# NASA Student Launch

# Centennial Challenge MAV Project

# 2015-2016 Proposal

# September 11, 2015

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

# Table of Contents

# Section 1. General Information

## 1) School Information/Project Title

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

## 2) Team Officials

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

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

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

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

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

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

## 3) Tripoli Rocketry Association Mentor

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

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

## 4) Team Members and Organization

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

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

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

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

The other leadership roles are website lead, outreach lead, and safety officer, which have also been selected based on experience. These are all former members that have filled these exact, or similar roles in the past and have the skills required to successfully execute the required tasks. The flow chart shown in Figure 1 depicts the current structure of the organization.

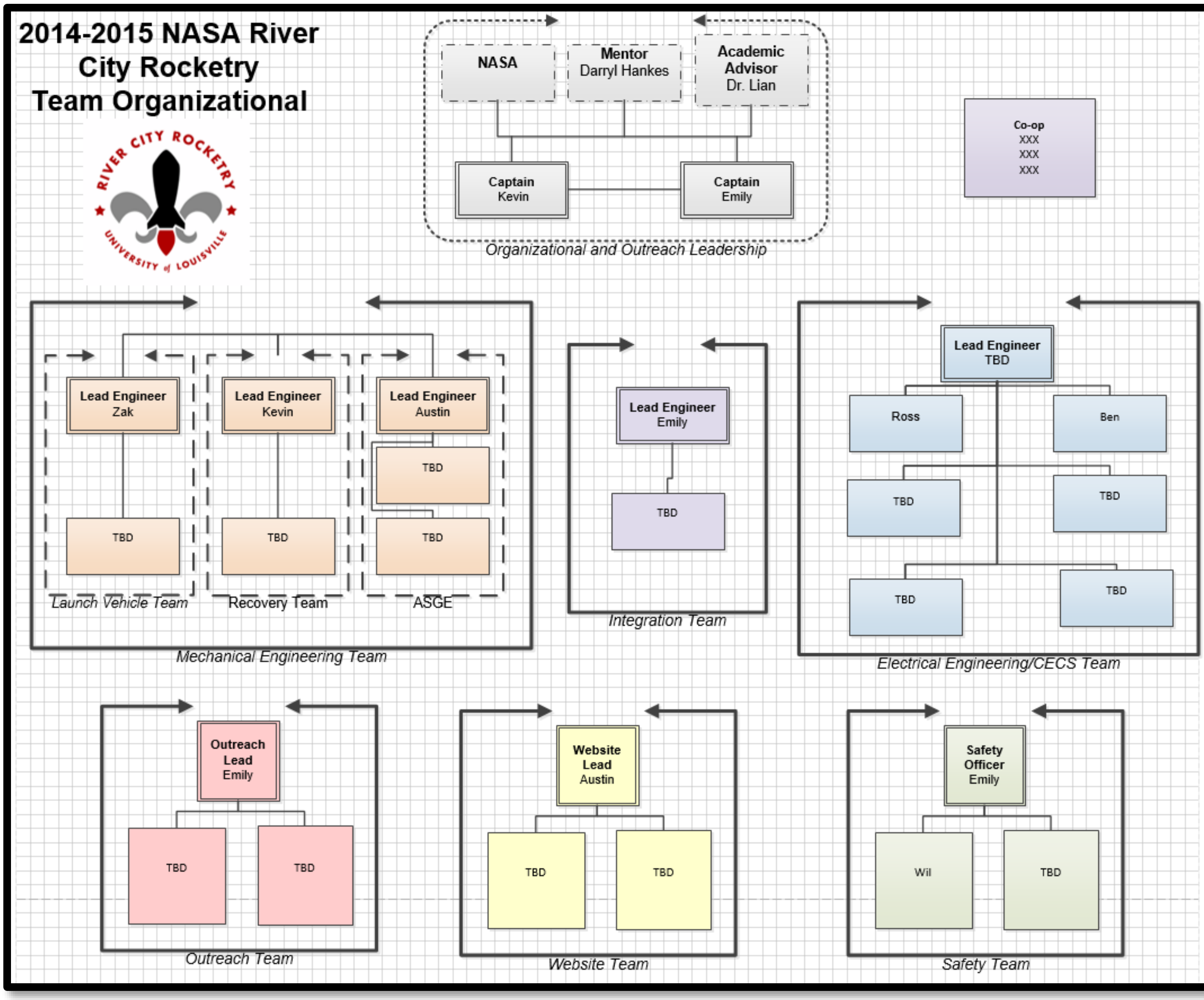



**Figure 1: 2015-2016 team structure.**

Due to the limited time, new team members haven't been able to be fully integrated into the team. A high interest exists to be a part of River City Rocketry. The team understands that most new members are brand new to rocketry. In order to have the most successful, educational, and engaging experience, time is taken to introduce new members to all possible aspects of the team. After new members have had some time to be exposed, they select the desired sub-team that they would like to work on. Currently, the new members haven't gained enough experience to completely understand which aspect of the project that they would like to work on. Therefore, the people under each of the sub-teams has yet to be determined.

