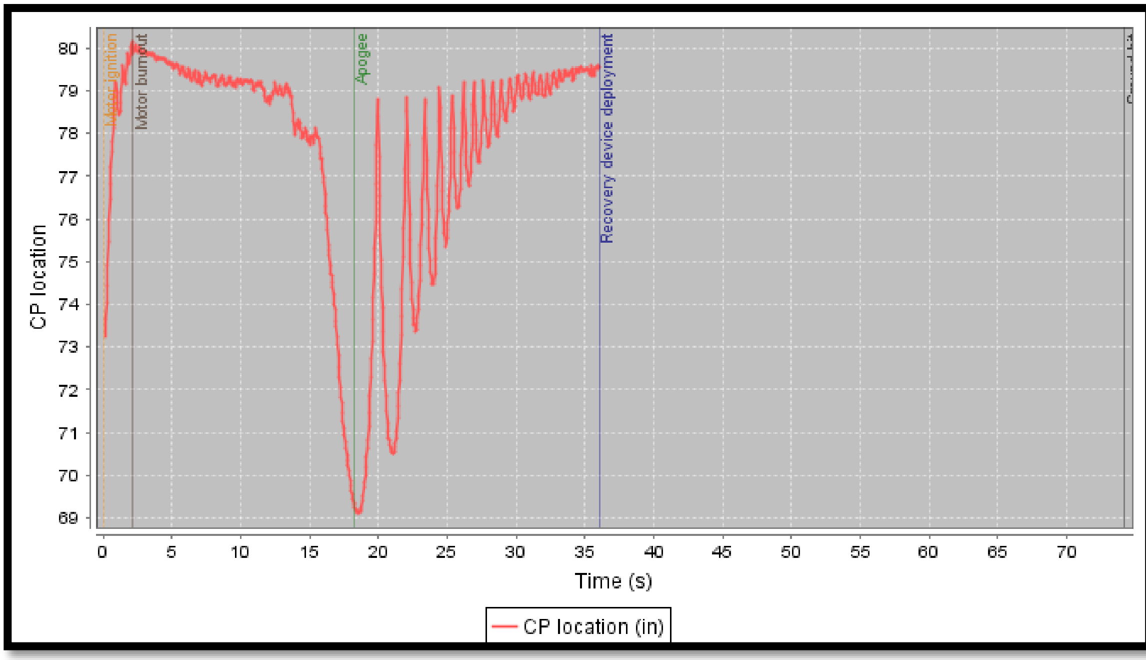


Figure 32: CP location vs flight time.

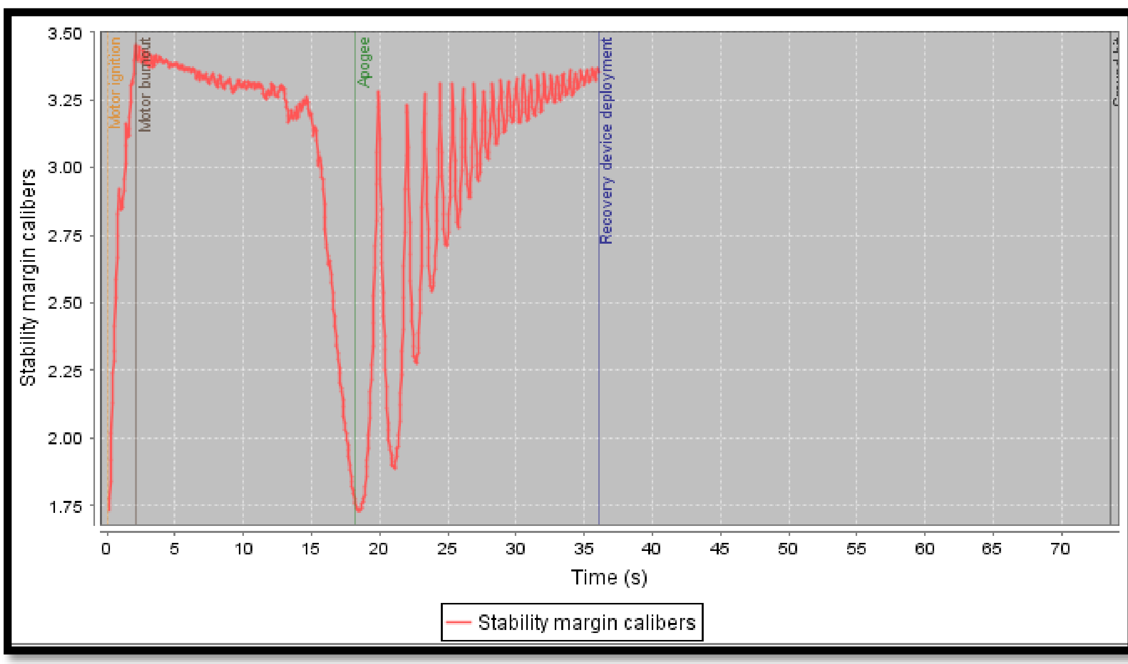


Figure 33: Stability margin vs. flight time.

Figure 32 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. Likewise, Figure 33 shows the launch vehicle stability margin during flight. During powered ascent and coasting to apogee, the stability margin increases, thus ensuring a stable flight.

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 XX, 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 L1720 three grain White Thunder 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 L1720 three grain White Lightnight motor is 3,660.0 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 has designed and launched a 1:2 scaled model of the full scale launch vehicle. The subscale launch vehicle has been used to test stability and integration of various systems seen in the full scale launch vehicle.

Table 16: Solutions to possible challenges set out in the Statement of Work.

3) Interfaces and Integration

Payload Containment

The Payload shall be contained inside the launch vehicle using retaining clips manufactured using a Fortus 400cc 3D-printer. The clip shall be mounted inside the Payload bay airframe. Figure 34 shows the design for the payload retaining clip.

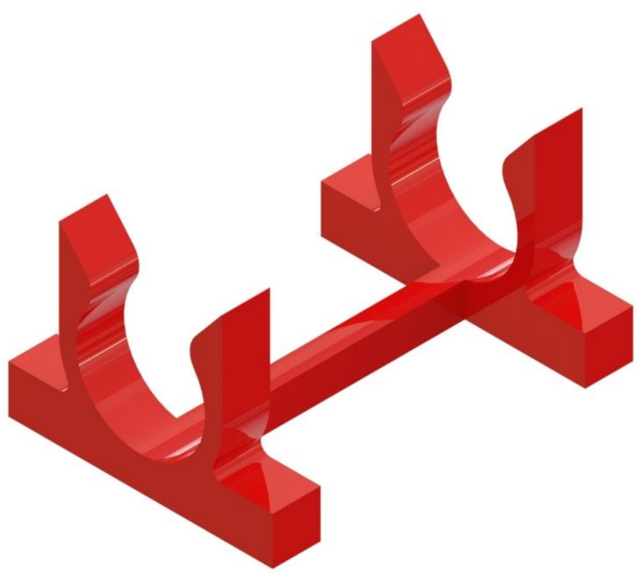


Figure 34: Payload retaining clips.

Two angled faces of the retaining clip serve as a guide for the payload capture device. Guidance allows for the payload to be placed precisely in the center of the clips even if an initial misalignment occurs. 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.

The retaining clip shall be installed within a machined medium density polystyrene foam assembly, shown below in Figure 35.

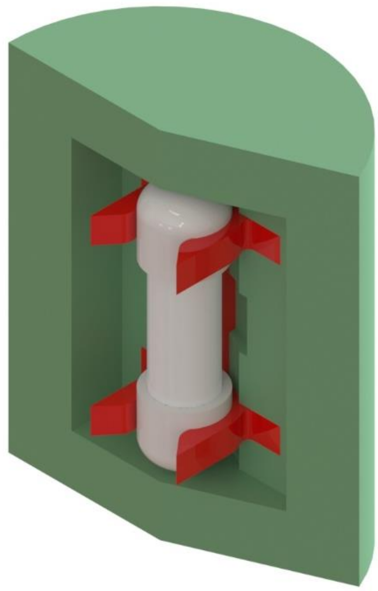


Figure 35: Payload containment assembly.

The foam will be the housing for the payload retaining clip. Once the payload is installed within the retaining clip, the foam will act to prevent the payload from moving vertically during flight. Medium density polystyrene foam was chosen due to its manufacturability and low cost.

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. 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 36 shows a depiction of the payload bay with the door in the closed position.

Figure 36: 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 an 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 37 shows the layout of the Payload bay door inside the track system.

Figure 37: 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 37 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 38

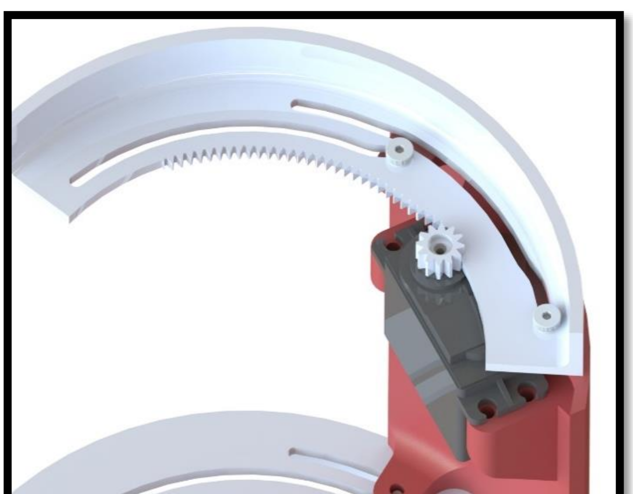


Figure 38: Payload bay rack and pinion mate.

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 39.

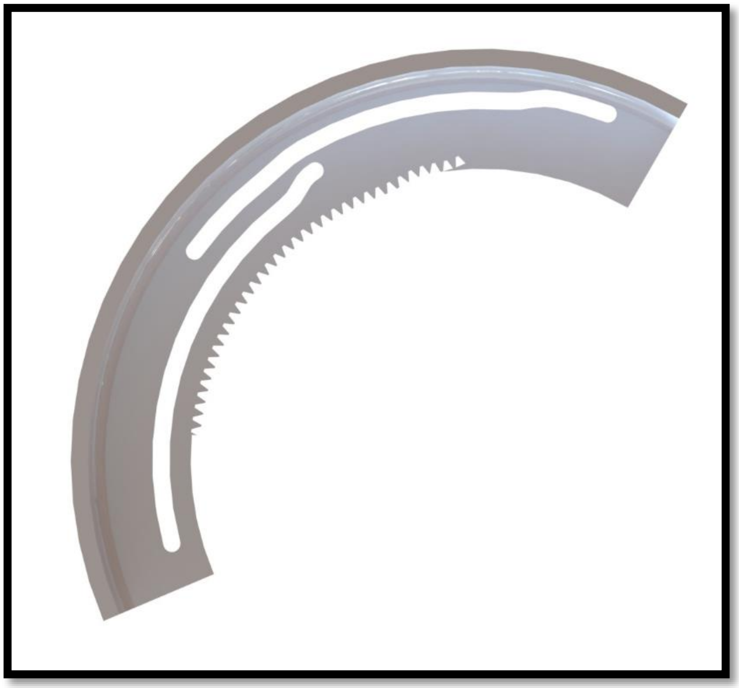


Figure 39: Rail guide track geometry.

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.

Breakaway Connector

With autonomy being a primary goal of the launch vehicle, a custom designed breakaway electrical connection shall be utilized. The connector maintain an electrical connection between the launch vehicle and ground station in order to actuate the door into the closed position upon installation of the payload. A rendering of the design is shown below in Figure 40.

Figure 40: Launch vehicle to AGSE breakaway connector.

The design features three separate terminals and contacts, each numbered in order to eliminate a mismatched connection. The contact body, shown in detail below in Figure 41, shall have the same face diameter as the external diameter of the launch vehicle, resulting in a seamless external finish, eliminating any effects of the connector on the laminar air flow surrounding the vehicle. Likewise, the internal flange of the connector shall be of the same diameter as the internal airframe, allowing a solid epoxy joint to be formed between the connector and the launch vehicle.

Figure 41: Breakaway connector contact assembly.

In the center of the connectors is an N52 Neodymium magnet which will hold the female and male connectors while the vehicle is in the AGSE. The magnets shall apply a holding force of 1.08 lb_f, which has been deemed sufficient to maintain the electrical connection while still allowing the connector the easily release when the vehicle is actuated to the vertical position. A section view of the connector is shown below in Figure 42 in order to illustrate the connection between terminal and contact.

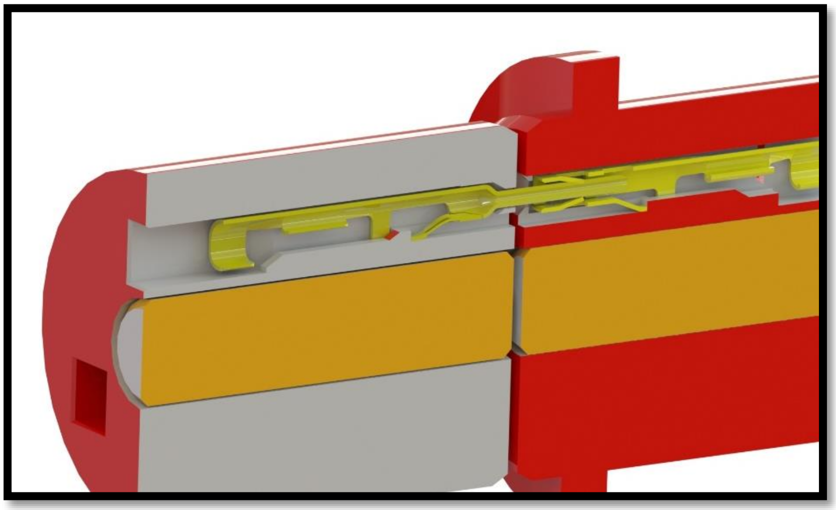


Figure 42: Section view of vehicle to AGSE breakaway connector.

The contacts and terminals have been donated by Samtec Inc. in order to make a custom breakaway connector. The each contact and terminal connection has 1.84 millimeters of penetration, creating and industry standard connection between launch vehicle and AGSE.

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 17.

Challenges	Solutions
Design the door such that the payload and payload capture device will fit during payload insertion.	Proper dimensional analysis has been conducted to ensure no clearance issues are present throughout the design and insertion of the payload into the payload containment bay.
The door shall be autonomously closed.	A breakaway connection has been designed that will allow the payload actuation device to be controlled via the AGSE master controller, and disconnect when the vehicle is raised to the launch ready position.
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 17. 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: 800ft.
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 a redundant system for ejection and deployment of main, with commercially available altimeters, 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 be utilized to contain the parachute compartment.
8. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle 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 that is attached to a ring type design that chokes the shroud lines of the parachute and overall diameter. This prevents the parachute from fully opening, causing it to act like a drogue parachute. The choking will be released at 800 feet, allowing the parachute to fully open to act like a main parachute. There will be redundant black powder charge that will ignite at 650 feet to ensure main inflation.

A linear actuation is the primary mechanism for pushing out the master link black powder container, releasing the shroud line rings. The secondary release mechanism will actuate at an altitude of 650 feet. The secondary release mechanism is a controlled black powder charge that is located inside the master link black powder container. The force from the black powder is enough to overcome the frictional force from the master link pins onto the shroud line rings and linear actuator if it were to get bound. Testing will be done to ensure enough black powder will break the frictional force between the master link and shroud line rings once the system has been manufactured.

Parachute lines are harnessed to a 5/16 inch quick link, swivel, and another 5/16 inch quick link that is secured by a water knot 1/3 of the overall shock cord length.

Changes since PDR

Original Design Summary

The original reefing system incorporated the same concept as the current configuration where the parachute's diameter will be choked by the shroud lines by forcing them through a slotted ring. With the design of a polyconical parachute, it allows for a hole in the top of the parachute where a center line will connect both the reefing ring and parachute. The original reefing ring is represented in Figure 43.

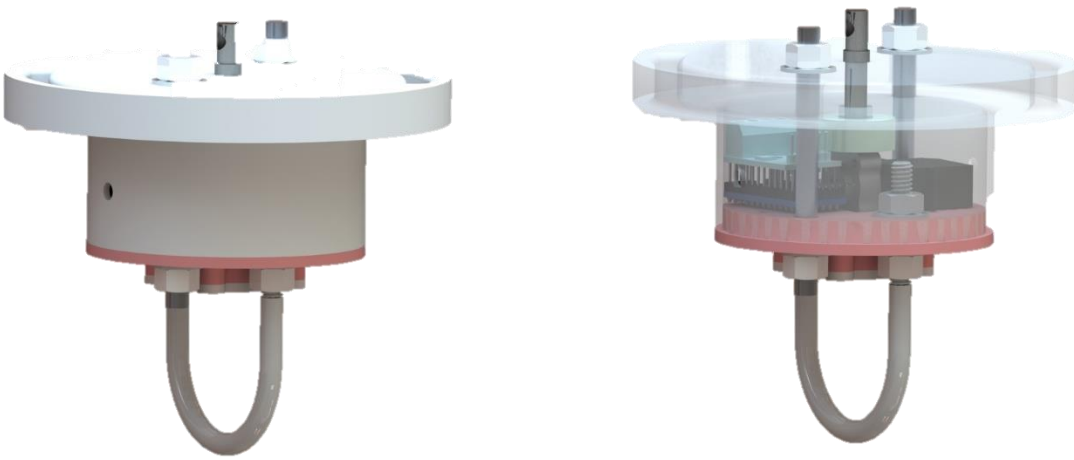


Figure 43: Reefing ring solid (left) and transparent isometric view (right).

The closer the ring is to the parachute, the smaller the diameter of parachute, creating a drogue parachute. The distance that the ring was from the top of the parachute was tpo be controlled by the center line. An ejection pin was placed on the top of the reefing ring, as indicated in Figure 44, where the top of the parachute could be tied off using parachord.

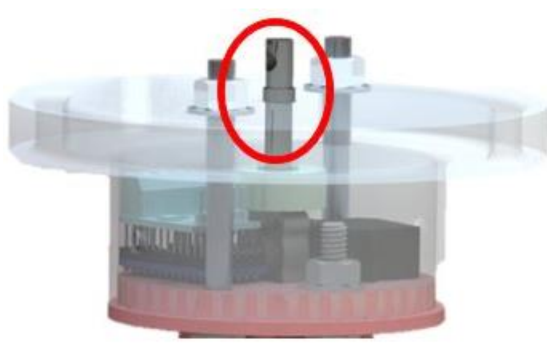


Figure 44: Ejection pin location.

Changes

The original design of the reefing ring posed several issues with transitioning the parachute from a drogue to main state. The first concern that raised issues was the tangling of the shroud lines before de-reefing occurs. If tangling got too severe the opening force of the inflation of the main wouldn't be strong enough to push the reefing ring downward. With this realization, the configuration of shroud line rings allowed for a claw type actuation that is further explained later in the section.

The second concern was our redundant system of a tender descender, as shown below in Figure 45, which was connected on the center line between the ejection pin and top of the parachute.

Figure 45: Tender descender.

This raised concern due to the lack of experience using the tender descender level 2 from Apogee Components. If the primary ejection pin were to be successful, a pulling force would occur from the electric match that would be connected to the tender descender.

To mitigate this problem, a disconnect device was implemented to allow power to be armed to the StratologgerCF from the nose cone AV bay via a SPDT switch. This allows no more than 1.09 pounds to detach the disconnect device while maintaining power to the StratologgerCF. A custom master link black powder container was designed to act as the primary and secondary system. A linear solenoid is used to push the master link away while the secondary is ejected by black powder.

The linear solenoid replaces the ejection pin to simplify the de-reefing process.

A swivel was added to the harness attachment point to allow the launch vehicle to spin while preventing tangling.

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

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

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

$$V=\sqrt{\frac{2mg}{\rho C_D A}} \quad (2)$$

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

$$A=\frac{m^2 g}{\rho C_d E g_c} \quad (3)$$

The nominal diameter of the diameter of the parachute was calculated using

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

the area, diameter, and velocity were calculated for the recovery system of the launch vehicle. The calculations for the parachute sizing are shown in Table 18 assuming worst case coefficient of drag.

C_D (worst case)	0.75
Mass (lbs)	34
Area(ft^2)	342.87
Diameter (ft)	20.89
Velocity (ft/sec)	10.66

Table 18: Parameters used to calculate parachute diameter.

Given the descent velocity of the system and the mass of each section, shown below in Table 19, 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 kinetic energy that the rocket will experience is laid out in Table 19 and characteristics of the launch vehicle during the reefed (drogue) state and de-reefed (main) state.

Section of rocket	Area (ft^2)	Diameter (ft)	Velocity (ft/s)
Reefed (Drogue)	9	3.39	60.74
De-Reefed (Main)	342.86	20.89	11.76

Table 19: Reefed and de-reefed characteristics.

Section of Rocket	Mass (lbs)	KE (ft-lb_f)
Nose Cone	6.20	60
Rest of Rocket	28.37	60

Table 20: Masses of individual sections of rocket.

Upon ejection, the parachute will be in a reefed state, to allow the functionality of a drogue parachute. A lower altitude for releasing main is acceptable because the parachute will already be outside of the launch vehicle when de-reefing occurs at 800 feet. A coefficient of drag test was performed to verify our coefficient of drag and to determine the appropriate reefing length. See Verification of Parachute Design: Coefficient of Drag Test for more details.

Attachment Scheme

The reefing system's main component is called the shroud line rings, as shown in Figure 46.

Figure 46: Reefing ring solid (left) and transparent isometric view (right).

The reefing system attaches to parachute by a strand of parachord that will latch around the eye bolt and center loop of the parachute. When attached the parachute will be in a reefed state.

Hardware that is used for attachment points are listed below in Table 21.

Component	Quantity
5/16 inch Quick Links	4
Ball Bearing Swivel	1
1/4 inch forged eyebolt	1

Table 21: Recovery hardware for attachment points.

The parachute lines converge onto the following connections. A 5/16 inch quick link to a ball bearing swivel and then another 5/16 inch quick link before its attachment point on a water knot 1/3 the way down the shock cord length.

The water knot is oriented closer to the nose cone while both ends of the shock cord are attached with a 5/16 inch quick link.

Figure 47: Top view actuation of reefing ring.

The reefing ring has two methods of deployment for redundancy. The primary method of de-reefing occurs with the shroud line rings, as shown in Figure 47, rotating a minimum of 180 degrees in opposite directions after actuation. This movement is illustrated above in Figure 47.

To create the rotating action of the shroud line rings, an actuation occurs using a linear solenoid. Figure 48 shows the pre-actuation. When actuation is at the maximum length, the master link black powder container falls out of position as shown in Figure 49.

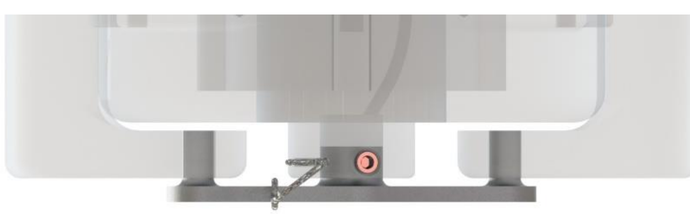


Figure 48: Master link black powder charge container in reefed state.

Figure 49: Master link black powder charge container in de-reefed state.

Given either the primary or secondary release mechanism, the master link black powder charge will eject as shown in Figure 49.

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 50.

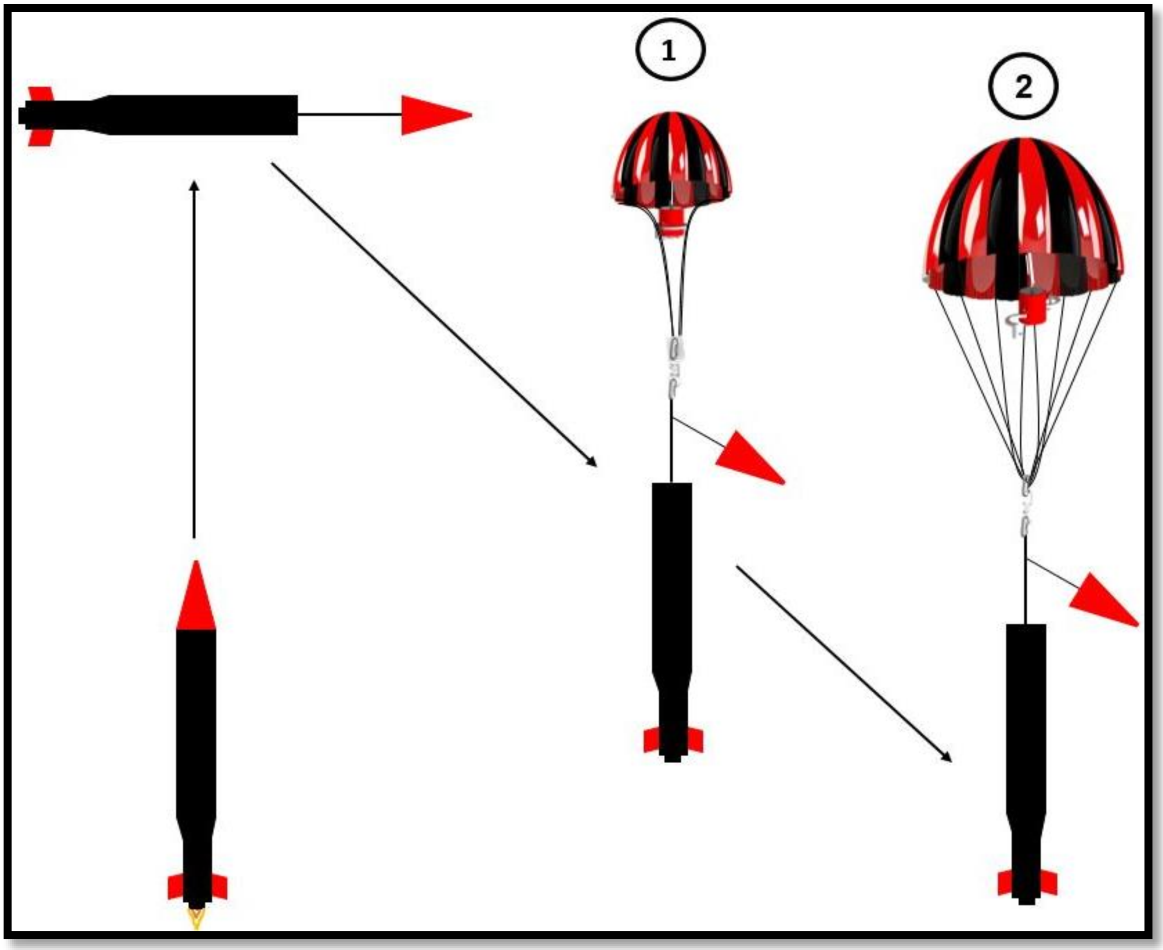


Figure 50: Recovery process.

A description of each event and altitude at which it occurs is listed below in Table 22.

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	Primary act of de-reefing allows main parachute to fully open.
3	650	Secondary act of de-reefing allows main parachute to fully open.

Table 22: 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 23 are the calculated drift values.

Wind speed	Drift (ft)
0	0
5	368.48
10	545.45
15	1105.45
20	1473.94

Table 23: 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 51.

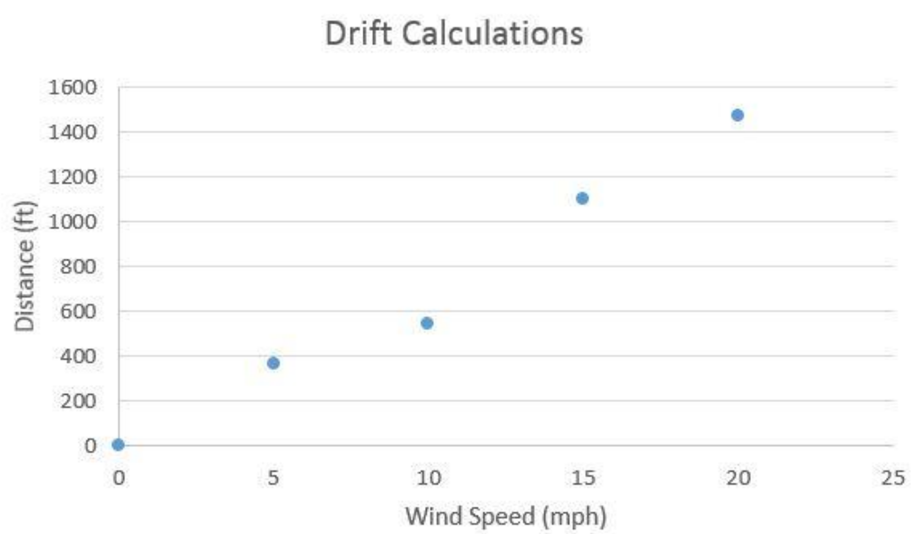


Figure 51: Distance rocket drifts from the pad for all wind speeds possibly encountered during a launch.

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, the team will be able to more accurately predict the drift on launch day.

A plot of altitude versus time for the sub-scale launch vehicle under main parachute is shown in Figure 52.

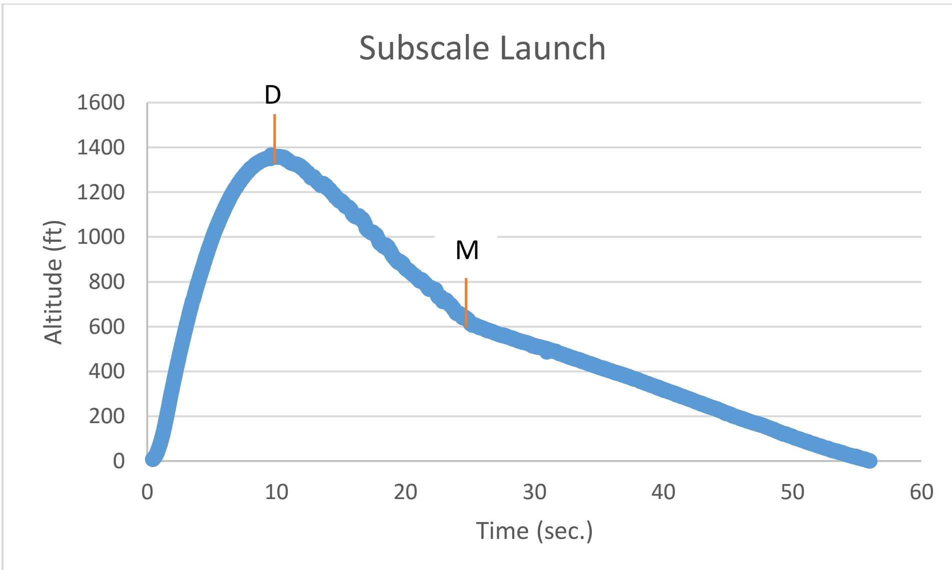


Figure 52: Stratologger data from sub-scale launch.

Standard dual deployment was used for the sub-scale launch. The sub-scale parachute was used as the main and a standard 12 inch parachute as drogue. Figure 53 shows a picture of the sub-scale parachute successfully recovering the rocket.

Figure 53: Subscale launch.

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 24.

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 system.

Table 24: 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 optimum geometry for the recovery system based on the characteristics shown in Table 25.

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 25: 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 eyebolt of the reefing system which will enable reefing.

Layout

The polyconical parachute will be manufactured in accordance to the schematic shown below in Figure 54.

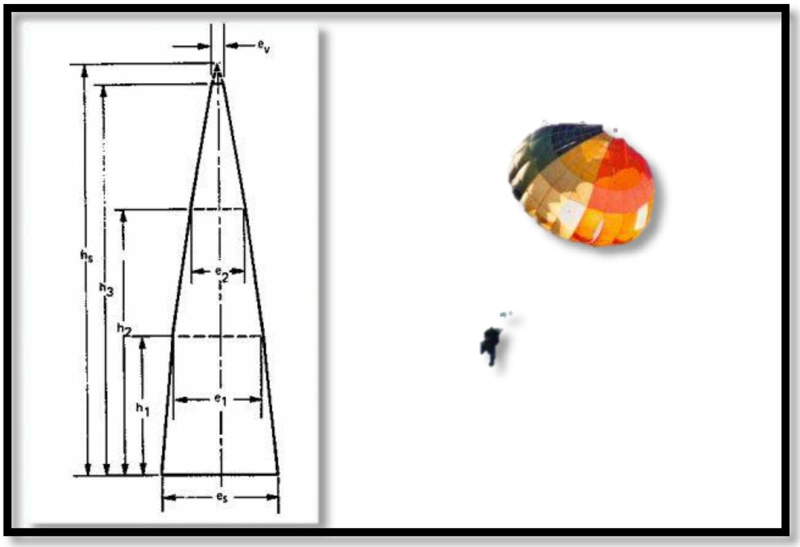


Figure 54: Polyconical schematic of one panel.

For ease of manufacturing the team has created a dimensionally driven layout shown below in Figure 55.

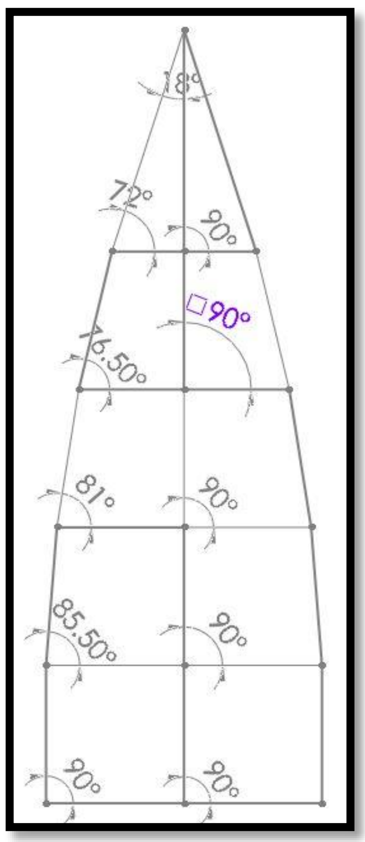


Figure 55: Polyconical scalable layout.

Since the team has little experience with center line reefing, an extensive amount of testing was performed and an appropriate reefing length was determined in Verification of Parachute Design: Coefficient of Drag Test.

The bay layout for the recovery system is uniquely designed. The recovery bay schematic is shown below in Figure 56.

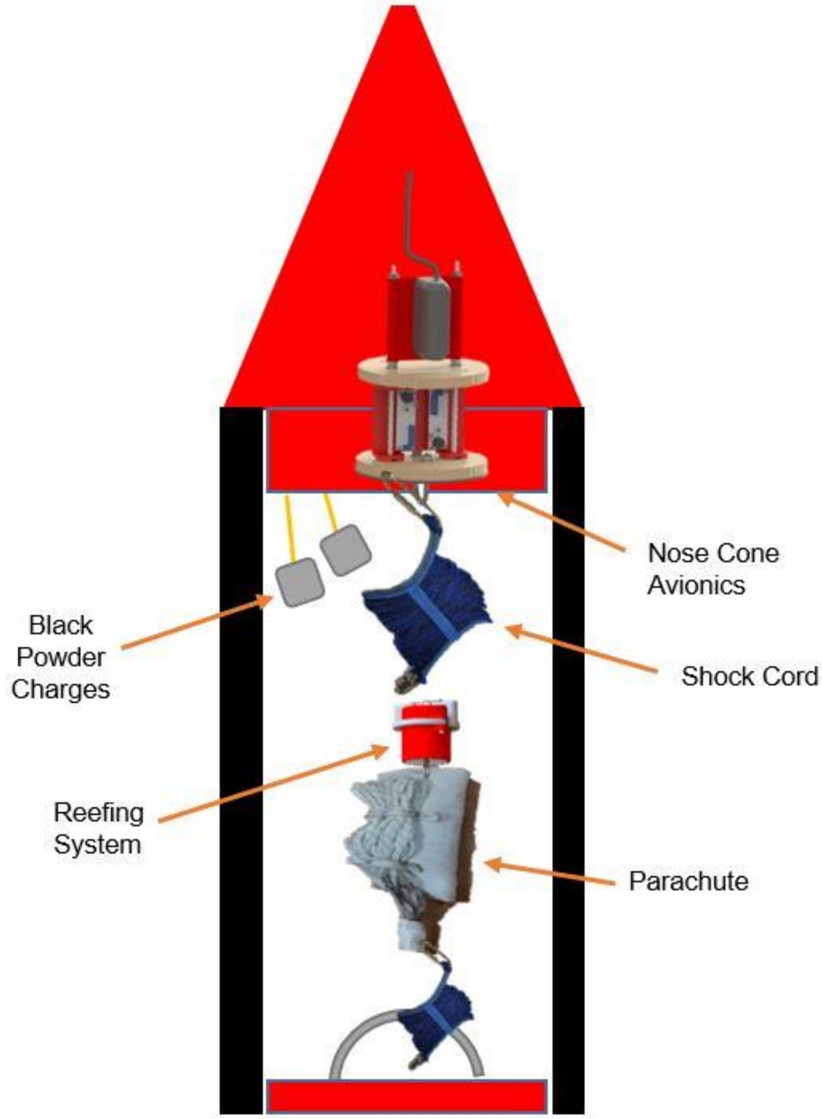


Figure 56: Recovery bay schematic.

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

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.

Table 26 shows the overall mass of the recovery system.

Material	Mass (lbs)
Rip Stop Nylon	1.21
Paracord	0.36
Reefing System	3.02
Quick Links	0.72
Swivel	0.25
Total	5.56

Table 26: Mass of Recovery system.

Each hem will be constructed by folding over the material two times. This will help prevent the material from fraying. The hem fold and stitch pattern are shown in Figure 57.

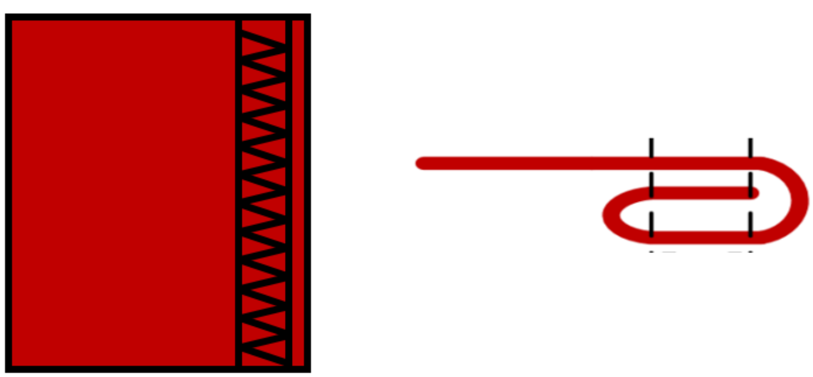


Figure 57: Hem line and stitch pattern for parachute.

The suspension lines will be made of 1/8 inch nylon para-cord with 400 lb tensile strength. 18 inches of line will be used for every location at which the lines need to be stitched into a panel and 12 inches when secured to another line.

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

Figure 58: Shock cord folding method.

Figure 58 shows the appropriate folding method to prevent the shock chord from getting tangled during deployment, the shock chord is folded accordion style and taped together using blue painters tape. The painters tape holds the shock chord together in an organized manner, but is also weak enough that it easily breaks during deployment.

Manufacturing process

The following procedure is laid out to demonstrate the folding of a sub-scale polyconical parachute.

Step 1

Lay out parachute and deployment bag as shown in Figure 59.

Figure 59: Parachute and deployment bag laid out.

Step 2

Pull the peak of the parachute and the attachment ring in opposite directions to straighten out the lines and reveal any tangles. Tangles can be dealt with by moving the attachment ring through the lines in the opposite direction of the twisted lines, essentially the same movement that tangled it but in reverse. Step 2 shown below in Figure 60.

Figure 60: Untangled parachute.

Step 3

Fold the panels such that each panel is folded in half and lying flat on another panel (except for the bottom one). This will place the center lines of each panel together and have all the lines on the other side. Step 3 shown below in Figure 61

Figure 61: First fold of parachute.

<u>Step 4</u>

Fold the parachute in thirds lengthwise with a zig zag fold so that it is the length of the deployment bag and the peak and lines are opposite each other. Step 4 is shown below in Figure 62.

Figure 62: Second fold of parachute.

Step 5

With the parachute folded as shown below in 63, stuff the parachute into the bag just enough to it is held firmly within.

Figure 63: Final fold of parachute.

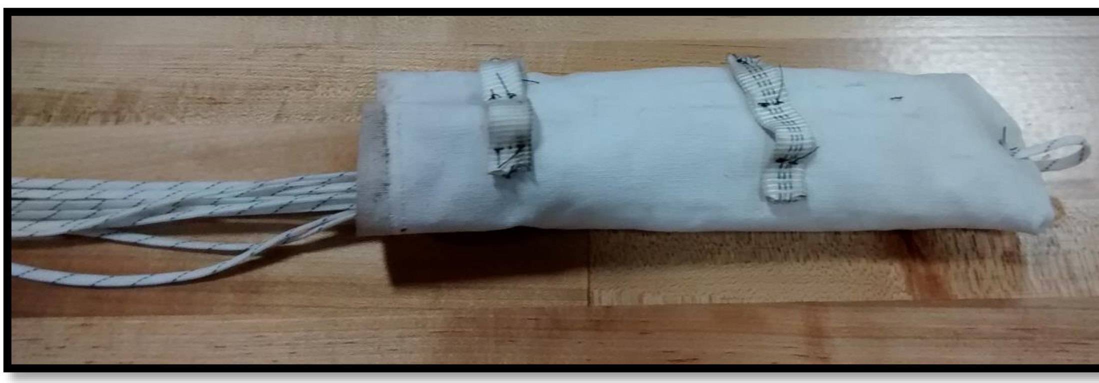


Figure 64: Parachute inserted in deployment bag.

Step 6

Using your line hook or similar device, pull the lines through the securing straps such that the lines travel through the loops and back, similar to a slip knot. Step 6 is shown below in Figure 65 and Figure 66.

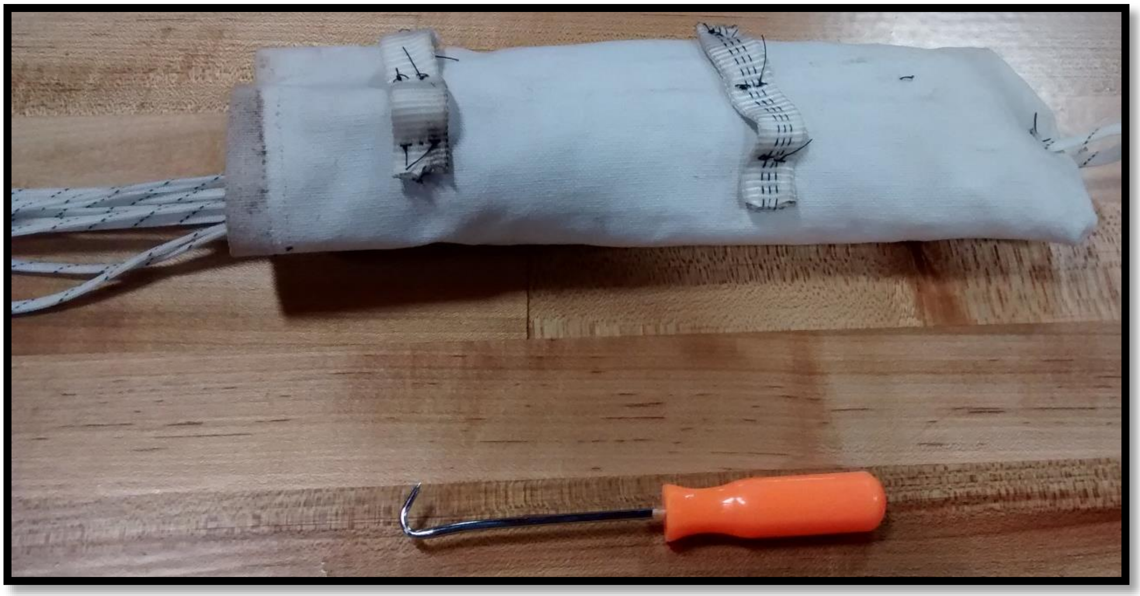


Figure 65: Organizing lines on deployment bag.

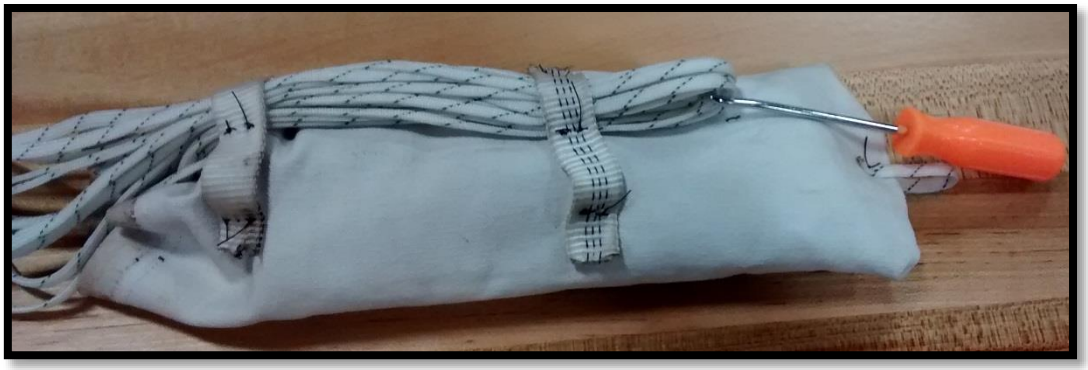


Figure 66: Pulling lines through deployment bag.

Step 8

A finished parachute. Ready to be used. See finished product below in Figure 67.

Figure 67: Folded parachute in a deployment bag.

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 68 shows the nose cone bulkhead assembly which displays the location of the Perfectflight StratologgerCF's. The bulkhead and U-bolt in Figure 68 will be mirrored on the lower half of the rocket. These U-bolts will displace the overall force that the parachute exerts throughout flight.

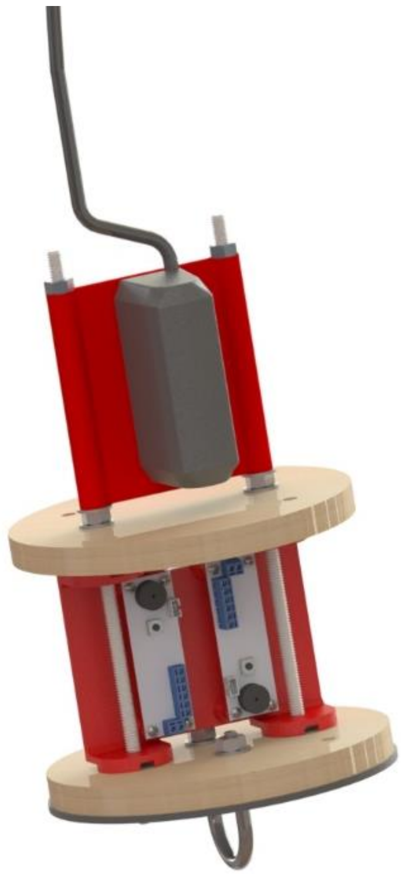


Figure 68: Nose cone bulkhead assembly.

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

Ejection Charge Electronics

For the deployment of the parachute, separation of the nose cone, PerfectFlite StratologgerCF shown below Figure 69. These will be used to ignite the ejection black powder charges.

Figure 69: PerfectFlite StratologgerCF

The PerfectFlite StratologgerCF altimeter records data at 20 samples per second with a 0.1% accuracy. In previous testing the StratologgerCF was capable of obtaining readings ±1 foot. The StratologgerCF can be configured to provide constant serial (UART) stream (9600 baud rate, ASCII characters) of the device's current altitude over ground. Proof of concept tests were performed to verify the electronics for recovery. See Reefing Electronics: Proof of Concept test procedure for more details.

For a full scale launch two redundant StratologgerCF's will be used to separate the rocket. The launch criteria for ejection to occur are shown below in Table 27.

	Ejection Charge Delay
Primary StratologgerCF	0 second delay at Apogee
Secondary StratologgerCF	2 second delay after apogee

Table 27: Full scale launch criteria for ejection.

Each altimeter will be locked into the ‘armed’ position by fastening a Featherweight screw switch, shown in Figure 70. The switches allow for easy arming of altimeters while the rocket is upright in the ASGE. Access holes will be drilled and marked on the outer airframe to allow for arming.

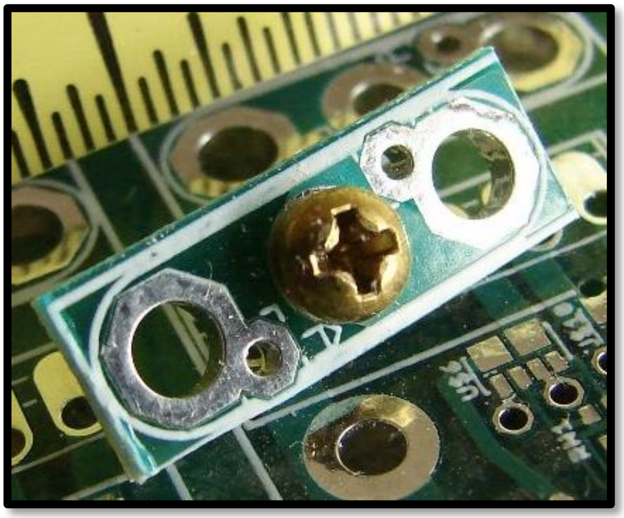


Figure 70: Featherweight screw switch.

The ejection charge electronics are composed of the following components:

Components	Quantity
PerfectFlite StratologgerCF	2
Electric Match	2
Featherweight Screw Switch	2
Duracell 9v battery	1 per strato
Black Powder	2.7 grams per Strato

Table 28: Ejection charge electronics components.

Both the primary and secondary StratologgerCF’s schematics are shown below in Figure 71.

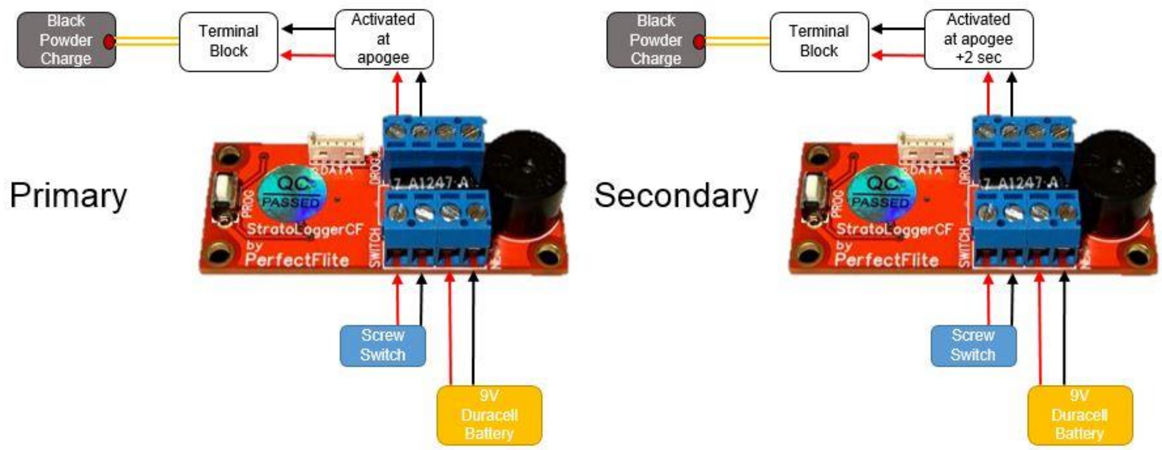


Figure 71: Primary and secondary ejection charge schematic.

The StratologgerCF's were tested for functionality in a simulated launch. A launch was simulated in a vacuum chamber shown below in Figure 72.