# 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 website:

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


**Figure 6: RiverCityRocketry.org home page.**

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

# Section 3. Safety

## 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 3 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 1.

| 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 1: 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 2.

| 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 2: 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 3. The matrix identifies each combination of severity and probability values as either a high, moderate, or low risk. The team's goal is to have every hazard to a low risk level by the time of the competition launch. Those that are not currently at a low risk level will be brought down through redesign, new safety regulations, or any other measures seen fit to reduce risk. Risk levels will also be reduced through verification of systems.

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

**Table 3: Risk assessment matrix.**

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

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

*Lab and Machine Shop Risk Assessment*

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus labs. The hazards assessed in Table 24 are risks present from working with machinery, tools, and chemicals in the lab.

*AGSE Launch Pad Functionality Risk Assessment*

The hazards outlined in Table 25 are risks linked to the launch pad functionalities of the AGSE. Due to the high importance of a stable launch tower, the system will be rigorously tested prior to any launches.

*Vehicle Actuation Device Risk Assessment*

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

*Igniter Installation Risk Assessment*

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

*Ground Station Risk Assessment*

The hazards outlined in Table 25 are risks associated with the ground station. The ground station provides the foundation for the entire AGSE, therefore risks associated with the ground station are critical to mission success.

*Payload Capture Device Risk Assessment*

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

*Stability and Propulsion Risk Assessment*

The hazards outlined in Table 26 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 27 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 28 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 29 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 30 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 | All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues. |

| | |
|---|---|
| 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. | |
| 5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its batter and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket. | The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day. |
| 6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127. | The team will comply with this rule and any determination the Range Safety Officer makes on launch day. |
| 7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the | 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 have a blast deflector integrated into the design. The team will be familiar with and comply with the minimum distance table at all launches. |

| | |
|---|---|
| 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. | |
| 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- | 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 |

| | |
|---|---|
| resistant or fireproof recovery system wadding in my rocket. | 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 4: 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

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

Prior to each launch, a briefing will be held to review potential hazards and accident avoidance strategies. In order to prevent an accident, a thorough safety checklist will be created and will be reviewed on launch day. Once all subsystem checklists are completed, a final checklist must be completed and final approval granted by the safety officer and captain. The safety officer has the right to call off a launch at any time if she determines anything to be unsafe or at a high risk level.

# 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. Technical Design: Vehicle

## 1) Applicable Formulations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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).

# 2) Stability and Construction

The launch vehicle and its internal structure will be constructed primarily of fiberglass, plywood, ABS plastic, and aluminum. The vehicle is designed to house a payload within its airframe. The payload will be located directly above a conical transition. This transition to a lower diameter airframe will facilitate efficiency of the rocket. The reduction in diameter will reduce the weight housed in the lower section of the rocket, thus raising the center of gravity of rocket and increasing stability.