Figure 72: Vacuum chamber and pump used for Stratologger tests.

Primary Reefing Ring Electronics

The electronics in the reefing ring are responsible for determining when to initiate de-reefing. A Bmp180 barometric pressure sensor will be used to determine altitude and a sealed linear solenoid will release the shroud line rings, initiating de-reefing. The conditions that need to be in place for de-reefing to occur are shown below in Table 29.

	Altitude (ft.)	**Velocity (ft/s)**
Conditions for de-reefing	25<altitude<800	-70<velocity<-50

Table 29: Conditions for de-reefing.

The above conditions need to both be true for three consecutive data points in order for de-reefing to occur. This is condition was added to mitigate the risks of a false reading. This extra safety measure and the conditions for de-reefing were developed while testing with a prototype (see Test Plan: Reefing Electronics and Black Powder Charge for more details).

The lower limit on the altitude condition was set at 25 ft. to eliminate the possibility of triggering de-reefing while assembling the rocket. The upper limit on altitude was set at 800 ft: the altitude for the deployment of the main. The limits on velocity were set to be +/- 10 ft/s from the drogue state terminal velocity +/- 10 margin of safety is still malleable; it will be finalized after a full scale test.

The reefing electronics are composed of the following components:

Reefing electronics components:
Arduino Pro Mini
Sealed linear solenoid
Lm7805 voltage regulator
Lm7812 voltage regulator
Bmp180 barometric pressure sensor
3x Duracell 9v battery
PerfectFlite Stratologger CF
2N4401 NPN transistor

Table 30: Reefing electronics components.

The primary reefing electronics schematic is shown below in Figure 73.

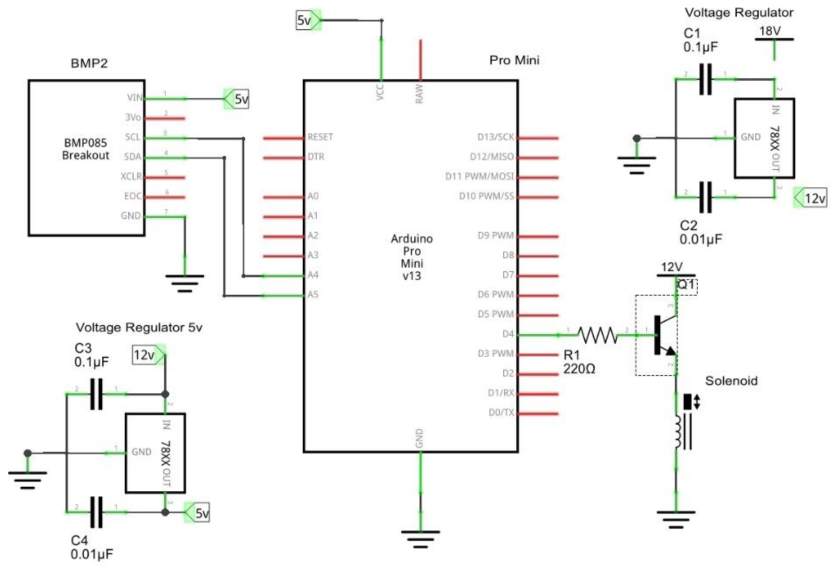


Figure 73: Primary reefing electronics schematic.

The electronics will be powered by 2 Duracell 9v batteries in series and regulated down to 12 and 5 volts with the Lm7812 and Lm7805 regulators respectively.

A prototype of the primary reefing electronics is shown below in Figure 74. To see the test plan and results, see Test Plan: Reefing Electronics and Black Powder Charge for more details.

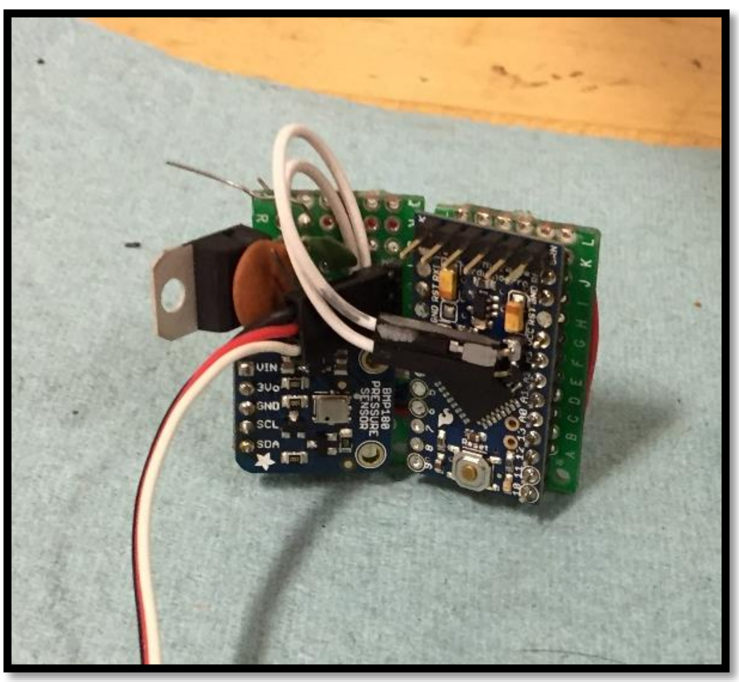


Figure 74: Primary reefing electronics prototype.

The primary reefing electronics will be fixed on a PCB; shown below in Figure 75.

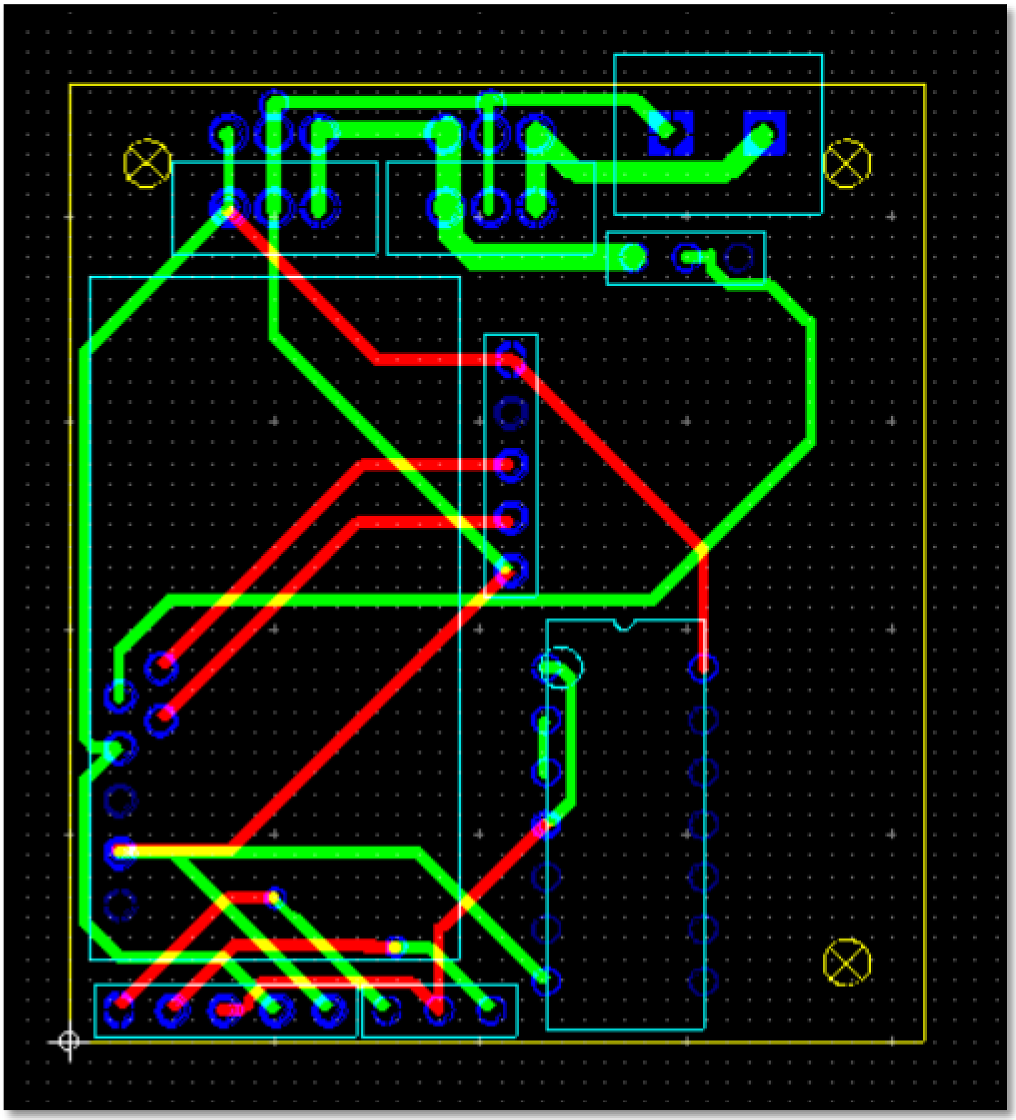


Figure 75: Reefing electronics PCB.

Secondary Reefing Electronics

The secondary reefing system will consist of the following components:

Components
PerfectFlite Stratologger CF
Duracell 9v battery
E-match
2N4401 NPN transistor
4010BC1 logic buffer
1BH62 diode
SPDT key switch

Table 31: Secondary reefing electronics components.

The secondary reefing electronics schematic is shown below Figure 76.

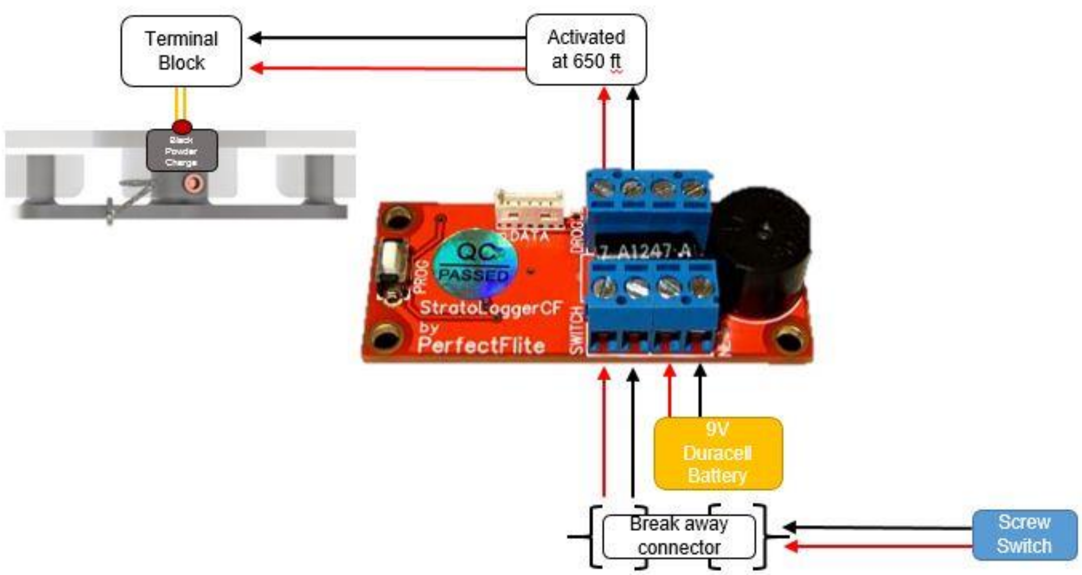


Figure 76: Secondary reefing electronics schematic.

The Stratologger will ignite a black powder charge at 650 ft. and will release the shroud line containment rings if they have not already been released by the primary reefing electronics at 800 ft. It will be housed within the reefing ring and will be powered with its own Duracell 9v battery.

The Stratologger will require a unique arming system in order to comply with proper arming procedure on the launch pad. Due to circumstances created by the fact that the Stratologger will be contained within the reefing ring, an arming system that can maintain 'armed' status after the ring has left the airframe is necessary. The arming system needs to fulfill the following requirements:

- Be accessible from outside the assembled rocket
- Have an 'arm' and 'disarm' mode
- Maintain 'armed' status even after the reefing ring has left the airframe
- Leave no dangling wires on the reefing ring

Three contacts will establish a conducting breakaway connection between an accessible SPDT switch in the nose cone and the arming circuitry on the inside of the reefing ring. This connection and the arming circuitry are shown below in Figure 77.

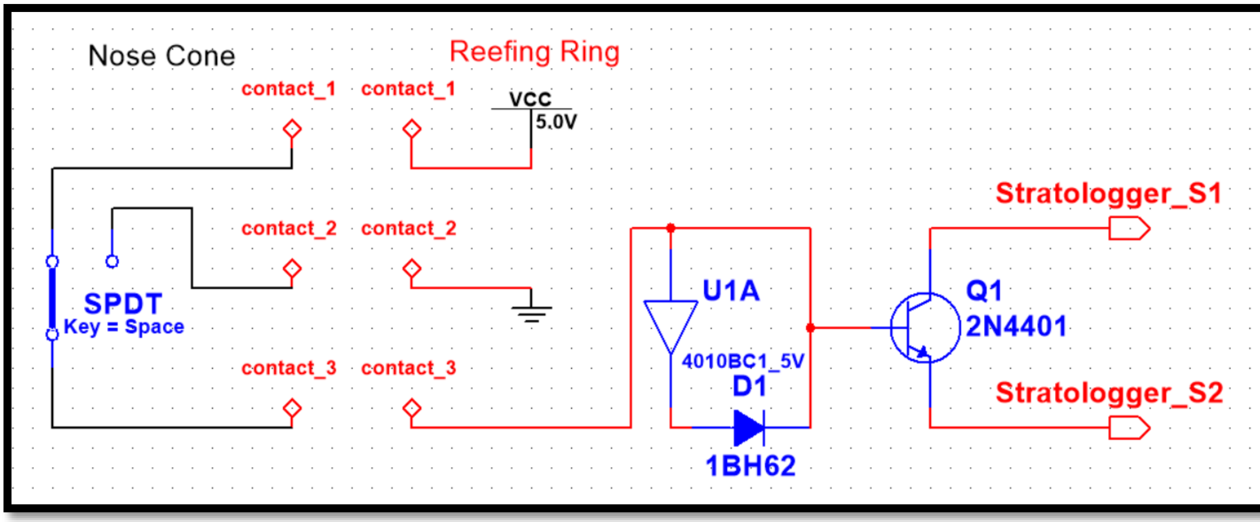


Figure 77: Secondary reefing electronics arming circuitry schematic.

The arming circuitry uses a simple state machine that will maintain the stratologger's 'armed' status even after the contacts connection between the reefing ring and SPDT switch have been broken. In this way the secondary reefing electronics can be armed and disarmed in a safe and reliable manner.

The arming circuitry will be fixed on the reefing electronics PCB.

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 32: 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 of 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 33.

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 33: AGSE sub-systems.

A rendering of the entire AGSE is shown in Figure 78.

Figure 78: AGSE in launch orientation.

The maximum dimensions of the AGSE are show in Table 34.

Mass (lb_m)	Width (in)	Height (in)	Length (in)
139.39	100.14	105.02	113.28

Table 34: Maximum 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 79.

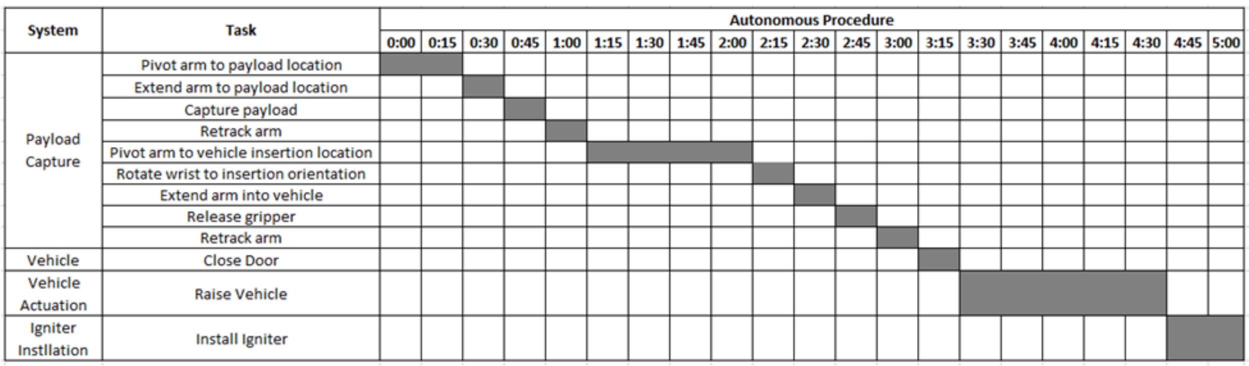


Figure 79: AGSE process timeline.

Analysis Guidelines

Throughout the design process of the AGSE a safety factor of 1.5 was pursued for all components. Designs below a factor of safety of 1.5, but above 1.0, were considered but these designs were re-evaluated until a factor of safety of 1.5 was achieved.

AGSE 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 80 defines dimensions of the AGSE.

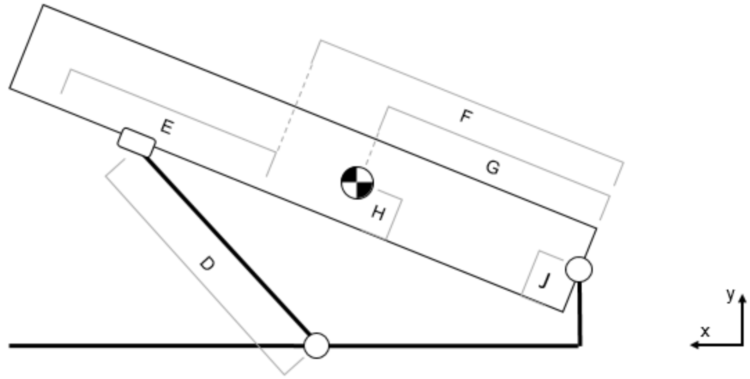


Figure 80: AGSE dimension definitions.

Figure 81 defines critical dimensions of the AGSE relative to the lower pivot point of the Launch Platform.

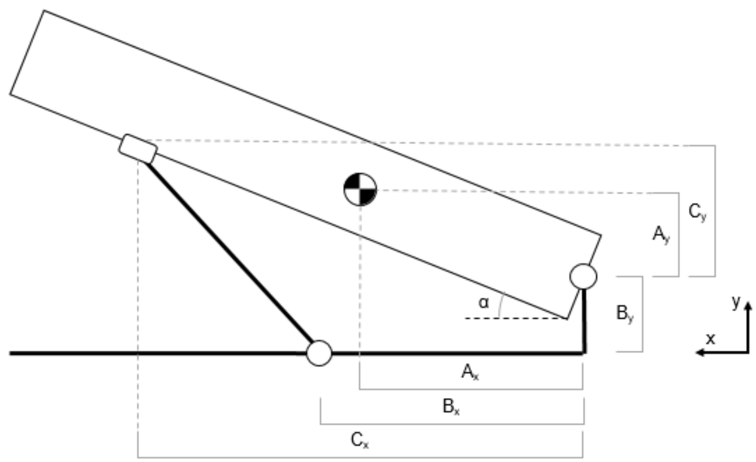


Figure 81: Critical AGSE dimensions relative to coordinate system.

Figure 82 defines the critical point forces applied to the AGSE.

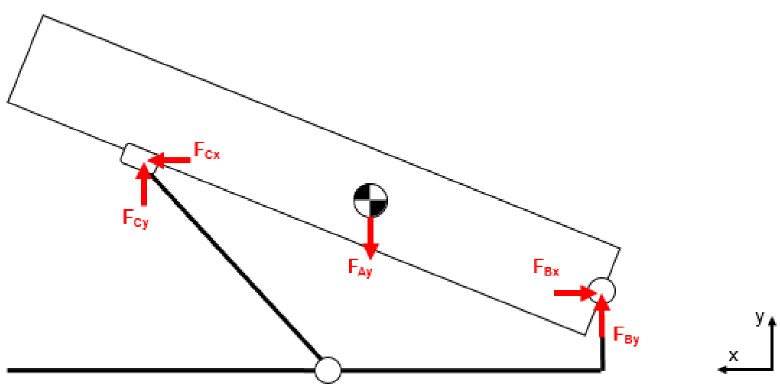


Figure 82: Critical point forces applied to the AGSE.

The following equations define the geometry and motion of the AGSE.

$$z=\sqrt{(B_x\text{-}J\sin(\alpha))^2+\left(B_y\text{-}J\cos(\alpha)\right)^2} \tag{5}$$

$$\beta=\tan^{-1}\left(\frac{B_y\text{-}J\cos(\alpha)}{B_x\text{-}J\sin(\alpha)}\right) \tag{6}$$

$$h=\frac{D}{\sin(\beta+\alpha)} \tag{7}$$

$$\theta=\sin^{-1}\left(\frac{z}{h}\right) \tag{8}$$

$$\gamma=180\text{-}\beta\text{-}\theta\text{-}\alpha \tag{9}$$

$$Q=h*\sin(\gamma) \tag{10}$$

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

$$A_y=\sin\left(\tan^{-1}\left(\frac{H}{G}+\alpha\right)\sqrt{H^2+G^2}\text{-}T\cos(\alpha)\right) \tag{12}$$

$$C_x=Q*\cos(\alpha)+J*\sin(\alpha) \tag{13}$$

$$C_y=Q*\sin(\alpha)\text{-}J*\sin(\alpha) \tag{14}$$

The following equations define the forces in the AGSE.

$$F_c=\frac{A_yF_{Ay}}{c_x\sin(\alpha+\theta)\text{-}\cos(\alpha+\theta)} \tag{15}$$

$$F_{Cx}=\cos(180\text{-}\gamma)\,F_c \tag{16}$$

$$F_{Cy} = \sin(180-\gamma)\, F_c \quad (17)$$

$$F_{Bx} = F_{Cx} \quad (18)$$

$$F_{By} = F_{Ay} - F_{Cy} \quad (19)$$

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

$$F_{Screw} = F_C \cos(\theta) + \mu F_{Track} \quad (21)$$

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

$$T = \frac{F_{Screw} L}{3e\pi} \quad (22)$$

where L is the lead 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 35 below.

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

Table 35: Force calculation parameters.

The parameters F_{Ay}, H, and G were all estimates of the AGSE system.

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 36.

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 36: Geometry variation specifications.

The simulation verified each combination as a valid option. 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 83. 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.

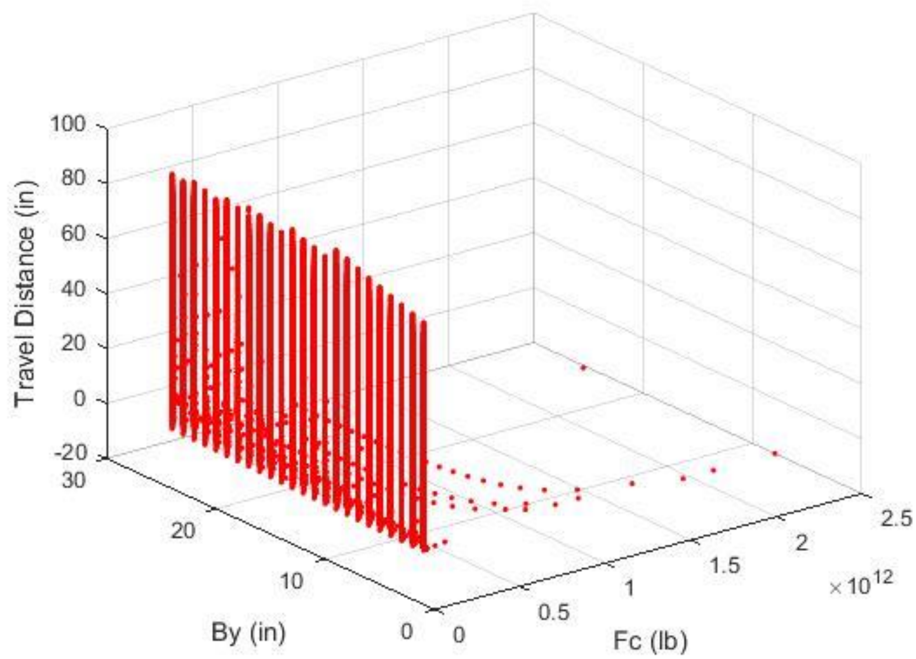


Figure 83: Simulation output plot.

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 84.

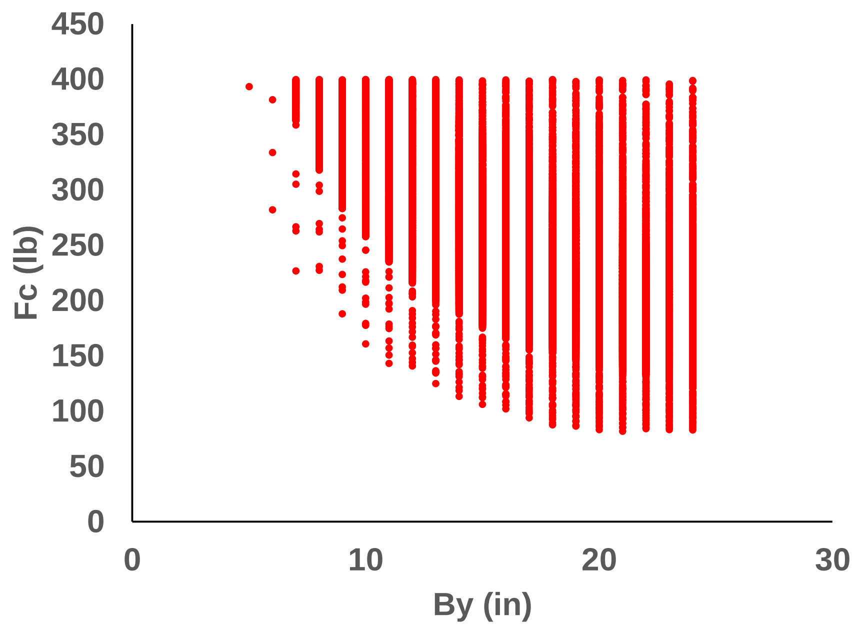


Figure 84: Maximum Fc force versus By distance.

By analyzing the data, a final configuration was chosen. The plot shown in Figure 84 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 input into an Access database to analyze the dataset to find the remaining geometry parameters. A summary of this configuration is shown in

Table 37.

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

Table 37: Summary of optimized AGSE configuration.

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

Table 38.

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 38: AGSE optimized configuration forces and torques.

These geometric parameters were used to influence the basic geometry of the AGSE.

2) System Controls and Integration

Overview

The relationships between all of the AGSE's electrical components are shown below in **Figure 85.**

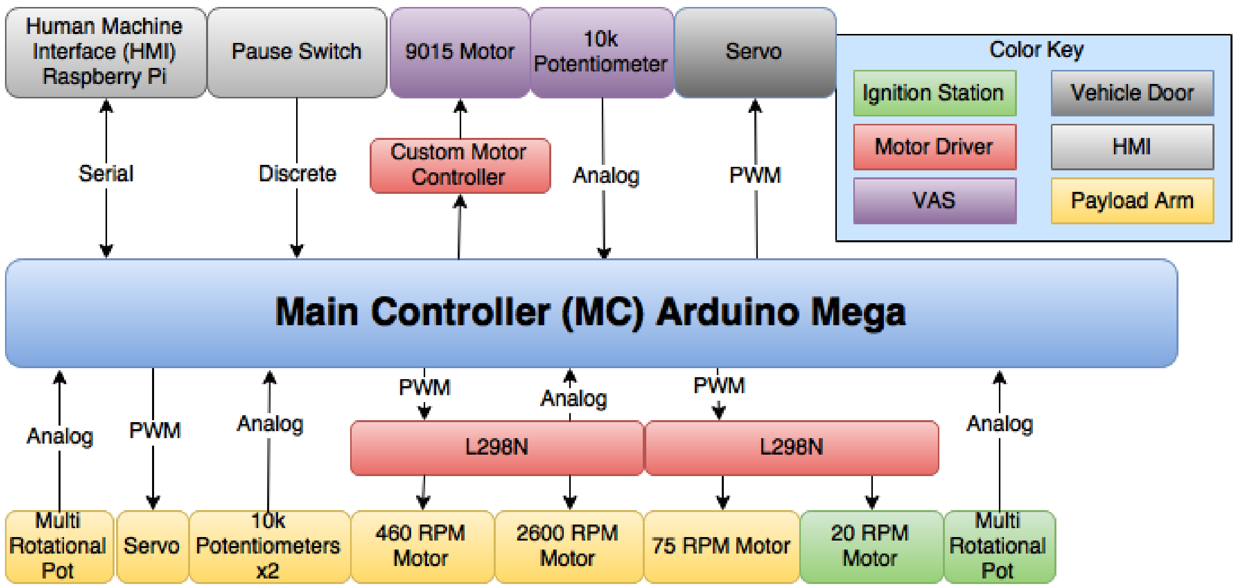


Figure 85: Controls overview.

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.

The MC and the various components that make up each subsystem are shown in greater detail in **Figure 86.**

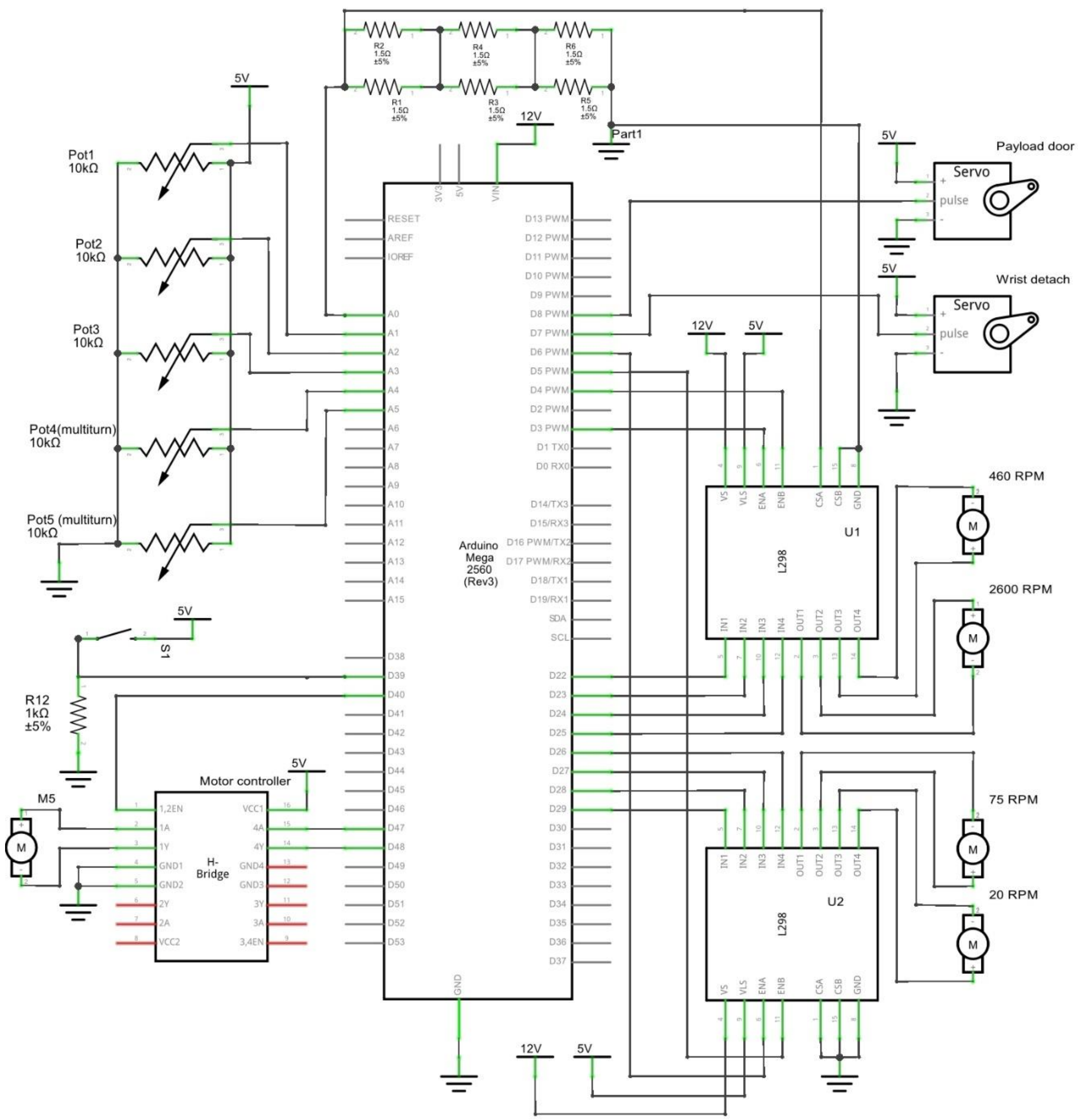


Figure 86: Controls schematic.

The pin numbers and connections shown above in the controls schematic are also shown in

Table 39.

Pin Type	Connection
PWM	SPST Switch
	U1 ENA
	U1 ENB
	U2 ENB
	U2 ENA
	servo PWM
	…
Analog	Current Sense
	10k pot
	10k pot
	10k pot
	10k pot (multi-turn)
	10k pot (multi-turn)
	…
Discrete	U1 IN1
	U1 IN2
	U1 IN3
	U1 IN4
	U2 IN4
	U2 IN3
	U2 IN2
	U2 IN1
	VAS EN1
	VAS EN2
	…

Table 39: Controls schematic pin types.

Main Controller PCB

A PCB will be created to manage all of the MC connections. The PCB will house the two L298n motor controllers and will manage the outgoing wires by using three RJ45 ports to connect to three CAT5 cables. The PCB design is shown in Figure 87.

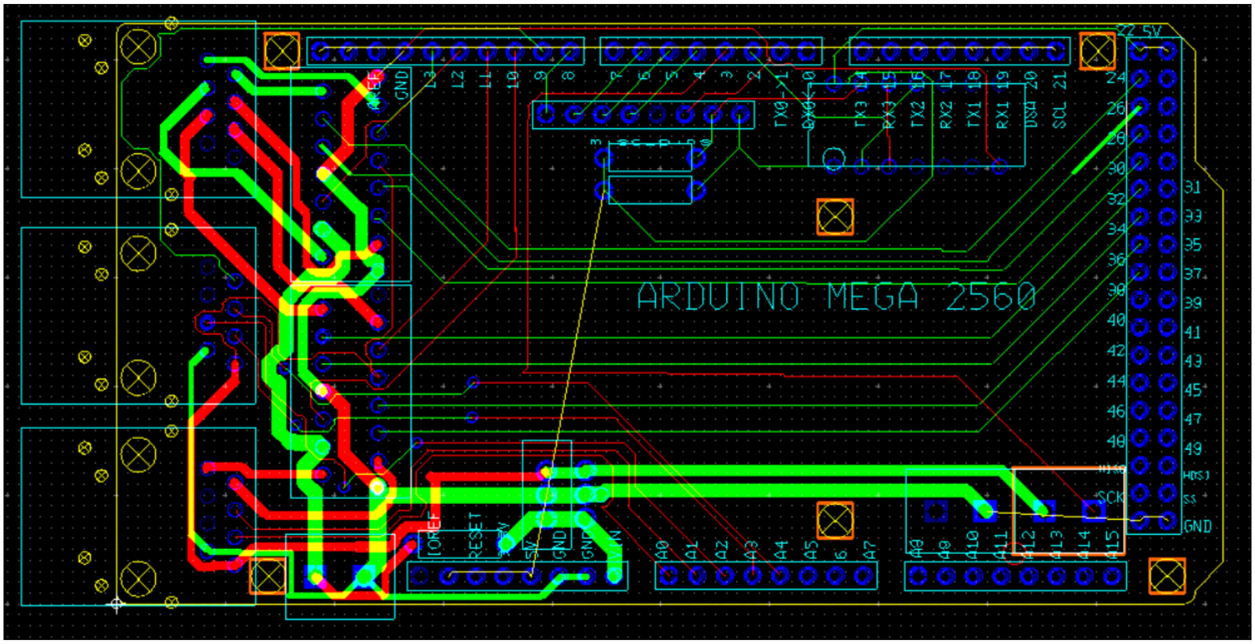


Figure 87: MC PCB.

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 location of the enclosure shared by the MC, battery, all motor drivers, and power management circuits, 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

The HMI will be housed in a custom 3D printed enclosure that will contain the Touchscreen, Raspberry Pi, and a switch. The enclosure will consist of two parts, the base and the cover. The cover includes features for mounting the switch and recessing the touchscreen. The cover will be secured to the base using four 10-32 UNC 2A ¾" long nylon thumb screws. Four additional thumb screws will attach the enclosure to the sub-frame. An exploded view of the HMI enclosure is shown in Figure 88.

Figure 88: Exploded view of HMI enclosure.

The main electronics for the AGSE will be housed in a custom 3D printed enclosure. The enclosure will consist of two parts, the base and the cover and will be 8"x8"x2". The cover will be cut from a 1/8" thick piece of transparent polycarbonate. The cover will be secured to the base using four 10-32 UNC 2A ¾" long nylon thumb screws. The base will also include mounting features for each electrical component. One set of mounting features with an Arduino Mega installed in the electronics enclosure is shown in Figure 89. A sealed USB connection for quick programming changes and advanced diagnostics is also shown in Figure 89. Wires routed throughout the AGSE will be protected with grommets and strain reliefs where necessary. The main electronics enclosure will be mounted forward of the articulating arms connection point to the sub-frame, therefore keeping the delicate electronics clear of any launch vehicle exhaust.

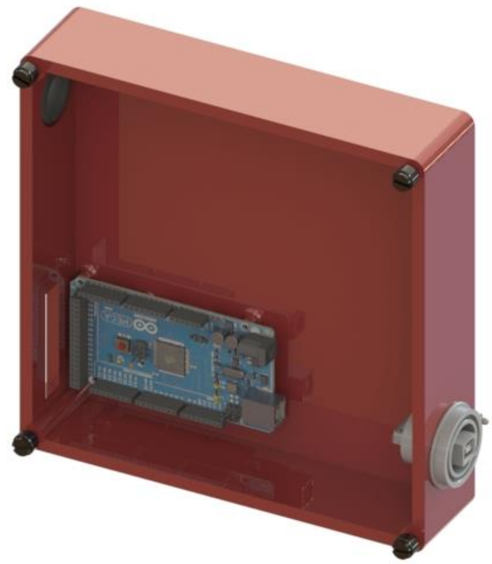


Figure 89: Main electronics enclosure.

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. The HMI will provide 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.

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 PDR

Change	Justification for Change
Replacement of ignition station rotary encoder with a multi-turn potentiometer	Rotary encoder introduces the risk of the ignition station's progress being lost if the pause switch is activated during operation. The potentiometer eliminates this risk.
Replacement of Talon SRX motor controller with a custom built controller.	Serial protocol was found to be unsupported by the Talon controller.

Table 40: AGSE electrical changes since PDR.

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
L7812c 5v regulator	1
855T control tower lights	2
12v DC toggle switch	1
SPST toggle switch	1
PiTFT 7" touch screen	1

Table 41: MC component list.

Detailed descriptions of MC components 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.
- Wi-Fi compatible; allows for connection to a database and data logging.

L7812 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; Four 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 90: 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.

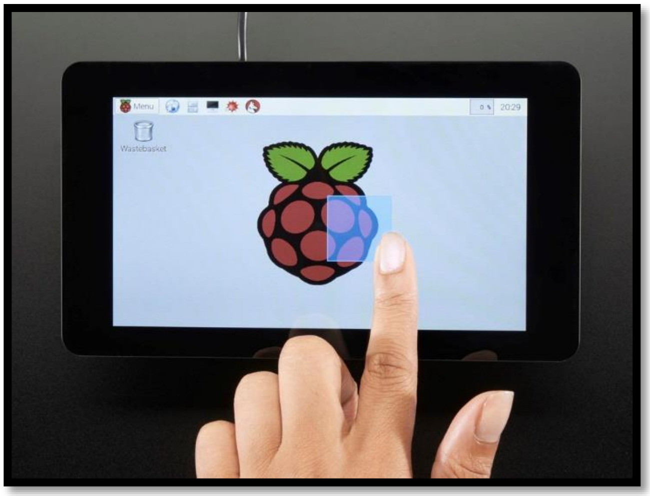


Table 42: HMI touchscreen.

Wire gauge analysis
Wire gauges for the AGSE were determined using

$$AWG=4.3122\ln\left(\frac{(\%Drop\times Voltage)}{(Current\times Length)}\right)+39.794 \qquad (23)$$

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 Table **43**.

		Current at max voltage(amps)	Length (feet)	Allowable %Drop	Max voltage (volts)	Resistance per length (ohms/ft)	AWG
Payload arm	Base pivot power	1.00	2	1	12	0.06000	27
	Servo/pot power	0.37	5	1	5	0.02703	24
	Individual data lines	0.04	5	1	5	0.25000	33
	Wrist power	1.60	5	2	12	0.03000	24
	Telescopic power	1.60	3	2	12	0.05000	26
VAS	VAS motor power	35.00	6	3	12	0.00171	12
	VAS pot	0.04	5	1	5	0.25000	33
Ignition station	Motor power	0.50	3	1	12	0.08000	28
	Multi-turn pot	0.04	3	1	5	0.41667	36
HMI	Power	2.00	6	2	5	0.00833	19

Table 43: AGSE wire gauge analysis.

The wire gauge analysis shows that 24 gauge CAT5 cable will be acceptable for a majority of components; the exceptions being the VAS motor power cables and the HMI power cables. Tests with individual motors will take place to determine the current at max voltage with the expected loads. This will allow for more accurate wire gauge determinations.

Power

The AGSE electrical components will be powered by the MK-ES17 12v battery. Voltage will be adjusted to suit the 5v systems via four 5v regulators in parallel as seen in Figure 91 and distributed to all systems according to Figure 92. Additionally, a master power switch will be included on the electronics enclosure to toggle power on and off.

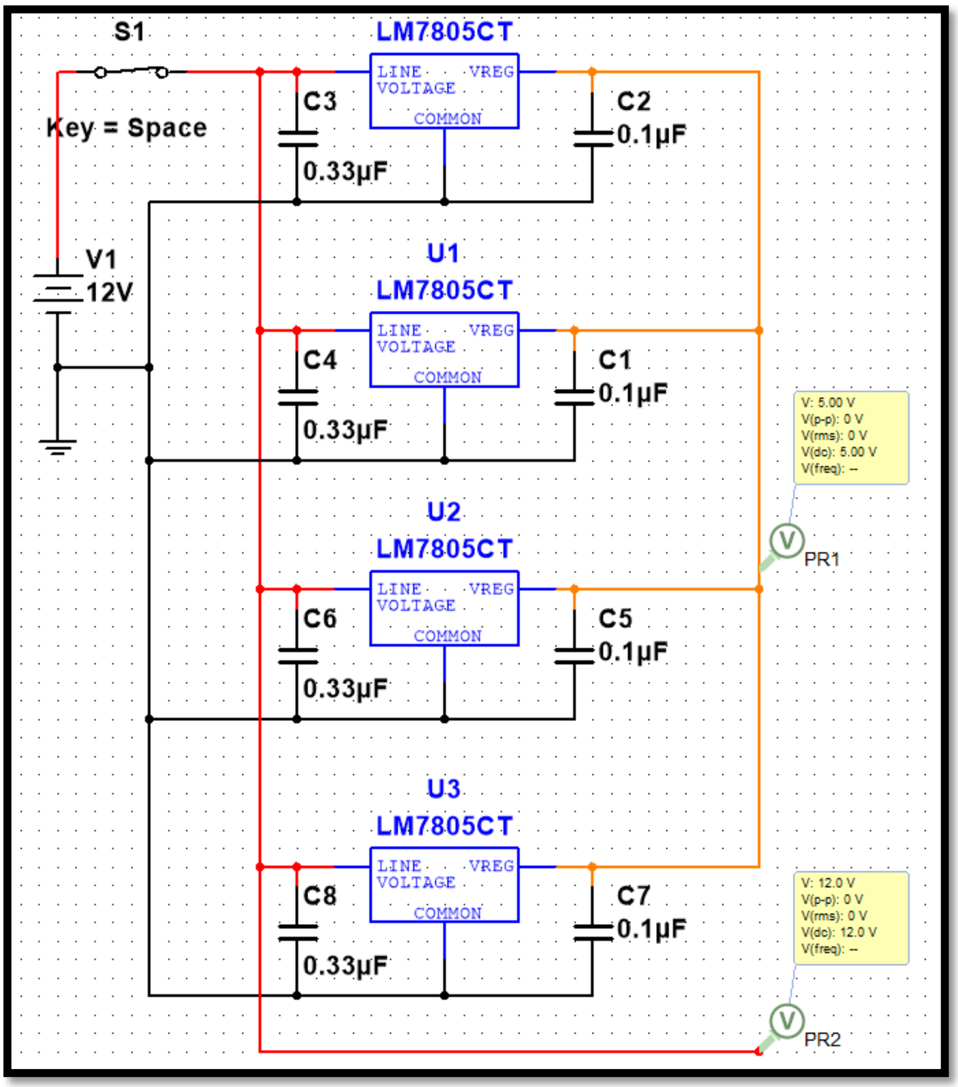


Figure 91: 5v regulation circuit

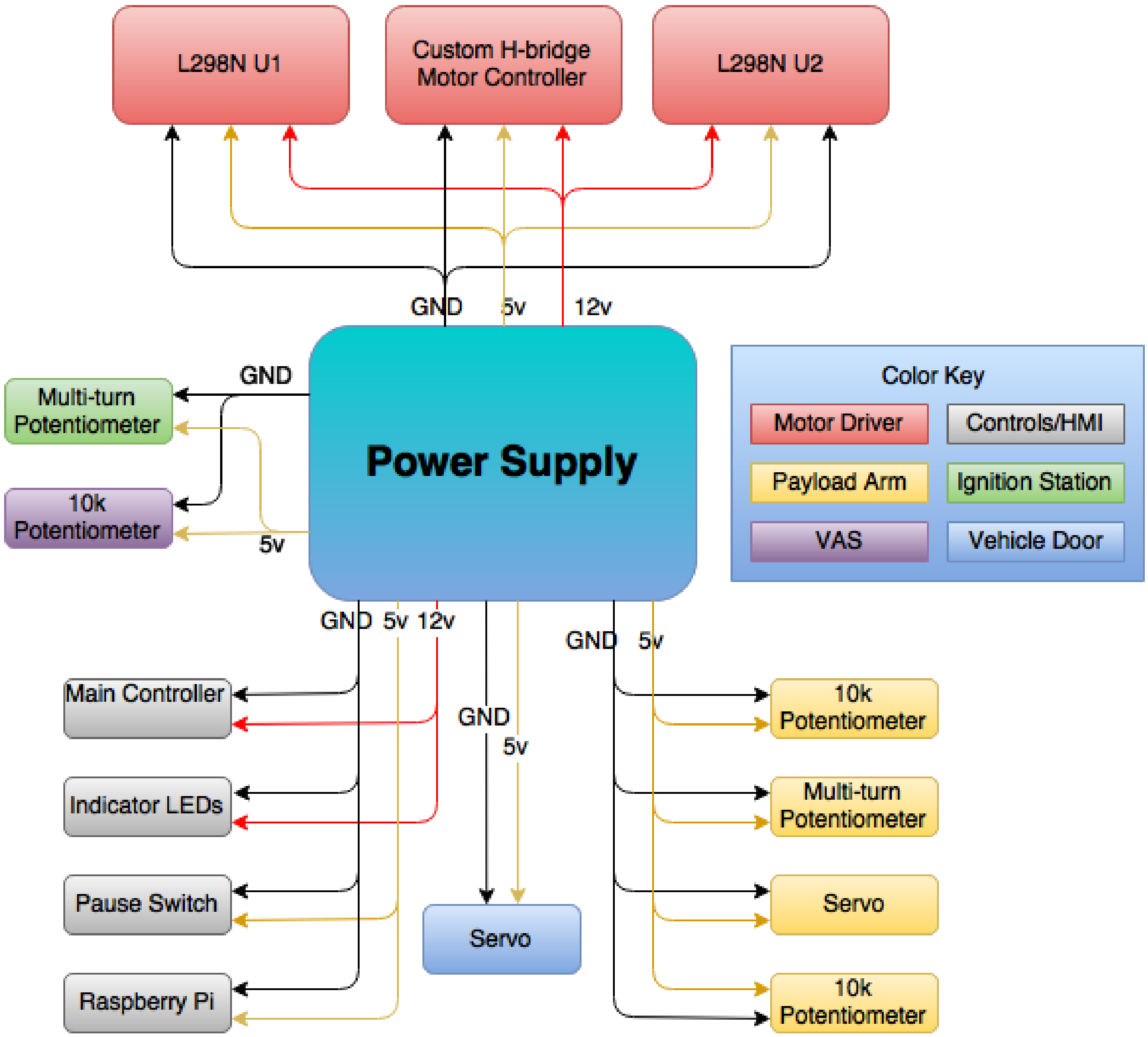


Figure 92: Power distribution diagram.

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 93 below.

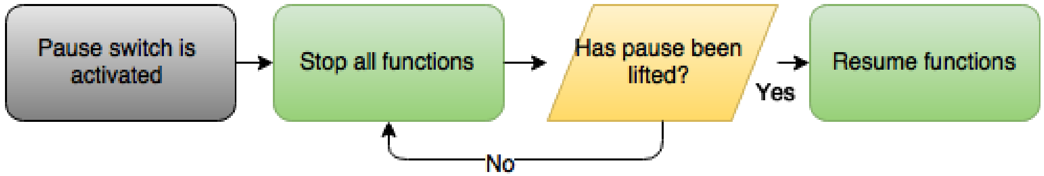


Figure 93: Pause sequence flowchart.

Testing with the SPST switch has also determined the need for a de-bouncing circuit to be implemented into the pause switch design. A bounce effect was observed when testing the pause switch, causing the pause function to be restarted 3-4 times within a 1ms window. A de-bouncing circuit has been added to the MC PCB to resolve this issue.

Upon activation, the pause function will stop any motor activity that may be happening at that moment. When the pause switch is deactivated, the program will return to executing any motor activity that may have been occurring before the pause. In order to start a motor from a dead stop, a duty cycle above that of the motor's dead-band must be applied. To avoid the potential problem of stopping a motor in its dead-zone, duty cycle functions will be written whose lowest value is above the dead-zone. Motor tests will be performed to determine each individual motor's dead-zone.

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.

Determine max current on motors.	Each motor will be tested with its intended load. Motors will be powered via the power supply and their max current draws recorded as they perform their intended tasks.	The recorded max currents are below those on the datasheets.

Table 44: System controls and integration future testing.

3) 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 45.

Mass (lb_m)	Width (in)	Height (in)	Length (in)
49.16	22.00	23.82	92.25

Table 45: Launch platform general dimensions.

A rendering of the launch tower assembly is shown in Figure 94.

Figure 94: Launch tower assembly.

Changes since PDR

The changes to the launch platform since the PDR are summarized in Table 46.

Change	Justification
Rail length decreased by 4.5 inches.	Manufacturability, all components can now be cut from a 4'x8' standard sheet.
Stability ring equally spaced.	Increased structural stability.
Launch vehicle resting point added.	Protect nose from damage while on pad.
Add fin alignment device.	Device added to ensure launch vehicle is in correct orientation for payload insertion.
Rail spacing diameter increased to 6.5".	Reduce friction on launch vehicle.

Table 46: Changes to the launch platform since PDR.

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 four 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 92 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 95.

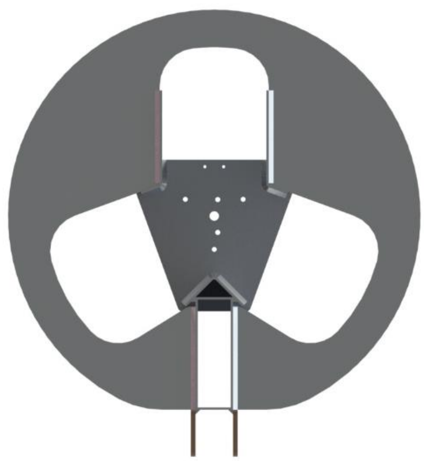


Figure 95: Launch rail configuration.

As configured, the sheet metal guide tower design limits the overall rotation of the launch vehicle during launch to 39.8 degrees. The limits of the rotation are shown in Figure 96.

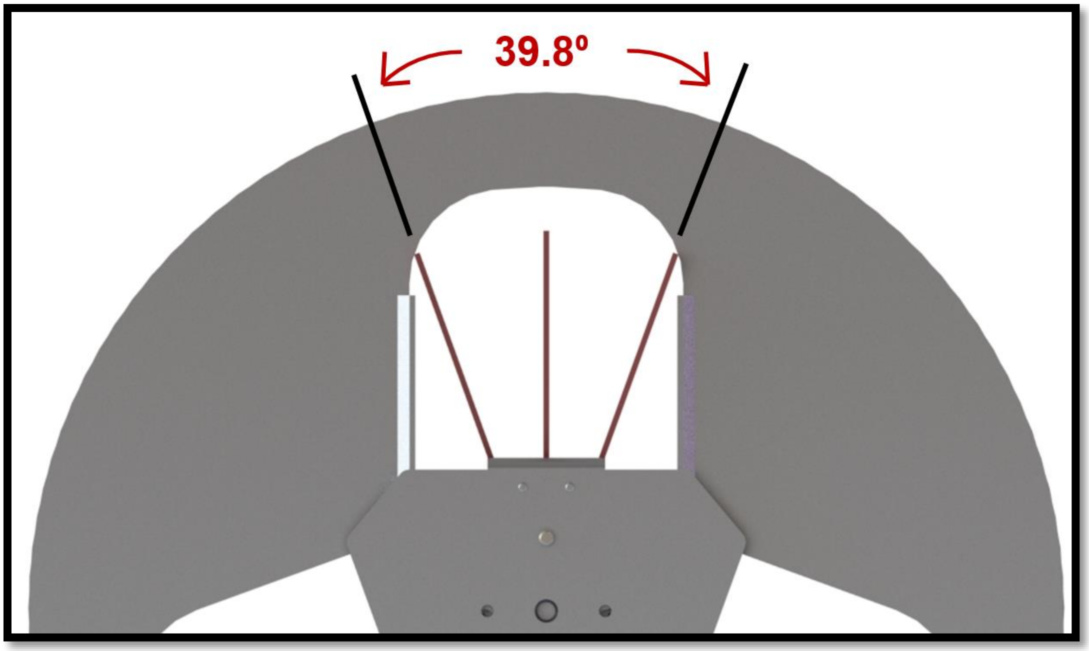


Figure 96: Diagram representing the limits of rotation for the rocket.

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 limits of this design.

The lower rail is shown in Figure 97.

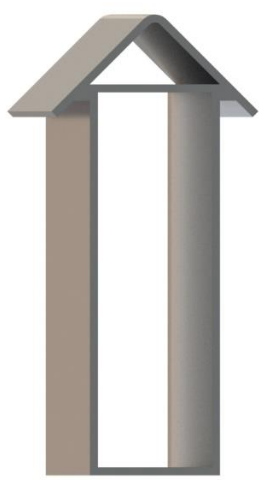


Figure 97: Launch platform lower rail.

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 92 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 98.

Figure 98: 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. Two different size rings will be used across the length of the launch platform. Three rings, will be full size and will extend to the bottom of the lower rail tube. The fourth ring, will be cut shorter to give clearance for the vehicle actuation carriage to pass. The shorter ring will be the second ring from the exit of the launch platform.

Base

The purpose of the base of the launch platform is to support the rocket once it has moved 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 99.

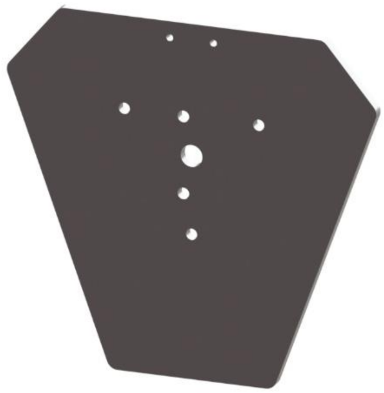


Figure 99: Launch platform base.

The base will be cut on a CNC waterjet from ¼" thick 6061-T6 aluminum plate. The base will be welded to each of the rails along each tangent edge. The base plate includes two ¼" clearance holes to attach the igniter installation device, and a ½" hole for the igniter to pass through as it enters the launch vehicle's motor. Additionally the base plate includes three threaded holes which will receive 5/16"-18 UNC 3A 1.25" long SHCS which shall support the weight of the rocket. The SHCS will space the rocket's nozzle away from the base plate and avoids resting the full weight of the rocket on the base plate.

Base Pivot

Two pivot plates will be welded to the lower launch rail. The pivot plates are shown in Figure 100.

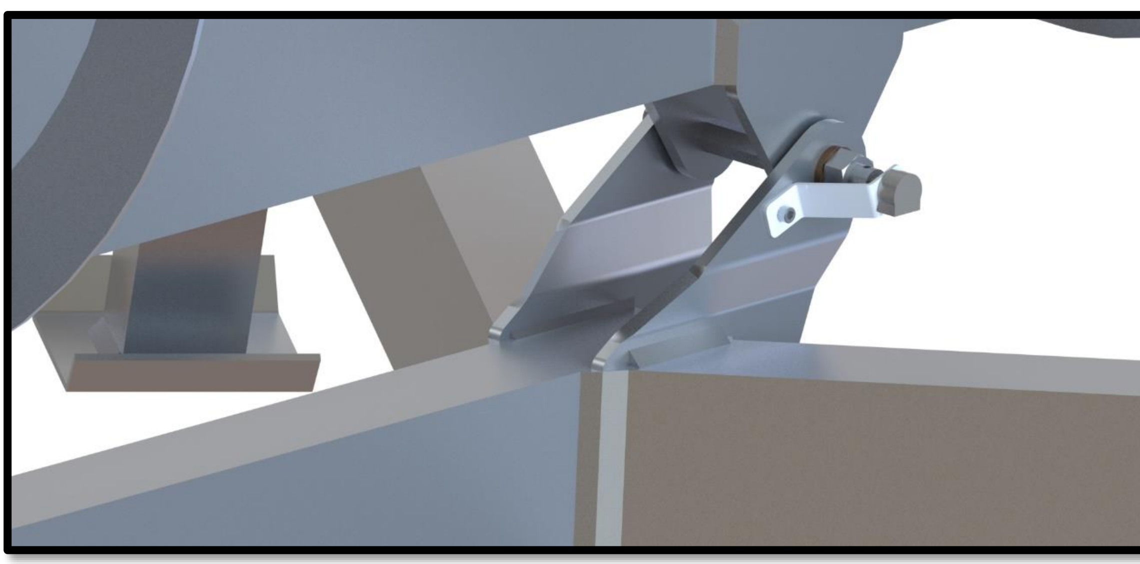


Figure 100: Launch platform base pivot point.

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 101.

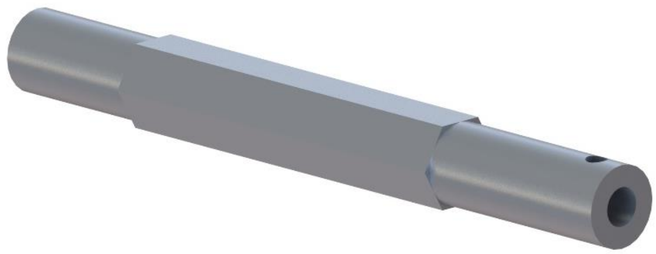


Figure 101: Base pivot axle.

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 the launch platform angle potentiometer. The launch platform angle potentiometer is discussed further in System Controls and Integration. The potentiometer interface is shown in Figure 102.

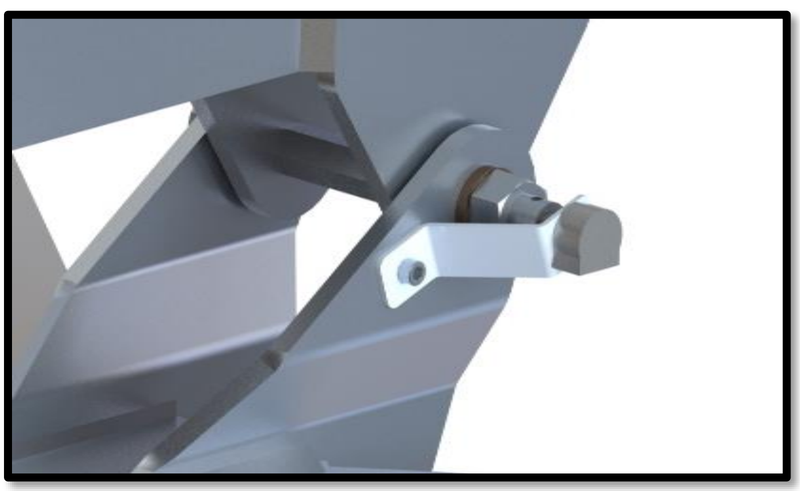


Figure 102: Base pivot potentiometer interface.

The potentiometer will be attached using a 1/16" sheet metal bracket. This bracket will be cut on a CNC waterjet and will be bent by hand. \The bracket will be secured using an 8-32 UNC 3A 1/4" long SHCS. The potentiometer will be attached to the bracket using the nut provided with the potentiometer.

Pivot Axle Analysis

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

$$\tau=\frac{2}{\pi r^3}\left(A\sqrt{\left(\frac{F_{By}}{2}\right)^2+\left(\frac{F_{Bx}}{2}\right)^2}\right) \tag{24}$$

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

$$\delta=\frac{A\sqrt{\left(\frac{F_{By}}{2}\right)^2+\left(\frac{F_{Bx}}{2}\right)^2}}{24EI}\left(3L^2-4A^2\right) \tag{25}$$

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

$$I=\frac{1}{4}\pi r^4 \tag{26}$$

The parameters shown in Table 47 were used in the shaft design calculations.

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

Table 47: Base pivot axle calculation parameters.

The results from these calculations are summarized in Table 48.

	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 48: Base pivot axle sizing calculations.

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

Launch Rail 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 49.

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 49: Material performance comparisons.

The deflection for each material was calculated using

$$\delta=\frac{PL^3}{3EI} \quad (27)$$

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

$$I=\frac{1}{12}\left[wh^3-(w-2t)(h-2t)^3\right] \quad (28)$$

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 103.

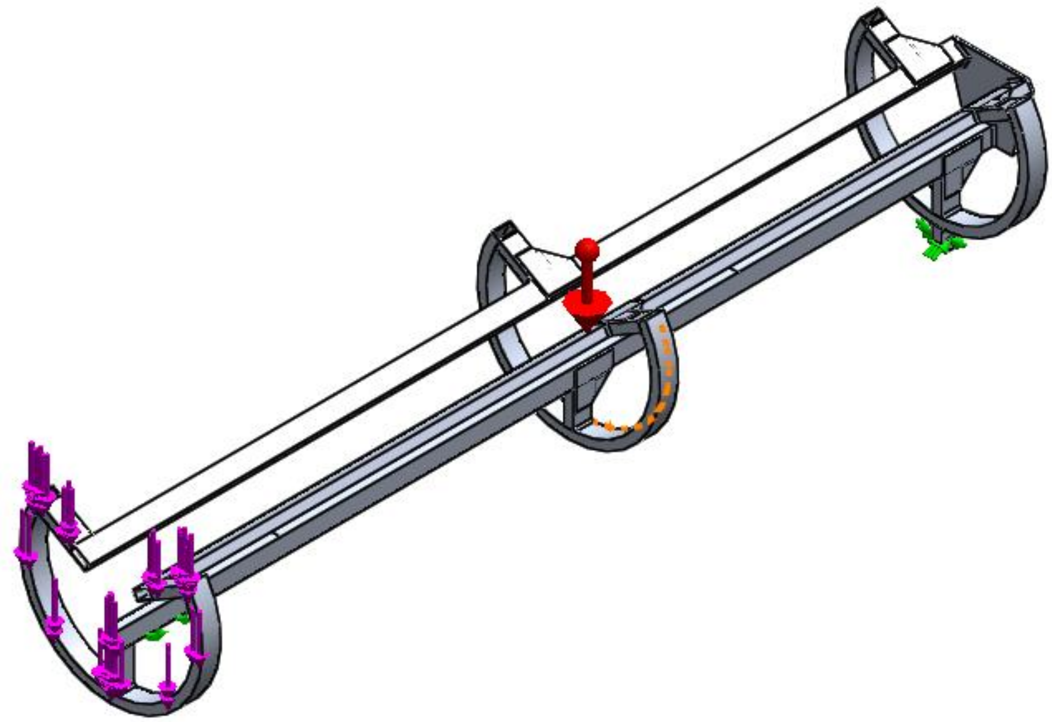


Figure 103: Structural tubing FEA model.

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 104.

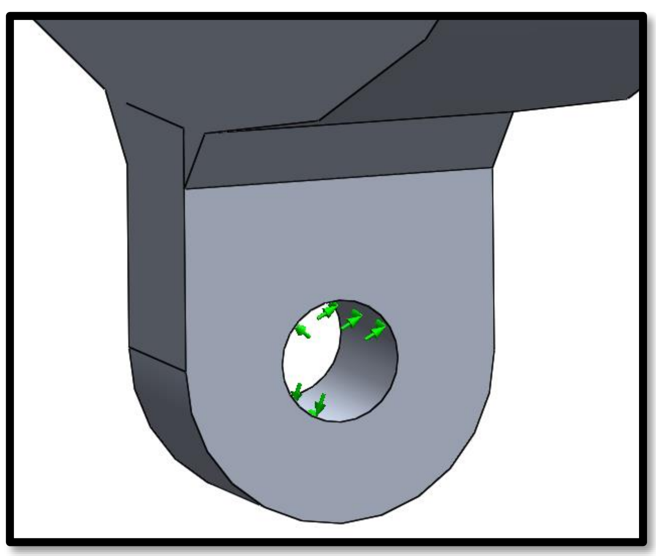


Figure 104: Base pivot fixed condition.

An additional fixed condition was placed at the front of the launch platform as shown in Figure 105.

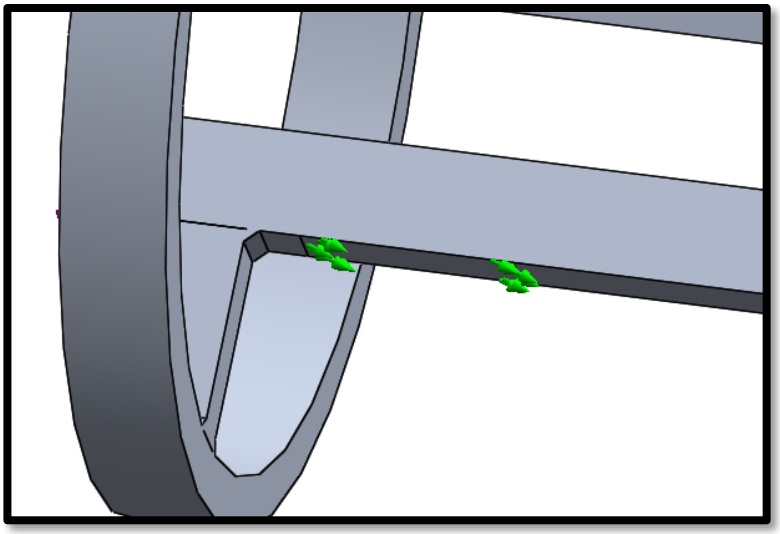


Figure 105: Actuation arm fixed condition.

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 106.

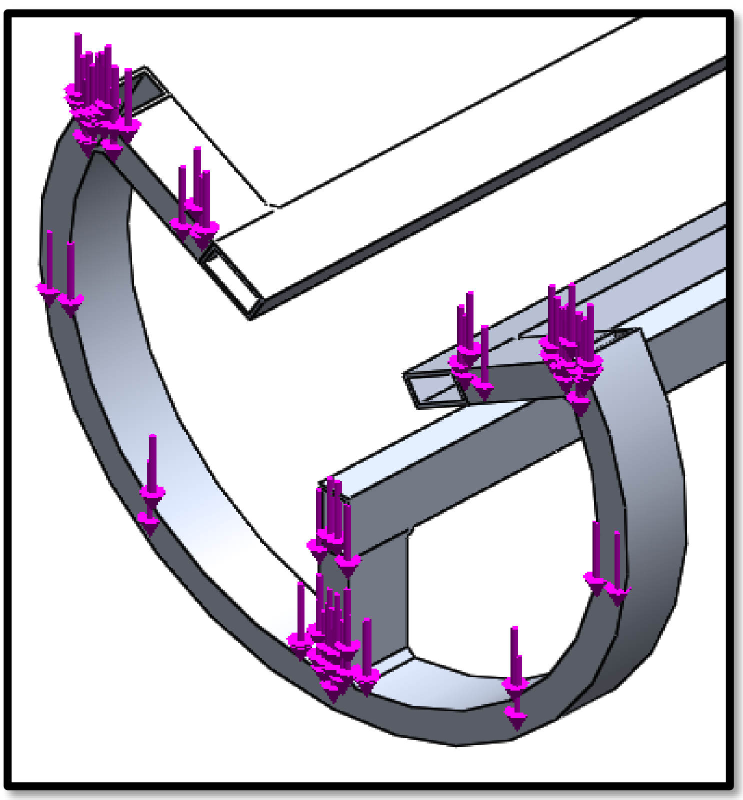


Figure 106: Simulation loading condition.

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 107.

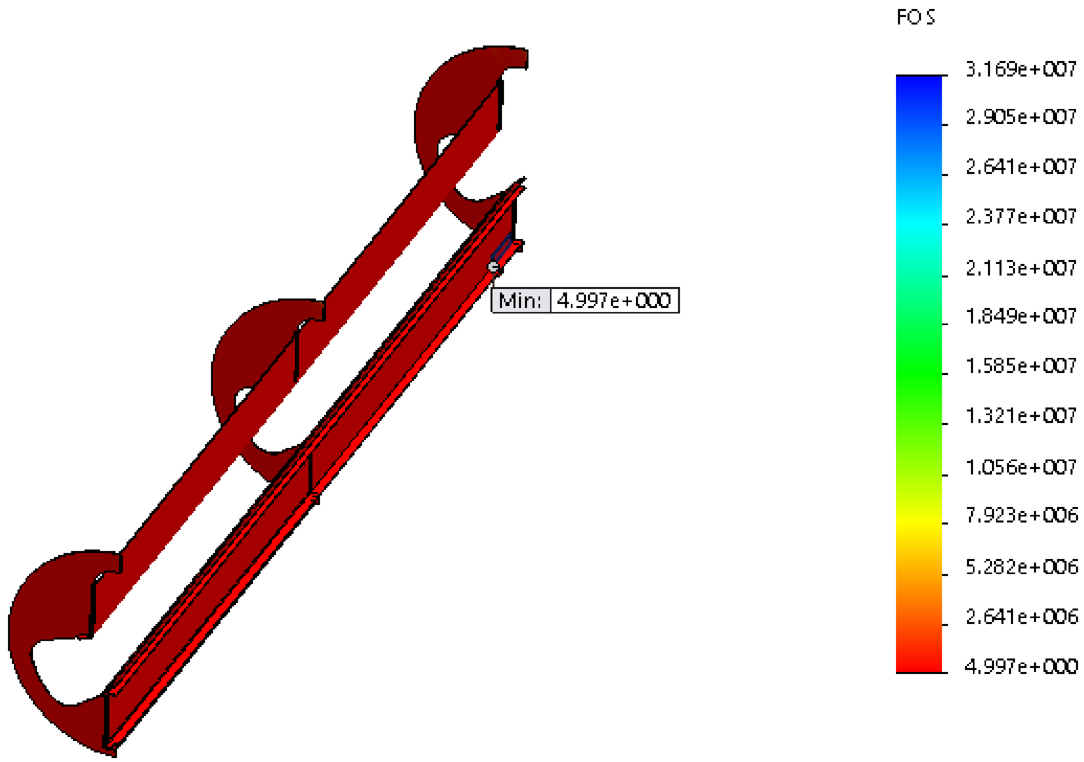


Figure 107: Sheet metal configuration factor of safety plot.

The deflection plot is shown in Figure 108.

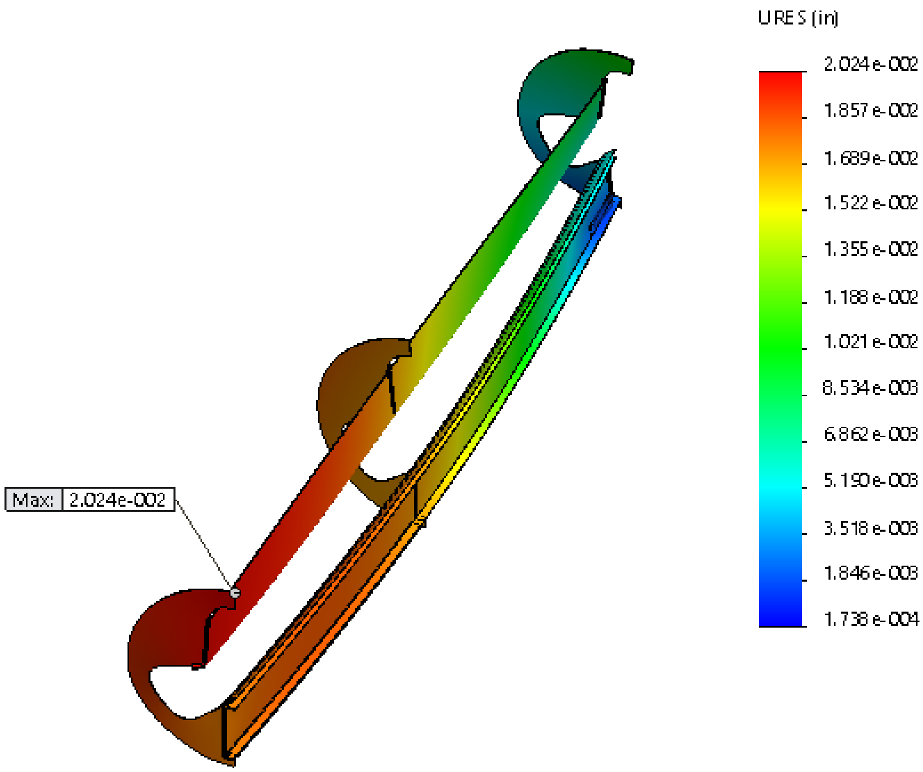


Figure 108: Sheet metal configuration deflection results.

A comparison of the max deflection, factor of safety, and weight of both configurations is shown in Table 50.

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

Table 50: 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 had an increased weight, the increased factor of safety and reduced deflections were worth the weight increase.

Based on the finding shown above in Table 50 and the ease of manufacturing the sheet metal configuration was chosen.

Final Launch Platform Configuration Structural Analysis

Additional analysis was completed to verify the final design of the launch platform. To simplify the solution process, the model was solved as a ½ symmetric model as shown in Figure 109.

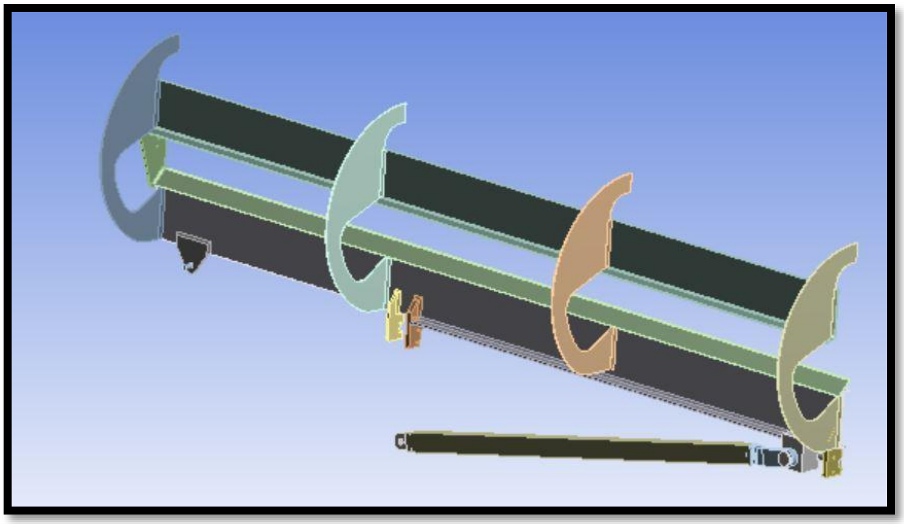


Figure 109: Launch platform FEA symmetry.

The scope of the analysis was focused on the launch platform weldment. In order to load the model in a realistic fashion a solid carriage simulant was made to replace many devices of the vehicle actuation system. The material of the carriage was defined as 6061 Alloy Aluminum to provide a conservative approximation of the carriage's stiffness.

In addition to the launch platform and simulant carriage, the articulating arms of the vehicle actuation system and the pivot axle were included in the simulation.

The stowed position of the AGSE was selected as the worst case scenario loading case for the launch platform. This position generates the highest internal loads in the AGSE.

Three fixed conditions were defined to the model. A cylindrical fixed condition was applied to the end of the articulating arm with all degrees of freedom fixed except the tangential or rotational degree. An additional cylindrical fixed condition was applied to the pivot axle constraining the same degrees of freedom as the first. The third fixed condition was applied to the inner race of the base pivot hex hole and fixed motion in the Z direction. The third fixed condition was utilized to prevent rigid body motion in the simulation. These fixed conditions are shown in Figure 110.

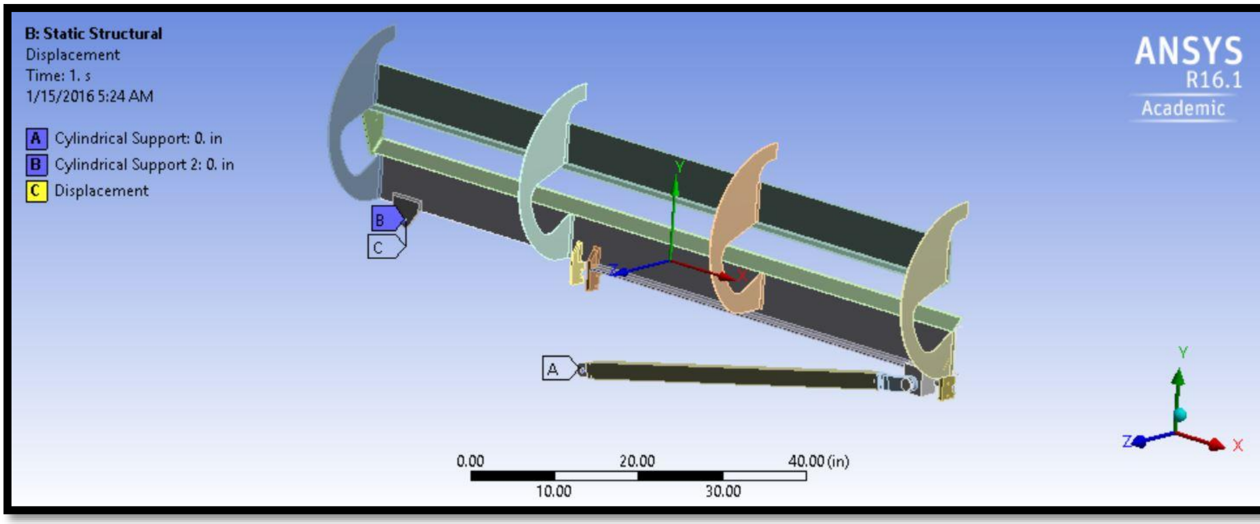


Figure 110: Launch platform FEA fixed conditions.

The simulation was loaded with standard Earth gravity acting in the negative Y direction and a single 20lb distributed load. The distributed load was positioned based on where the launch vehicle would contact the launch rail. The distributed load is shown in Figure 111.

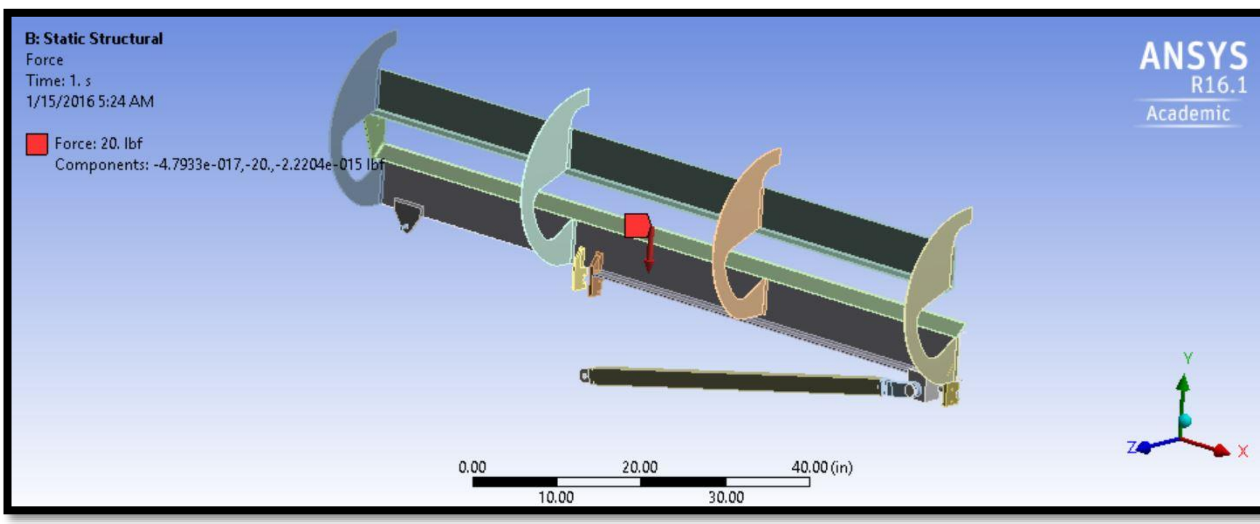


Figure 111: Launch platform FEA loading.

The factor of safety results from the simulation of the launch platform are shown in Figure 112.

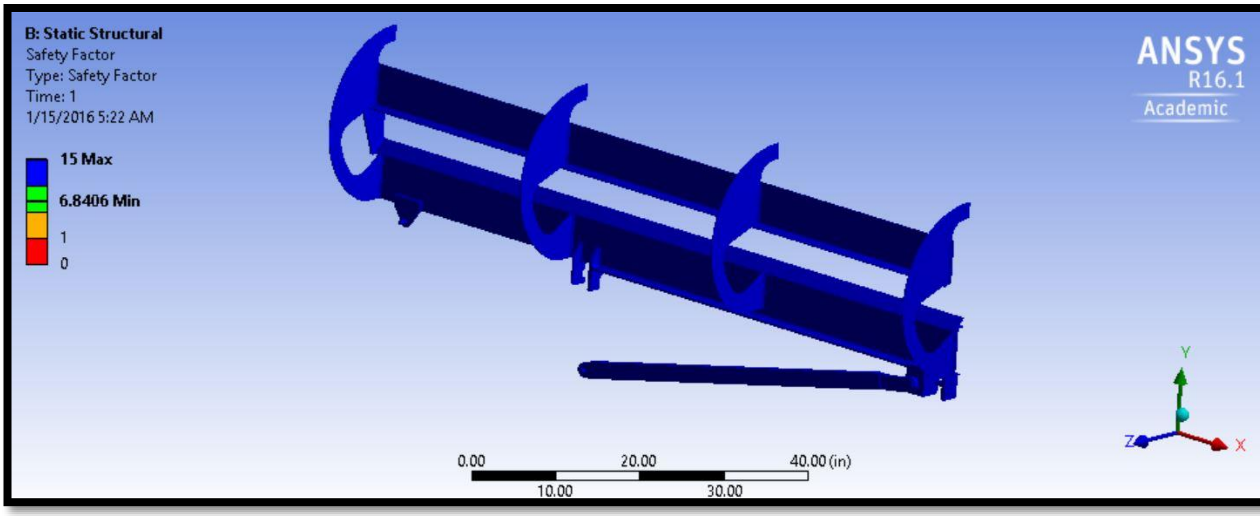


Figure 112: Launch platform FEA factor of safety results.

With a minimum safety factor of 6.8, the launch platform design was deemed acceptable.

The deformation results from the simulation of the launch platform are shown in Figure 113.

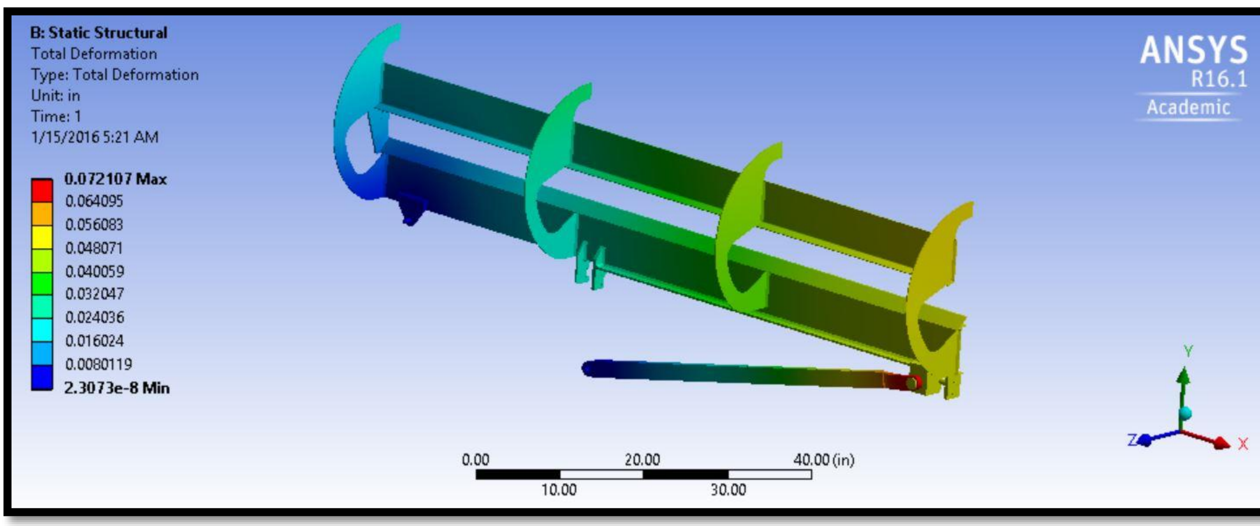


Figure 113: Launch platform FEA deformation results.

Based on the simulation, the maximum deformation of the AGSE was found to be .072. This was deemed to be an acceptable deflection when compared to the deflection of the team's 2014-2015 AGSE which was larger than 1 inch.

The reaction loads from the simulation are shown in Table 51. These reaction loads verified the original internal load approximates from the AGSE geometry optimization were indeed conservative.

Base pivot point		Articulation pivot point	
X (lb_f)	Y (lb_f)	X (lb_f)	Y (lb_f)
-146.84	22.36	146.84	33.16

Table 51: Launch platform FEA reaction loads.

4) 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 45.

Mass (lb_m)	Width (in)	Height (in)	Length (in)
28.83	8.00	5.19	63.43

Table 52: Vehicle actuation device general dimensions.

A rendering of the vehicle actuation device is shown in Figure 114.

Figure 114: Vehicle actuation device.

Changes since PDR

The changes to the vehicle actuation device since PDR are summarized in Table 53.

Change	Justification
Actuation arms shortened.	To allow launch platform to be shortened and allow full actuation.
Pivot point insertion depth standardized.	Simplifies simulation and manufacturing.

Table 53: Changes to the vehicle actuation device since PDR.

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. The carriage will be actuated along the length of the track using a ball screw. 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 115.

Figure 115: 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 CNC waterjet. 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 116.

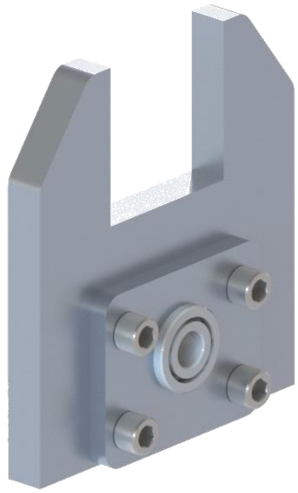


Figure 116: Removable bearing mount plate.

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. Four 5/16”-18 tapped holes will be included to attached the removable plate to the fixed mounting plate. 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 117.

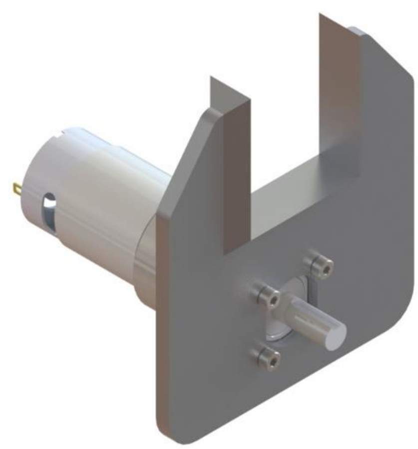


Figure 117: Motor mount plate with motor.

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 16 mm long socket head cap screws. This plate will be welded along all tangent edges to the launch platform’s lower rail tube.

The front end of the track will include a thrust bearing mounting plate. The thrust bearing mounting plate is shown in Figure 118.

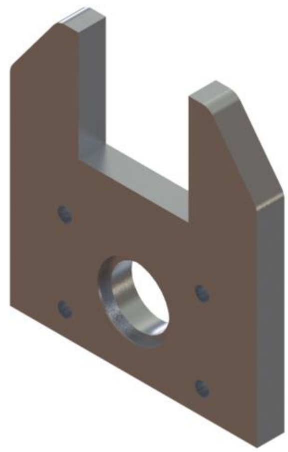


Figure 118: Thrust bearing mount.

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. Four 5/16”-18 tapped holes will be included to fasten the thrust bearing assembly to the thrust bearing mount. The thrust bearing mount will be welded along all tangent edges to the launch platform’s lower rail tube, VAS track, and the front ring. The entire thrust bearing assembly will be discussed later.

Carriage

A rendering of the carriage assembly is shown in Figure 119.

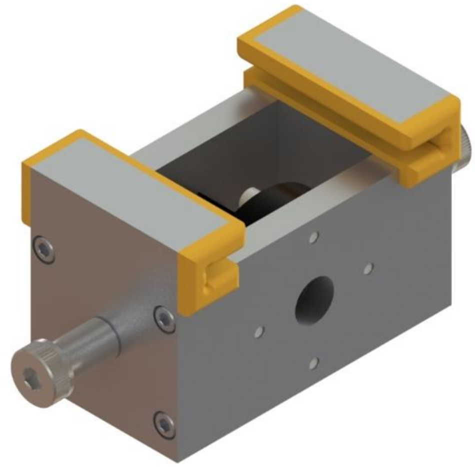


Figure 119: Carriage assembly.

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 120.

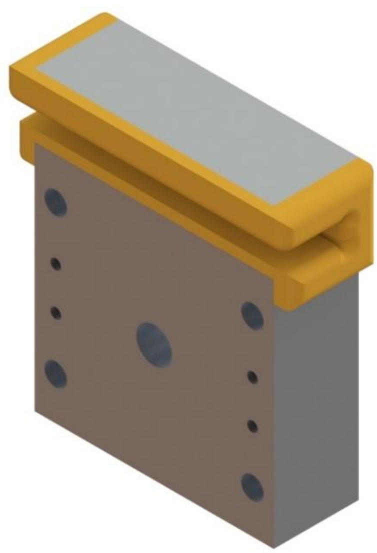


Figure 120: Carriage track engagement plate.

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 dowels will be 1” long and will be 316 stainless steel. 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 121.

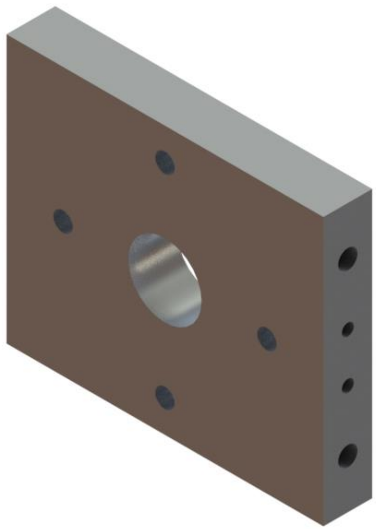


Figure 121: Ball screw engagement plate.

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.

Actuation Arms

A rendering of the actuation arms is shown in Figure 122.

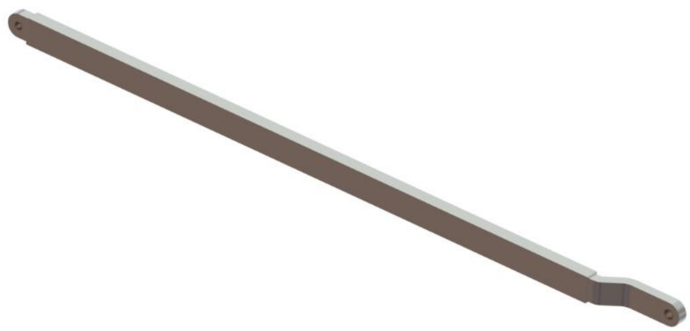


Figure 122: Actuation arms rendering.

The actuation arms will be constructed from two 1"x2" 1/8" wall 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 123.

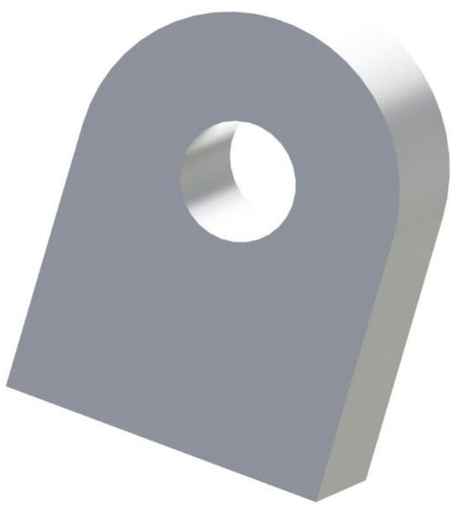


Figure 123: Lower pivot point.

The lower pivot point will be inserted into the actuation arms to a depth of 0.625" 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 124.

Figure 124: Upper pivot point.

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

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.

Thrust Bearing

As discussed earlier a thrust bearing assembly, will also be used at the end of the track 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 entire thrust bearing assembly is shown in Figure 125.

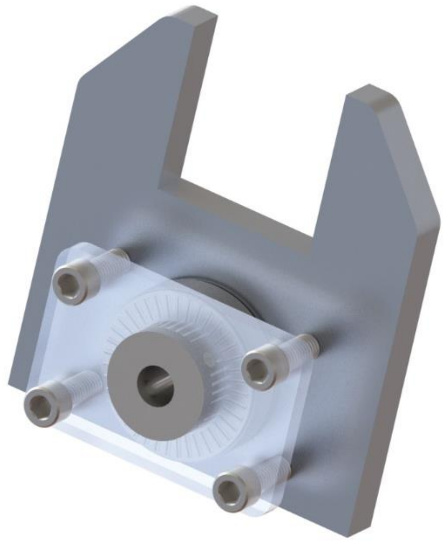


Figure 125: Thrust bearing assembly.

The thrust coupler is shown in Figure 126.

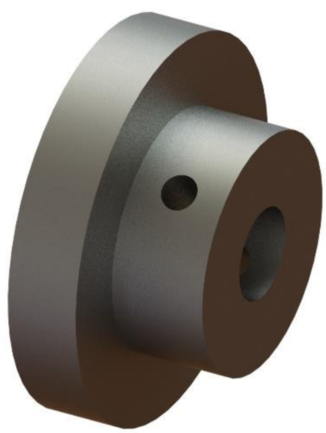


Figure 126: Thrust coupler.

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 as shown earlier.

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 127. The overall reduction of the gearbox is 26.9:1 and will provide a stall torque of 3.55 ft-lbs.

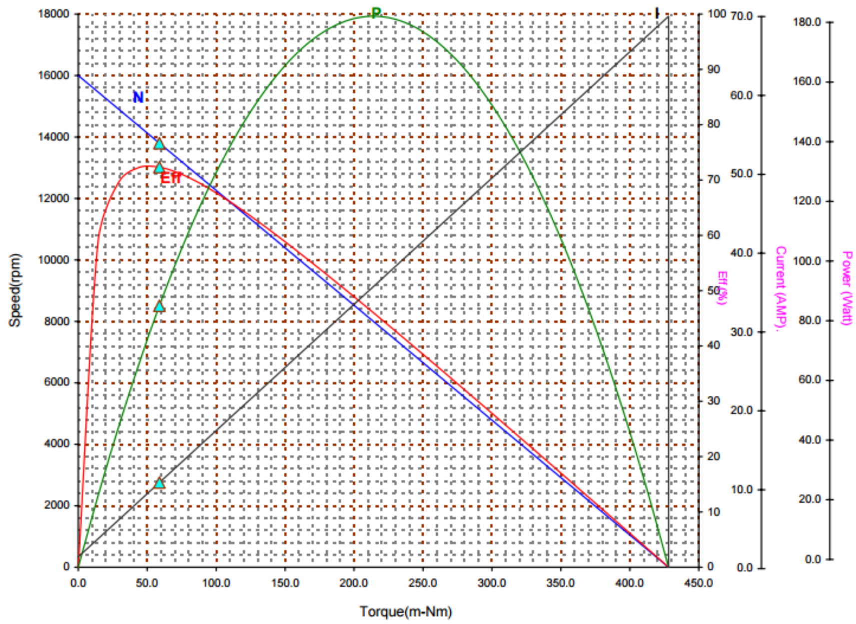


Figure 127: AndyMark 9015 motor performance curve.

Ball Screw Buckling Analysis

Analysis was completed to correctly size the ball screw. The primary failure mode of the ball screw is buckling and the Euler buckling equation was used to determine the critical load of the ball screw. The equations below have been generalized for a column structural element.

The Euler buckling load was calculated using

$$P_E = \frac{\pi EI}{(L')^2} \tag{29}$$

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

$$I = \frac{\pi R^4}{4} \tag{30}$$

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

$$L' = \frac{L}{\sqrt{C}} \tag{31}$$

where L is the column length and c is the column end fixity term. An alloy steel ball screw was selected and analyzed given the information shown Table 54 ACME screw properties and dimensions and buckling coefficient term for buckling analysis.

Modulus of elasticity (E)	30,000 ksi
Radius of ACME screw (R)	0.24 in
Column length (L)	48 in
Column end fixity (C) for uniform column, axially loaded, fixed ends	4

Table 54. Ball 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 55.

Factor of safety	1.5
Allowable load	892.98 lb

Table 55. Buckling analysis results.

Based on the results of the calculations, the selected ball screw will be sufficient for the expected load on the screw. The specific size and lead of the ball screw was selected based on the required torque and travel time requirements discussed earlier.

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 128.

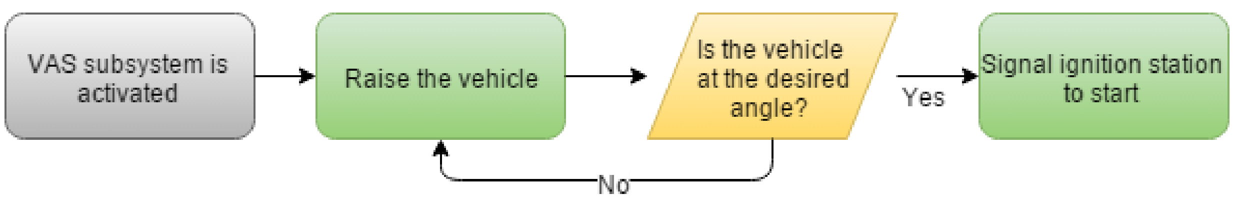


Figure 128: VAS flowchart.

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 CIM 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 CIM motor's maximum current draw for this application of 25A.

2.5" CIM motor

The 2.5" CIM motor will be used to actuate the vehicle. Torque calculations and the motor's performance curve put the max current at 25A for 12v.

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 56 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 56: 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,	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.

raise the vehicle, and insert the igniter		
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 57: 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 58: 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	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 59: VAS electrical future testing.

5) 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 60.

Mass (lb_m)	Width (in)	Height (in)	Length (in)
34.58	73.02	29.98	91.67

Table 60. Sub-frame general dimensions.

A rendering of the sub-frame is shown in Figure 129.

Figure 129: AGSE sub-frame assembly.

Changes since PDR

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

Change	Justification
HMI mount added.	HMI was to be included in final product.
Payload capture device mount modified to also mount HMI.	Reduce structural elements necessary to mount HMI.
Add launch platform rest.	Provides method to completely unload vehicle actuation system.
Wire routing access holes added.	Routing holes were necessary to properly wire AGSE.

Table 61: Changes to the sub-frame since PDR.

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 130.

Figure 130: 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 131.

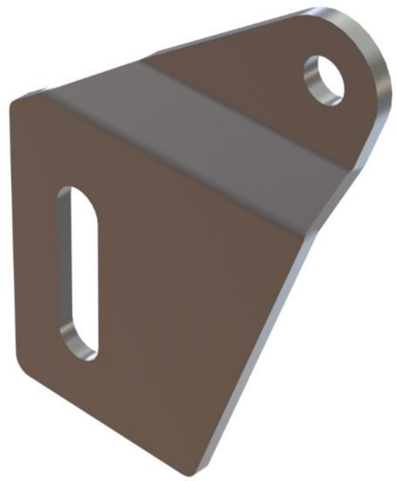


Figure 131: Base pivot bracket.

The base pivot brackets will be cut on a CNC waterjet and will be bent on a CNC press brake. 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 pivot points will have a bronze bushing installed to reduce friction in the joint. The bronze bushing will have a shaft diameter of 0.5" and a depth of 0.25". The bushing will also include a 0.875" wide and 0.125" deep flange to retain the bushing 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 132.

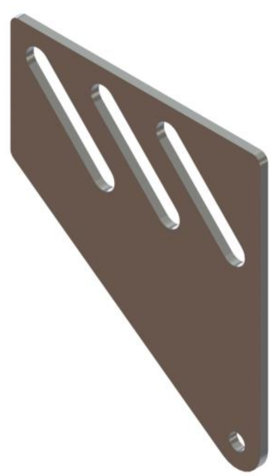


Figure 132: Actuation pivot plate.

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 actuation plates will also have a pivot axle welded into the pivot points on the plate.

Payload Capture Device and HMI Mount

The payload capture device and HMI will be mounted using a cantilever structure as shown in Figure 133.

Figure 133: Payload capture device and HMI mounting.

The cantilever structure will be comprised of 2”x2” 1/8” thick wall 6061-T6 aluminum structural tubing, 1/8” 6061-T6 aluminum gussets and a 1/8” thick 6061-T6 aluminum HMI interface plate. The structural tube will be machined using a manual lathe, the gussets and HMI interface plate will be cut on a CNC waterjet. The structural tubes and HMI interface plate have wire routing holes to help manage wire organization. These holes will be lined with grommets or other precautions will be taken to ensure wires are not severed. The cantilever structure will be welded together along tangent edges.