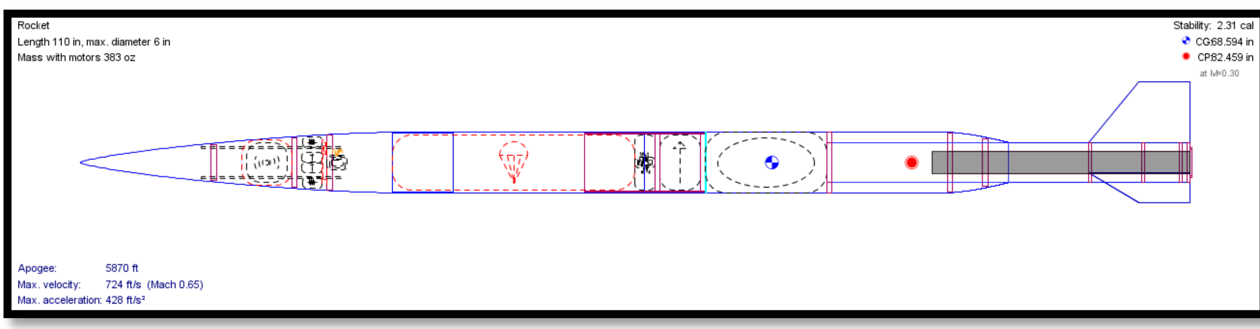



**Figure 7: Preliminary OpenRocket simulation of 2015-2016 launch vehicle.**

Figure 7 shows the preliminary layout of the launch vehicle. The vehicle is designed such that the payload system will be located directly above the airframe transition at the center of gravity. The figure also shows a single recovery bay. The reasoning for the single recovery bay is further discussed in Section 5.

For stability, the rocket will use three clipped delta fins. The clipped delta fins were chosen due to the known efficiency of their shape. Further analysis will be performed to verify efficiency and flow characteristics of the fin shape. The tip and root chord lengths are 5 inches and 10 inches respectively, providing a stability margin of 2.31 with the motor installed. Although four fins typically provides better aerodynamic qualities than three fins, the chosen configuration was chosen for integration purposes with the Autonomous Ground Support Equipment (AGSE).

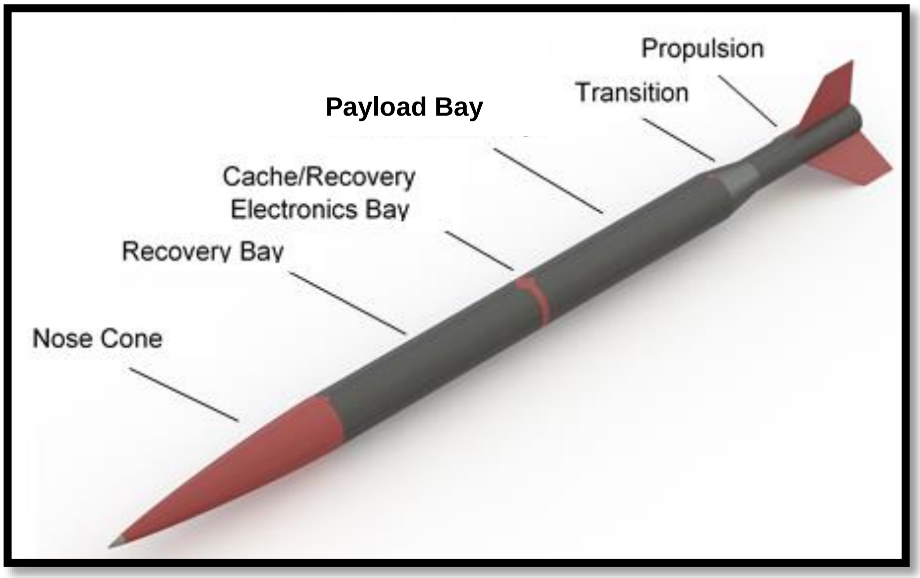



**Figure 8: Full scale launch vehicle.**

The launch vehicle will utilize removable fins. Similar systems have been used in the past with great success. Using positives and negatives of previous designs, the team will build upon old designs, to create a safe and reliable fin system. A removable fin system allows for safer transport of the propulsion section of the launch vehicle. With the fins removed, the risk to damaging the fins during transit is mitigated. Additionally, the system allows for the ability to test the effects of different fin styles with regards to stability of the rocket. The fin dimensions may also be altered in order to increase or decrease the stability of the rocket as parameters become more concrete.

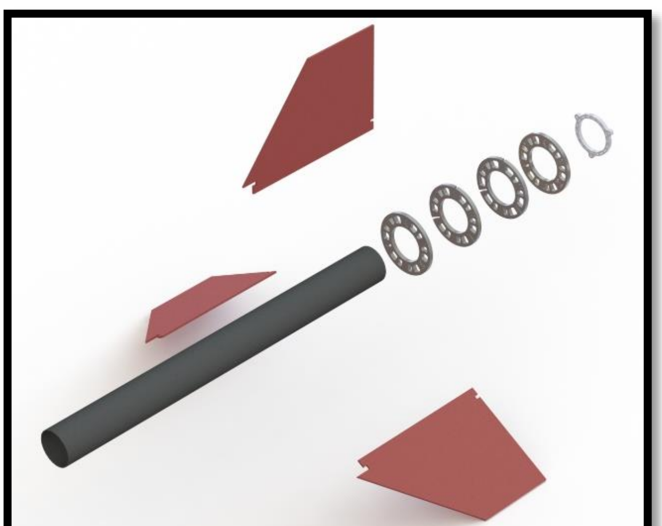


**Figure 9: Exploded representation of removable fin system.**

The launch vehicle is composed of 5 primary sections, outlined in Table 5 below.