Pivot Axle Sizing Analysis

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 62.

	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 62: Base pivot axle sizing calculations.

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

Sub-frame Structural Analysis

A finite element analysis was completed to verify the final design of the sub-frame. To simplify the solution process, the model was solved as a ½ symmetric model as shown in Figure 134.

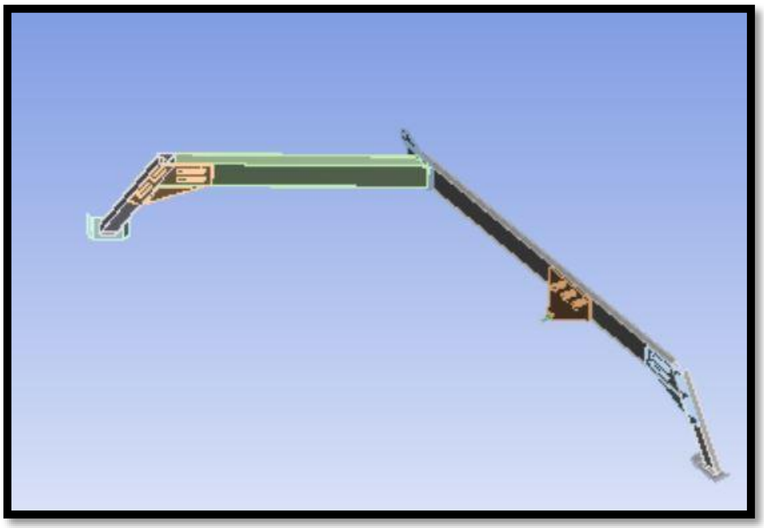


Figure 134: Sub-frame FEA symmetric model.

The scope of the analysis was focused on the sub-frame weldment. The results of the launch platform final configuration structural analysis were used to determine the loading condition for the sub-frame simulation. The loading case for this analysis is shown in Figure 135.

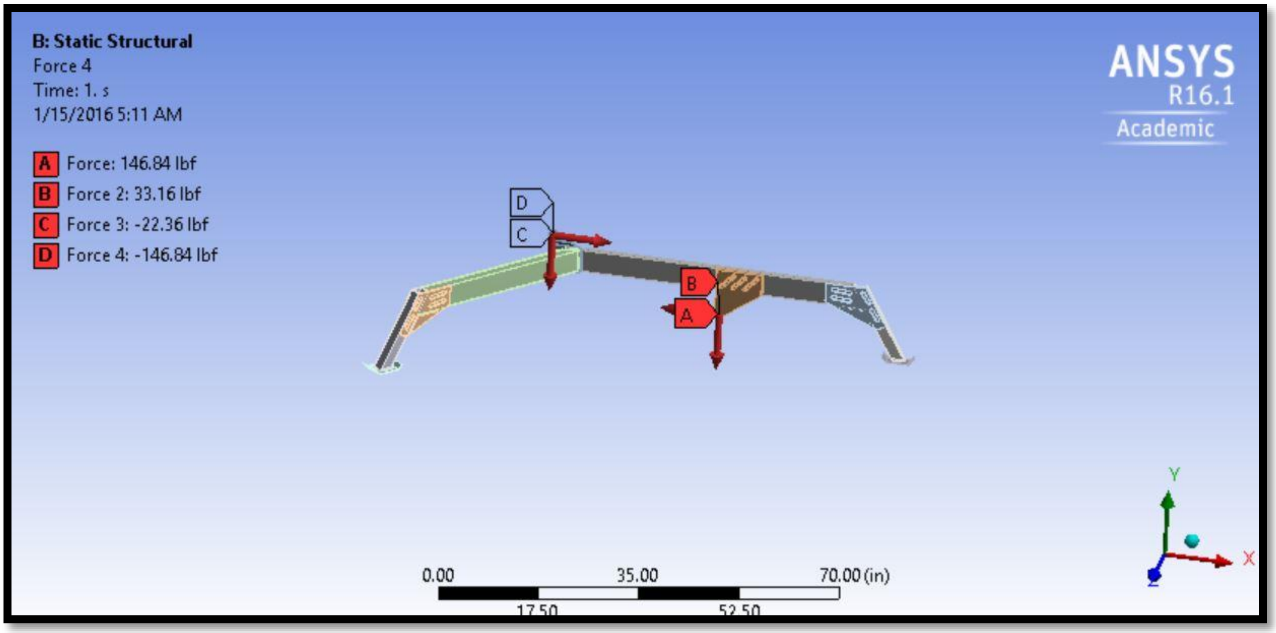


Figure 135: Sub-frame FEA loading case.

Two fixed conditions were applied to the model. The front foot was fixed in all three directions. The rear foot was fixed on in the X direction. These fixed conditions are shown in Figure 136.

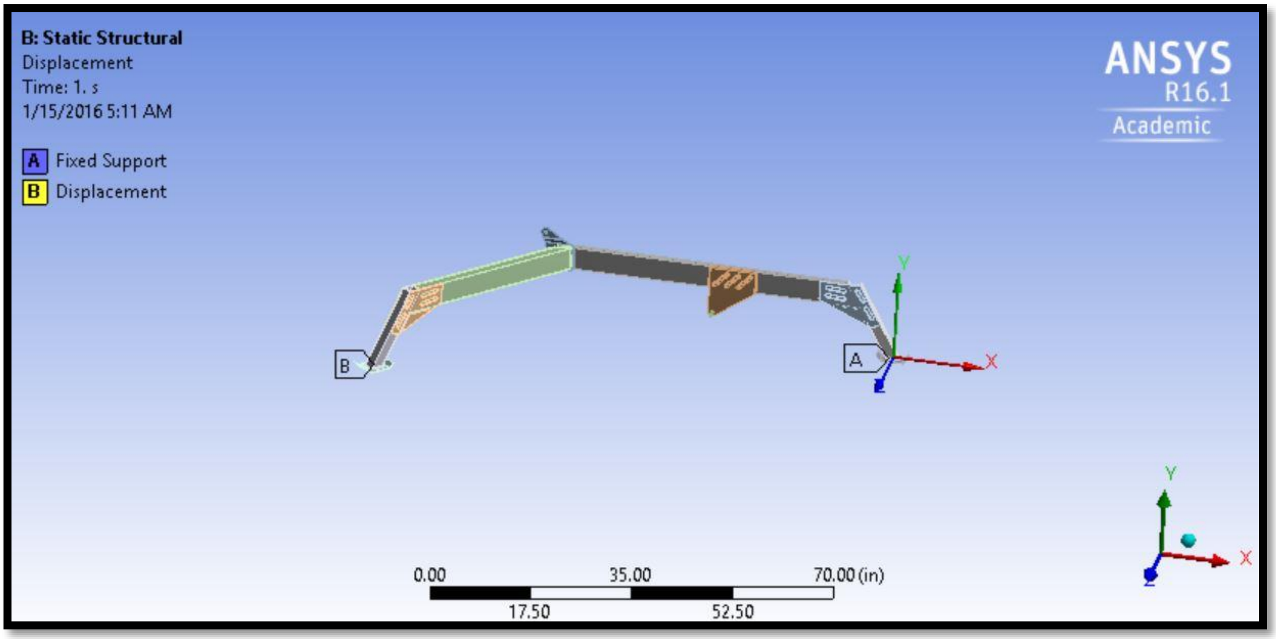


Figure 136: Sub-frame FEA fixed conditions.

The simulation was loaded with standard Earth gravity acting in the negative Y direction and the reaction loads from the previous launch platform analysis. The factor of safety results from the simulation of the sub-frame are shown in Figure 137.

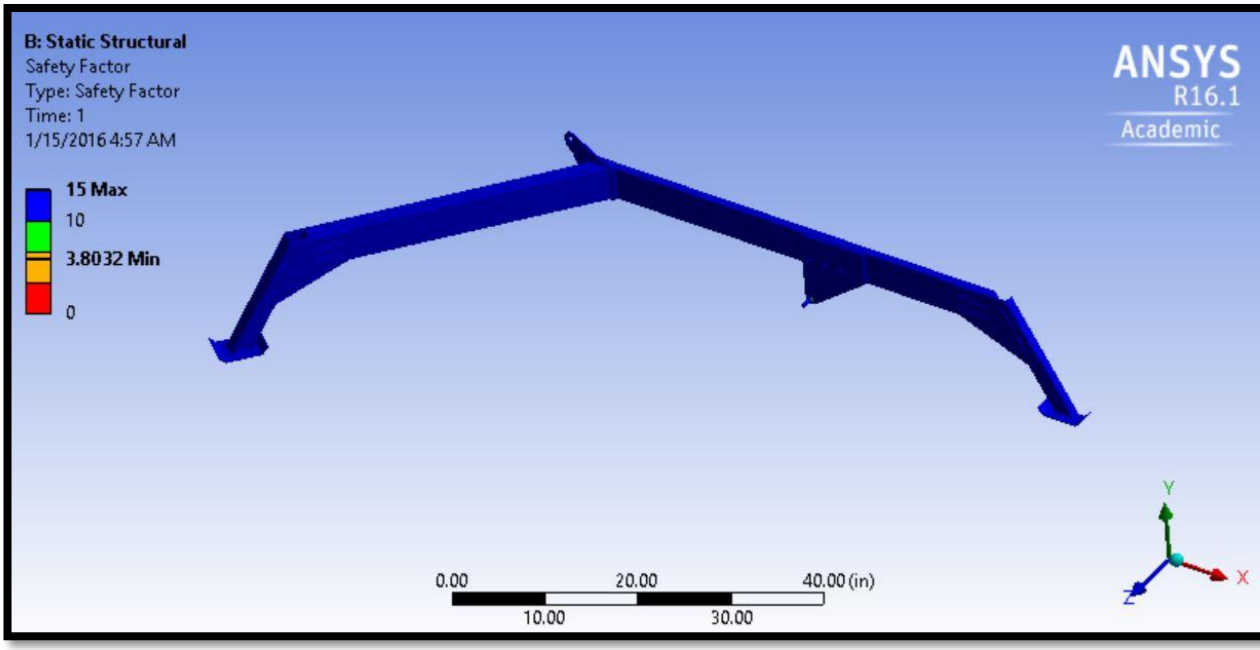


Figure 137: Sub-frame FEA factor of safety results.

With a minimum safety factor of 3.8, the sub-frame design was deemed acceptable. The deformation results from the simulation of the sub-frame are shown in Figure 138.

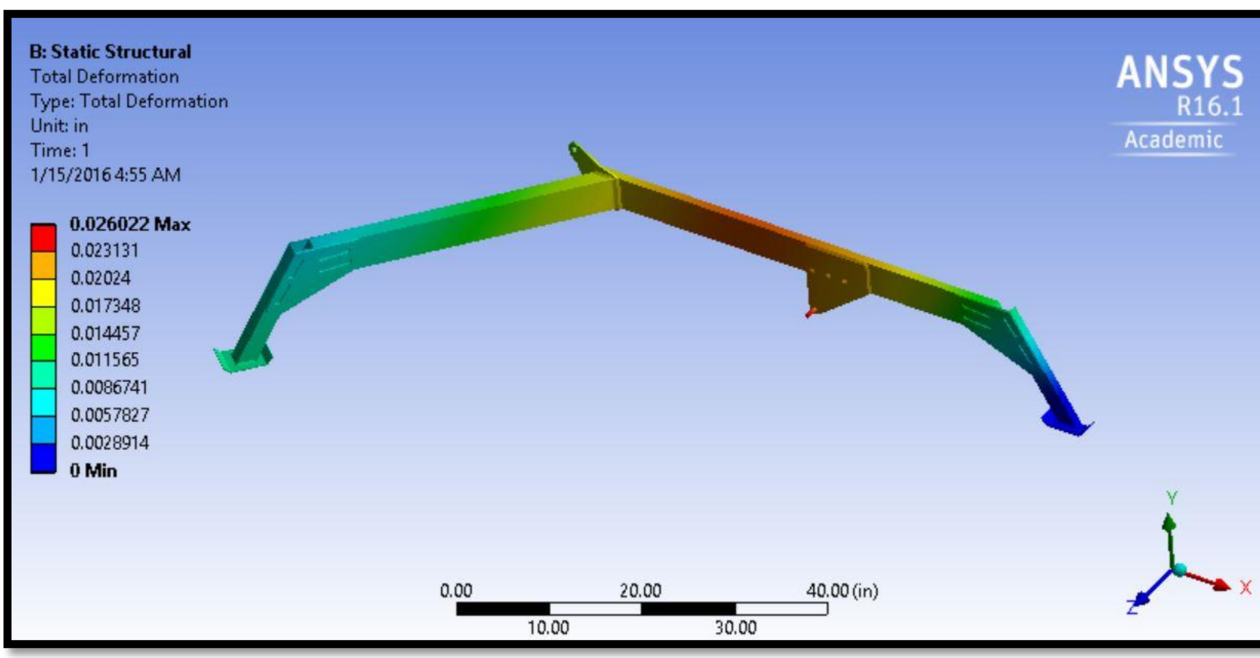


Figure 138: Sub-frame FEA deformation results.

Based on the simulation, the maximum deformation of the sub-frame was found to be 0.026 inches.

Stability Analysis

Stability will be continually analyzed throughout the manufacturing process of the AGSE. During the design phase, stability was continually analyzed to ensure the idea footprint for the AGSE was designed. This culture will be transitioned into the manufacturing phase as manufactured components will be compared to the design specifications ensuring tolerances are met and the approximated weights were correct. The current approximate center of gravity location is represented in Figure 139 as the yellow sphere.

Figure 139: AGSE center of gravity location.

During the launch of the launch vehicle, the AGSE will experience a different loading case that is not as much based on the center of gravity. The primary factor in stability of the AGSE during launch, is the launch vehicles orientation and the direction of the trust. Figure 140 shows that the direction of the thrust from the launch vehicle when launched from an angle 85 from horizontal will be well within the footprint of the AGSE. Therefore, stability during launch is not of concern.

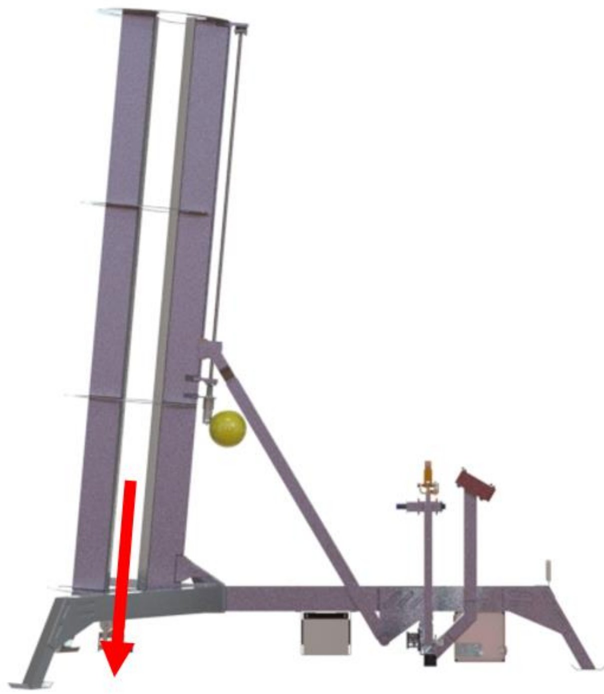


Figure 140: Rocket thrust direction.

6) Payload Capture Device

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 63.

Mass (lb_m)	Width (in)	Height (in)	Fully Extended Length (in)
5	5.56	5.67	45.11

Table 63. Payload capture device general dimensions.

A rendering of the payload capture device is shown in Figure 141.

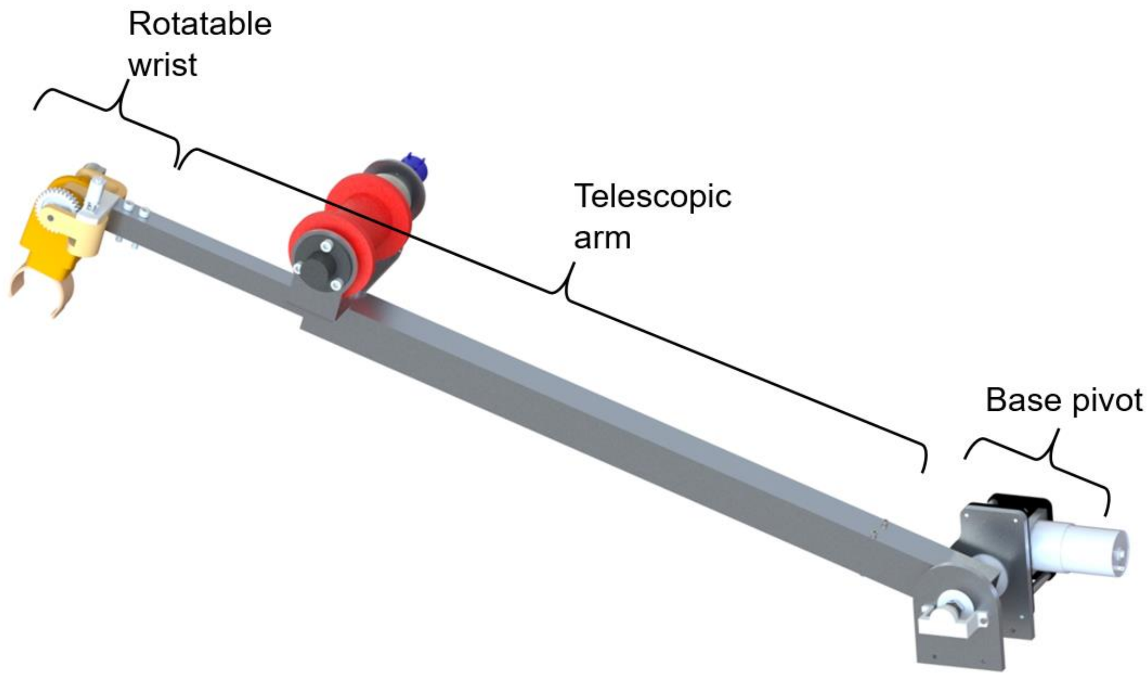


Figure 141. Payload capture device rendering.

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 in order to perform the required maneuvers. This allows the payload capture device to be able to reach the minimum distance of 12 inches outside the AGSE.

When in the fully retracted state, the payload capture device is compact enough to be able to rotate towards the AGSE for insertion of the payload without having interference with the AGSE or the rocket.

A rendering of the telescopic arm is shown in Figure 142.

Figure 142. Telescopic extension arm (outer tube transparent for clarity).

The telescopic arm will consist of the following components:

Component Name	Component Description	Quantity
Inner Tube	¾" 6061-T6 aluminum structural tube, 1/16" thick	1
Outer Tube	1 ¼" 6061-T6 aluminum structural tube, 1/16" thick	1
ACME screw	16 in long, ¼ - 16 ACME screw	1
Delrin Sliders	Custom machined.	8
DC Motor	ServoCity	1

Table 64: Telescopic arm component list.

The telescopic arm will consist of two structural tubes. The inner tube will have Delrin sliders mounted on each exterior face and the outer tube will have sliders mounted on each interior face of the tube. A detailed view of the Delrin sliders mounted on the inner tube are shown in as shown in Figure 143.

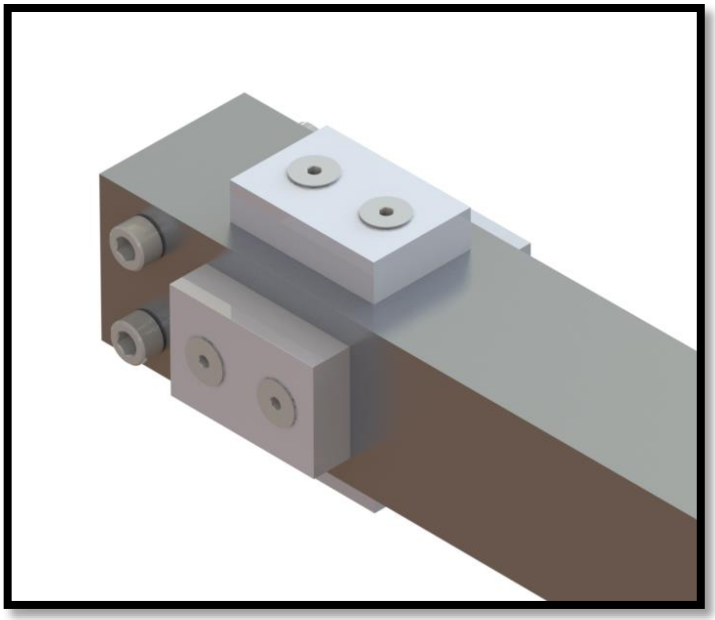


Figure 143: Detailed view of Delrin sliders.

These sliders provide a smooth surface for the two tubes to slide against as the telescopic arm extends and retracts while preventing any side to side movement. Additionally, due to the placement of the sliders, they act as physical stops which prevent the system from over extending or trying to retract too far, helping prevent damage.

The actuation of the telescopic arm is performed by utilizing a motor to rotate the ACME screw. An ACME screw was chosen so that when the arm needs to be held in a desired position, the motor is not stalled. The ACME screw rotates in a threaded plate that is fixed in the inner tube. The ACME screw and plate configuration allow for the inner tube to extend and retract with based on the rotation of the ACME screw.

As a result of the telescopic arm actuating, it is critical to manage the wires that are needed for the wrist and gripper assembly in order to prevent over tensioning or pinching wires between the inner and outer tubes. Organization will be achieved via a wire spool, which is shown in Figure 144.

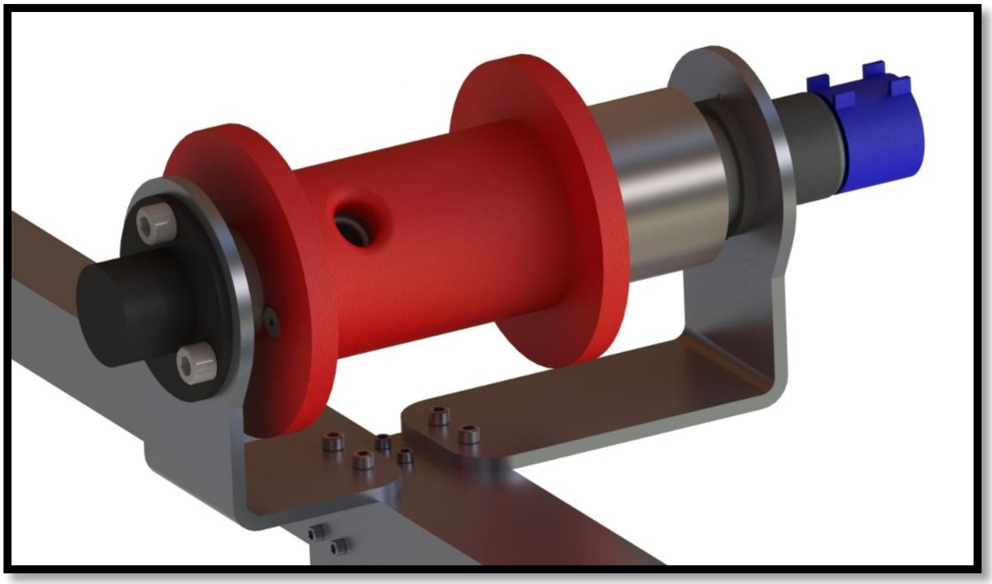


Figure 144. Payload arm wire spool.

The spool is broken up into two components in order to allow for mounting on the shaft. One half of the spool has a flat feature where it mates with the shaft, as shown in Figure 145.

Figure 145: Wire spool (only one half shown for clarity).

The flat spot is a keying feature which will lock the spool in place on the shaft and prevent it from rotating with respect to the shaft.

In order to route the wires from the base of the payload capture device, through the spool, and up to the gripper assembly, an Adafruit slip ring will be utilized. This allows for the wires to be routed from the base of the payload capture up to the spool, where the slip ring is located. The wires are then connected to the fixed half of the slip ring and mounted to the bracket that supports the spool. The shaft on which the spool is mounted, is hollow and connected to the slip ring. This causes the rotating portion of the slip ring to rotate with the spool shaft. The shaft and the spool have corresponding holes for the wires to be routed out of and coiled onto the spool.

In order to keep the wires taught, the shaft will be spring loaded. 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 shaft and the other end is mounted to the bracket as shown in Figure 146.

Figure 146: Cross section view of the constant force spring on shaft.

While the constant force spring provides the necessary tension to eliminate slack in the wires that have a potential to get tangled or pinched in the device, placing a load on the wire connections must be avoided. Applying a load on the wire connections could result in unwanted, broken connections. In order to prevent this, a strain relief mechanism will be used.

Since a DC motor is being used to drive the telescopic arm, feedback cannot be retrieved from the motor as to the precise location of the arm. However, knowing a precise location is critical for the payload capture device to be able to extend and retract the exact distances required in order to successfully retrieve and place the payload. With this in mind, a potentiometer will be used to retrieve this information.

A ten turn potentiometer will be mounted onto the bracket and connected to the shaft. The spool is appropriately sized so that it will not rotate more than ten times and break the potentiometer. This provides feedback to the system on the location of the telescopic arm as shown in Figure 147.

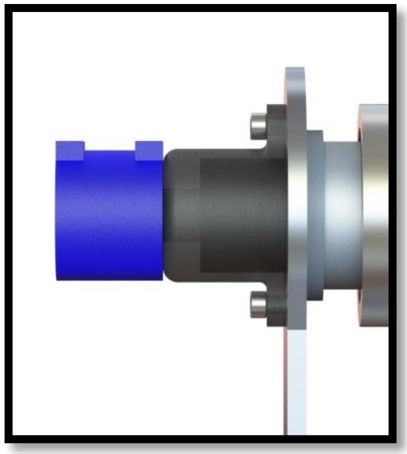


Figure 147: Potentiometer and mount for wire spool (potentiometer mount transparent for clarity).

The shaft will be machined on a lathe out of Delrin, due to its light weight properties. Additionally, since wires must be routed through the interior of the shaft and exit via a hole in the shaft, rough edges must be avoided in order to prevent chafing of the wires. The edges for the holes will be rounded to prevent any sharp edges. A cross section view of the shaft in the wire spool assembly is shown in Figure 148.

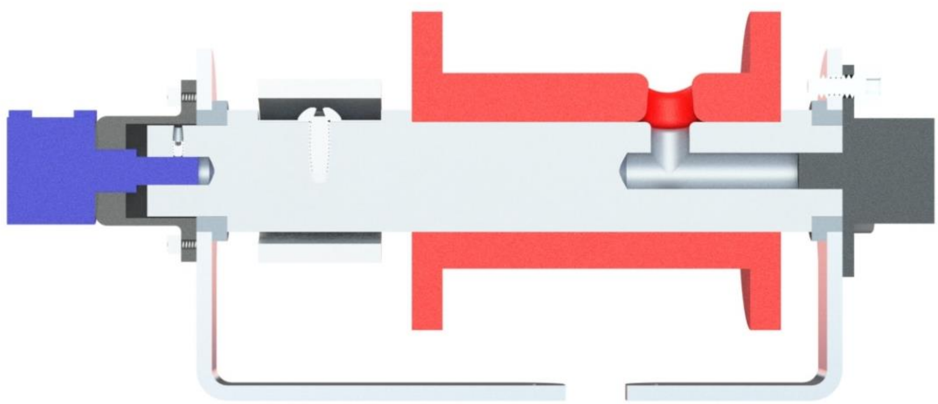


Figure 148: Cross section view of the wire spool assembly and shaft.

The shaft will be supported by two brackets which are mounted to the outer tube. The shaft will ride in two custom, Delrin bearings to provide a smooth rotational surface.

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 149. This gearbox will be paired with a 12V, 75RPM, 160 oz-in gear motor. This motor was selected based on the Base Pivot Motor Torque and Speed Analysis.

The worm gearbox was selected to prevent 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 149.

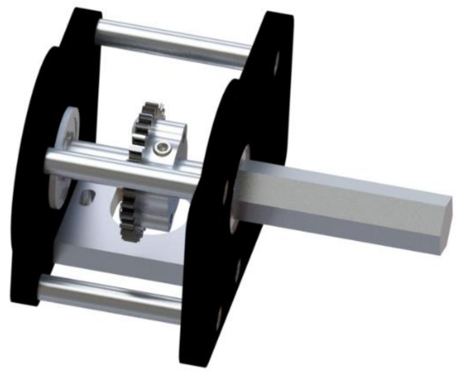


Figure 149. Telescopic arm pivot gearbox.

Feedback must be sent to the central processor from the rotation base pivot point to know how the payload capture device is oriented. This will be accomplished via a potentiometer which will be connected to the shaft of the base. The potentiometer will be mounted to the base pivot wall with a 3D printed mount as shown in Figure 150.

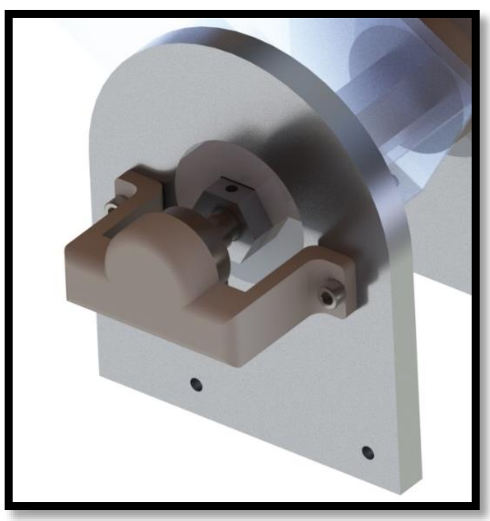


Figure 150: Base pivot potentiometer mount.

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. Testing will be completed to verify the 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 153.

Figure 151: Payload capture gripper device.

The gripper device is attached to the gripper assembly via a locking paddle. When in the start position, the paddle compresses the gripper and is locked into place, as shown in

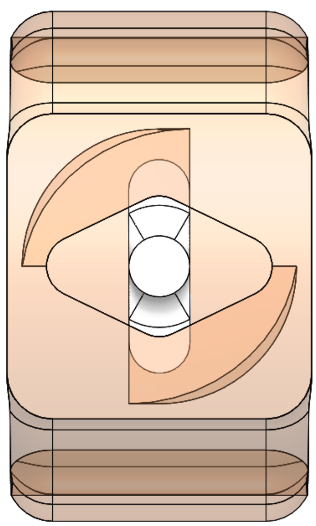


Figure 152: View of transparent gripper with paddle in locked orientation.

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 153.

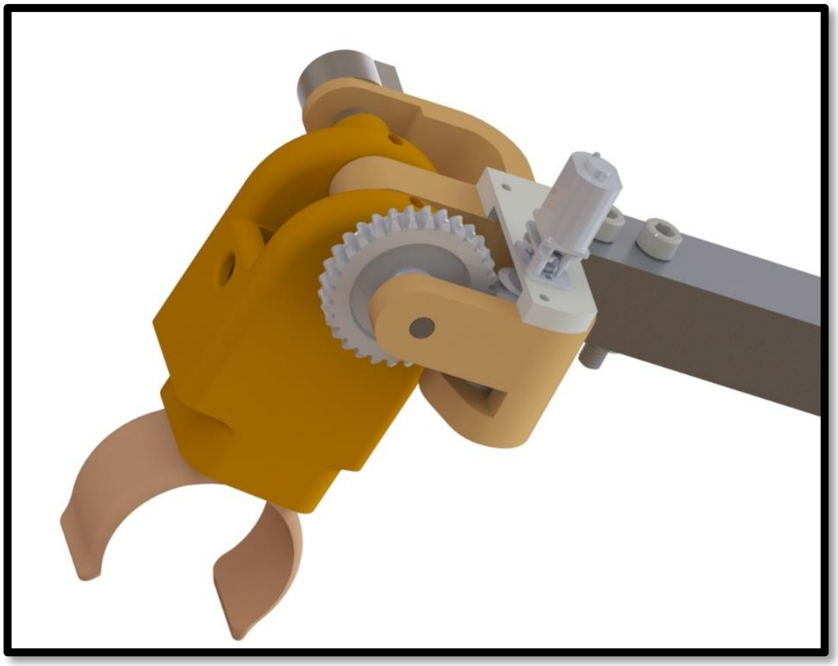


Figure 153. Payload capture device wrist.

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. A potentiometer will be integrated into the wrist to provide position feedback to the central processor.

In order to prevent gear slippage for this gear configuration, a two piece 3D printed ABS plastic support system will be used as shown in Figure 154.

Figure 154: Gear support system and wrist connection.

This support system will house the wrist gear motor and give support to the worm gear from both sides to prevent it from slipping off of the spur gear during actuation.

Analysis

ACME Screw Buckling Analysis

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 telescopic arm will be actuated using a 16-inch long, ¼-16 ACME screw.

The Euler buckling load was calculated using

$$P_E=\frac{\pi EI}{(L')^2} \quad (32)$$

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

$$I=\frac{\pi R^4}{4} \quad (33)$$

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

$$L'=\frac{L}{\sqrt{C}} \quad (34)$$

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 54 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 65. 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 55.

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

Table 66. 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.

ACME Screw Required Motor Torque and RPM Analysis

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

$$T=\left(\frac{wd_m}{2}\right)\left(\frac{f\pi d_m+L\cos\alpha_n}{\pi d_m\cos\alpha_n-fL}\right) \tag{35}$$

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 67.

Lift load (w)	0.57 lbs
Mean diameter of thread contact (d_m)	0.2055 in
Running friction (f)	0.2

ACME screw lead (L)	0.063 in/rev
Thread angle calculation ($\cos\alpha_n$)	1

Table 67. System properties used to calculate ACME screw torque.

Based on the calculated torque and assuming an operating efficiency, a 12V DC micro gearmotor from ServoCity was selected to ensure that the torque requirements were met as shown in Table 68.

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

Table 68. Assumed motor efficiency and required torque.

Along with the torque of the motor, the RPM of the motor was taken into consideration. The telescopic arm needs to go from a fully retracted to fully extended position in the allotted time frame. The minimum required RPM was calculated for the motor. RPM calculations and RPM of the selected motor are shown in Table 69.

Time allotted	15 sec
Required RPM	1042.62
Selected motor RPM	2600

Table 69. Motor RPM requirements and specification.

Base Pivot Motor Torque and Speed Analysis

In order to ensure that the motor selected for the base pivot was appropriately sized, calculations were done to determine the required torque using the parameters shown in Table 70.

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

Torque was calculated using

$$T=w_1x_1+w_2x_2 \quad (36)$$

where w_1 is the weight of the telescopic arm, x_1 is the center of mass of the telescopic arm, w_2 is the weight of the payload, and w_2 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 71.

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

Table 71: 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 12V DC, 75 RPM, 160 oz-in motor. RPM calculations and RPM of the selected motor are shown in Table 72.

Time allotted	105 sec
Required RPM	34.29
Selected motor RPM	75

Table 72: Motor RPM requirements and specification.

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 155**.

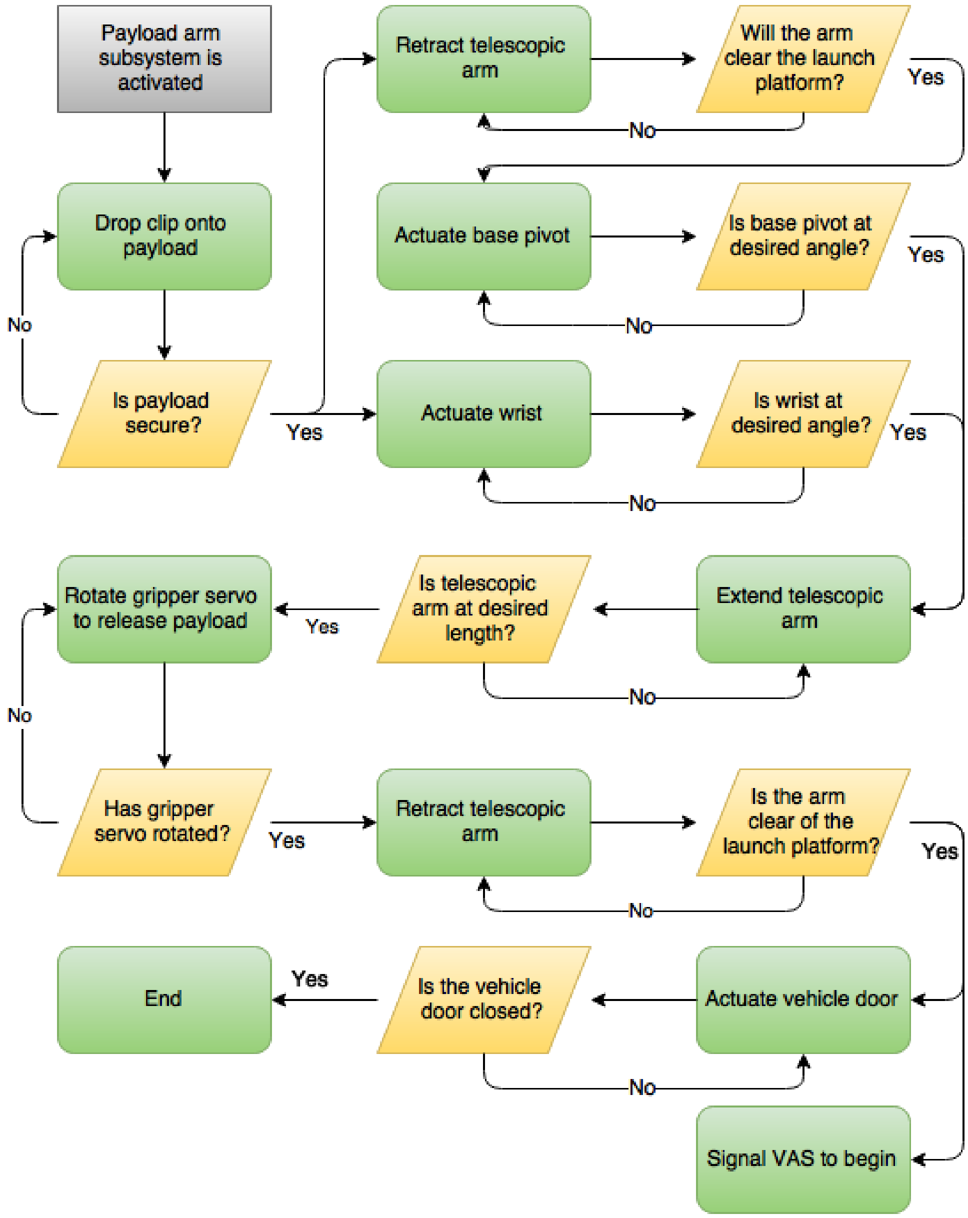


Figure 155: Payload capture system flowchart.

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 73: 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 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.

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 74 shows the foreseen design challenges for the payload capture system and their chosen solutions.

Challenge	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 74: 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 75 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, erect 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 75: 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 verification of payload capture will be tested to	T-value is less than 10% of the average measured value.

	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 76: Payload arm electrical future testing.

7) 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 77.

Mass (lb_m)	Width (in)	Height (in)	Depth (in)
1.52	5.54	8.5	1.94

Table 77: Igniter installation device general dimensions.

The ignition installation device is shown in Figure 156.

Figure 156: Igniter installation device.

Changes since PDR

Change	Justification for Change
Selected belt geometry and material.	Original plan to print belts fell through because of machine maintenance.
System size increased.	New belt geometry required larger pulleys.
Spool assembly further defined.	Spool assembly needed to be designed for manufacturing.
Friction brake adjusted.	Stronger, more reliable design.
Removed slip ring.	Simplified design

Table 78: Changes to the igniter installation device since PDR.

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. However in the event of damage, this device can easily be re-manufactured. The device has been broken down into several components which have been outlined below.

Belt Housing

The belt housing consists of two 3D printed ABS plastic joining brackets and two laser cut 1/8” thick transparent polycarbonate plates. These components will be bolted together using eight 10-32 UNC 3A 1.375” long SHCS and associated nuts. The primary purpose of the belt housing to keep the belts aligned and ensure they remain free of debris. The belt housing is shown in Figure 157.

Figure 157: Igniter belt housing.

Both the upper and lower joining brackets will have a guide hole cut to guide the ignitor in and out of the belts. This guide hole extends as close as possible between the belts.

The lower joining bracket also serves as the mounting location for the igniter spool which will be discussed later.

Belts

Two Urethane crown top belts will be used to grip the ignitor. The Urethane belts will be cut to length from stock material and will be fused together. Prior to fusing, the belts will be machined on a manual mill to cut a center grove in them. The center grove will help guide the ignitor through the assembly. One of the belts is shown in Figure 158.

Figure 158. Igniter installation belt.

Tensioners

The tensioners will be 3D printed out of ABS plastic and each will include one ¾” long ¼”-20 UNC-2A cap screw. The cap screws will provide an adjustment point for the tensioners. The tensioners will wrap over the igniter installer and connect directly to the bottom belt pulley axles. The bottom pulley axles will be constrained in slots that allow the adjustment of the tensioners. One tensioner assembly is shown in Figure 159.

Figure 159. Igniter installation tensioner assembly.

Power Transmission

To drive the ignitor installation device a 12V DC 20rpm gear motor will be used. It has a maximum torque of 185 oz/in. The motor will be directly connected to one of the upper pulleys. The motor will be mounted using four M3 16mm long SHCS. The motor will be stood off the back of the igniter station using a 1/8” thick delrin puck. The puck will be sized to match the face of the gearmotor, and will have through holes for the bolts to cross through.

Figure 23. Belt Motor

The two lower pulleys will drive each other with an integrated 32 tooth gear. The 32 tooth gear will transfer rotary motion from one belt to the other and will ensure both belts push the ignitor through the assembly. The two lower pulleys are shown below in Figure 160.

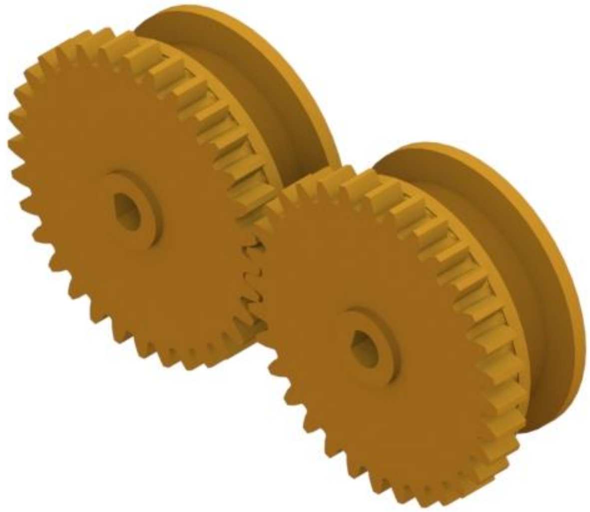


Figure 160: Ignitor installation device lower pulleys.

Ignitor Spool

An ignitor spool will also be 3D printed out of ABS plastic and is shown in Figure 161. The wire spool has a diameter of 1.25 in. A friction damper is included alongside of the spool. The damper will apply friction to the spool to maintain a constant resistance while inserting the ignitor. The resistance while help straighten the ignitor while it is being inserted into the launch vehicle.

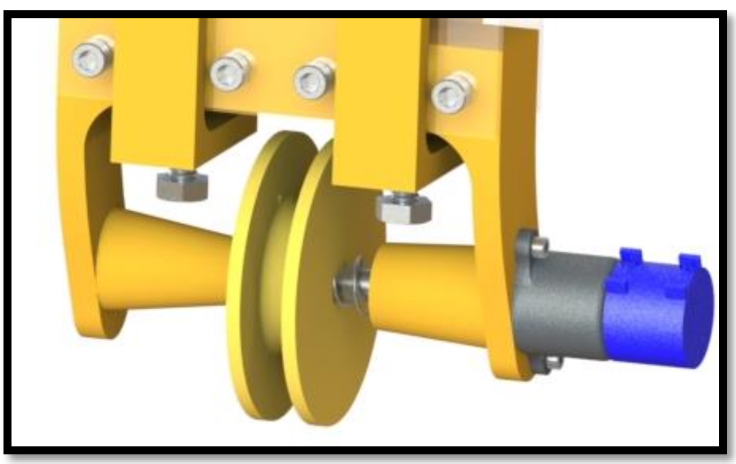


Figure 161: Igniter spool.

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.

A potentiometer will be attached to one side of the spool so the central controller can verify the igniter has been fully inserted. This potentiometer will determine the number of turns the spool has made, once the spool has reached that number, the motor will be turned off.

Spool Sizing Analysis

The potentiometer selected for the ignitor installation device is limited to 10 turns. To ensure the ignitor could be fully installed within 10 turns of the spool analysis was completed.

The equation used to calculate the number of turns required to fully install the ignitor was

$$T=\frac{L}{\pi D} \quad (37)$$

where L is the travel distance of a fully installed ignitor, and D is the diameter of the spool.

Below, Table 79 summarizes the parameters and results of the motor RPM calculations.

Parameter	Value
L	19.1 in
D	1.25 in
T	4.86 revs

Table 79: Motor RPM calculation parameters.

This analysis calculates the number of revolutions required based on a worst case scenario where the igniter does not overall itself.

Motor Sizing Analysis

The final motor selection was determined based on the task time limit discussed early. The following equation was used to calculate the minimum motor RPM to install the ignitor within the allotted time frame

$$RPM=60\frac{L}{ct} \quad (38)$$

where c is the outermost circumference of the driving pulley, and t is the time requirement of the task.

Below, Table 80 summarizes the parameters and results of the motor RPM calculations.

Parameter	Value
C	5.86 in
L	19.1 in
t	15 secs
RPM	13.04 rev/min

Table 80: Motor RPM calculations.

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 162 below.

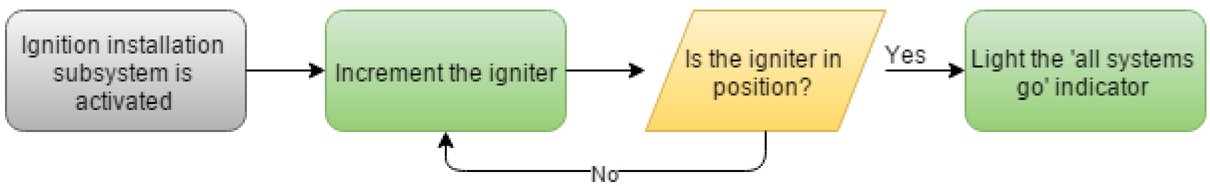


Figure 162: Ignition station flowchart.

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

The 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

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

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.

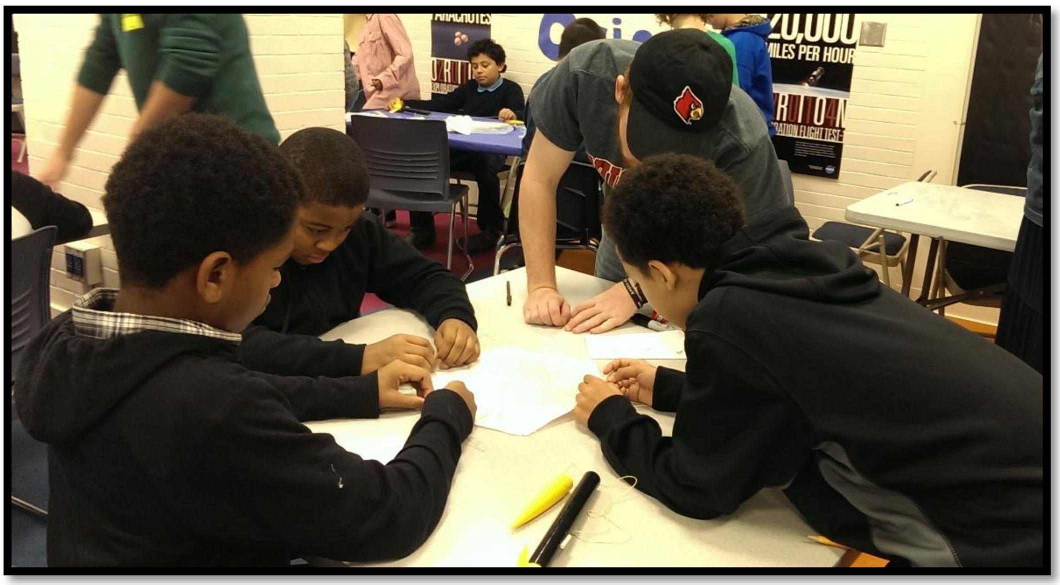


Figure 163: Ross assisting students in assembling their parachute.

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 164: 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 165: 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.

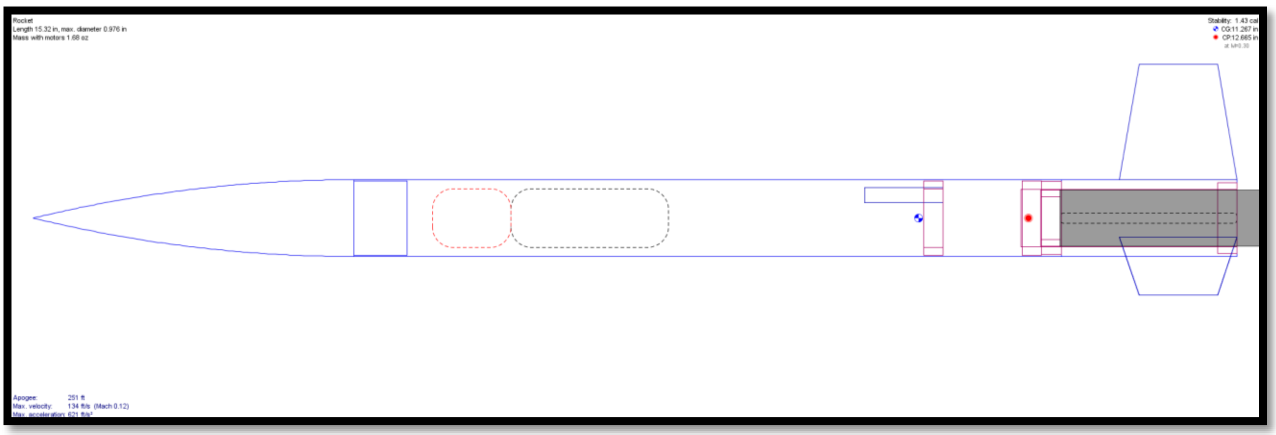


Figure 166: OpenRocket simulation created by students.

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 167: Carlos helping student prepare her rocket for launch.

<u>Six Week Exploring Rocketry and Engineering Program</u>

The goal of this program is to not only talk about rocketry, but to introduce students to the variety of disciplines of engineering that are involved. 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.

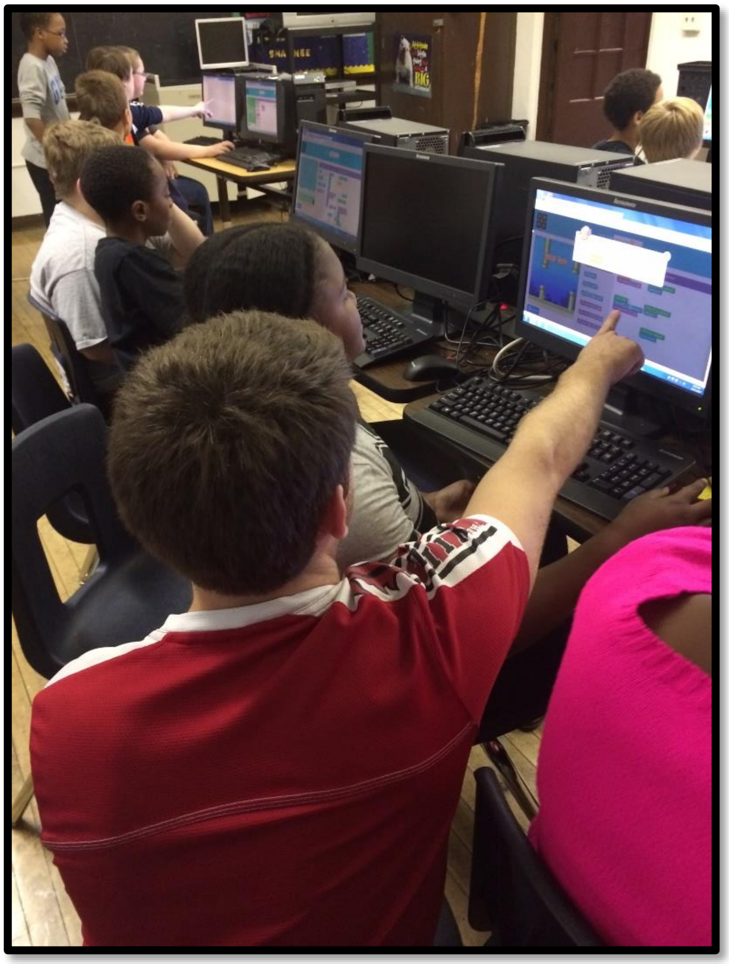


Figure 168: David teaches students how to program a game on code.org.

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.

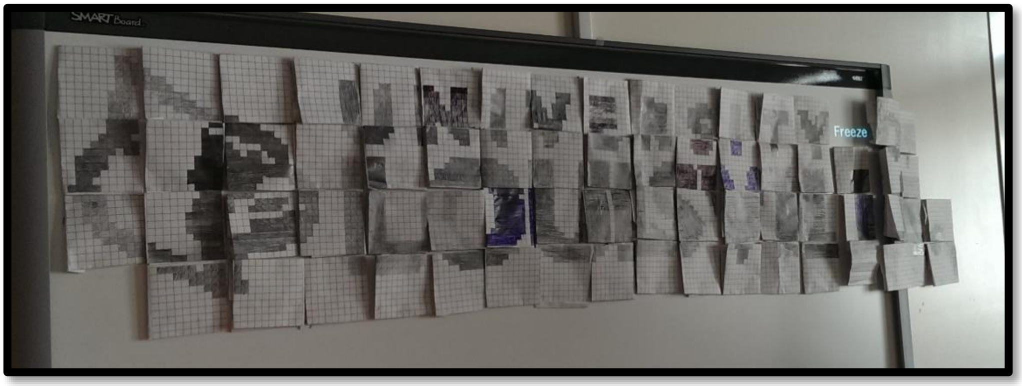


Figure 169: The satellite message that students decoded.

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.

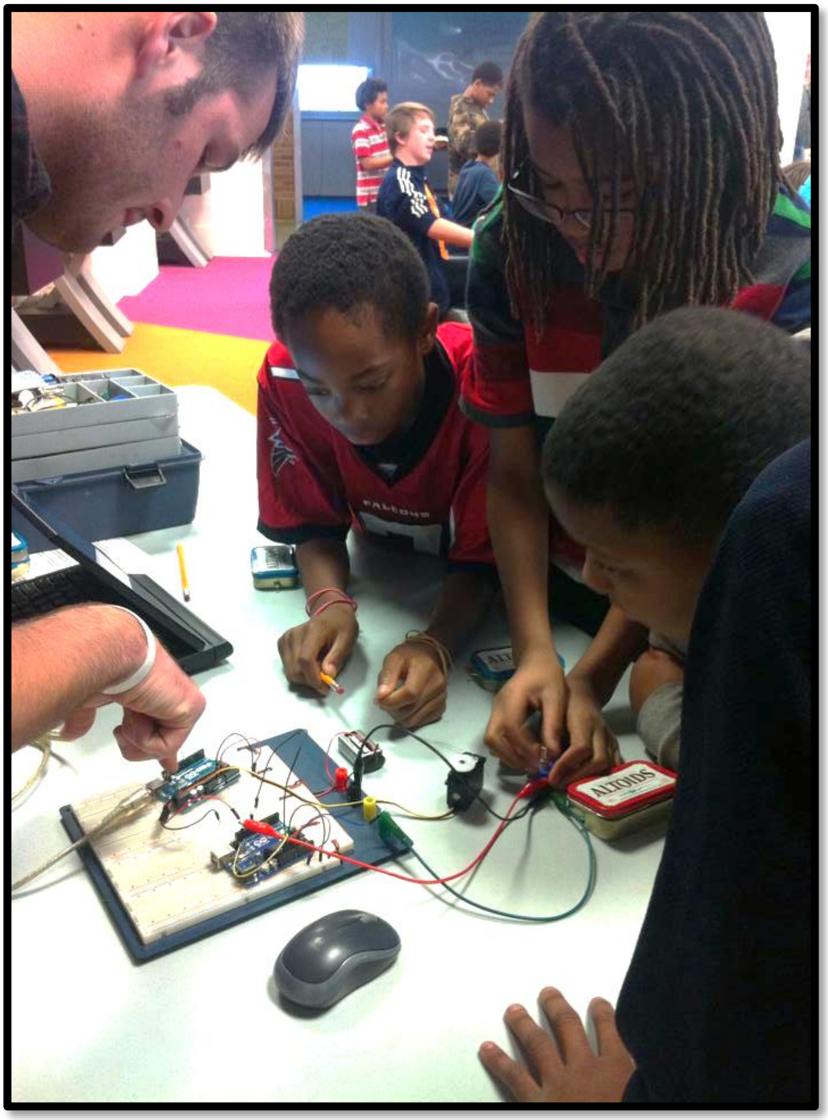


Figure 170: Sherman shows students a circuit that he built and how it works.

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.

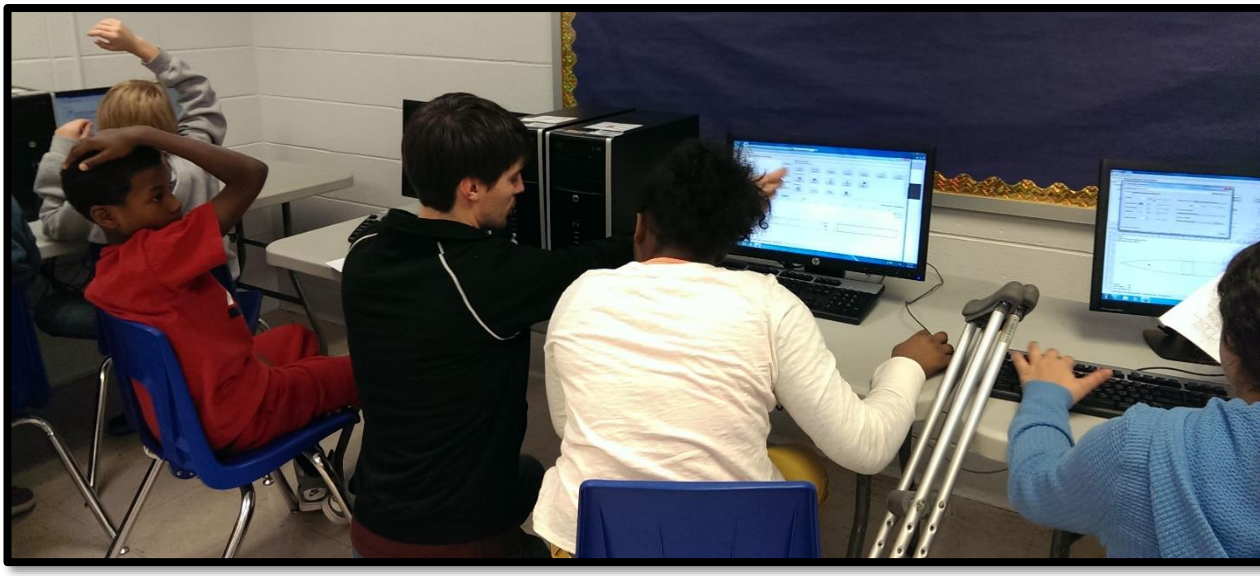


Figure 171: Gregg helps student with her OpenRocket simulation.

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.

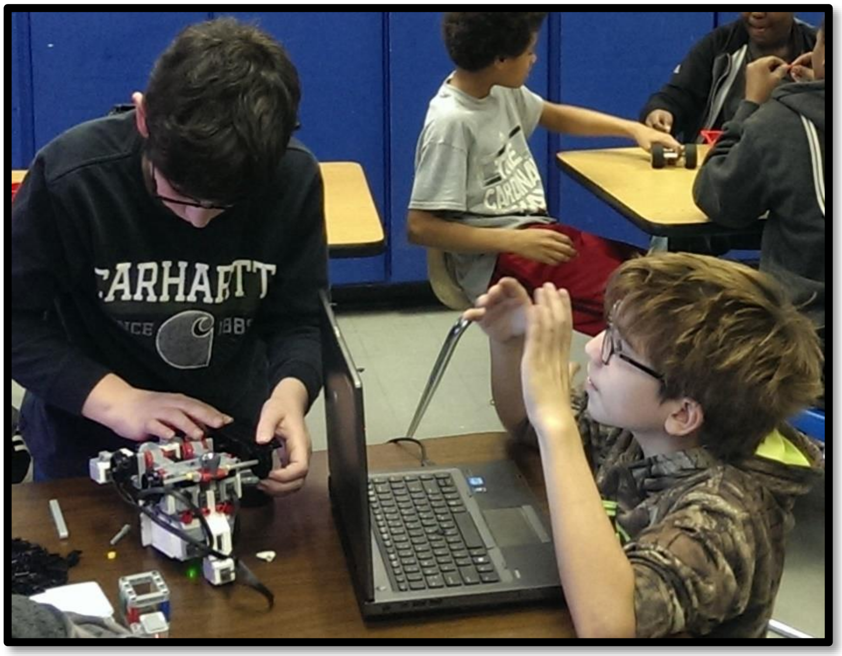


Figure 172: Students discuss designs and modifications to their program.

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 173: 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 174: 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 175: 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 176.

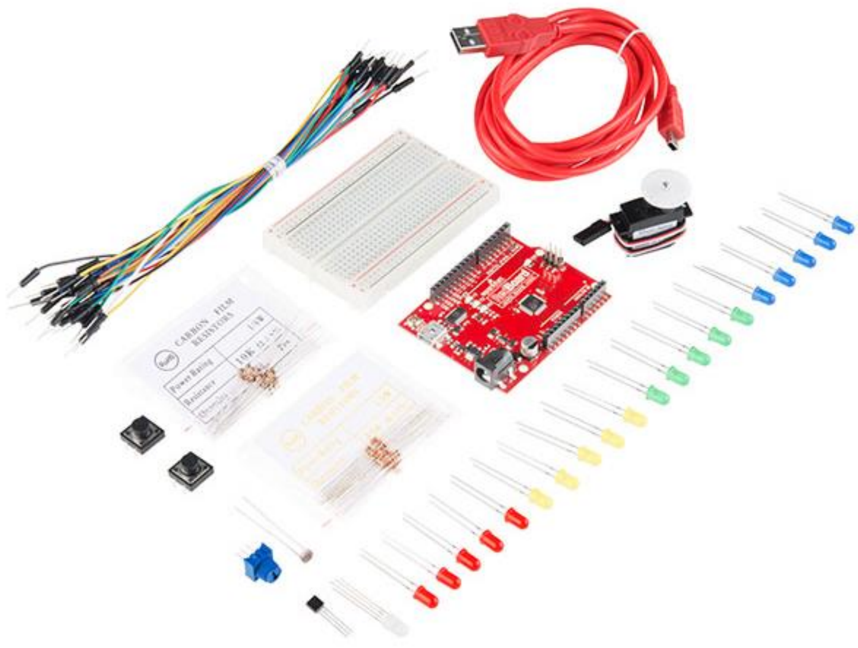


Figure 176: SparkFun Mini Inventor's kit.

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 2016.

An Elementary level version is being introduced into the team's curriculum as well. Sticking with the theme of robotics, the team has recently purchased Bristle Bot kits. This program will involve a short lesson on basic circuits, electricity, and Newton's laws. Following the lesson, student's will get to build their own robots. Once the robots are complete, the students will combine their robots with their knowledge of Newton's laws to perform a series of experiments. River City Rocketry is excited to officially kick off this program on January 25th.

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 177: 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. The planning for the event has officially started and the team is enthusiastic about another year with the exposition.

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 putt on a STEM camp geared toward earning the Dr. Luis W. Alvarez Supernova Award. While the camp lasts four days, River City Rocketry was in charge of running the "Out of this World" module, which focused on space exploration. Newton's laws, moment of inertia, the NASA student launch project, and rocket designs were discussed during the lesson. Rockets were also built and launch. This camp involved approximately 100 students.

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 178: 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 was 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 had a display set up so that when students were in between events, the team could talk to them about the previous year's project. This was a good way to show the students how programming can be applied into something beyond their Lego Mindstorm robots.

Figure 179: Emily and Kevin giving a presentation to the competitors and educators at the FIRST Lego League Regional Competition.

At the end of the day, while all of the teams were waiting for the final results of the competition, River City Rocketry representatives gave a presentation to all of the students, parents, and educators present. Here the team was able to talk about what River City Rocketry does as a team and relate that to the students' projects. This was an opportunity to share how the team designs, manufactures, and tests their project 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 hosted a regional qualifier for the competition. Approximately 900 students in K-12 were in attendance. The University of Louisville invited River City Rocketry to participate by setting up a booth to talk with students throughout the day. The team will brought the rocket from last competition as well as other competition materials to discuss with the students. This was 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 information shown in Table 81 details the number of students and types of interactions made so far this year.

Date	Event	Education				Outreach	
		Direct Interactions				Direct Interactions	
		K-4	5-9	Educators (5-9)	Educators (other)	5-9	Educators (5-9)
08/02/15	Little Big Carnival	30	20	2	1		
10/08/15	Barrett Middle School - RCR					21	3
10/17/15	MathMovesU	22	75	12	1		
10/19/15	Wheeler Elementary Estes Launch		15	2	1		
11/14/15	FIRST Lego League Robotics Regional Competition					240	52
12/28/15	Scouting STEM Camp	45	50	8			
Totals		97	160	24	3	261	55
Total Overall	600						

Table 81: Completed educational engagement events this season.

The team has already reached out to 160 middle school aged students through direct educational programming. With the current events planned, the team will surpass 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.

The following is a list of outreach events that the team currently has scheduled for the season.

- *Bristle Bots with Kennedy Montessori Elementary*- this event will launch our Bristle Bots program on Jan 25th. There will be 15 students and one educator in attendance.
- *Science Gala with a Twist* – this event will involve outreach to 200 prominent STEM educators in the Louisville area. We will be discussing what NASA student launch is about, what we do as a team, and launching paper rockets.
- *Engineering Exposition* – On March 5th, from 9-5, the team will be talking about the physics of rockets, building paper rockets, and discussing what NASA student launch is. The team expects to have 400 elementary and middle school students attend the sessions to learn about rockets and launch their own paper rockets. Additionally, the team expects to have nearly 60 teams registered for the middle school water rocket competition.

The team is still working to set up several more events throughout the remainder of the season. One of the features of the updated website is the outreach page. This page highlights some of the team's premier activities. Additionally, educators and parents can request an event to be held at their school. This may be a program that the team currently offers or something that is custom to the need of the group. This will help to streamline the process in setting up outreach events with local schools and encourages schools that the team hasn't worked with to reach out and build a relationship with the te

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 Table 82.

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 82: 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.

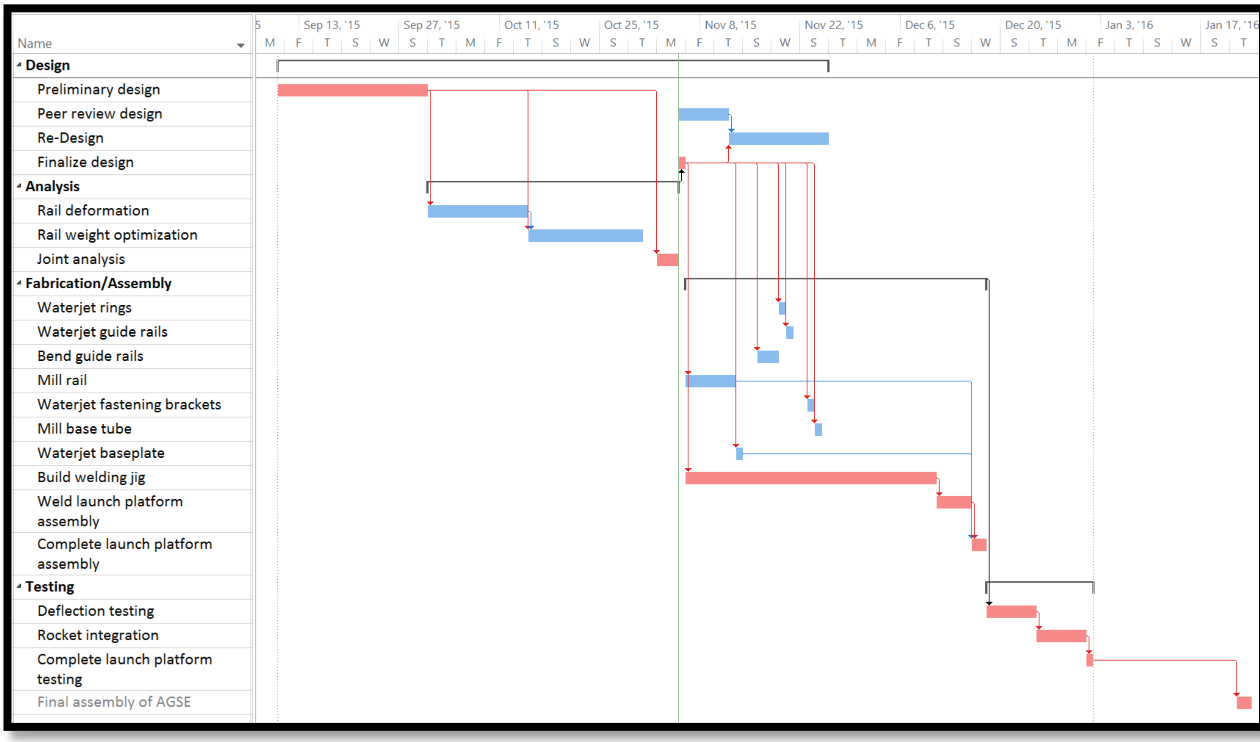


Table 83: Launch platform project timeline.

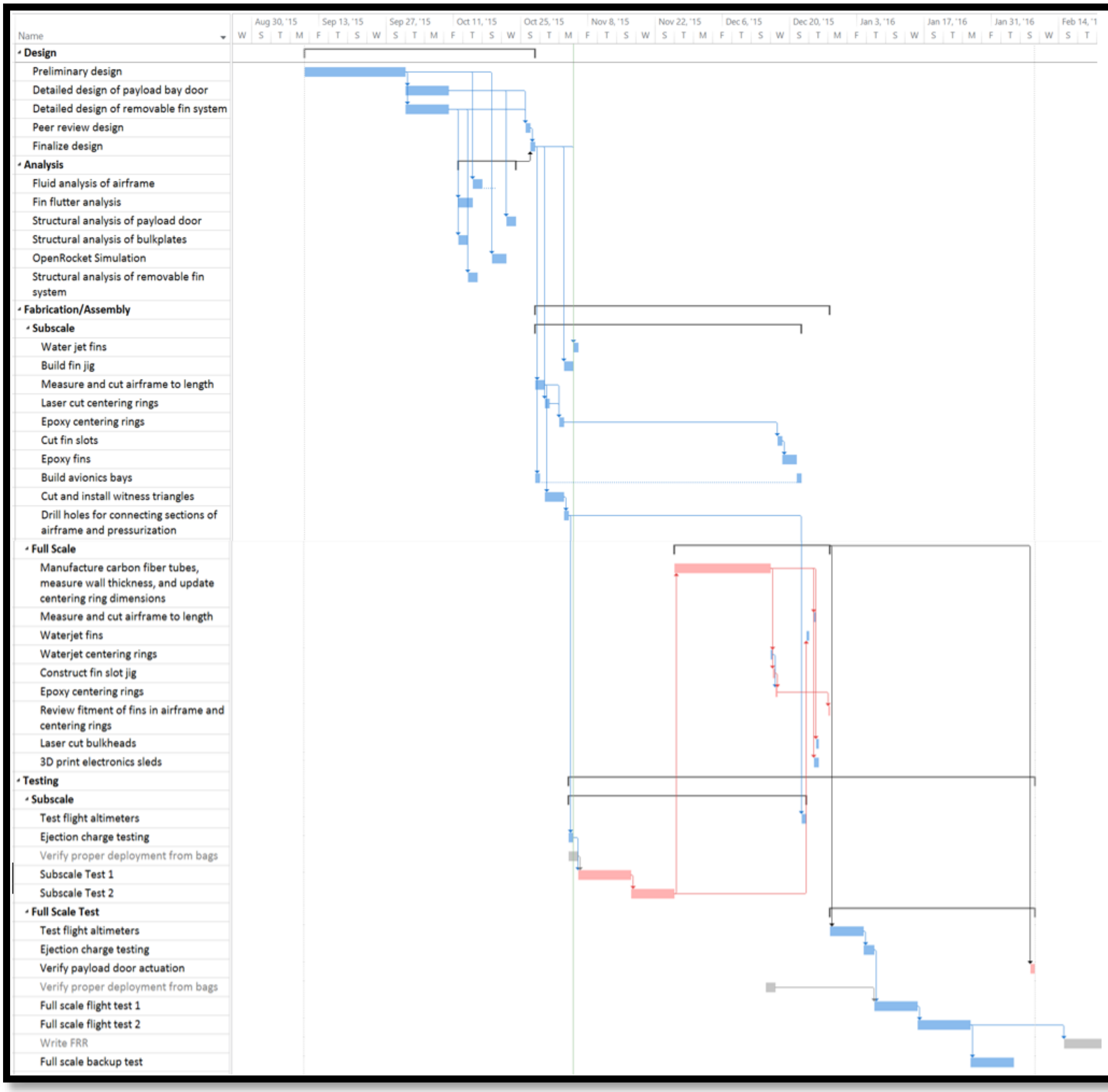


Table 84: Launch vehicle project timeline.

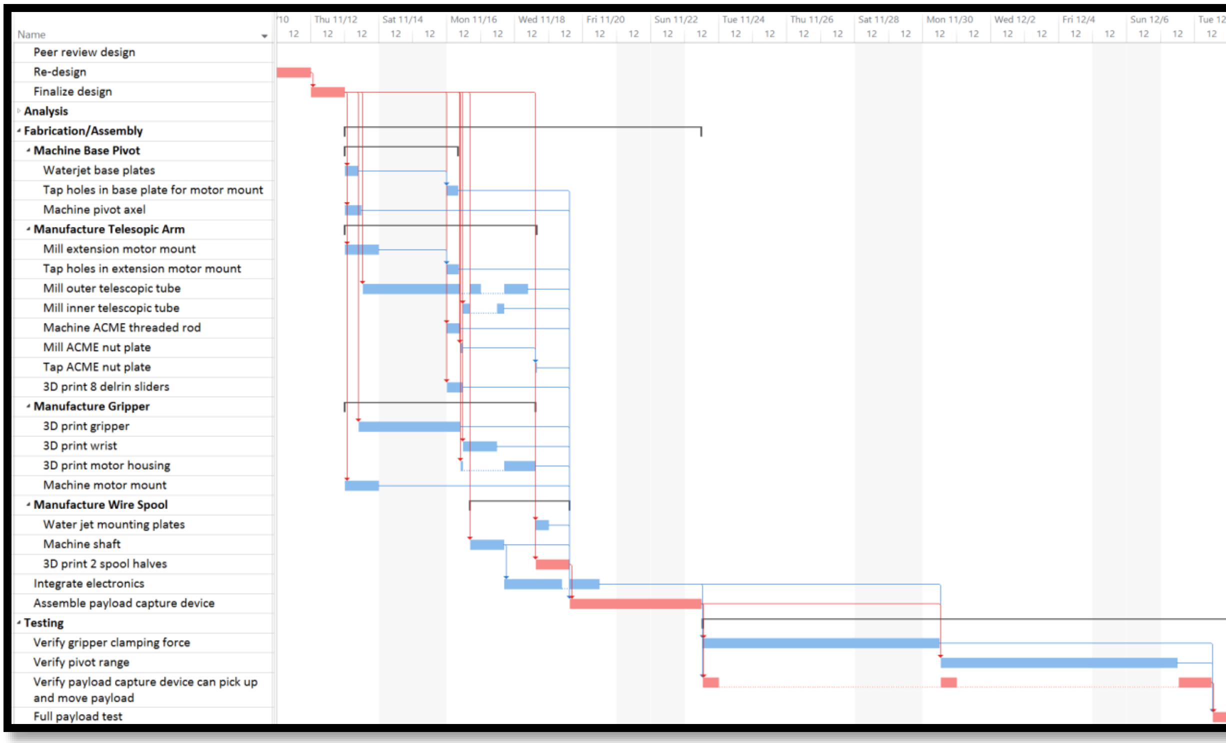


Table 85: Payload capture project timeline.

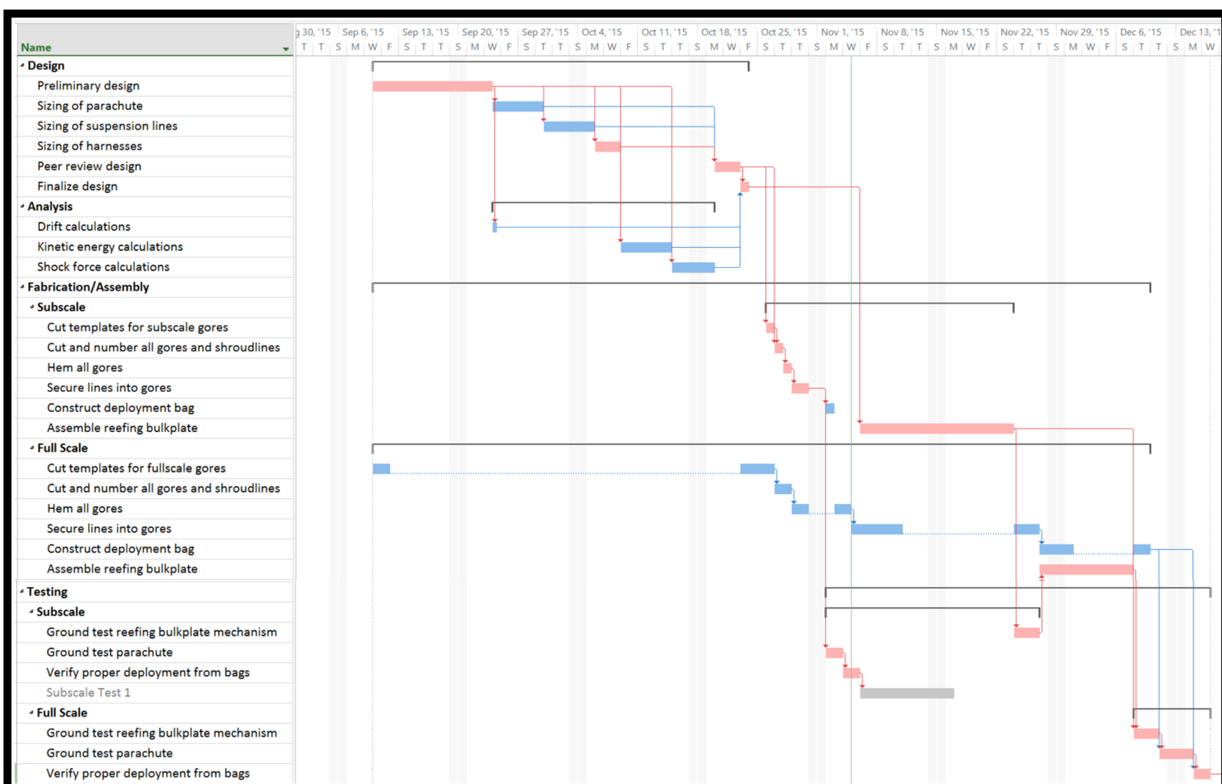


Table 86: Recovery project timeline.

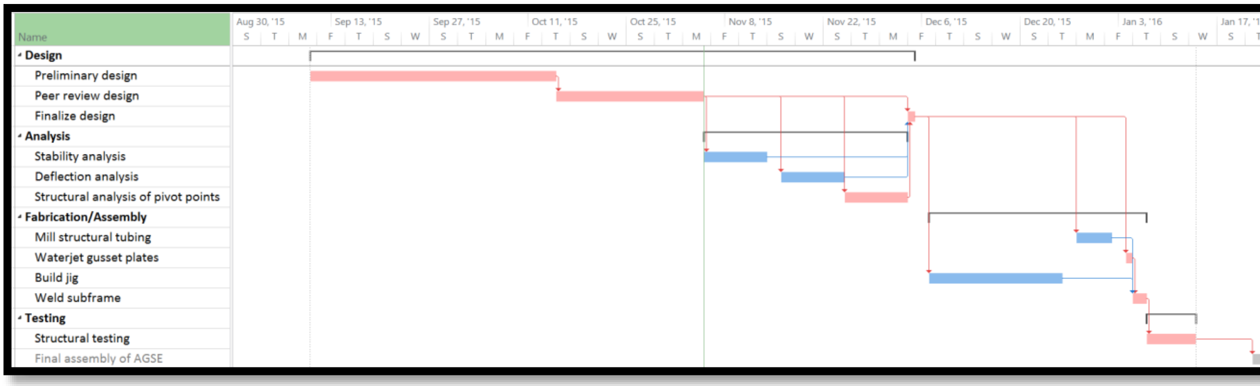


Table 87: Sub-frame project timeline.

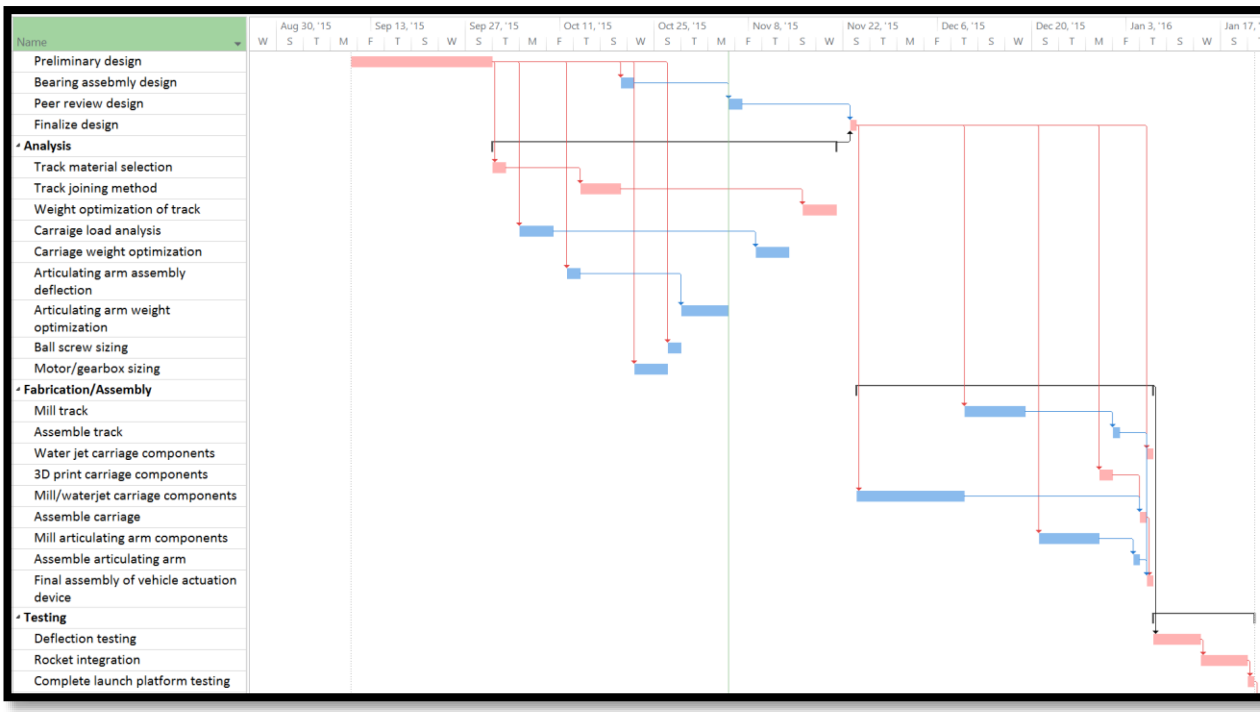


Table 88: Vehicle actuation device project timeline.

In order to avoid overloading particular team members or sub teams, each of the timelines were completed and resource leveled. This helped to assure that predictions on time to complete certain tasks, or a group of tasks, are realistic.

So far, the team has stayed on track between PDR and CDR with the exception of a few manufactured parts. This is due to the fact that required machinery have been down for maintenance. However, the machinery has recently become available and strides have been made to get those portions of the project back on track.

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 180, and how resources have been allocated.

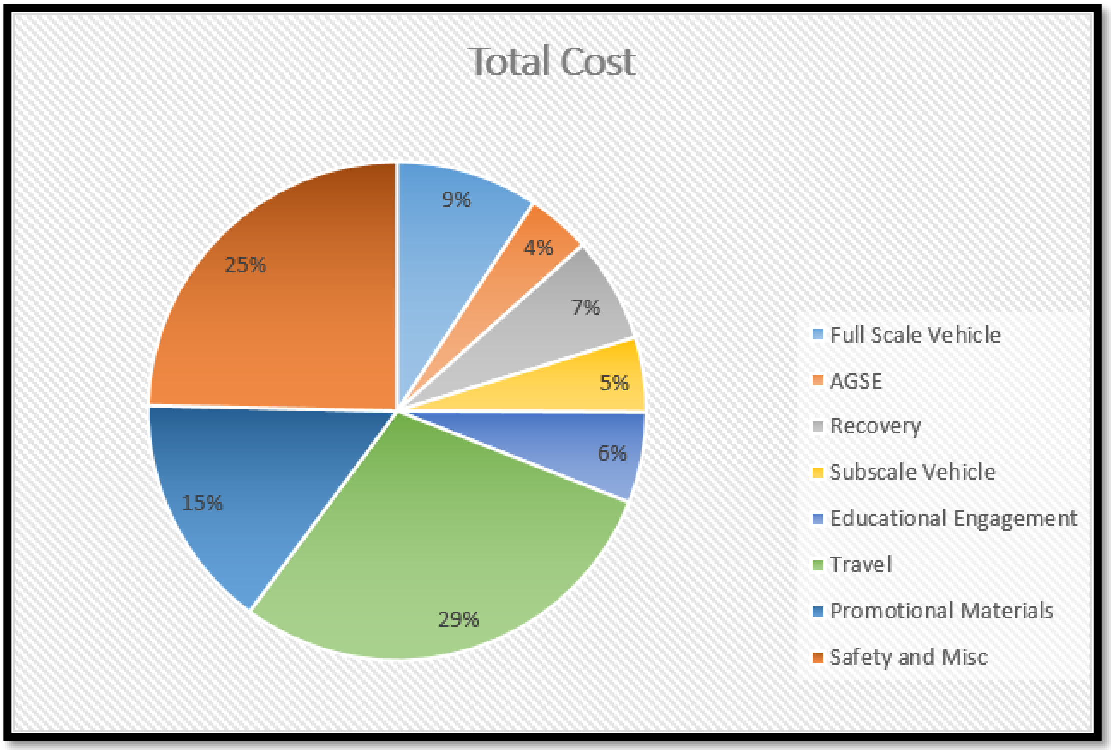


Figure 180: Comprehensive breakdown of entire project budget.

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 89.

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
Dr. Kelly Donation	$10,000.00
Alumni Donation	$500.00
Samtec	Donation of 1030 aluminum extrusion
Total	**$33,098.85**

Table 89: 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 90.

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
Dr. Kelly	Generous donor, on the board of trustee's advisors for the University of Louisville, and rocket enthusiast.
Alumni	Supporters of the University of Louisville.

Table 90: 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.

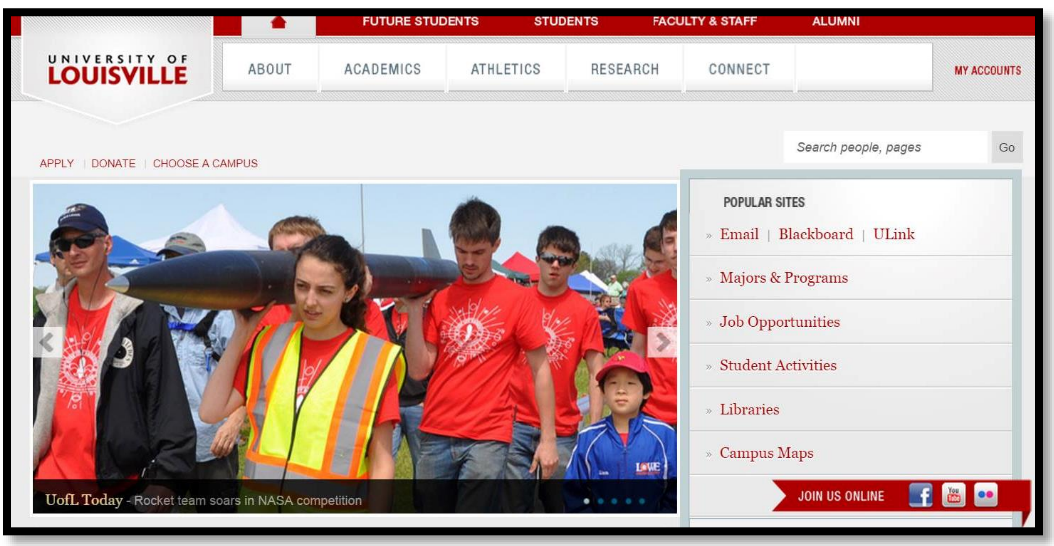


Table 91: River City Rocketry on the front page of the University of Louisville website.

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 92: 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 is excited about what they can bring to 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.

Featuring a custom made parachute with a reefing system, the team has continued to carry on the tradition of designing and manufacturing unique recovery systems. This year has allowed the team to grow even more with the introduction of manufacturing our own carbon fiber tubes, as well as utilizing welding on the AGSE. The team prides themselves in the fact that each system is unique and can be manufactured completely by team members.

In addition to pushing the limits of design, the team's educational outreach has been incredible this year. The 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. With several new programs in the book this year, the team has been able to provide a variety of unique experiences to local students.

The teams website has also seen an upgrade since PDR, which highlights a lot of what the team does well. While maintaining a professional page, viewers can access a wealth of information including but not limited to: documentation, current and former team members, outreach, and much more!

The team continues to strive to be the best that they can be and bring something that is unique to the competition every year. The team is now in the height of the manufacturing phase for all full scale systems and is beginning to perform full scale tests to ensure the success of the mission at hand.

Appendix I – Test Procedures

1) Reefing Electronics: Proof of Concept

Introduction

A proof of concept test for the reefing electronics' pressure sensor was performed in a ground test in which a rocket launch was simulated in a vacuum chamber. By placing the barometric pressure sensor inside the vacuum chamber, the team was able to simulate the ascent to a high altitude by lowering the chamber's pressure. A descent was simulated by slowly bringing the pressure of the chamber back to room pressure. By simulating a launch, the team was able to verify the electronics' functionality in a general way and also determine the accuracy of the measurement in comparison with a control.

Test Criteria

The following sections describe information regarding what is being tested and requirements that are to be met in order to classify the test as passed or failed.

Items to be Tested

- Basic electronics hardware functionality
- Reefing electronics software
- System accuracy

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
1	Electronics hardware functionality.	Electronics run for the duration of a launch without failure.
2	Reefing electronics software.	Data reported by electronics resembles a continuous ascent and a descent.
3	System accuracy	The reefing electronics initiate de-reefing at the same time as a control group of PerfectFlite Stratologgers.

Table 93: Pass/fail criteria for all requirements tested.

Setup

Equipment

Equipment	Details
MicroSD card logger	Attached to the reefing electronics for data collection and storage.
Vacuum chamber and pump	Used to simulate an ascent and descent by the creation of a low pressure environment.
3 PerfectFlite Stratologgers	Used as a control group because of their proven reliability in determining recovery events.

Table 94: Equipment required for test.

Setup

Place the vacuum chamber and pump, both shown below in Figure 181, on the floor. Make sure the vacuum pump is off and valve on vacuum chamber is in the off position so that a premature vacuum does not occur. Attach the pump's rubber hose to the nozzle on the side of the chamber and plug the pump into a wall socket.

Figure 181: Vacuum chamber and pump.

Safety Notes

When operating the vacuum pump and chamber, make sure safety glasses are worn at all times in case any seals are broken during pressurization.

Procedure

Step 1: Place the reefing electronics inside the chamber.

Step 2: Arm the reefing electronics by connecting the Duracell 9 volt battery and hitting the reset button on Arduino Pro Mini. Await flashing from LED lights aboard the Arduino Pro Mini board.

Step 3: Seal the chamber with the acrylic slab.

Step 4: Flip the chamber nozzle to the upwards position and activate the power switch on the pump to slowly lower the pressure within the chamber: simulating a rocket ascent.

Step 5: After 30 seconds shut off the pump and turn the chamber nozzle to a horizontal position to slowly introduce pressure back into the chamber, simulating a descent.

Step 6: When the pressure has returned to room pressure remove the acrylic slab and retrieve the microSD card.

Step 7: Verify that the reefing electronics are recording and taking appropriate data.

Step 8: Reset the microSD card in the reefing electronics.

Step 9: Place the reefing electronics inside the chamber along with 1 of 3 Stratologgers.

Step 10: Arm the reefing electronics by connecting the Duracell 9 volt battery and hitting the reset button on Arduino Mini: await flashing from LED lights aboard the Arduino Mini board. Flip switch on the Stratologger board allow for beeping cycle to take place. When the Stratologger is ready an endless cycle of 3 consecutive beeps will take place until a pressure change is enabled.

Step 11: Seal the chamber with the acrylic slab.

Step 12: Flip the chamber nozzle to the upwards position and activate the power switch on the pump to slowly lower the pressure within the chamber: simulating a rocket ascent.

Step 13: After 30 seconds shut off the pump and turn the chamber nozzle to a horizontal position to slowly introduce pressure back into the chamber: simulating a descent. Note when the Stratologgers indicate main parachute deployment with a red LED and when the reefing electronics indicate main with its actuator.

Step 14: Repeat the procedure process until all 3 Stratologgers have been tested alongside the reefing electronics.

Data and Results

Requirement 1: [Basic electronic functionality] – **PASS.** The electronics performed as expected in terms of maintaining power for the duration of the test. The duration of this test was one hour; an amount of time that sufficiently resembles pad time + launch time.

Requirement 2: [Reefing electronics software] **– PASS.** The data reported by the reefing electronics resembled a continuous ascent and descent. A graph of the simulated altitude is shown below in Figure 182.

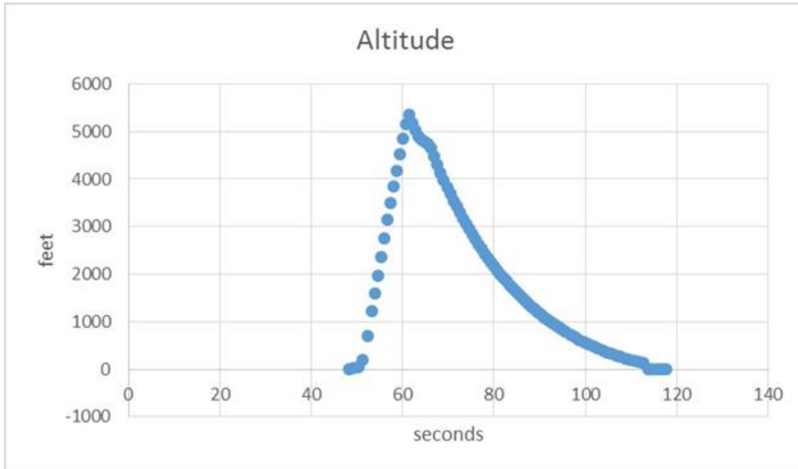


Figure 182: Vacuum test launch simulation.

An additional component of the software is its velocity algorithm. This was also verified as a part of the software requirement. A trend-line was found for the descent portion of the simulated launch so that a plot of its derivative could be compared to a plot of the velocity as calculated by the reefing electronics. This comparison is shown below in Figure 183.

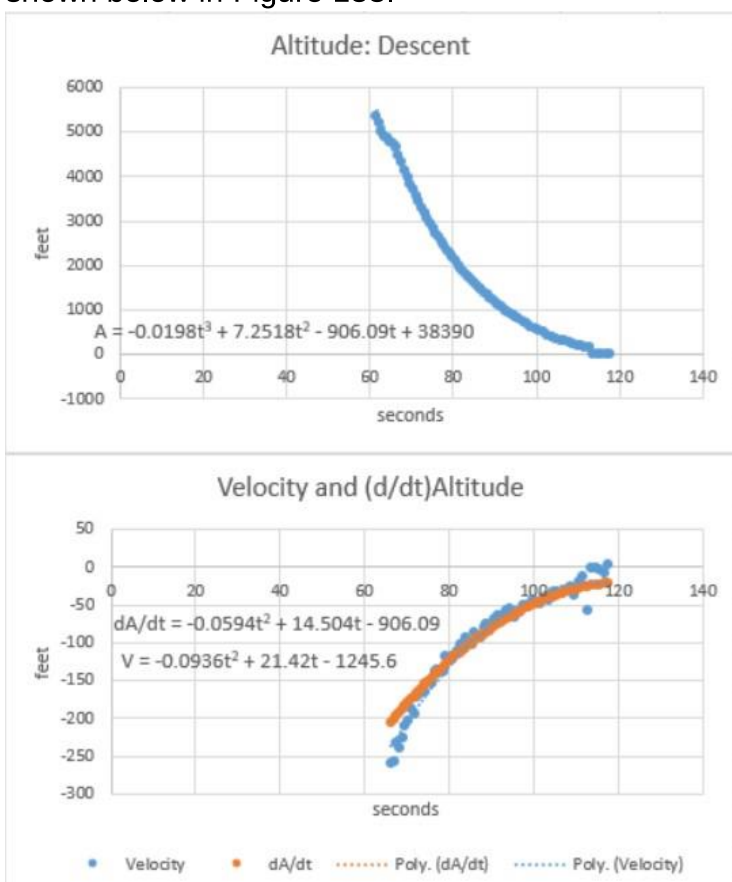


Figure 183: Vacuum test launch simulation: verification of velocity algorithm.

The degree to which these two plots agree verifies that the velocity algorithm performs as expected.

Requirement 3: [System accuracy] – **PASS.** The reefing electronics were verified to be accurate by a comparison with a control group of 3 Stratologgers.

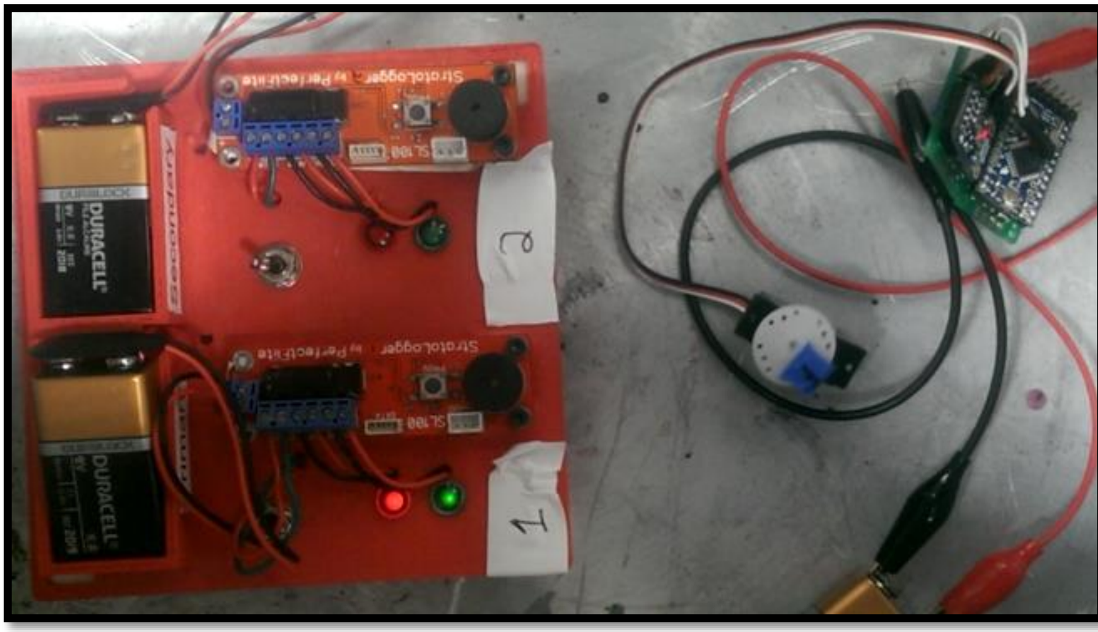


Figure 184: System accuracy test 1 @ 1m:40s

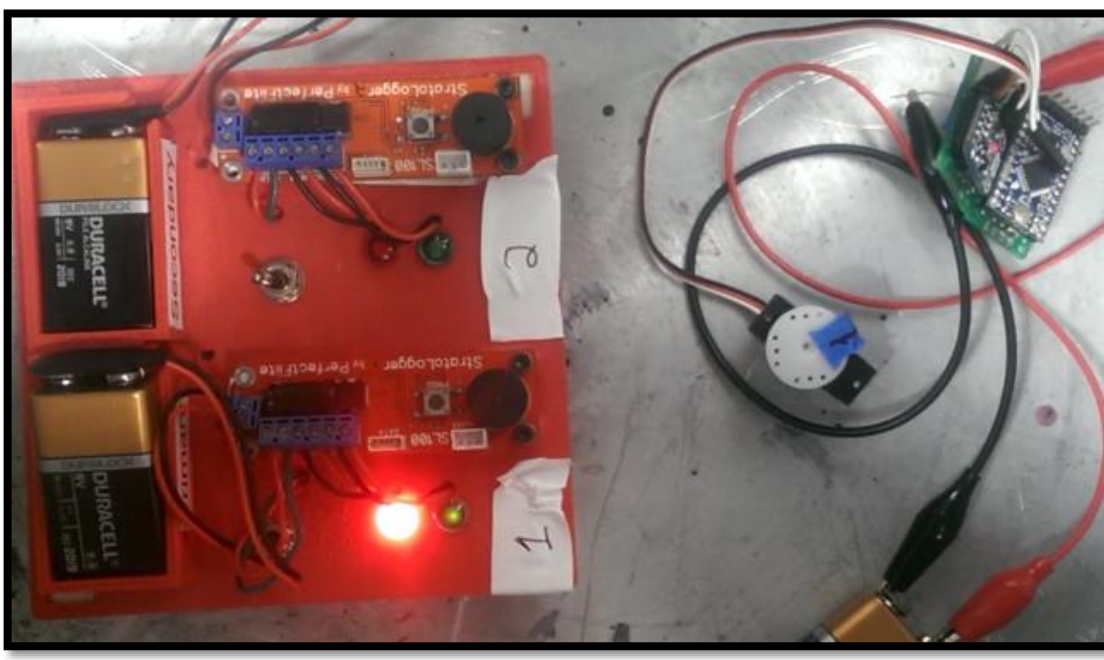


Figure 185: System accuracy test 1 @ 1m:41s

One of these system accuracy trials is shown above in which it can be seen that within a one second time frame both the Stratologger's LED indicated drogue and the reefing electronics servo turned.

Kevin Compton

Kevin Compton

Test Engineer(s) Name

Test Engineer(s) Signature

Ben Stringer

Ben Stringer

Test Engineer(s) Name

Test Engineer(s) Signature

December 15th, 2015

Date Completed

2) Test Plan: Reefing Electronics and Black Powder Charge

Introduction

A test was conducted to ensure that the reefing electronics would perform as expected in the presence of pressure changes caused by the ignition of a black powder charge. Because the reefing ring will be using a barometric pressure sensor to determine altitude, the reefing electronics are sensitive to changes in pressure. This test was conducted to ensure that the pressure spike caused by the ignition of a black powder charge would not simulate the conditions for de-reefing, causing a premature deployment of the main.

The risk of a premature main at apogee is introduced when considering that a black powder charge must negate and exceed the vacuum of the upper airframe in order to separate the nose cone. This spike in pressure caused by the black powder charge is felt by the reefing electronics and interpreted as a sharp dip in altitude. If this perceived altitude drop were to exceed 4,480 feet, the reefing electronics would interpret this phenomena as meeting the conditions for a deployment of the main. In order to assess this risk, a ground test was conducted to determine the magnitude of this perceived altitude spike.

Test Criteria

The following sections describe information regarding what is being tested and requirements that are to be met in order to classify the test as passed or failed.

Items to be Tested

The magnitude of the perceived dip in altitude felt by the reefing electronics in the presence of pressure spikes caused by the ignition of black powder charges within the upper airframe.

1.1 Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
1	Magnitude of spike in feet.	Magnitude of spike is less than 4,480 ft with a margin of safety.

Table 95: Pass/fail criteria for all requirements tested.

Setup

The following sections describe information about the setup and approach being used for the test.

Equipment

- Upper section of the launch vehicle
- Reefing electronics and microSD card with a microSD card reader
- Electronics test bay
- 6 inch Nose Cone
- 6 inch by 27 inch upper airframe
- 27 foot long shock cord
- 2 3/8 inch quick links
- Wire strippers
- 9v Duracell battery or equivalent
- Crescent wrench
- Black powder, 2 grams per test
- Electric matches, 1 per test
- Black powder container, 1 per test
- Safety glasses for all personnel participating and observing
- Extra battery to ignite electric match

Setup

The reefing electronics and microSD card with a microSD card reader was secured within the electronics test bay. The upper airframe and nose cone was then assembled with the electronics test bay enclosed.

Safety Notes

Due to the hazard of black powder, personal and observers are required to wear safety goggles at all times as soon as arrived on site. During each test, all personal and observers should drop the current task and keep all eyes and ears directed toward the testing area. A statement and countdown from 3 for each trial is required for maximum alertness from any surrounding personnel.

Procedure

Step 1: Since this test utilizes the upper section of the launch vehicle, nose cone and upper section of the air frame, use a replicated 6 inch diameter 5:1 Von Karman nose cone and a 6 inch diameter by 27 inch long upper piece of airframe to simulate an apogee separation.

Step 2: Since the team has a 9 foot tall rocket, cut a length of shock cord 27 feet long.

Step 3: Tie a loop knot 1/3 of the way down the shock cord length to create a mounting point for the electronics test bay.

Step 4: Attach 2 3/8 inch quick links: one attaching the shock cord and nose cone, while the other attaches to the shock cord and bulk plate on the other end of the upper airframe tube.
Step 5: Drill 4 holes, all evenly spaced around the piece of airframe, and in the center of the electronics bay to allow the barometric pressure sensor to read an adequate amount of air.
Step 6: Open the electronics test bay and place the reefing electronics in an orientation that allows for the electronics test bay to be close and be sealed.
Step 7: Attach the electronics test bay to the loop knot with a 3/8 inch quick link.
Step 8: Connect the 9V battery to the reefing electronics and press the 'reset' button on the Arduino Pro Mini to ensure a clean start. Make sure that the microSD card is in its slot.
Step 9: Drill a big enough hole on the bottom of the black powder container to allow electric match to be slotted through the bottom of the black powder container, orientating the electric match head toward the top of the container. Wrap electric tape around the bottom of the black powder container so that no black powder will leak out.
Step 10: Pour 2 grams of black powder into the black powder container.
Step 11: With the remaining space in the black powder container, insert any type of tissue paper.
Step 12: Connect the leads of the electric match to the terminal blocks on the nose cone bulkhead.
Step 13: Assemble the two halves of the rocket.
Step 14: Take the wires connecting to the other end of the terminal blocks and be 40 feet perpendicular to the test rocket.
Step 15: Ensure all safety glasses are on and all personal are observing the test area.
Step 16: Countdown from 3 and connect leads to extra battery.
Step 17: Ensure black powder charge went off and that it is safe to approach the test rocket.
Step 18: Disconnect disposable electric match and disconnect electronic test bay.
Step 19: Open the electronic test bay and obtain microSD card and extrapolate data into an excel document.
Step 20: Repeat procedural steps 2 more times.

Data

The results of 3 trials are shown below in **Figure 186**.

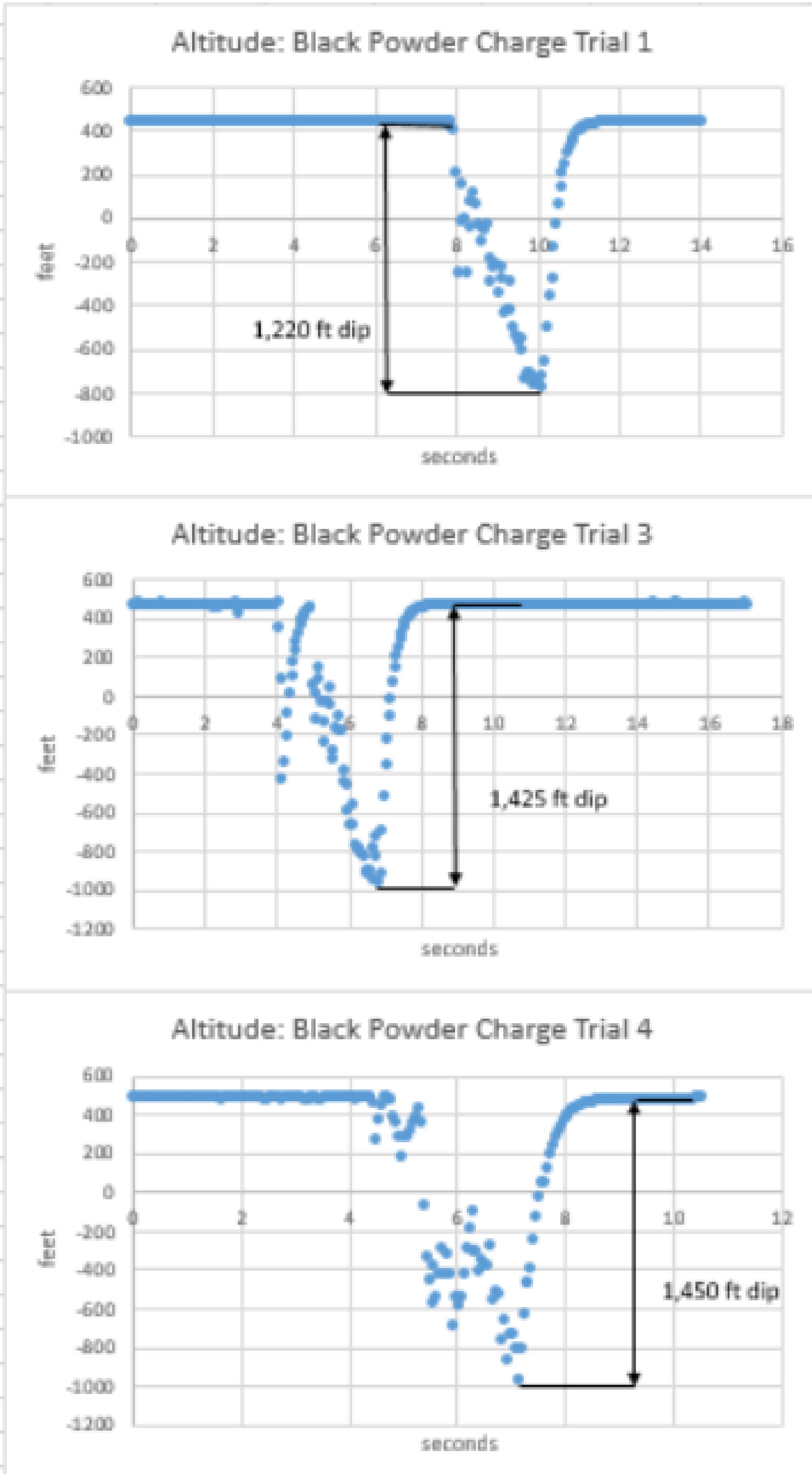


Figure 186: Reefing electronics and black powder test.

Results

Requirement 1: [Magnitude of perceived altitude dip] – **PASS.** The above results show that the largest dip is 1,450 ft; well below the 4,480 ft that would risk a premature main. The results conclude that a premature main due to a black powder charge pressure spike is low risk.

Conclusion

Unforeseen pressure phenomenon such as those caused by the ignition of a black powder charge pose risks to the reefing electronics. Measures to mitigate against these unwanted phenomenon were taken in the reefing electronics software. The criteria for altitude and velocity were made to be stricter so that the chances of these phenomenon causing a premature main became less likely.

It was also found during this test that these stricter criteria also served to filter out other unwanted pressure phenomenon such as the pressure increase caused by aggressive airframe assembly. It was discovered that the following readings were produced during airframe assembly.

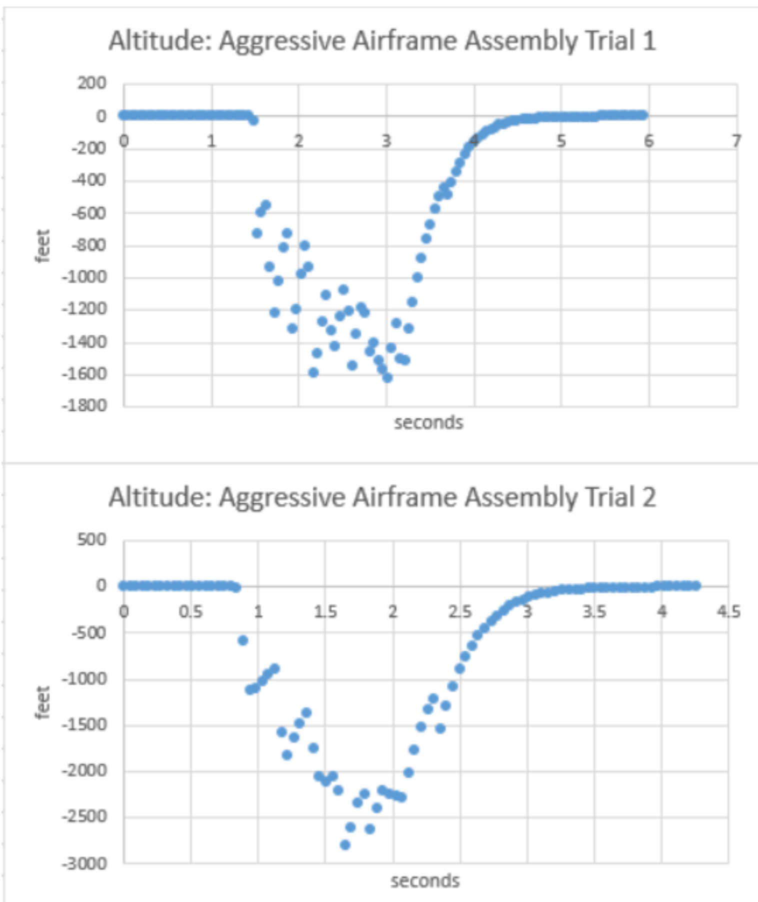


Figure 187: Phenomenon spike found during assembly of test rocket.

While more severe in terms of the magnitude of the spikes, the risk that this phenomena poses to a premature deployment of the main is more easily mitigated than the black powder charge pressure spikes. Since the reefing electronics will be zeroed at the launch pad, they will be programmed to exclude negative altitudes.

Both the risks caused by the black powder charge and airframe assembly have been mitigated.

Kevin Compton — *Kevin Compton*

Test Engineer(s) Name — **Test Engineer(s) Signature**

Ben Stringer — *Ben Stringer*

Test Engineer(s) Name — **Test Engineer(s) Signature**

December 18th, 2015

Date Completed

3) Test Plan: (Subscale Ejection Charge Testing)

Introduction

In order to ensure successful recovery of the launch vehicle, ground testing of the recovery ejection charges shall be performed.

Test Criteria

The following sections describe information regarding what is being tested and requirements that are to be met in order to classify the test as passed or failed.

Items to be Tested

Ejection charges are properly sized in order to successfully separate the launch vehicle during recovery.

Items Not Tested

Structural integrity of the launch vehicle shall not be tested.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
1	Recovery section of the launch vehicle shall separate from electronics bay.	Recovery bay successfully separates, forcing the parachute and shock cord to be removed from the recovery bay.

Table 96: Pass/fail criteria for all requirements tested.

Setup

The following sections describe information about the setup and approach being used for the test.

Equipment

- Subscale launch vehicle shall be utilized ensure proper volume of the recovery bay.
- An electronic ignition station shall be utilized in order to ignite the ejection charge from a safe distance.
- Prepared black powder ejection charges shall be utilized in order to separate the section.

Setup

Ejection charges shall be inserted into the appropriate terminal block of their associated recovery bay. Recovery bays shall be attached to the corresponding sections of the electronics bay in accordance with the launch vehicle.

Safety Notes

All spectators and testers shall be a minimum of 12 feet from the launch vehicle during testing. No person or object shall be directly in front of or being launch vehicle during ejection charge testing.

Procedure

Step 1: Prepare ejection using the specified amount of black powder measured using the black powder measuring kit located in the explosives box.

Step 2: Connect the prepared ejection charge to the specified terminal block.

Step 3: Assemble the electronics bay and recovery bay using the #4-40 UNC nylon shear pins.

Step 4: Connect the electronic ignition station to the terminal block.

Step 5: Ensure the area is clear around the launch vehicle.

Step 6: Fire the ejection charge using the electronic ignition station.

Data

Only visual inspections were performed during this test, data is to be included.

Results

Requirement 1: [Bay Separation] Trial 1–**FAIL**

Upon initial test, the ejection charge did not successfully separate the recovery bay from the electronics bay.

Requirement 1: [Bay Separation] Trial 2–**FAIL**

Second test did not successfully separate the recovery bay from the electronics bay.

Requirement 1: [Bay Separation] Trial 3–**PASS**

Ejection charge successfully separate the recovery bay from the electronics bay.

Zachary Wright

Zachary Wright

Test Engineer Name

Test Engineer Signature

1/2/15

Date Completed

4) Test Plan: (Subscale Launch Vehicle)

Introduction

In order to verify the full scale launch vehicle design, a subscale launch vehicle shall be launched. This test shall verify the overall structure and flight characteristics of the full scale launch vehicle.

Test Criteria

The following sections describe information regarding what is being tested and requirements that are to be met in order to classify the test as passed or failed.

Items to be Tested

Overall flight characteristics and launch vehicle design shall be verified as safe.

Items Not Tested

Reefing recovery system shall not be tested due to the inability to create a 1:2 scale model of the system. The system shall be tested independently with a different scale model.

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
1	Vehicle shall maintain stability during flight.	Vehicle is successfully launched with no anomalies occurring during flight.
2	Vehicle shall be recoverable and reusable.	Vehicle is recovered with minimal damage and may be launched again.
3	Vehicle shall perform as similarly to the full scale vehicle as possible.	Vehicle maximum velocity is within 20% of the full scale prediction.

Table 97: Pass/fail criteria for all requirements tested.

Setup

The following sections describe information about the setup and approach being used for the test.

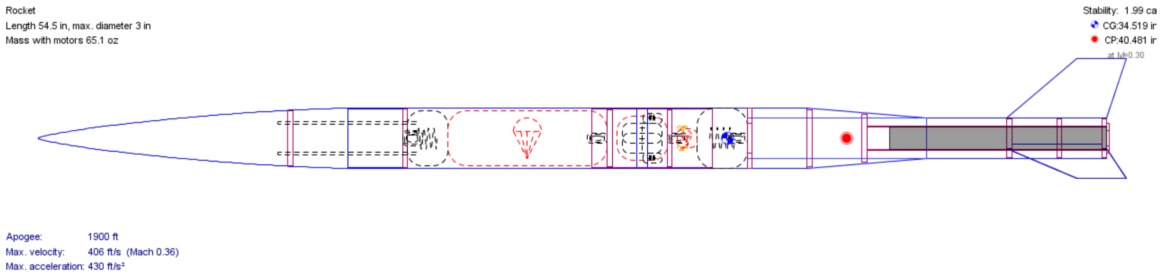
Equipment

- A standard launch rail and rail button configuration has been utilized in order to launch the subscale vehicle.

- Primary and secondary altimeters have been utilized in order to ensure successful recovery and usable data is recovered from the subscale launch vehicle.
- A subscale parachute has been utilized to verify the overall design of the parachute and recover the launch vehicle.
- A standard 12V direct current launch system was utilized. This is the same configuration that will be used during the full scale launch.

<u>Setup</u>

The subscale launch vehicle was loaded using a standard dual deploy system with a separation point at the electronics bay located in the center of the vehicle. The configuration is shown below.



<u>Safety Notes</u>

All spectators and launch attendees shall be at the appropriate distance from the launch vehicle as outlined by NAR standards.

Procedure

<u>Step 1:</u> Verify the batteries being used for altimeters possess a minimum of 8.7V.

<u>Step 2:</u> Install recovery electronics into Electronics bay.

<u>Step 3:</u> Install charges into proper terminal blocks for the outlined recovery schematic.

<u>Step 4:</u> Place the drogue parachute and recovery wadding into the drogue recovery bay and fit the electronics bay to the drogue parachute bay.

<u>Step 5:</u> Place the main parachute and recovery wadding into the main recovery bay and fit the electronics bay to the main parachute bay.

<u>Step 6:</u> Install #4-40 UNC nylon shear pins in predrilled holes.

<u>Step 7:</u> Place subscale launch vehicle on launch rail.

Step 8: Arm recovery electronics.

Step 9: Insert motor igniter into launch vehicle.

Step 10: Ensure all attendees are at a safe distance from the launch vehicle.

Step 11: Launch the subscale vehicle.

Data

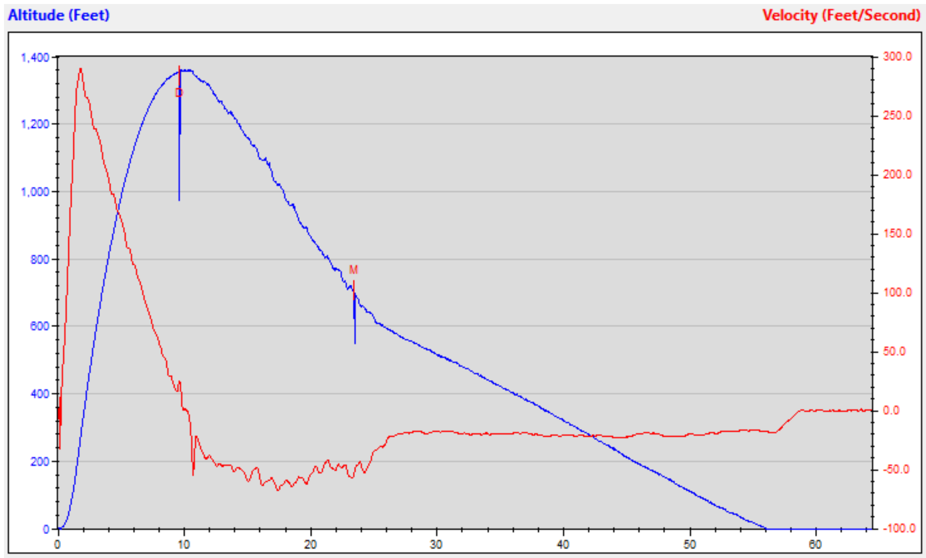


Figure 188: Primary altimeter flight results.

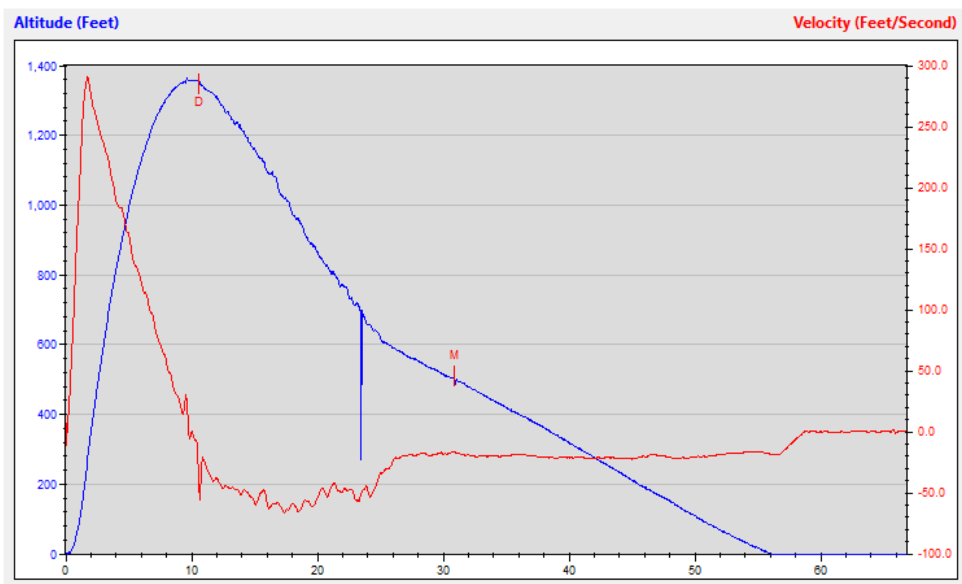


Figure 189: Secondary altimeter flight results.

Results

<u>Requirement 1:</u> Flight Stability – **PASS**

The steady climb of the altitude and velocity vs. time graphs indicate that the vehicle was stable during the entire flight.

<u>Requirement 2:</u> Reusability – **PASS**

The launch vehicle was in a state that it was able to be launched again should it have been deemed necessary.

Requirement 3: Vehicle Similarity – **PASS**

The launch vehicle maximum acceleration was within 15% of the full scale launch vehicle, indicating the similarity of the subscale to full scale launch.

Zachary Wright

Zachary Wright

Test Engineer Name

Test Engineer Signature

1/3/2015

Date Completed

5) Verification of Parachute Design: Coefficient of Drag Test

Introduction

A test was constructed to verify the parachute design by obtaining a coefficient of drag with the parachute reefed and de-reefed. This test is designed as a verification because within the rocketry community there is a wide range at which the coefficient of drag is represented in different parachute designs. Since a centerline reefing system is being used, this test will assist in deciding the appropriate length that is required to make the parachute behave like a drogue for 4,480 feet.

The risk of having an invalid coefficient of drag will result in the construction of a larger/smaller parachute. This can result in a lower altitude of the launch vehicle due to the added weight or an extended drift due to a large parachute. In order to simulate the velocity that the parachute will experience during flight, a vehicle was used to pull the parachute at a similar velocity.

Test Criteria

The following sections describe information regarding what is being tested and requirements that are to be met in order to classify the test as passed or failed.

Items to be Tested

- Subscale poly-conical parachute (reefed)
- Subscale poly-conical parachute (de-reefed)

Pass/Fail Criteria

The following table describes the requirements that are being tested and the specifications to be able to accept tested requirement as a passed requirement.

ID #	Requirement	Pass/Fail Criteria
1	Parachute in reefed state provides adequate coefficient of drag	$.6 < C_D < .8$
2	Parachute in de-reefed state provides adequate coefficient of drag	$.7 < C_D < .85$

Table 98: Pass/fail criteria for all requirements tested.

Setup

The following sections describe information about the setup and approach being used for the test.

Equipment

- Sub-scale poly-conical parachute
- Prototype reefing puck
- 1/4 inch quick link
- Vehicle
- 1/2 inch by 8 foot conduit pipe
- 1/4 inch eyebolt and nut
- Parachord
- Force gauge

Setup

Secure the conduit pipe to the rear of the vehicle as shown below in **Figure 190**.

Figure 190: Subscale parachute testing rig.

By securing the conduit pipe in the orientation shown, the parachute avoids the blunt body effects that occur right behind the vehicle. Towards the end of the metal rod is a pulley where the parachute was attached and connected to a force gage.

Safety Notes

During assembly safety glasses should be worn by all personal working on apparatus and during testing. The driver can mitigate this rule if vision is impaired from safety glasses.

Before the test is initiated, make sure the parking lot is empty and no traffic is coming toward the test vehicle.

Procedure

Step 1: Take conduit and drill a 1/4 inch hole 2 inches from either end of the piece of conduit.
Step 2: Secure a piece of 1/4 inch threaded rod through the pre-drilled hole with two 1/4-20 inch nuts.
Step 3: Place a pulley on top of the 1/4 inch threaded rod and secure it with two more 1/4-20 inch nuts.
Step 4: Take test vehicle and secure the conduit pipe on two locations on the rear face of the vehicle as shown in **Figure 190**.
Step 5: Ratchet strap the conduit pipe to the rear face of the car to ensure minimum movement when parachute gets inflated during testing.
Step 6: Mount the force gage, using ratchet straps, in the inside so that it is suspended in the center of the test vehicle. This will allow the force of the parachute to be the only pulling force that the force gage experiences during each test.
Step 7: Secure a line from the force gage, around the pulley and to the sub-scale parachute quick link. Make the sure this line is long enough so that the parachute can full inflate while avoiding the blunt body effects that the test vehicle creates.
Step 8: Record the temperature and wind speed on the day of testing.
Step 9: Align test vehicle in a diagonal direction of open parking lot to get maximum duration for each trial.
Step 10: Accelerate test vehicle up to 30mph ± the wind speed (add or subtract wind speed based off of direction of wind). One team member is needed to read the force gage while another team member is writing down the forces that the parachute is experiencing during each trial.
Step 11: Take average of the force readings and record in data sheet.
Step 12: Repeat test 3 times for every scenario: de-reefed, reefing ring at 0 inches, and at 15 inches.

Data

The results of three separate tests, with three trials a piece are shown in

Table **99**.

Test No.	Description	Velocity [mph]	Force [lbf]	Density of Air [lbf*s^2/ft^4]	Effective Area [ft^2]	C_d		
1	Reefed state 15nches	30	14	0.002507	3.408	1.69		
2	Reefed state 15nches	30	15	0.002507	3.408	1.81		

3	Reefed state 15nches	30	14	0.002507	3.408	1.69	Avg.	1.73
4	Reefed State 0 inches	30	5	0.002507	2.49	0.83		
5	Reefed State 0 inches	30	4	0.002507	2.49	0.66		
6	Reefed State 0 inches	30	5	0.002507	2.49	0.83	Avg.	0.77
7	De-Reefed state	30	16	0.002507	7	0.94		
8	De-Reefed state	30	20	0.002507	7	0.90		
9	De-Reefed state	30	23	0.002507	7	0.95	Avg.	1.16

Table 99: Coefficient of drag test results.

Results

The data received selected the desired reefing state of 0 inches from the center of the parachute to the top of the eyebolt on the reefing ring. By reefing at 0 inches rather than 15 inches the parachute will experience lesser force that will reduce drift since the launch vehicle will descend at an appropriate drogue velocity under reefed state.

1.2 Requirement 1: [Adequate coefficient of drag for reefed state] – **PASS**
As shown in
Table 99 column C_D the parachute in a reefed state of 0 inches was able to acquire a coefficient of drag between the range $.6 < C_D < .8$.

1.3 Requirement 2: [Adequate coefficient of drag for de-reefed state] – **PASS**
As shown in
Table 99 column C_D the parachute in a de-reefed state was able to acquire a coefficient of drag between the range $.75 < C_D < 0.95$.

Kevin Compton | *Kevin Compton*

Test Engineer(s) Name | **Test Engineer(s) Signature**

Emily Robison | *Emily Robison*

Test Engineer(s) Name | **Test Engineer(s) Signature**

1/9/2016

Date Completed

Appendix II – 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*
- *CTI3660-L1720-WT-P motor*
- *Motor retainer*
- *Dead blow*
- *#10-32 Shoulder Screws (x6)*

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 #10-32 Shoulder 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.* ______________________________

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

Required Equipment:

- *Clear black powder capsules (x2)*
- *E-matches (x2)*
- *Drill*
- *1/8" drill bit*
- *Electrical tape*
- *Scissors*
- *Black powder*
- *Paper towels*
- *Black powder measurement kit*

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 5.4 cc's specified amount of black powder as outline up to line on container. Fill excess space with a piece of paper towel to ensure black powder remains in contact with the pyrotechnic tip of the e-match no matter the orientation of the capsule.
6. ___ Repeat steps 2 through 4 four times.

7. ___ Store modified capsules and e-matches in explosives box.

⚠ DANGER E-matches are explosive. The black powder charges and leads must be kept clear from batteries and any open flames in order to avoid accidental firing.

GPS Preparations

Required Equipment:

- *GPS unit(s) (x1)*
- *GPS charger*

1. ___ Check GPS unit(s) for full charge. If not fully charged, charge GPS unit(s).

Launch Day Procedures:

Lower Sustainer GPS Installation

Required Equipment:

- *Nosecone GPS*
- *M3 screws (x2)*
- *Socket set*
- *Lower sustainer door*
- *GPS tracking device*

1. ___ Check nosecone GPS 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.

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

Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	2	5	Low	Team members must wear long sleeves and safety glasses whenever working with metal parts.
Handling carbon fiber tow.	Use in manufacturing airframe.	Splinters in skin.	4	3	Low	Team members are required to wear cut resistant gloves, long sleeves, and safety glasses when handling carbon fiber.
Electric shock while welding.	Improper PPE and welding technique.	Severe injury to the operator. Possibly death.	1	5	Low	All team members must undergo official training from either a FirstBuild employee or other professional before welding.
Radiation and burns from welding.	Improper use of PPE.	Mild to severe burns to skin.	1	5	Low	A welding helmet, heat resistant jacket and gloves, and close toed shoes must be worn at all times while welding.
Intense light from welding.	Improper use of PPE.	Injury to eyesight may occur. May result in loss of eyesight at an early age if welding without proper PPE over long periods of time.	1	5	Low	A welding helmet, fitted with a filter shade must be worn at all times while welding.

Table 100: Lab and machine shop risk assessment.

AGSE -Launch Platform Functionality Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severit y 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	1	3	High	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by

		pad, the rocket's path will be unpredictable.				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. Deflection analysis has been performed to ensure that the rocket will be free to move. See Launch Platform Final Configuration Structural Analysis for more details.

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.

					Moderate	All personal will be required to maintain a minimum safe distance away from the AGSE during operation. The analysis of this joint was included in the Launch Platform Analysis. See analysis for more details.
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. Analysis has already been performed to ensure that the system is safe. See Subframe Structural Analysis for more details.

Base pivot axle shears.	Too high of a load for the designed axle to carry.	The shaft could deflect or completely fail, resulting in a mission failure.	1	5	Low	Analysis has been performed to ensure that the axle is large enough to carry the necessary load with a minimum factor of safety of 1.5 and can be manufactured given the available tooling. See Base Pivot Axle Bending Analysis for more details.

Table 101: Launch platform 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 or damage to the rocket.	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)	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

	on tracks and/or carriage.					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. Analysis has already been performed to verify the articulating arms can support the load it will see. See Launch Platform Final

					Moderate	Configuration Structural Analysis for more details.
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 have been 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 in case of misalignment during transportation.
Carriage to power screw nut connection fails.	Material failure.	Power screw spins without advancement of nut, causing vehicle actuator to be motionless.	1	5	Low	Proper bolt and mounting plate specifications have been determined. A similar system was used in River City Rocketry's 2014-2015 design and signs of material degradation have yet to be observed.
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	1	4	Moderate	Analysis has been performed to adequately size the power screw with a minimum factor of safety of

		platform may fall or be at risk of falling back to horizontal.				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. 3. Carriage and track interfaces. 4. Articulating arm.	Minor to serious injuries to personnel working with, around, and transporting the vehicle actuator. Possible damage to surrounding equipment.	2	4	Moderate	Guards will be installed to protect objects and personnel from entering pinch point areas. Personnel will be required to remain clear of AGSE during operation, and will maintain a minimum safe distance away until the system has been deemed safe by the safety officer. Wires, tubing, and other systems will be routed away from pinch point areas to avoid possible damage.
Vehicle is not lifted at a high enough rate.	The motor was not sized correctly.	Vehicle won't be lifted with-in time requirement.	2	3	Moderate	Analysis has been performed to ensure the proper motor was selected.
Personal injury from AGSE.	Personnel in close proximity while AGSE is in operation.	Personal injury.	2	3	Moderate	Power will be disconnected from AGSE prior to working on the system or surrounding systems. When the AGSE is powered on all

						personnel will be at a minimum safe distance away.
Non-Functioning and unresponsive system.	Break in wires.	1. Rocket will not 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.
H-bridge overheats.	Poor thermal relief.	1. Rocket will not raise or lower. 2. Rocket will stall at position.	1	4	Moderate	Heat sinks with adequate wattage rating will be used.
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 102: Vehicle actuation 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	3	Moderate	Sharp edges of the igniter installer should be filed down and de-burred.

		2. Igniter installation wire becomes cut, exposing wire causing false signal to be sent, prematurely igniting the motor.				
Igniter is not fully installed in motor.	1.Igniter slips during installation 2. Igniter gets tangled prior to insertion 3. Igniter is not straight upon insertion	Possible catastrophic failure of rocket motor during ignition; loss of vehicle, 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, the igniter will be spooled below the ignition station. The wire will then be straightened via a belt system prior to entering the rocket.
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. Testing will be performed with a simulated motor which has been built.
Damage to igniter.	Extruder assembly applies enough pressure to igniter assembly to shear igniter wire.	Unresponsive igniter.	1	5	Low	The igniter will be heavily shielded and protected from sharp edges. The igniter installation system will be inspected for any possible sharp edges prior to each run of the AGSE.
Igniter prematurely lights.	1. Ignitor circuit is prematurely energized.	Injury to personnel working around AGSE, damage to systems onboard AGSE.	1	5	Low	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. All preliminary tests of the system will be run with a simulated motor, significantly reducing the hazard should the igniter prematurely light.
Non-functioning and unresponsive.	1. Break in line. 2. Error in code.	Igniter installation fails, leading to mission failure.	1	4	Moderate	The igniter installer will be run through a series of tests, verifying each of the functionalities of the system upon assembly 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 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. Wiring schematics will be available to avoid wiring the driver incorrectly.
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 103: Igniter installation risk assessment.

AGSE – Sub-Frame Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sub-frame feet sink into ground.	1. Insufficient surface contact between foot and ground. 2. Ground is too soft.	Ground station doesn't sit high enough for vehicle actuation. Launch platform unstable.	2	4	Low	Feet will be sized to provide adequate surface contact. Weather conditions will be monitored prior to and on launch day to anticipate ground conditions. When the launch platform is in a vertical position, there is still approximately 4 inches of clearance, allowing for the sub-frame to sink some before seeing interference issues. If the ground be so soft that the ground station starts sinking, a dryer spot should be found to set the ground station or the launch should be postponed.
Unstable sub-frame.	1. High winds. 2. Unstable ground. 4. Sub-frame footprint.	Sub-frame falls resulting in possibly injury to surrounding personnel.	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 sub-frame has been designed to include three wide contact points to increase stability.
Sub-frame bows/sags.	Material failure.	Carriage may jam, launch platform will be unstable.	1	4	Moderate	Testing will be performed prior to launch day to ensure the ground station performs as expected when it has been completely assembled. Analysis has been performed to verify the current

						design. See Sub-Frame Analysis for more details.
Sub-frame 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 the ground station performs as expected when it has been completely assembled. Analysis has been performed to verify the current design. See Sub-Frame Analysis for more details.
Sub-frame interference.	Sub systems collide with ground station structure.	Sub-systems won't be able to complete their tasks.	2	5	Low	All components have checked for interference with solid models in all possible orientations of each assembly in the solid models. The models are exact representations of the parts that are to be built. Therefore, there should be no interferences during assembly. Components will also be physically checked during assembly. Systems that can be manually actuated on launch day will be manually actuated to check for interferences in case of misalignment that may have occurred during transportation.

Table 104: ASGE – Sub-frame 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. 5. High noise levels	Arm fails to retrieve and load payload.	1	4	Moderate	Once the entire system has been assembled, a series of tests will be run to test the entire functionality of the system and to ensure each sub-assembly works together. Preliminary testing of payload capture electronics has begun.
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 once system motors are received and the assembly has been completed. Similar grips were used in River City Rocketry's 2014-2015 design and successfully aided in the completion of the mission. This provides confidence in the reliability of the current design.
Failure to insert payload.	1. Payload is dropped. 2. Payload is not aligned properly to	Payload is not loaded into rocket.	1	3	High	Testing will be completed to verify payload is gripped and properly oriented when entering rocket, consistently placing the payload

	enter rocket and/or retaining clips.					into the rocket. This test will be performed upon the completion of the payload bay in the rocket and the payload capture device.
ACME screw buckles.	ACME screw is not appropriately sized and cannot support the required weight.	Payload capture device completely fails, leading to mission failure.	1	5	Low	A buckling analysis has been performed to verify that the ACME screw will carry the required loading required for the payload capture device. See ACME Screw Buckling Analysis for details.
Motor for ACME screw cannot rotate the screw.	Motor does not have enough torque.	Payload capture device will be unable to move, resulting in mission failure.	1	4	Low	An analysis was performed to determine the required torque for the system to operate. The selected motor meets the requirements. See ACME Screw Required Motor Torque and RPM Analysis for details.
Cannot complete required extension and retraction motions for the payload capture within the allotted time.	The motor selected to drive the ACME screw does not have a high enough RPM to complete the task in the allotted time.	The payload retrieval will take longer to complete than expected, risking being over time.	1	4	Low	An analysis was performed to determine that the required RPM of the motor in order to complete all tasks on time. See ACME Screw Required Motor Torque and RMP Analysis for details.
Motor for base pivot cannot rotate the payload capture around the pivot.	Motor does not have enough torque.	Payload capture device will be unable to move, resulting in mission failure.	1	4	Low	An analysis was performed to determine the required torque for the system to operate. The selected motor meets the requirements. See Base Pivot Motor Torque and RPM Analysis for details.

Cannot complete required rotation about base pivot for the payload capture within the allotted time.	The motor selected to drive the ACME screw does not have a high enough RPM to complete the task in the allotted time.	The payload retrieval will take longer to complete than expected, risking being over time.	1	4	Low	An analysis was performed to determine that the required RPM of the motor in order to complete all tasks on time. See Base Pivot Motor Torque and RPM Analysis for details.
Signal noise between potentiometer and motor supply lines.	Wires are harnessed together and routed through the same path.	The potentiometer readings, which indicate the position of the gripper, will give false readings.	1	5	Low	Knowing the potential for signal noise, shielded wire has been selected for the wires in the payload. Additionally, motor lines and potentiometer lines have been kept separate where possible. This allows for the necessary wires to be isolated from each other.
Wires become pinched between inner and outer tubes.	Wires are not held taught.	Loose connection to electronics in the gripper assembly.	1	5	Low	The spool has been designed to alleviate this risk. When the system is complete, the wiring will be closely monitored to ensure that wires are not pinched.
Worm gear on gripper assembly skips.	Ample support not provided for gears.	Gripper assembly doesn't rotate.	1	5	Low	Additional support structure has been built that supports the shafts for the gears, ensuring that the gears will engage and not skip.

Table 105: Payload capture 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 crashes while running program.	1. Loss of power. 2. Break in communication line.	AGSE fails to operate.	1	5	Low	Testing will be completed to ensure all components maintain communication and systems do not crash. Analysis has been completed to ensure that power supply and wire sizes will allow for power to be supplied reliably to all systems.
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 106: 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. 2. Communication failure between	Vehicle fails to launch.	1	3	High	Redundancies will be implemented to ensure the igniter safety system performs as expected.

	switch and controller. 3. Code error.					
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.
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 107: 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.
Old rocket motor.	Motor not used within a year of manufacturing date.	Potentially unstable rocket motor.	1	5	Low	Only rocket motors purchased by the team during the current season will be used. The manufacture date will be verified prior to launch.
Centering rings fail.	Centering rings cannot carry the load seen during flight.	Rocket motor goes through the rocket.	1	5	Low	An analysis has be performed, verifying that the centering rings can carry the worst case scenario load that will be seen during a launch.

Table 108: 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 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. The separation section will be ground tested prior to each test flight to ensure that the black powder charges are appropriately sized. The same testing was performed

						prior to the sub-scale test launch. See Test Plan: (Subscale Ejection Charge Testing) for details on the test setup. 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 appropriately 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.	1, 2. Rocket follows ballistic	1	5	Low	Deployment bags have been specially made for the parachutes. This will allow for an organized

	2. Parachute lines become tangled.	path, becoming unsafe.				packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Parachute deployment has been both ground tested and flight tested verifying that the setup results in repeatable successful results. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Rocket descends too quickly.	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design. All custom made parachutes were extensively ground tested to validate the design. Subscale versions were built and tested to verify the coefficient of drag.
Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3	3	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.
Parachute has a tear or ripped seam.	Parachute is less effective or	The rocket falls with a greater	2	5	Low	Through careful inspection prior to packing each parachute, this

	completely ineffective depending on the severity of the damage.	kinetic energy than designed for, causing components of the rocket to be damaged.				failure mode will be eliminated. Rip stop nylon was selected for the parachute material. This material prevents tears from propagating easily. In the incident that a small tear occurs during flight, the parachute will not completely fail.
Parachute or chords become burnt.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Parachutes will all be packed in their own, custom deployment bag that is made out of Nomex, a fire retardant material. With proper packing of the parachute and use of Nomex, this failure mode is unlikely.
Recovery system separates from the rocket.	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1,2. Parachute completely separates from the component, causing the rocket to 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.
Shroud line ring does not open.	Master link black powder container is not released.	Rocket will continue to fall under drogue parachute.	1	4	Moderate	A dual redundancy system is being used to eject the master link black power container. Once the container is ejected, the force from the shroud lines will easily push the hinged brackets out of the way, allowing the parachute to fully open. All systems will be ground tested prior to flight. Testing on these systems is already underway. See Test Plan: (Subscale Ejection Charge Testing) for details.
Linear solenoid does not push out the master link black powder container.	Master link black powder container is not released.	Rocket will continue to fall under drogue parachute.	1	4	Moderate	Once the linear solenoid is obtained, testing will begin to ensure that the force is great enough to push the master link black powder container out. In the event that the linear solenoid fails, a redundant, black powder system will be used to eject the link.
Reefed parachute state provides too much drag.	Parachute is not appropriately sized.	Rocket will drift too far.	1	4	Moderate	Testing on the sub-scale parachute in a reefed state was performed to understand the properties of the reefed

						parachute. The data collected from this test was used in sizing the full scale parachute. A full scale test will be performed to validate the calculations and to ensure that there are no unexpected scaling effects. See Test XXX for details on the sub-scale test.

Table 109: 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	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.

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

Table 110: 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 angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees.	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground.	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the ground being extremely soft at local launch sites and in Huntsville, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.
Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated

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

Extended periods of time without rain or snow.	N/A	Ground is hard	3	5	Low	Extended periods of time without moisture results in a very hard ground. This increases the damage that could be incurred upon recovery. However, due to the decent velocity, even with hard ground, the rocket should not get damaged at all.
Rocket motor sees unpredicted thermal cycling and/or extreme temperatures during storage.	Motor is improperly stored.	Potentially unstable rocket motor.	1	5	Low	Pro75 motors are rated to be stored at temperatures between -5 and 30ºC. The team storage space for the rocket motors never exceeds the allowable temperature range.
Temperature at the field is different than that of the facility used to manufacture rocket.	Average temperature of manufacturing facility is moderate while some launches may occur during more extreme temperature conditions.	Sections of the rocket won't fit together or have a tight fit due to swelling or shrinking depending on ambient temperature.	1	5	Low	When sections of the rocket are tested for fit, they must be easily removable to allow for swelling or shrinking of the tubes. Sections will also be checked at the field on launch day. If the fit is too tight, light sanding can be performed. This is critical to ensure that sections intended to separate during flight can do so.

Table 111: 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.
CO_2 emissions.	Travel to launch sites and competition.	Destroying the ozone layer.	4	1	Moderate	While the effects of CO_2 emissions cannot be reversed, the amount produced is negligible.

Table 112: Hazards to environment risk assessment.

Appendix IV – Drawing Package

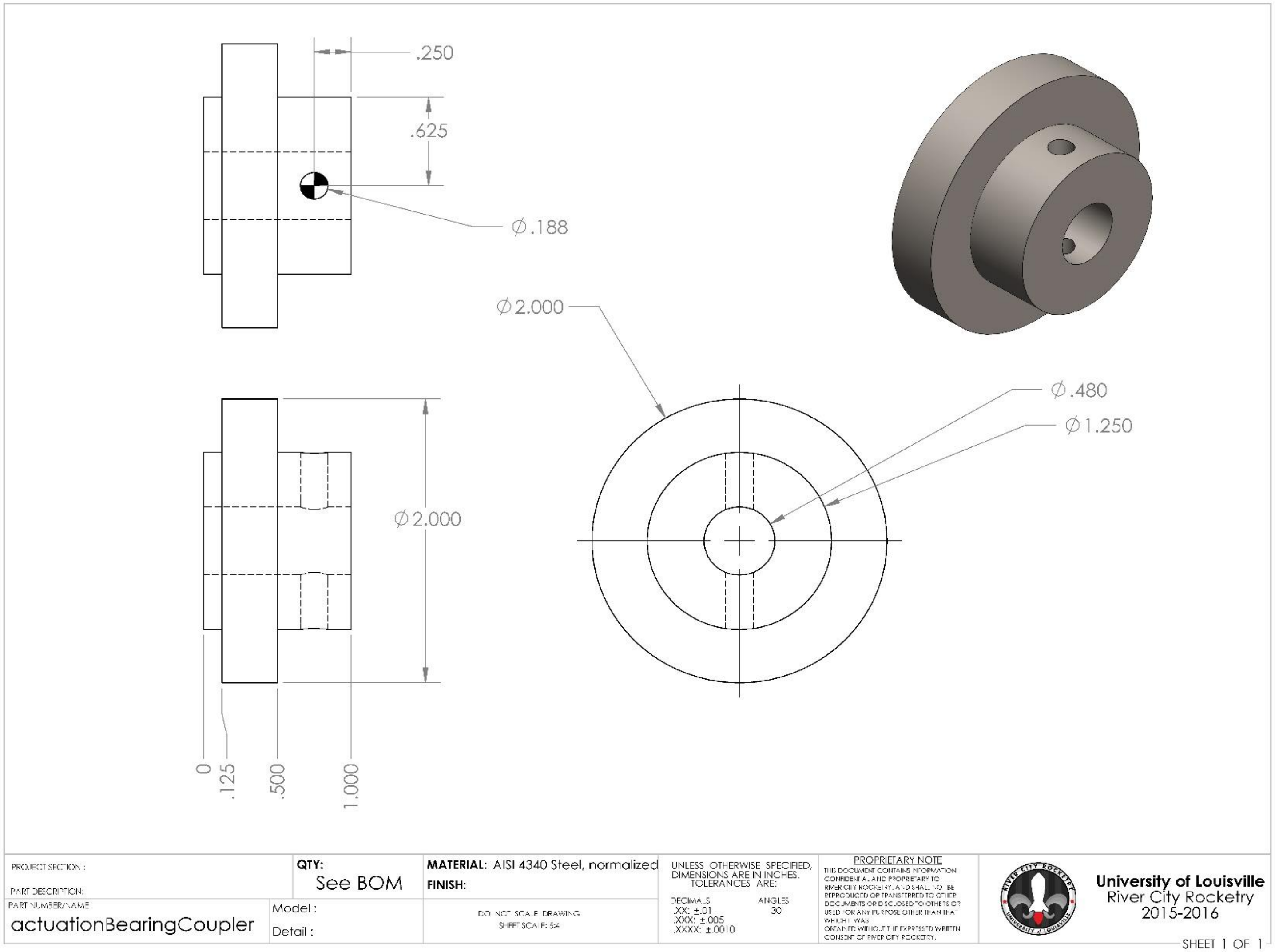


Figure 191: Actuating bearing coupler drawing.

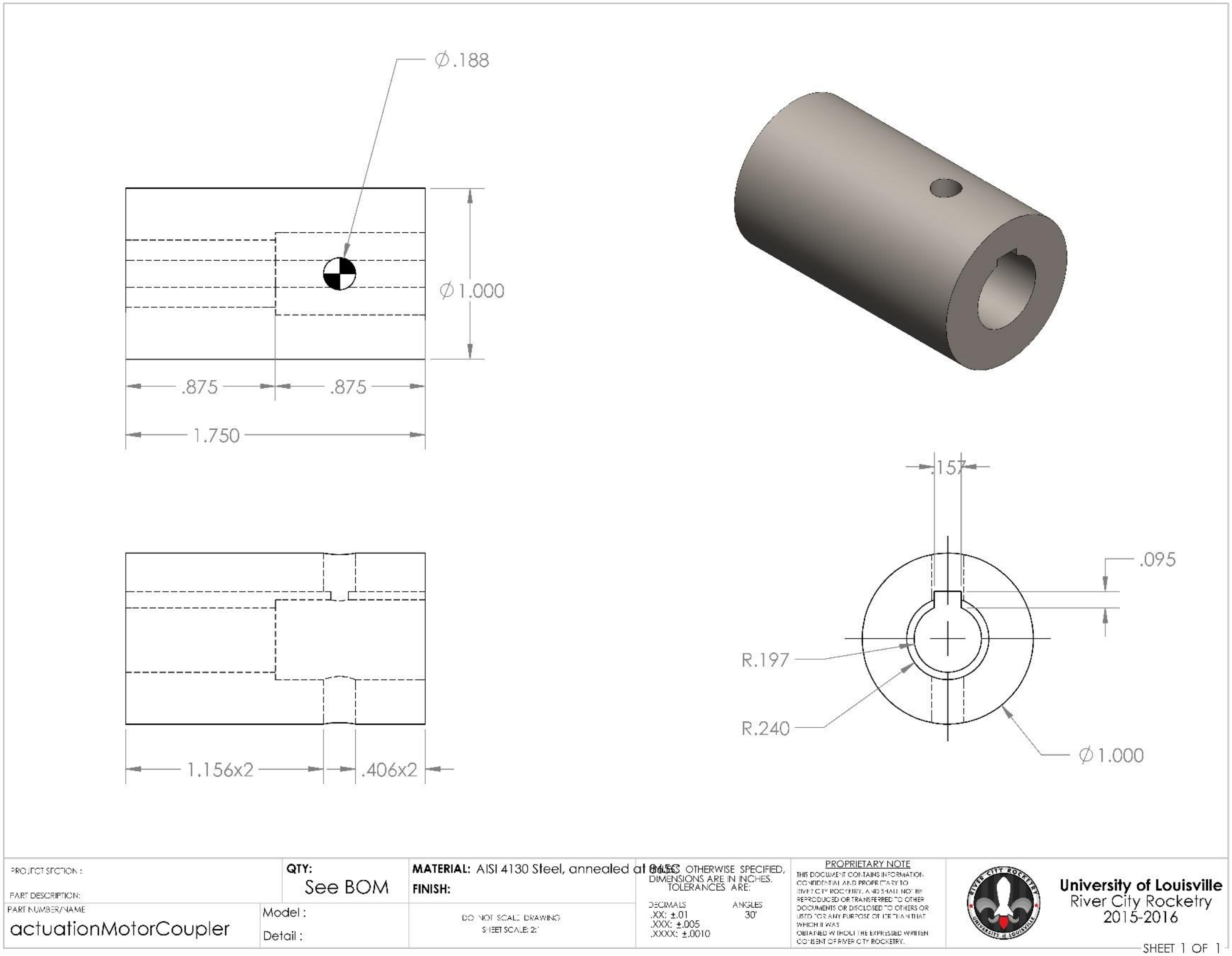


Figure 192: Actuation motor coupler drawing.

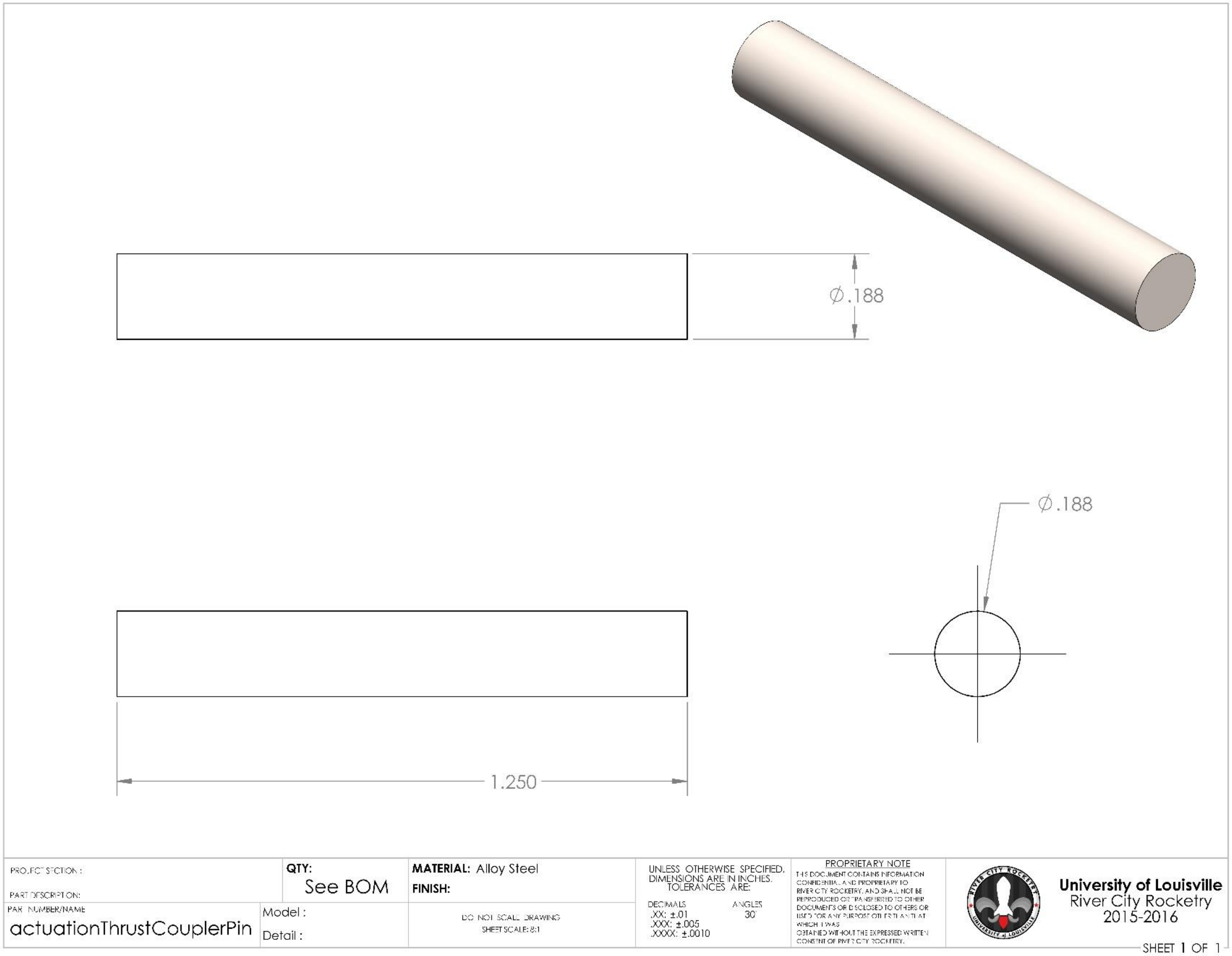


Figure 193: Actuation thrust coupler pin drawing.

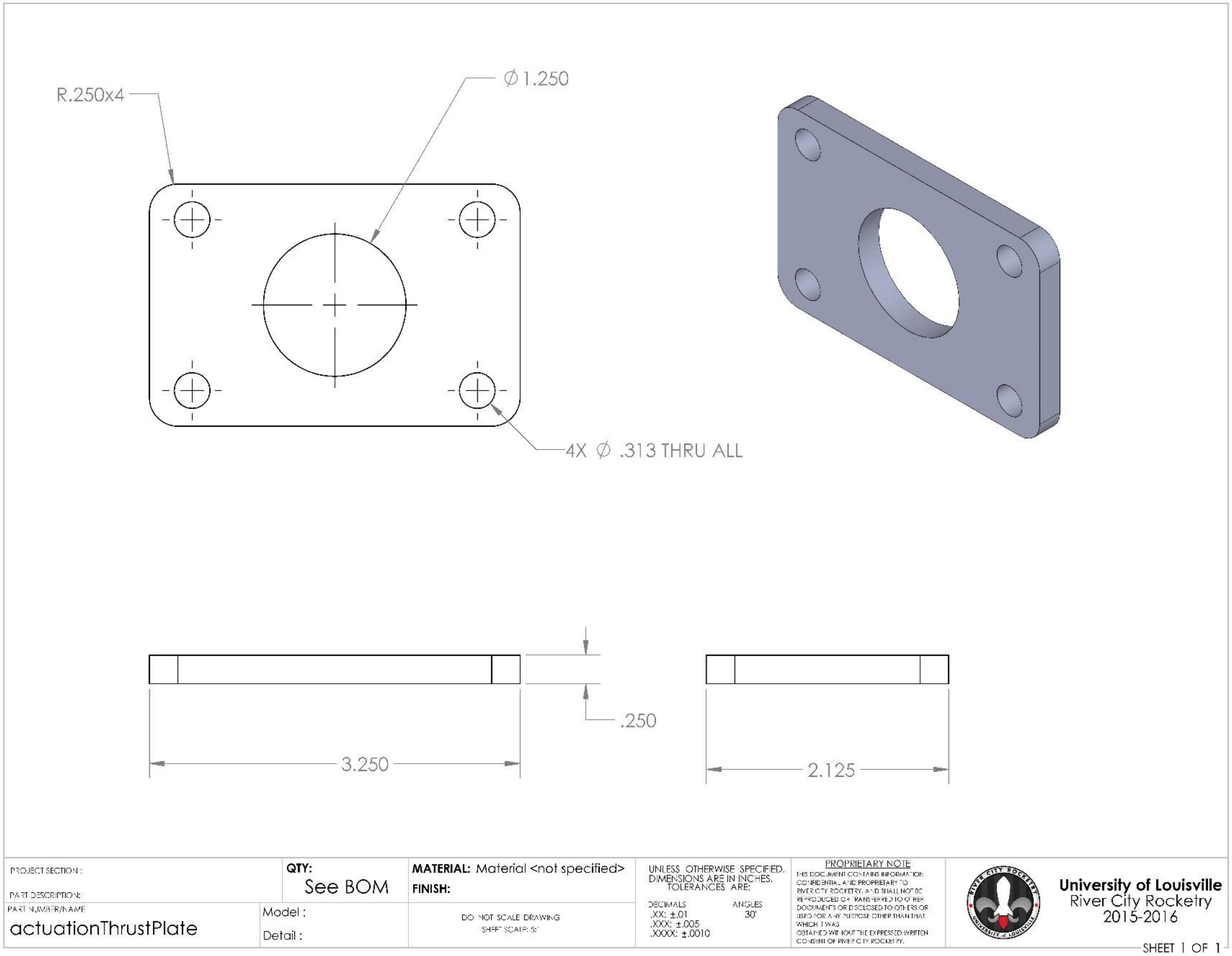


Figure 194: Actuation thrust plate drawing.

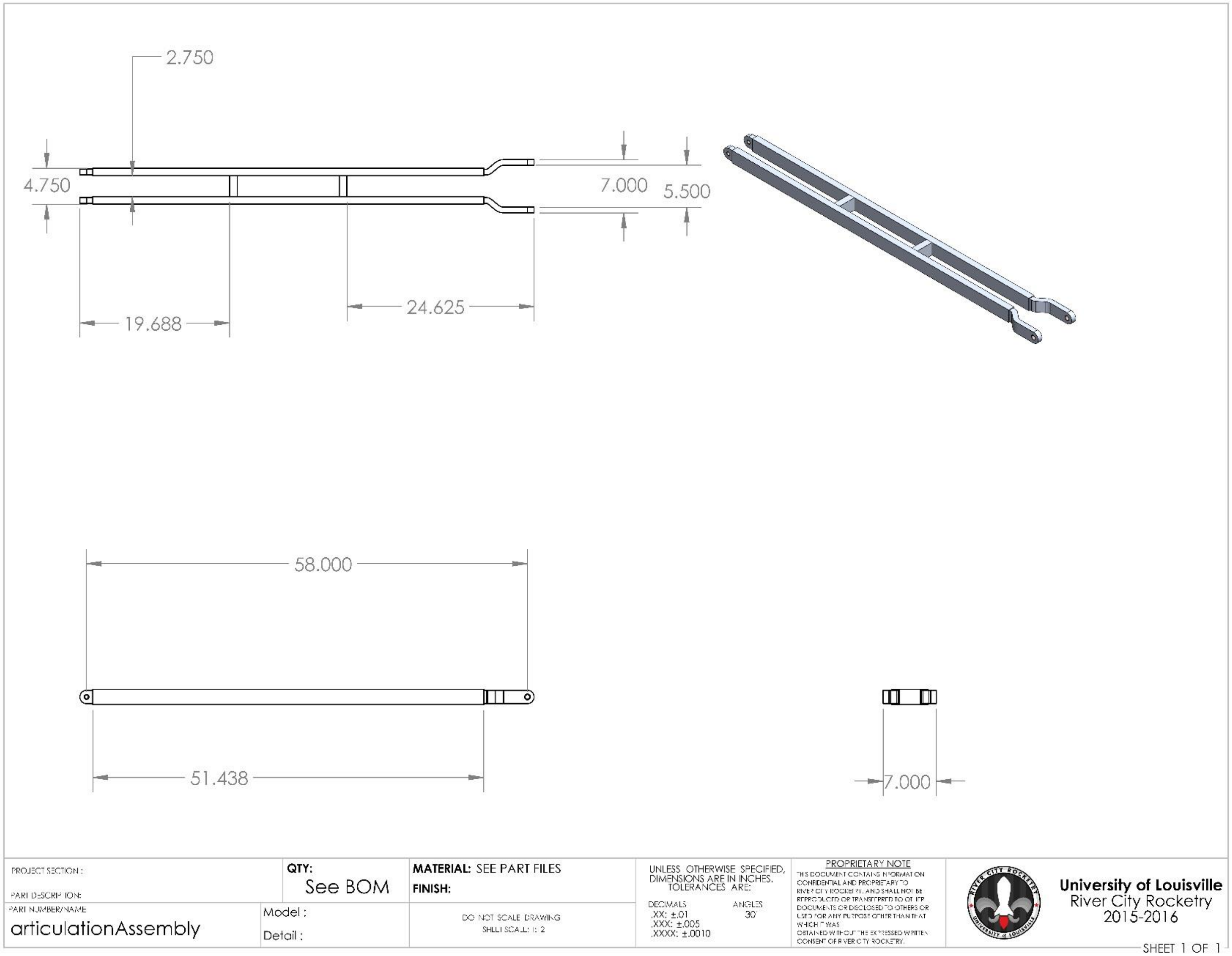


Figure 195: Articulation assembly drawing.

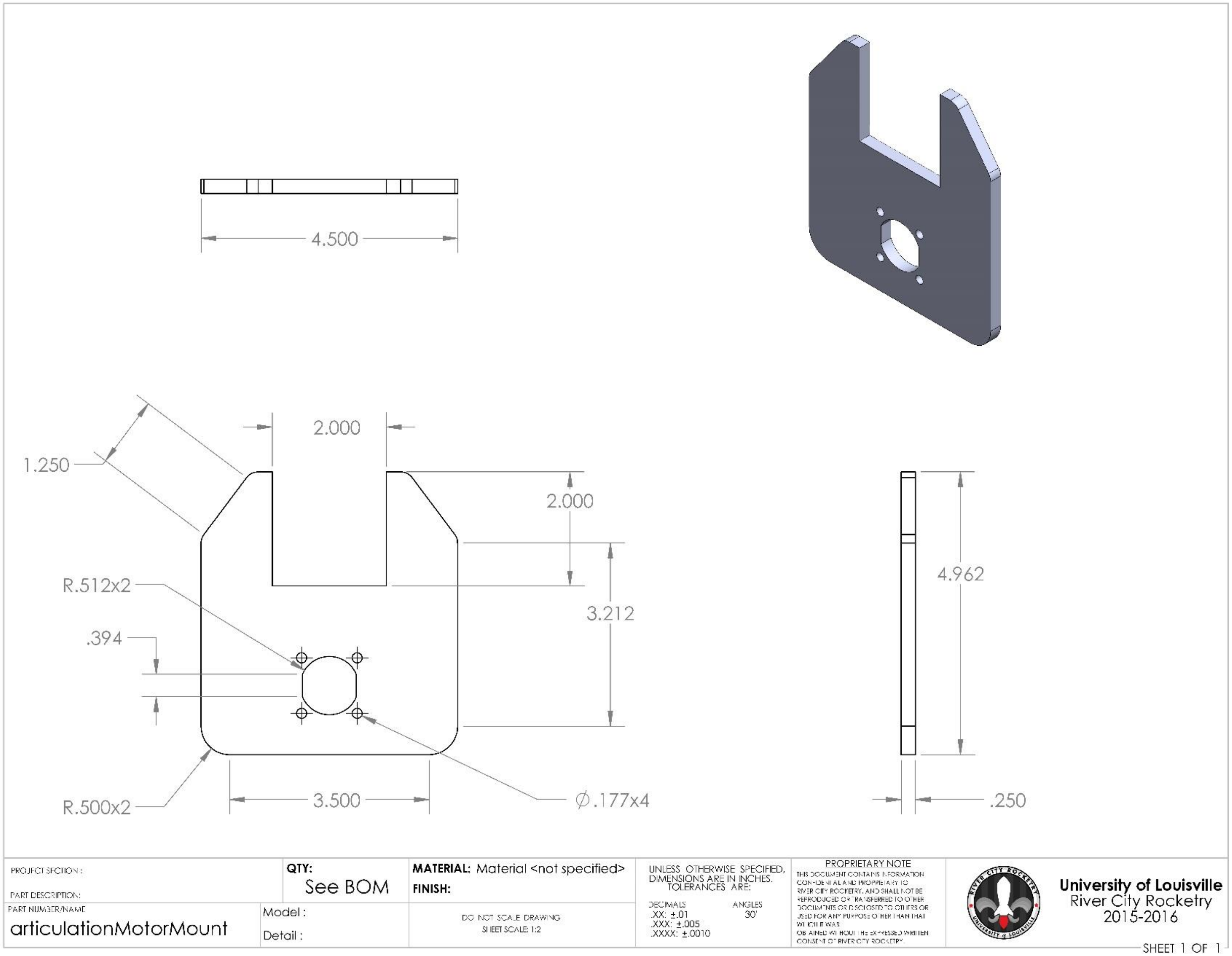


Figure 196: Articulation motor mount drawing.

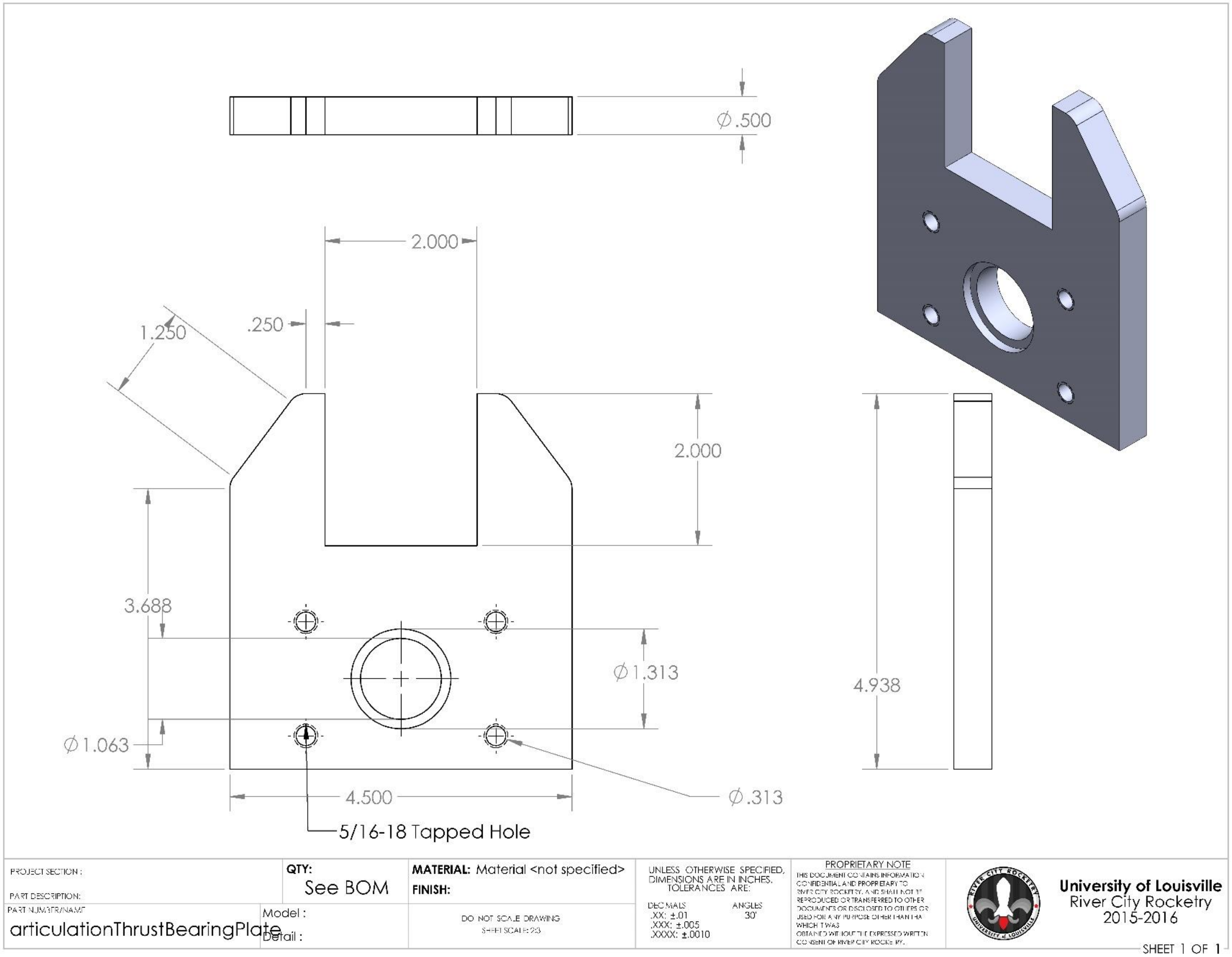


Figure 197: Articulation thrust bearing plate drawing.

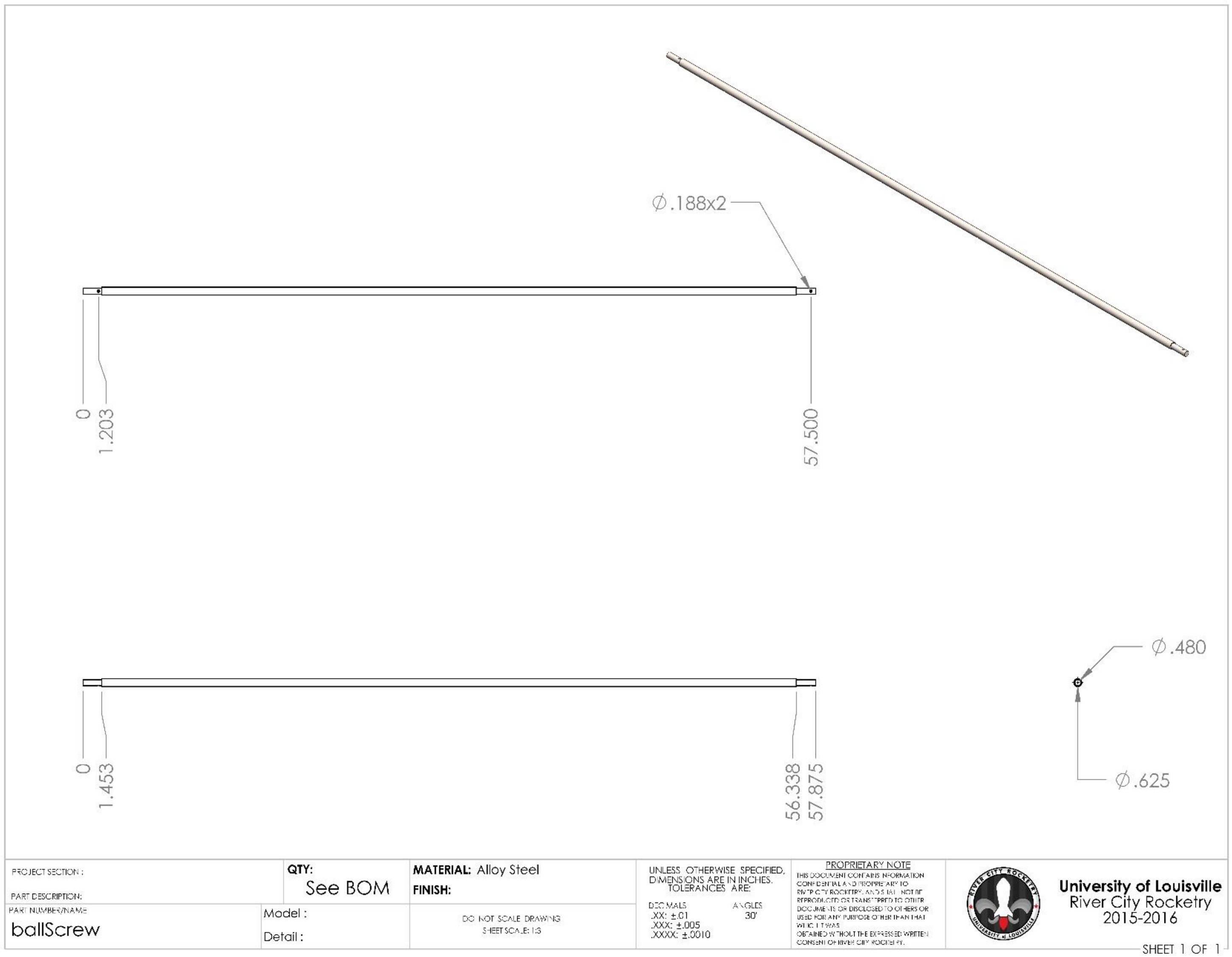


Figure 198: Ball screw drawing.

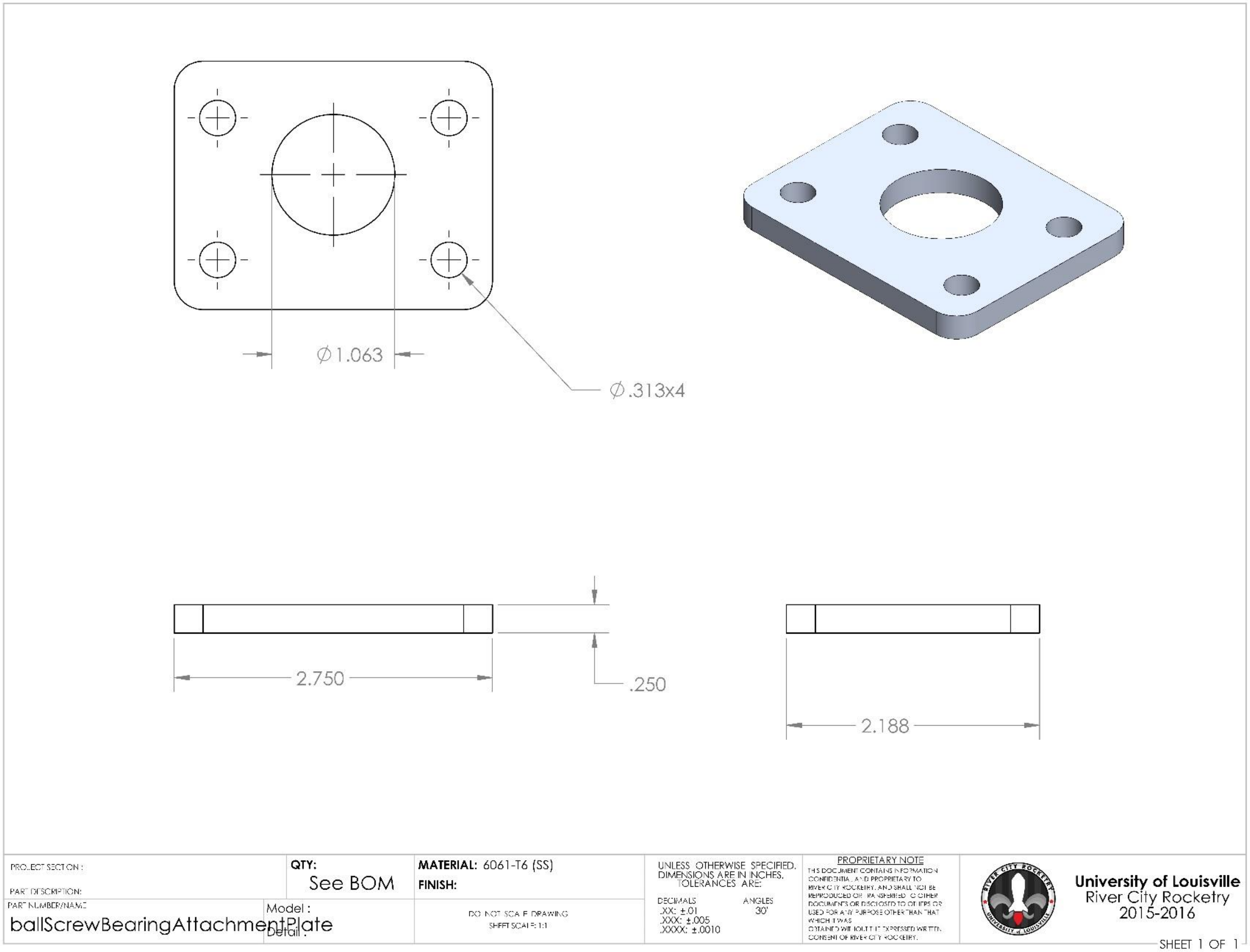


Figure 199: Ball screw bearing attachment plate drawing.

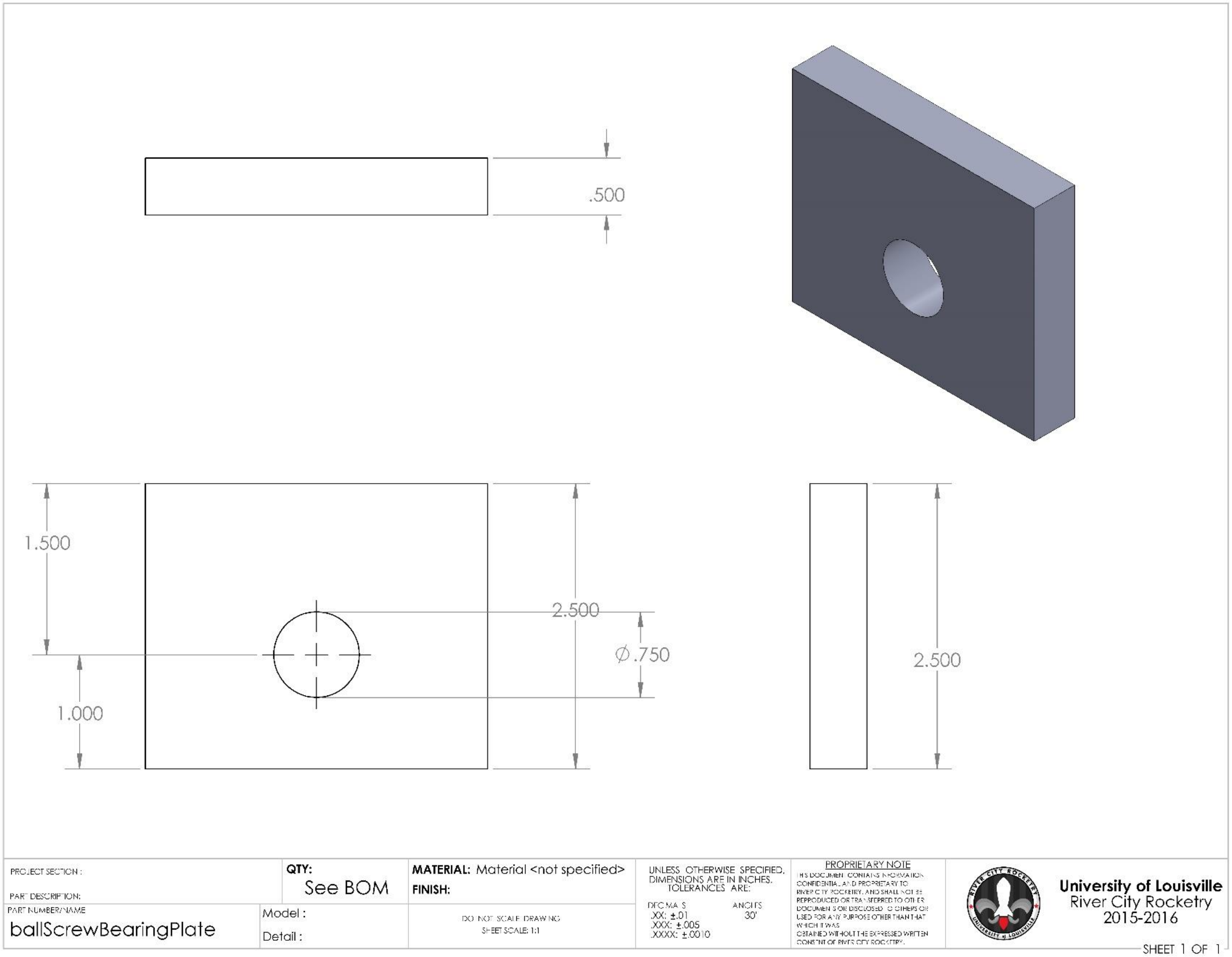


Figure 200: Ball screw bearing plate drawing.

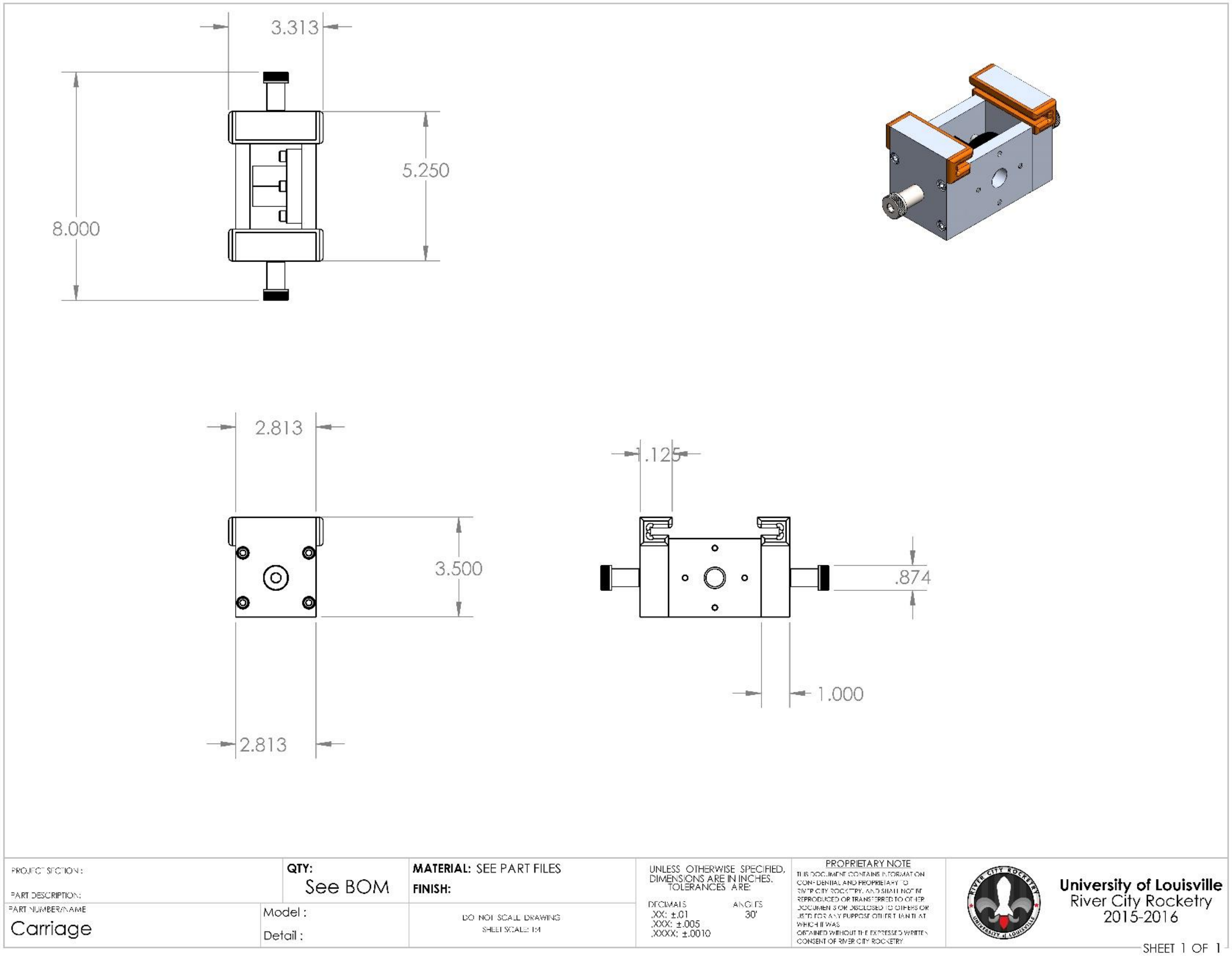


Figure 201: Carriage drawing.

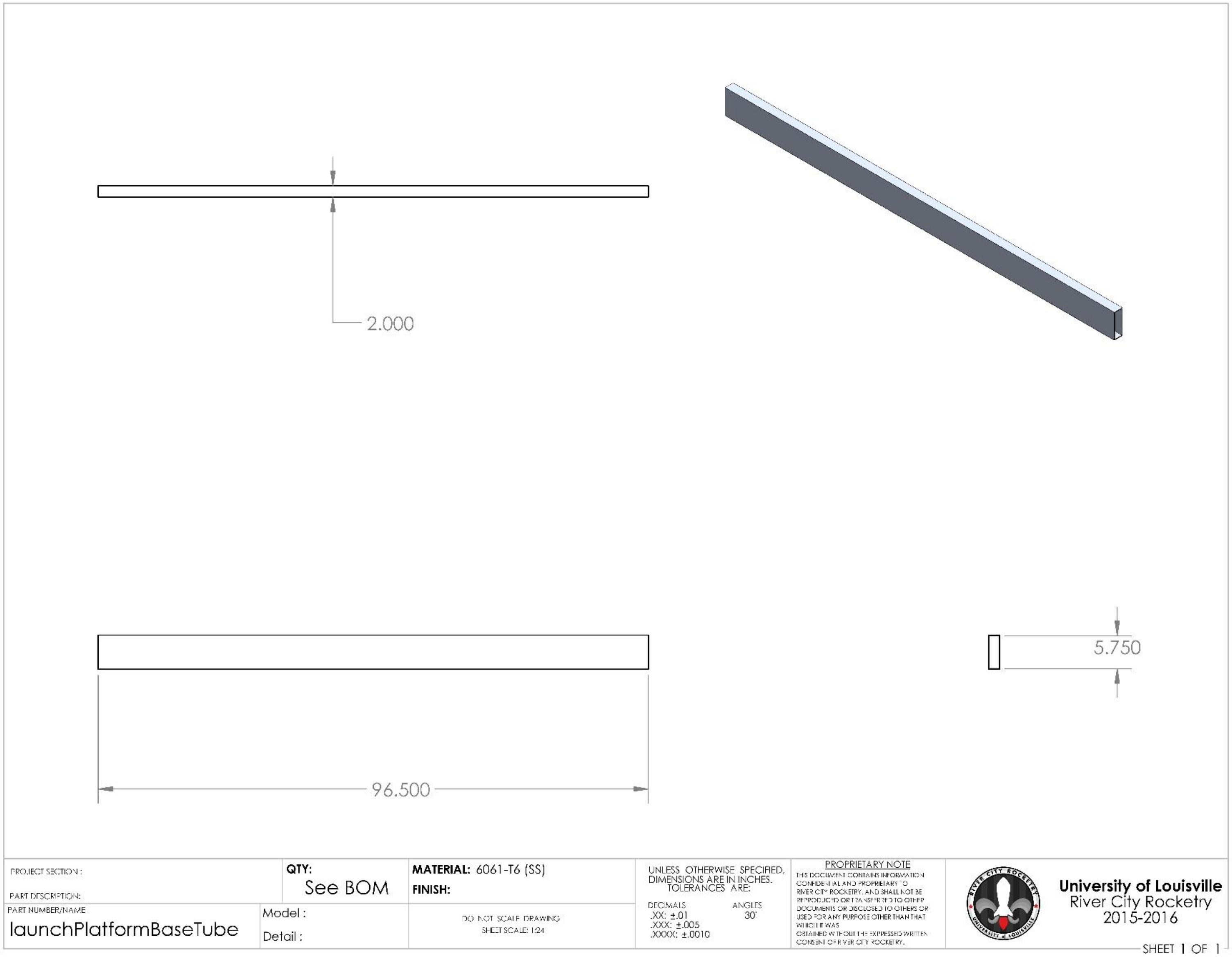


Figure 202: Launch platform base tube drawing.

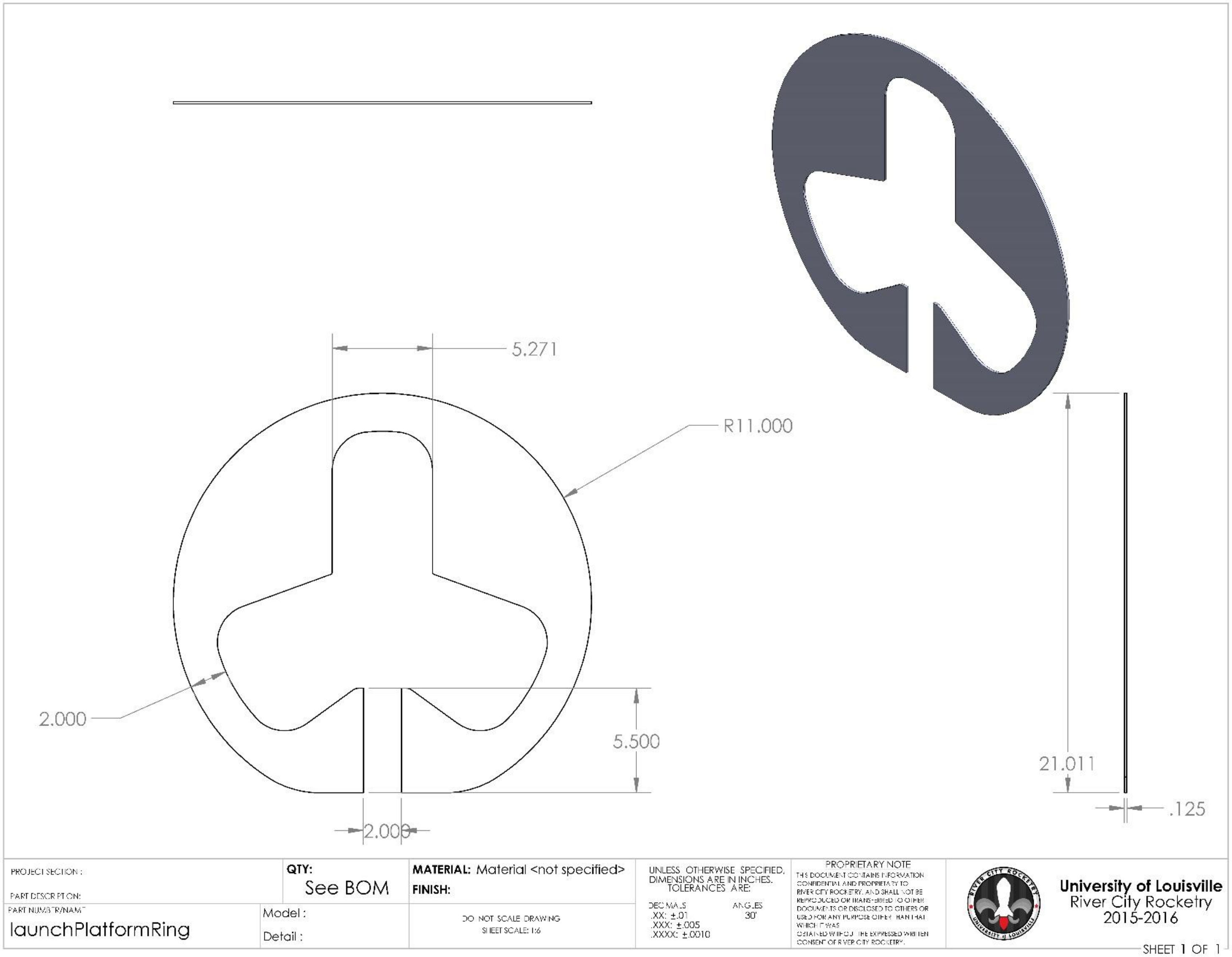


Figure 203: Launch platform ring drawing.

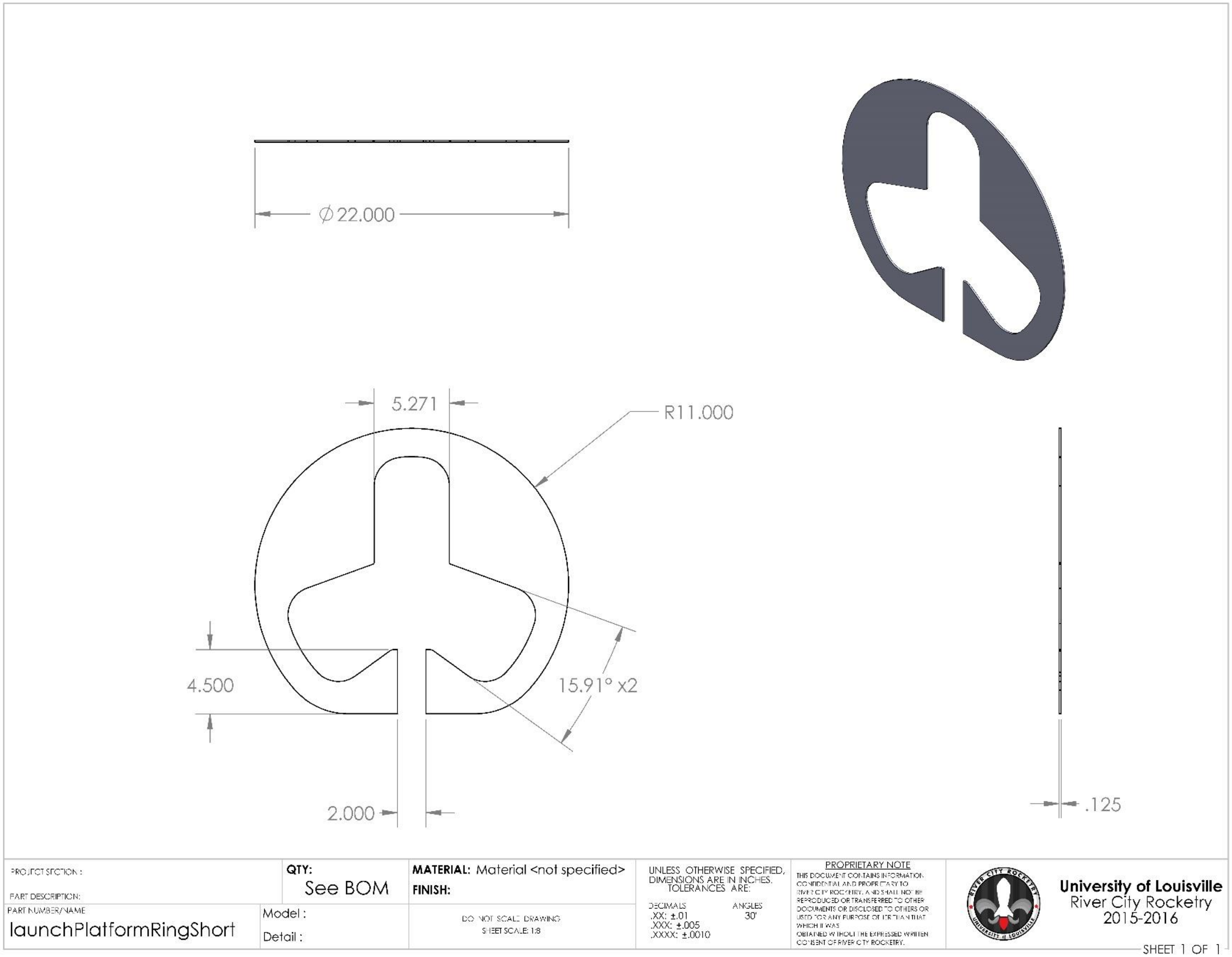


Figure 204: Launch platform ring short drawing.

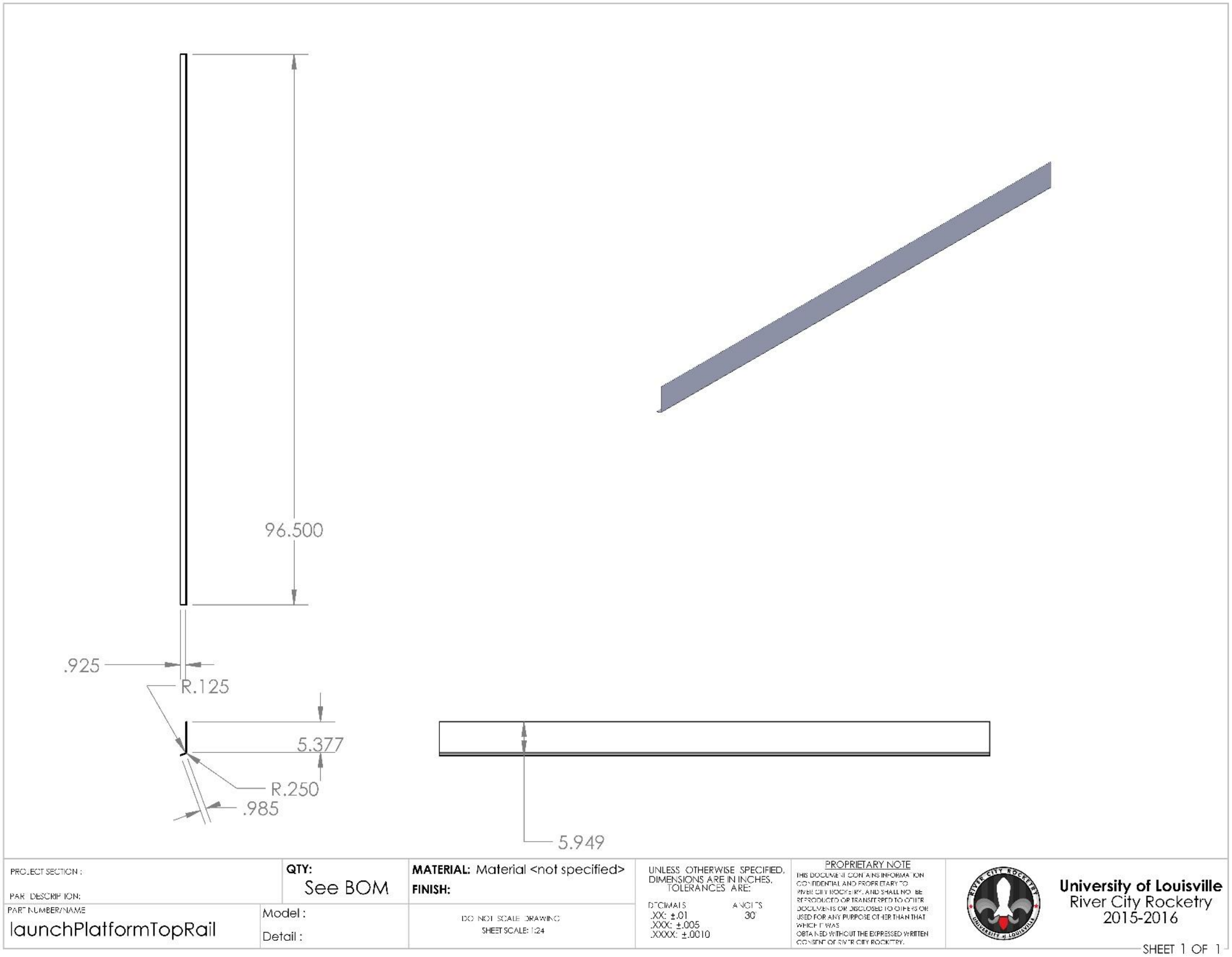


Figure 205: Launch platform top rail drawing.

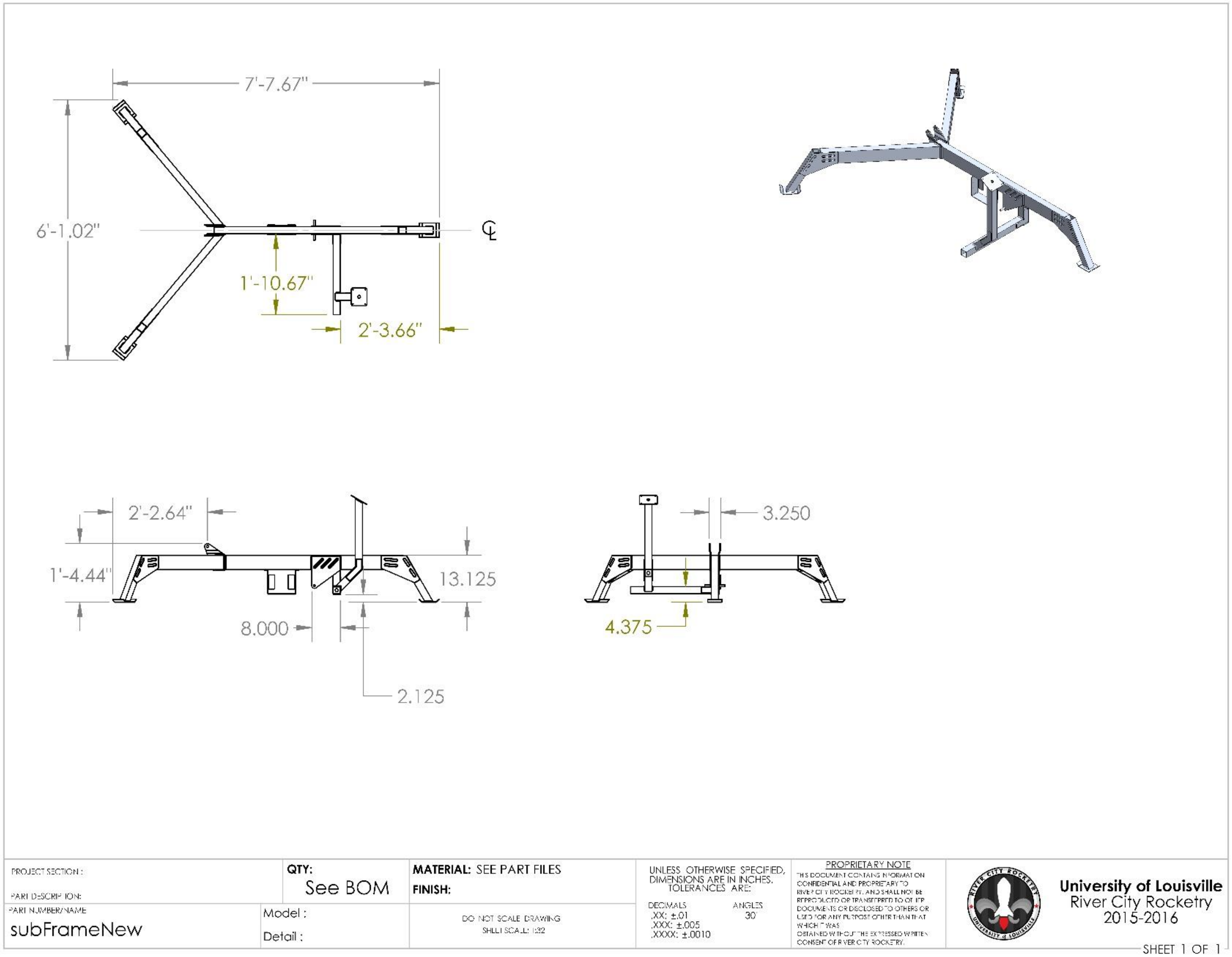


Figure 155: AGSE Sub Frame

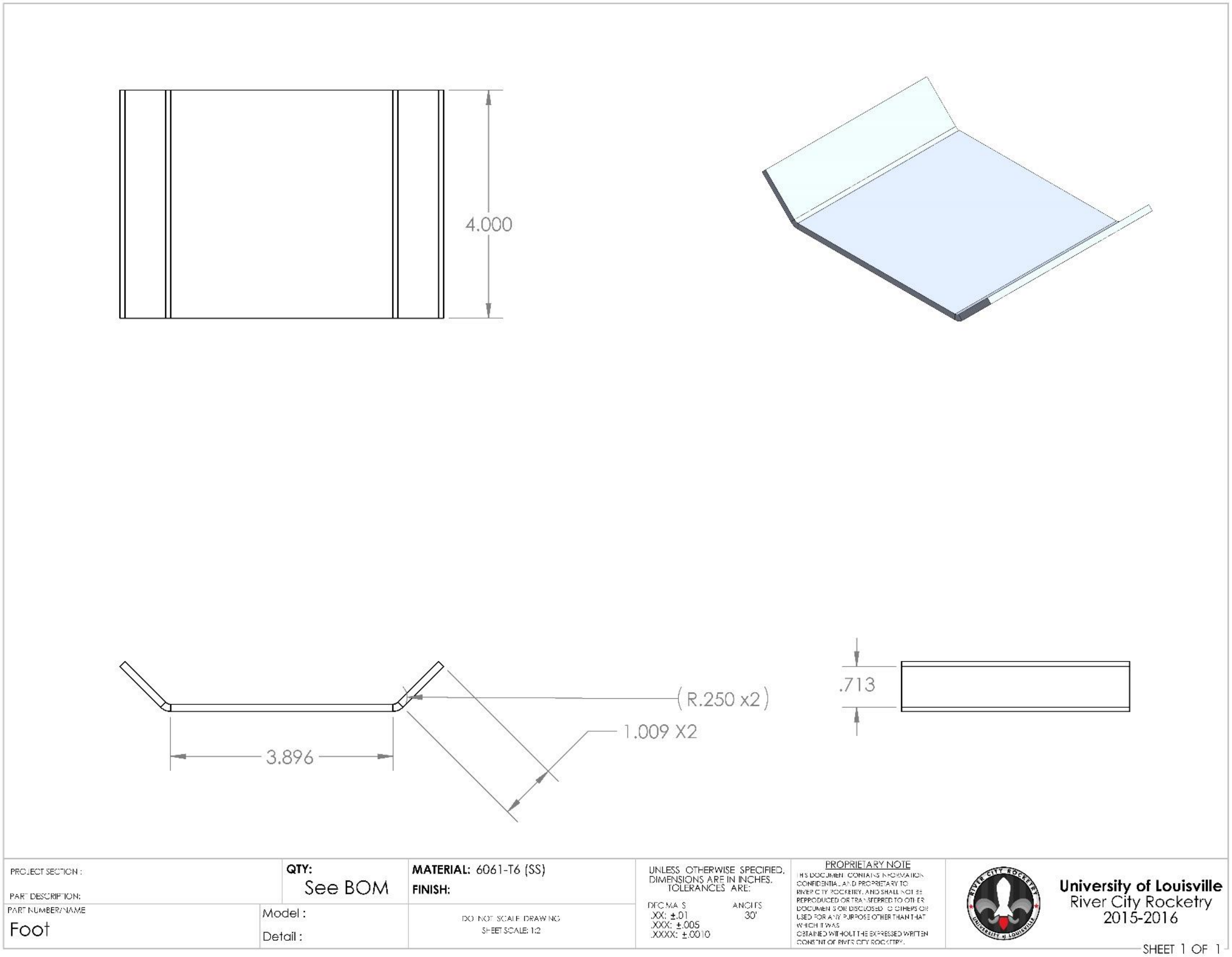


Figure:156 AGSE Sub Frame foot

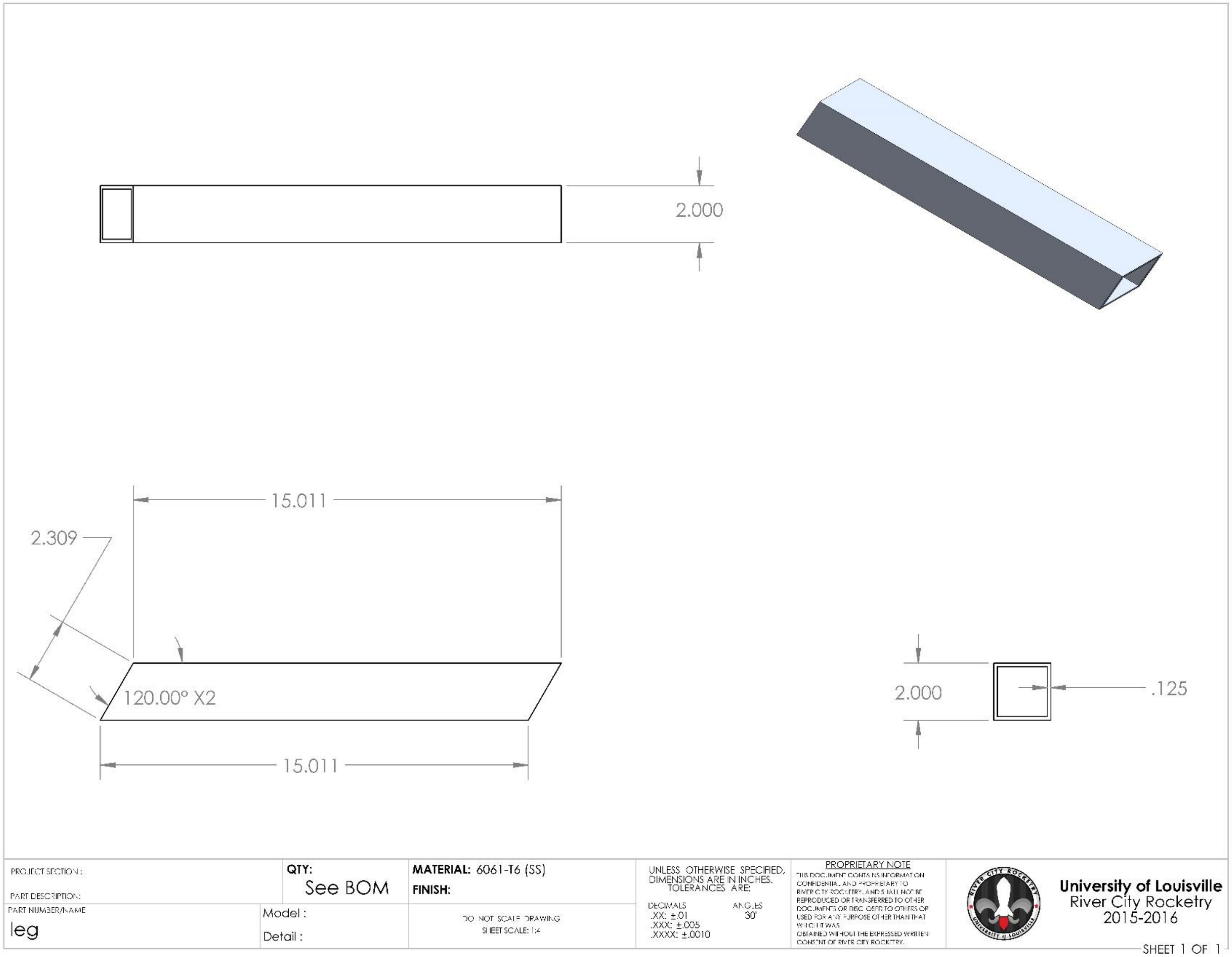


Figure 157: AGSE Sub Frame Leg

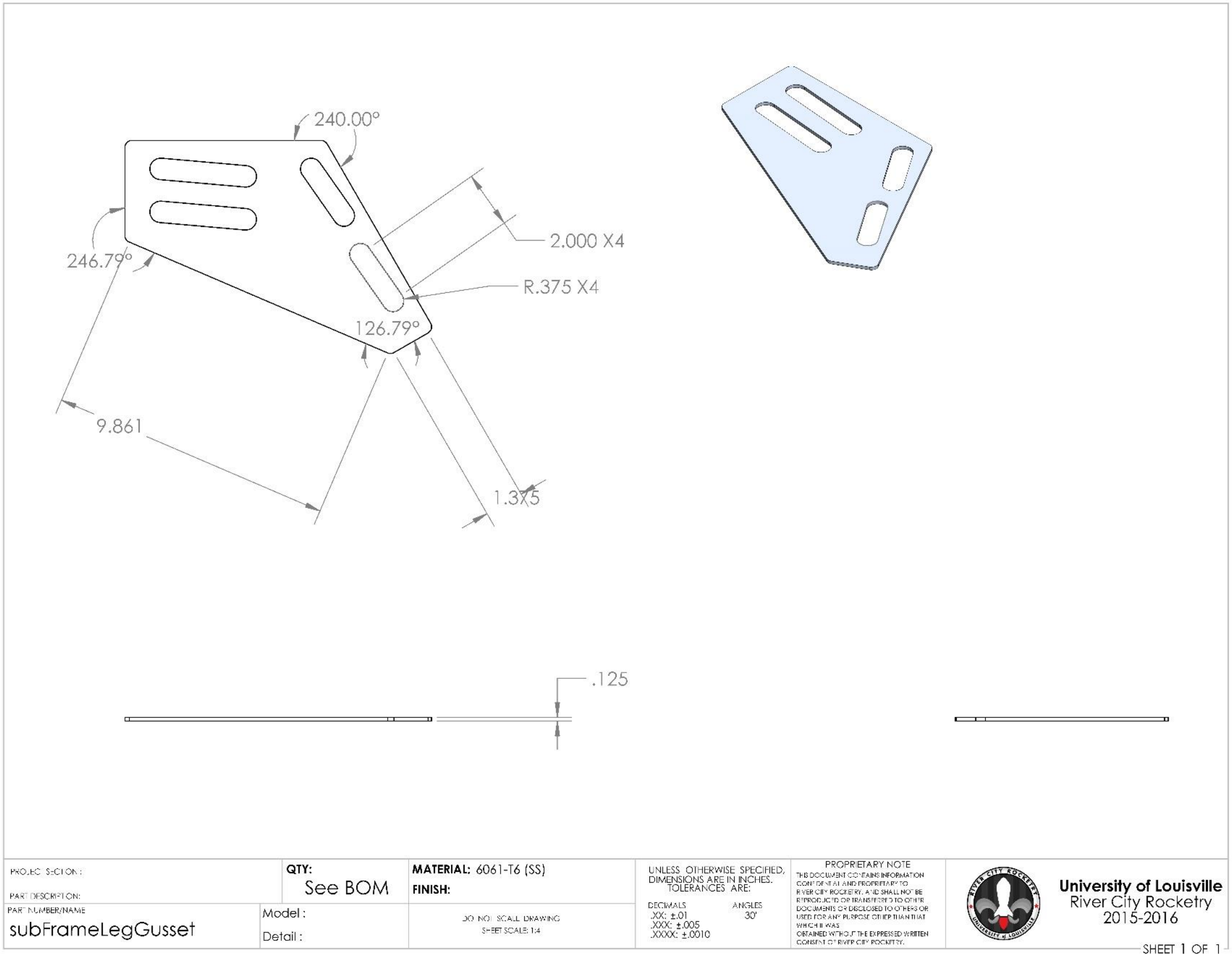


Figure 158: AGSE Sub Frame Leg Gusset

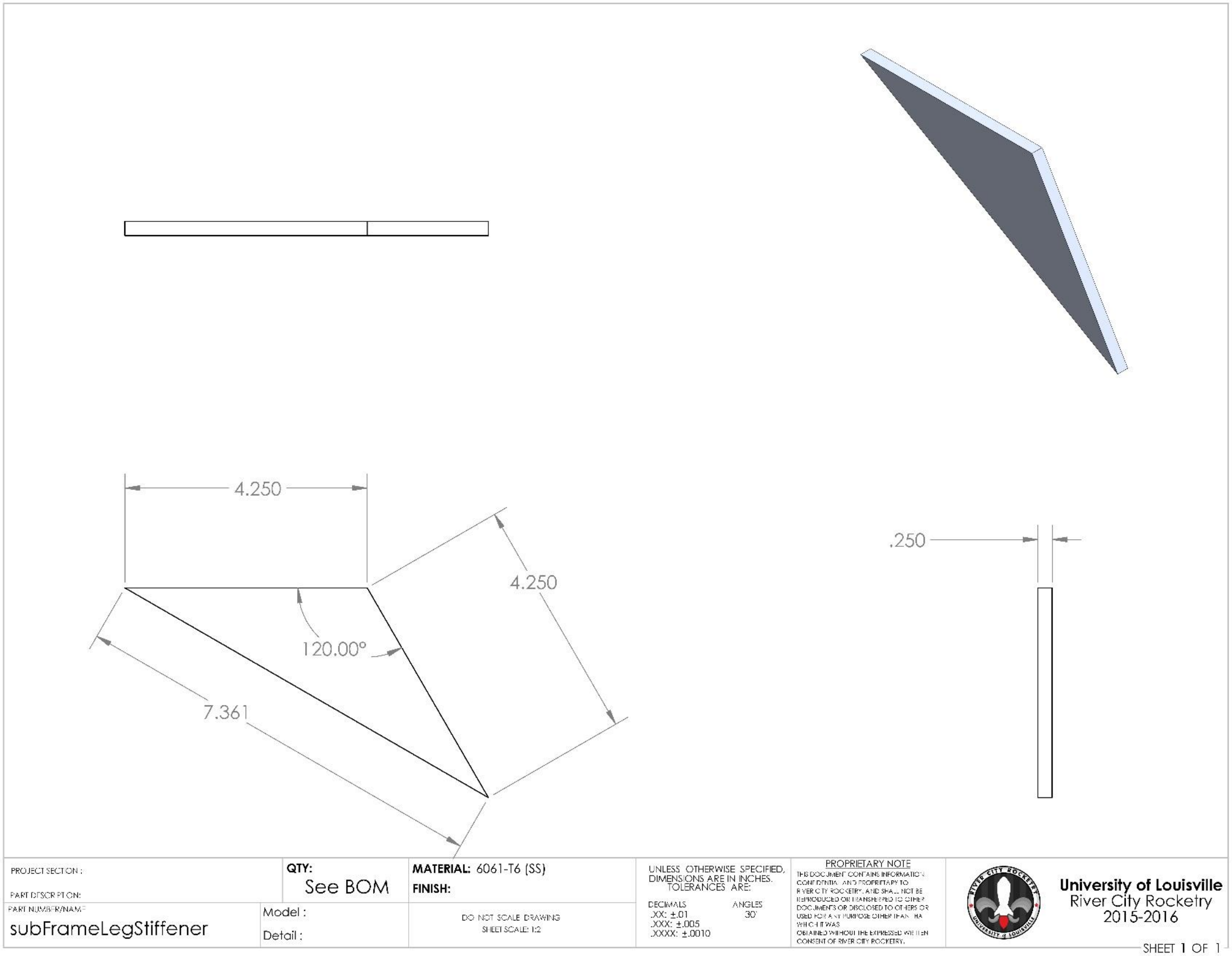


Figure 159: AGSE Sub Frame leg Stiffener

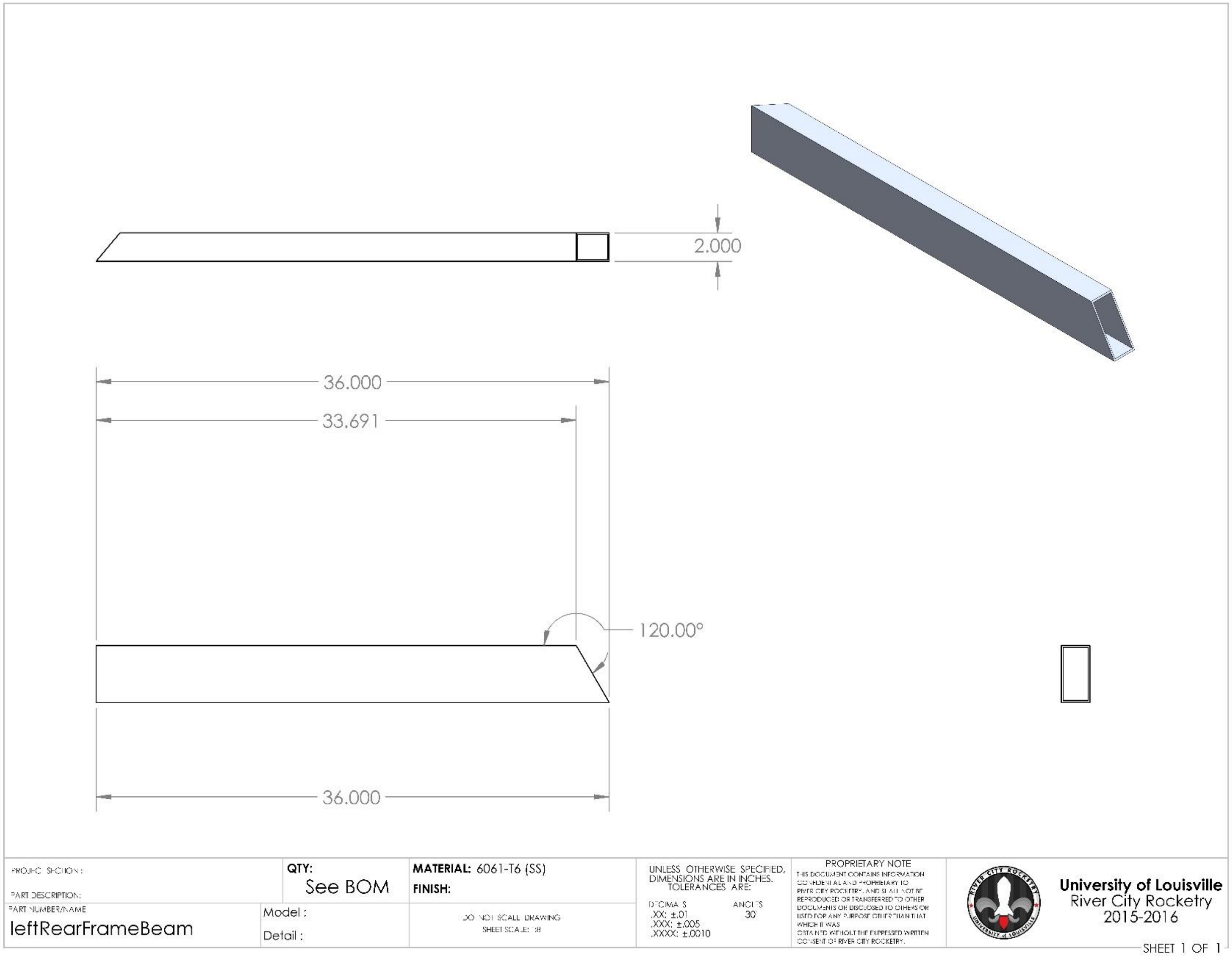


Figure 160: AGSE Sub Frame Left Leg Rear Frame Beam

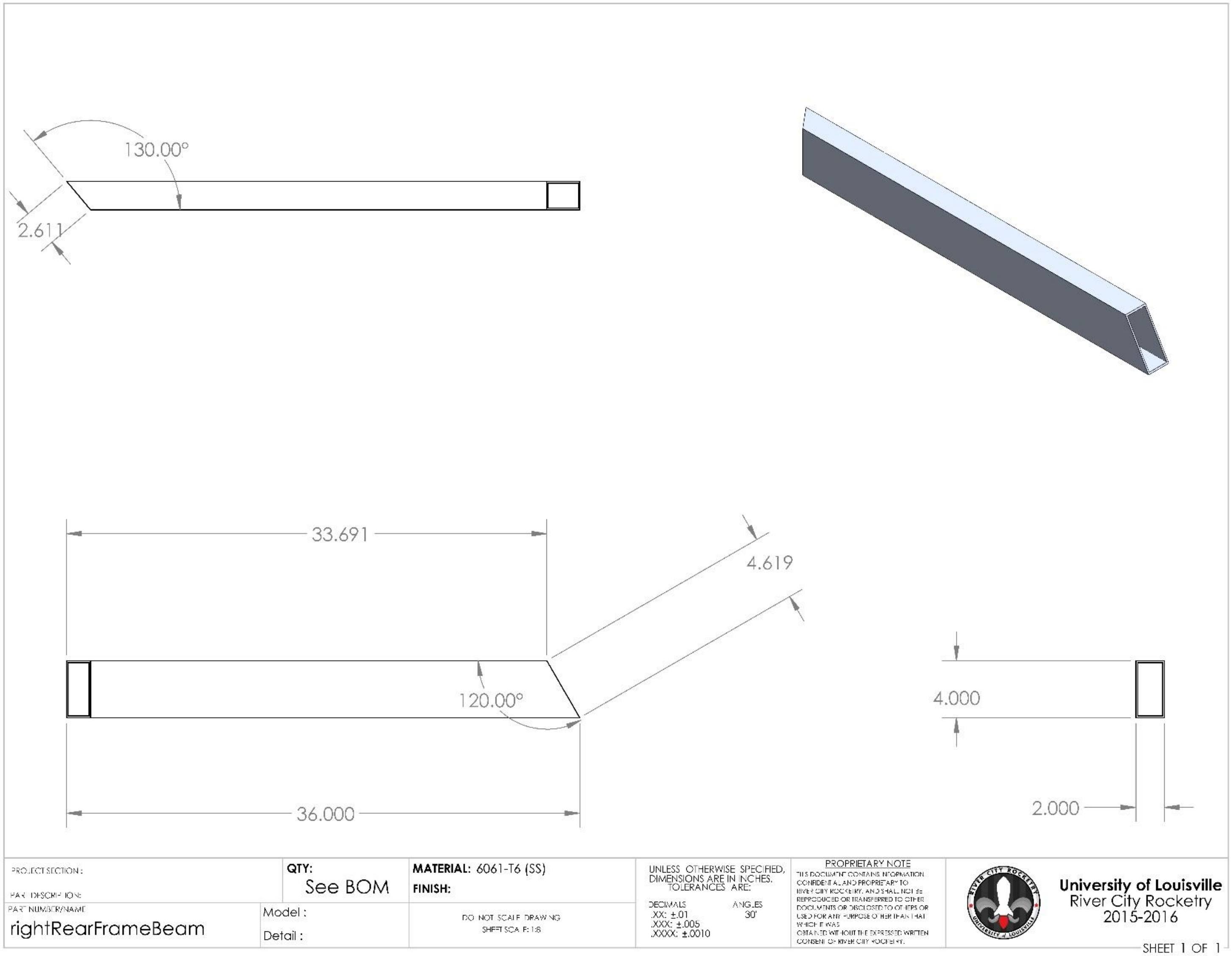


Figure 161: AGSE Sub Frame Right Rear Leg Beam

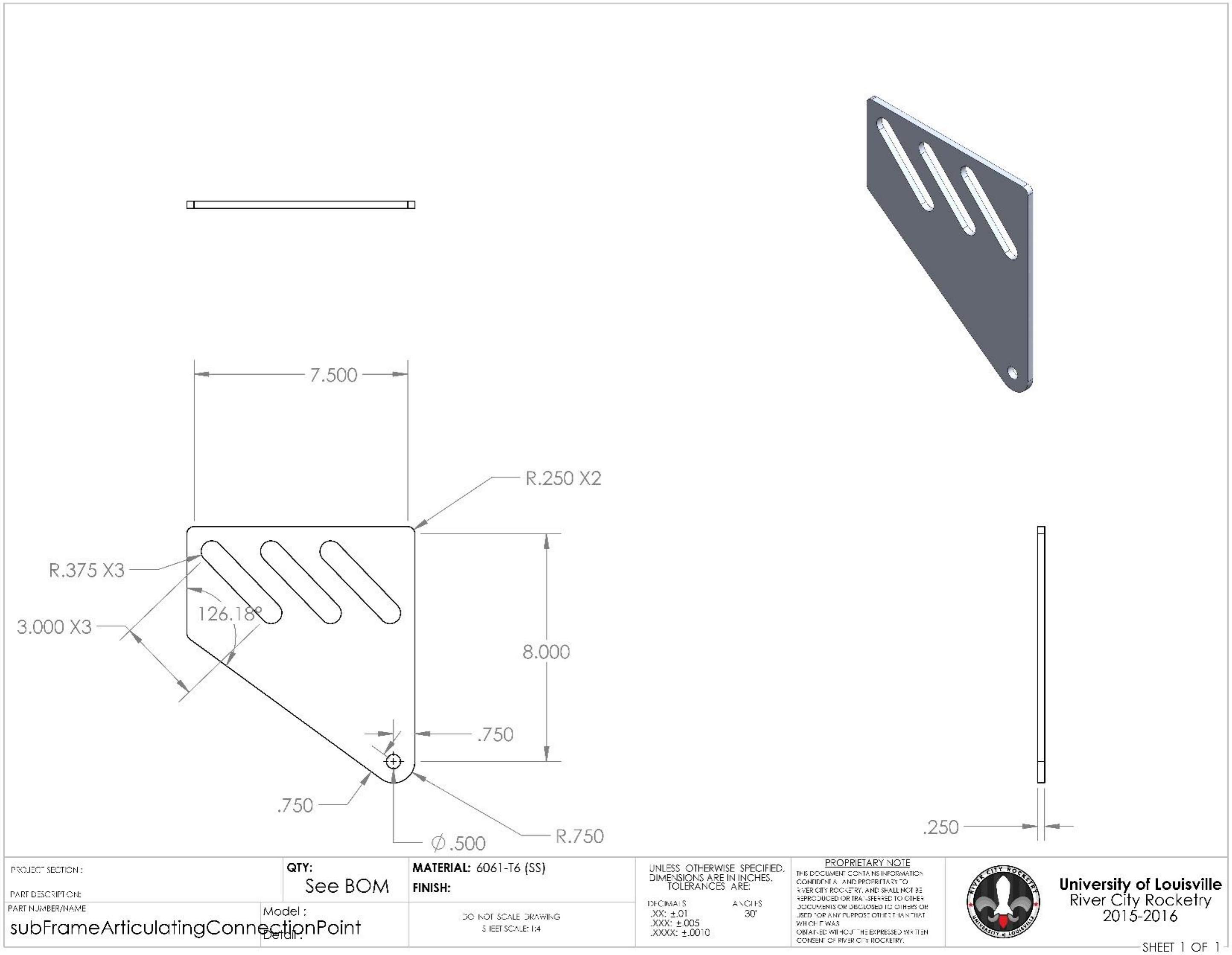


Figure 162: AGSE Sub Frame Articulating Point

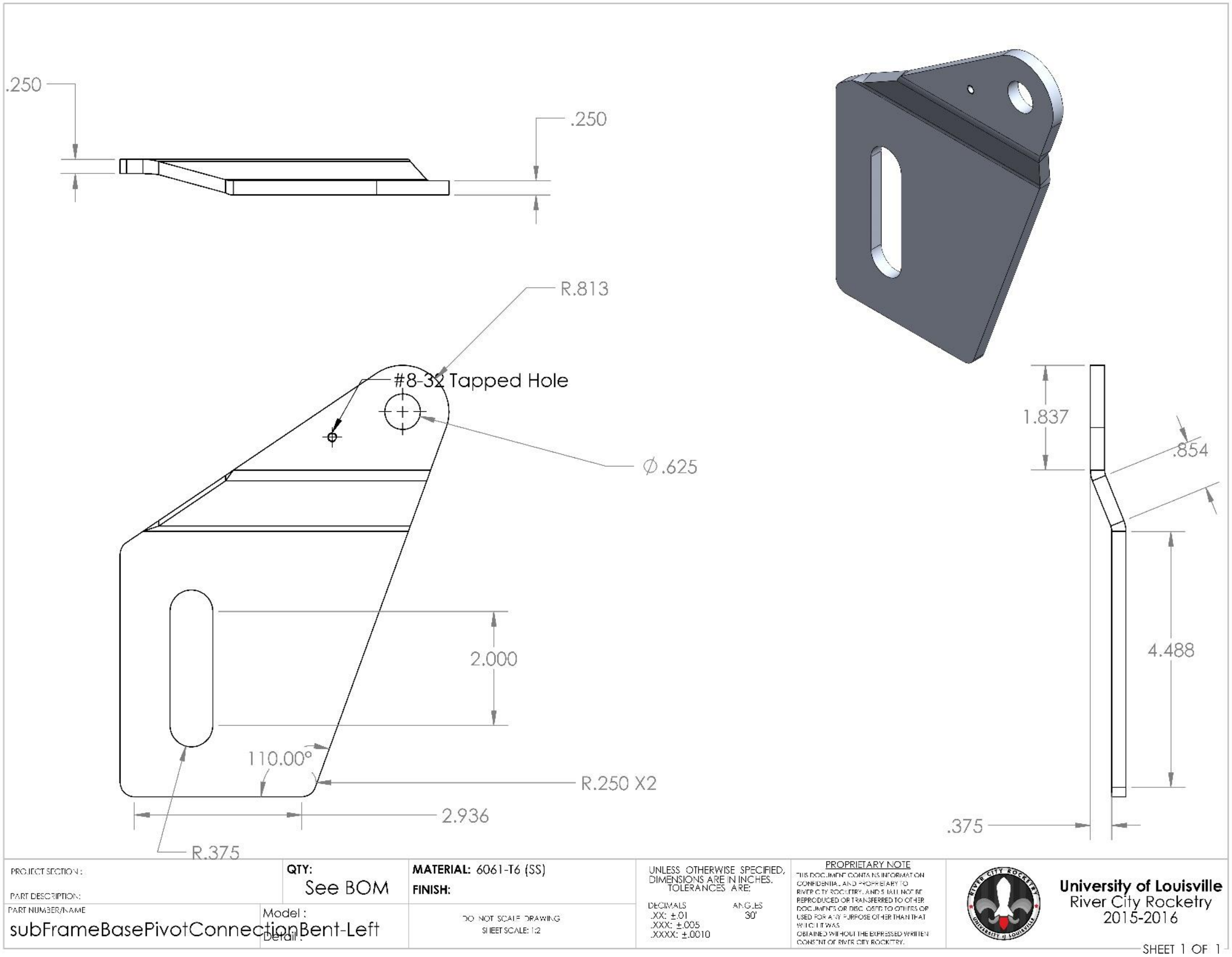


Figure 162: AGSE Sub Frame Base Pivot Left Bent

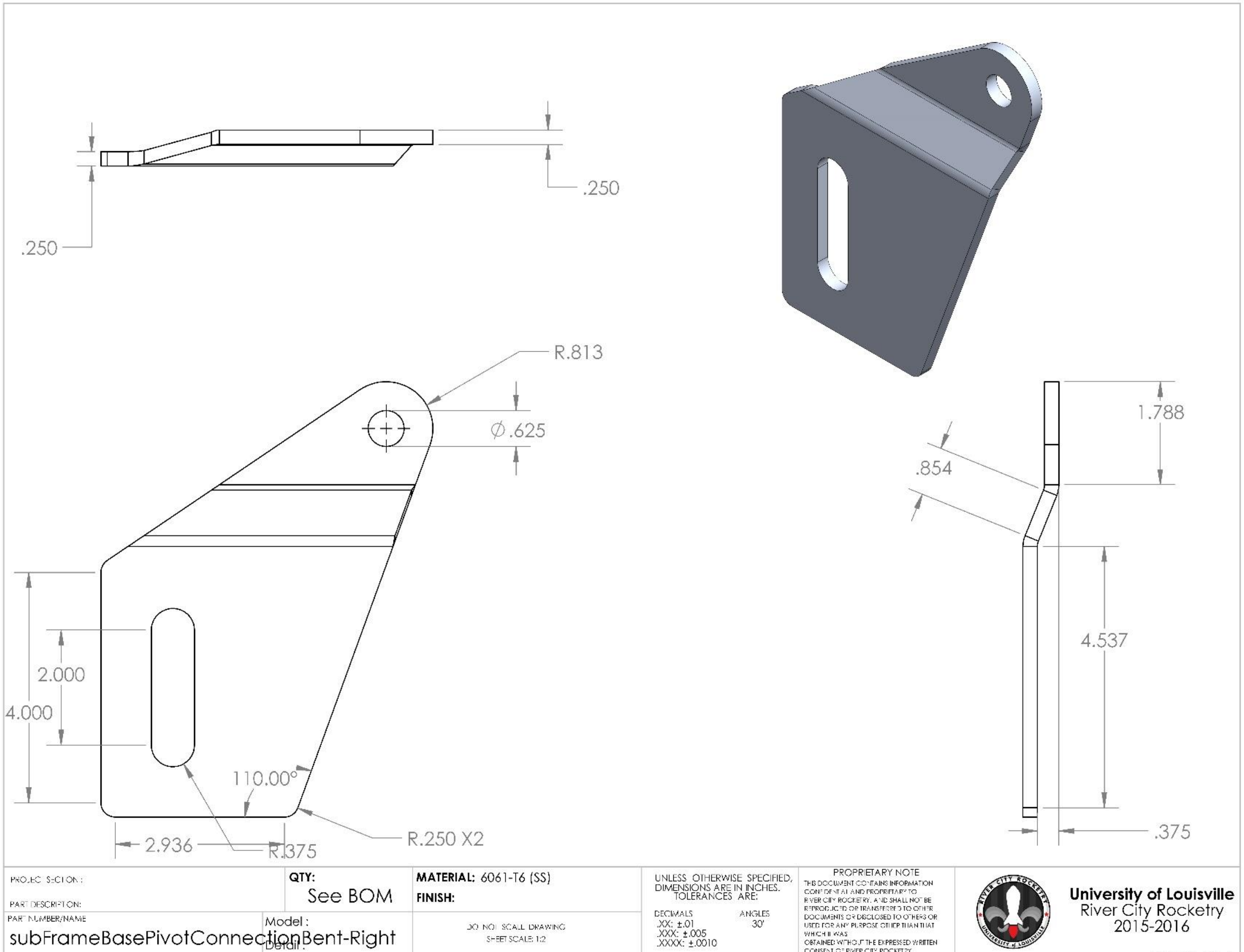


Figure 163: AGSE Sub Frame Base Pivot Right Bent

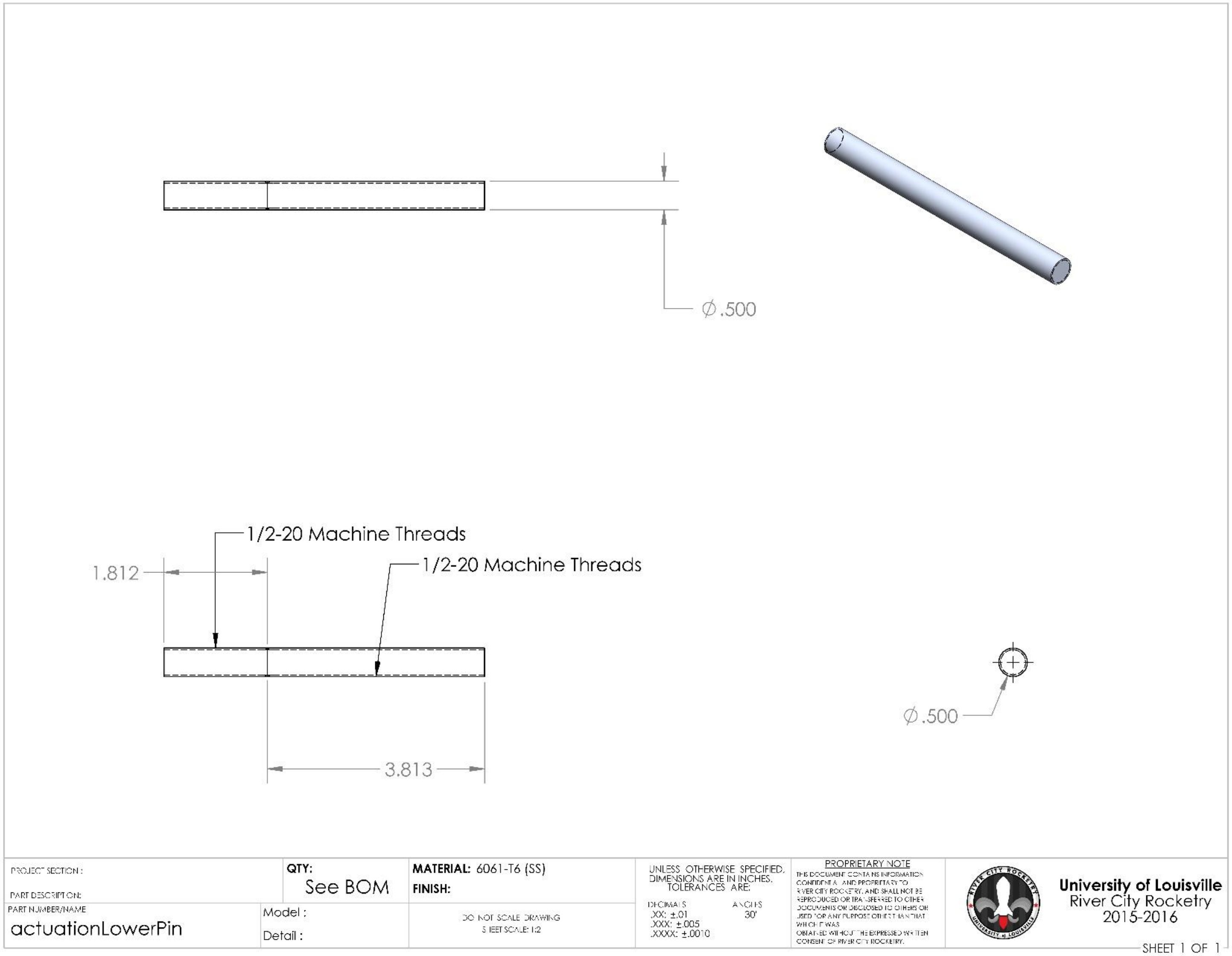


Figure 164: Actuation Lower Pin

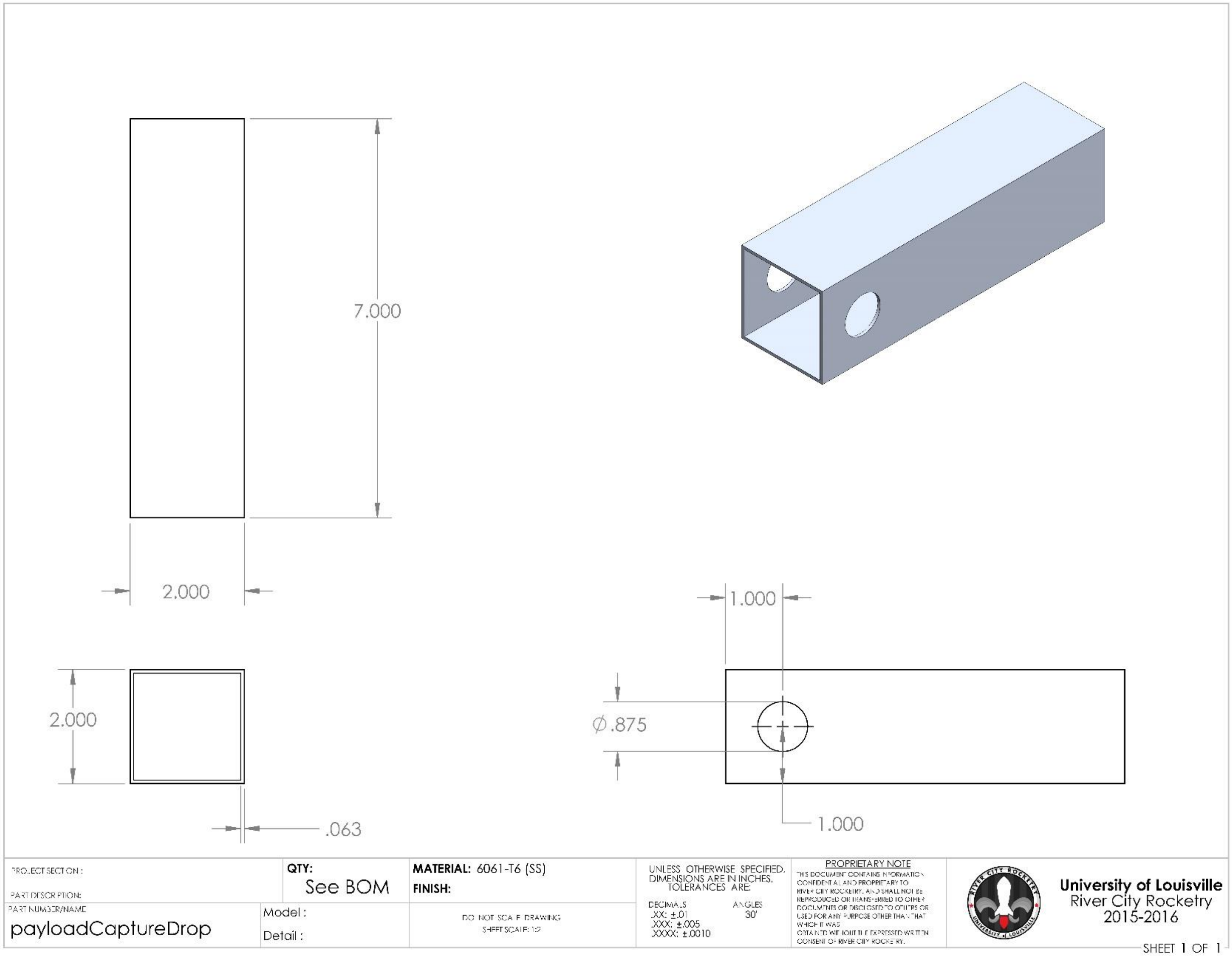


Figure 165: Payload Capture Drop

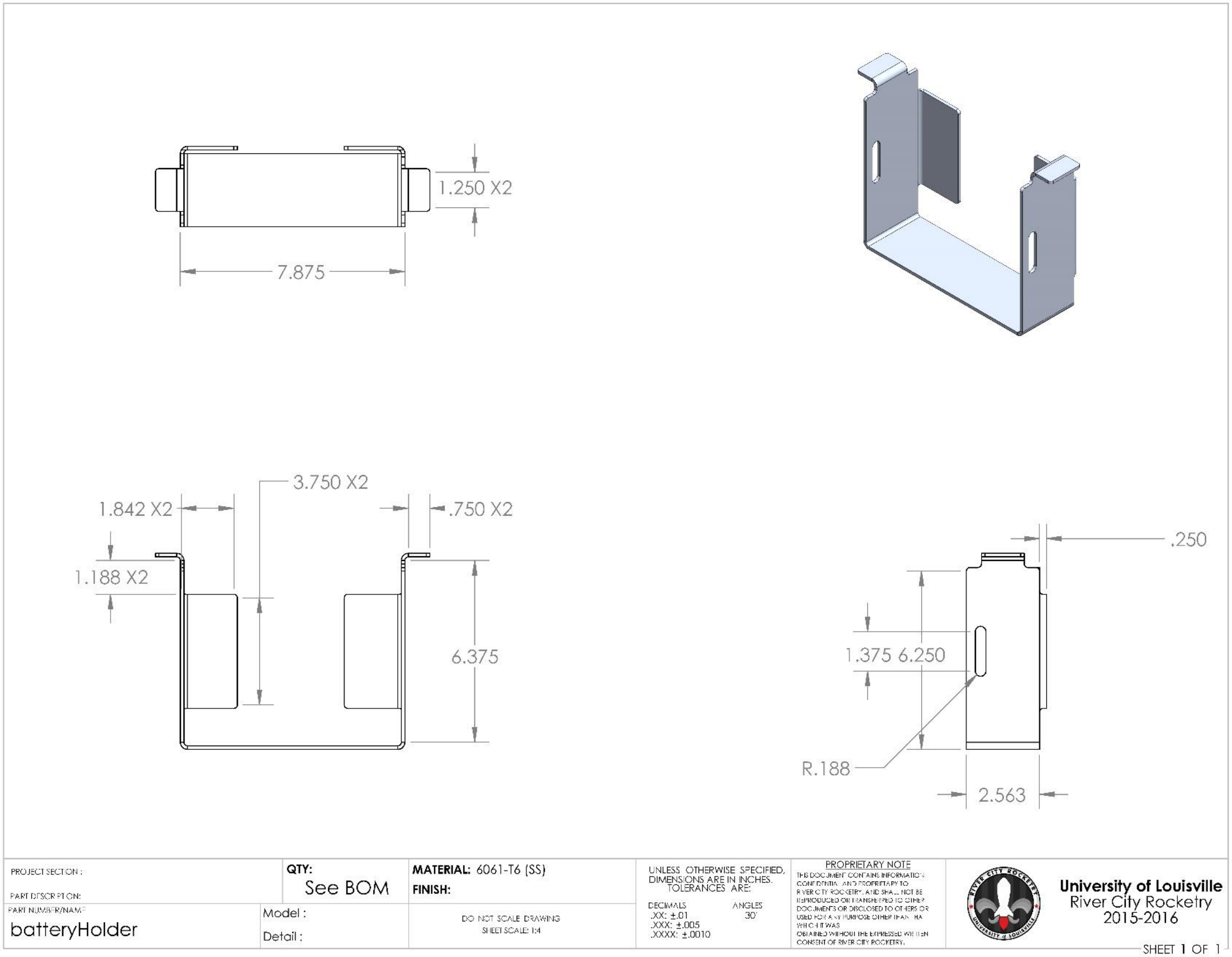


Figure 166: Battery Holder

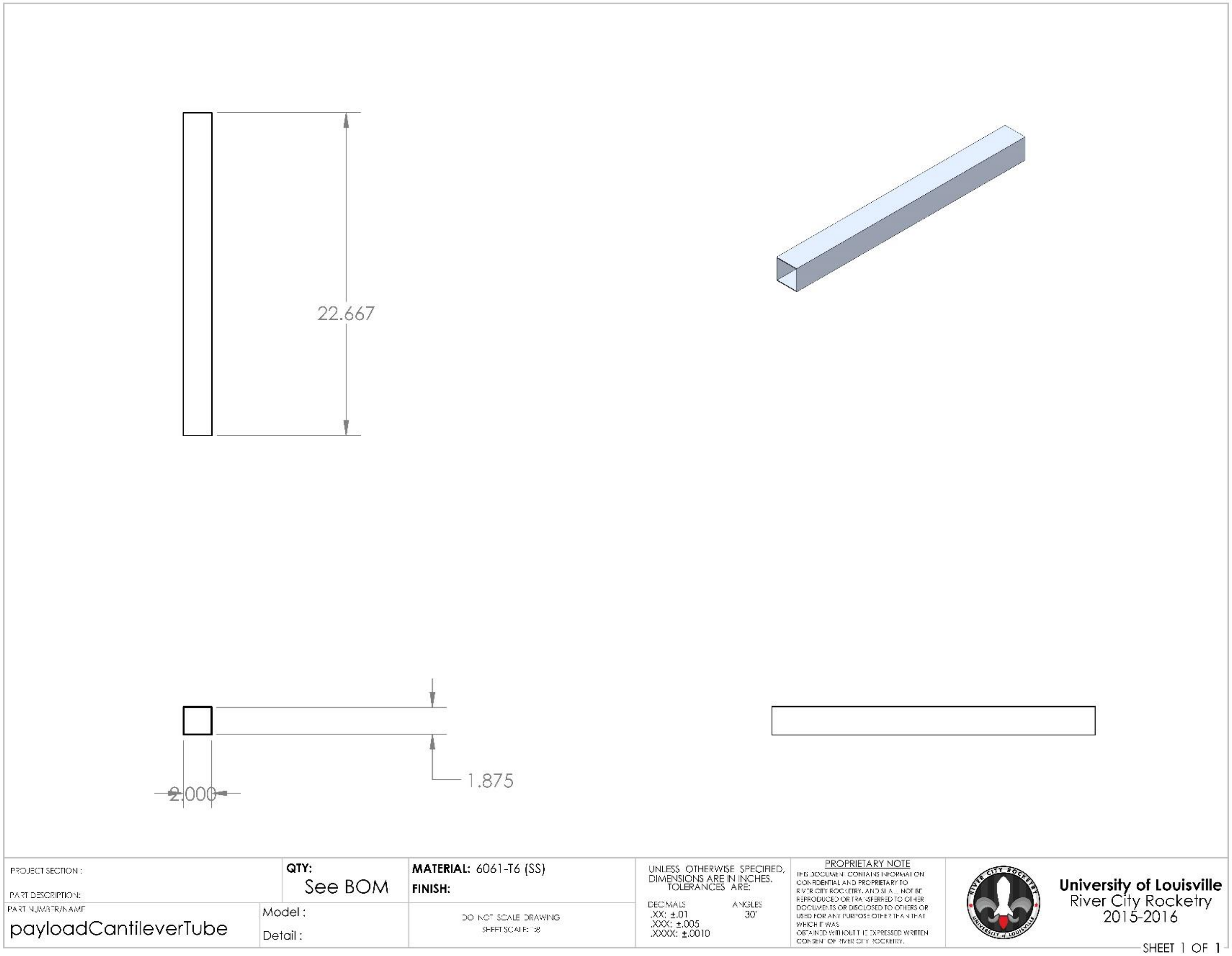


Figure 167: Payload Cantilever Tube