| Section of Launch Vehicle | Material | Diameter | Length |
|---|---|---|---|
| 5:1 Von Karmen Nose Cone | Fiberglass | 6” | 30” |
| Recovery Bay | Fiberglass | 6” | 30” |
| Payload Bay | Fiberglass | 6” | 30” |
| 6in to 4in Conical Transition | Fiberglass | 6”-4” | 6” |
| Propulsion Bay | Fiberglass | 4” | 18” |
| Total Launch Vehicle Length | | | 114” |

**Table 5: Dimensions of primary launch vehicle sections.**

With a strict focus on efficiency, the lengths of each bay were chosen assuming the maximum needed volume of each sub section. By assuming this maximum, the team hopes to reduce the bay sizes, thus reducing the overall length and weight of the rocket. This also provides the worst case scenario dimensions that the AGSE must be able to support.

The Von Karman Nosecone, seen in Figure 10, was chosen due to its performance and efficiency at subsonic speeds.

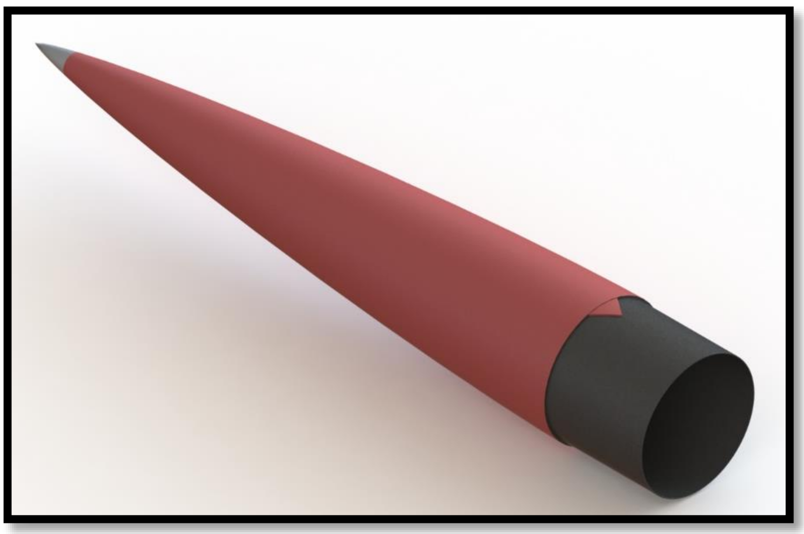


**Figure 10: Von Karman nosecone.**

The internal dimensions of the Von Karman nosecone allows for the containment of an avionics bay, thus allowing an efficient use of space.

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, section which will not be separating through the course of the flight will be joined with 6-32 SHCS.  Different threads have been selected for the separating and non-separating sections in order to prevent accidental installation of metal screws into separating joints and vice versa.

All bulk plates, centering rings, and permanently secured sections of the rocket will be epoxied using Glenmarc's G5000 two component filled epoxy. This epoxy was chosen for its superior strength, as seen in Table 6.

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

**Table 6: G500 epoxy material properties.**

# 3) Propulsion

Utilizing the open source software, OpenRocket, the team was able to simulate a number of motor configurations. The motor chosen for the current configuration is a Cesaroni Technology Inc. reloadable two grain L990 Blue Streak. The team will use the Cesaroni six grain Extra Long 54mm aluminum reloading case in conjunction with this motor. This motor configuration, as shown in **Error! Reference source not found.** has a total impulse of 2,771.0 Ns and a maximum and average thrust of 1,702.7 N and 991.0 N, respectively.

| | |
|---|---|
| **Manufacturer** | Cesaroni Technology |
| **Classification** | L990 |
| **Diameter** | 54 mm |
| **Length** | 64.9 cm |
| **Total Weight** | 2,236.0 g |
| **Propellant** | 1,417.0 g |
| **Average Thrust** | 991.0 N |
| **Maximum Thrust** | 1,702.7 N |
| **Total Impulse** | 2771.0 Ns |
| **Burn Time** | 2.8s |

**Table 7: CTI L990 Blue Streak motor properties.**

The thrust curve for the selected motor is shown in Figure 11.

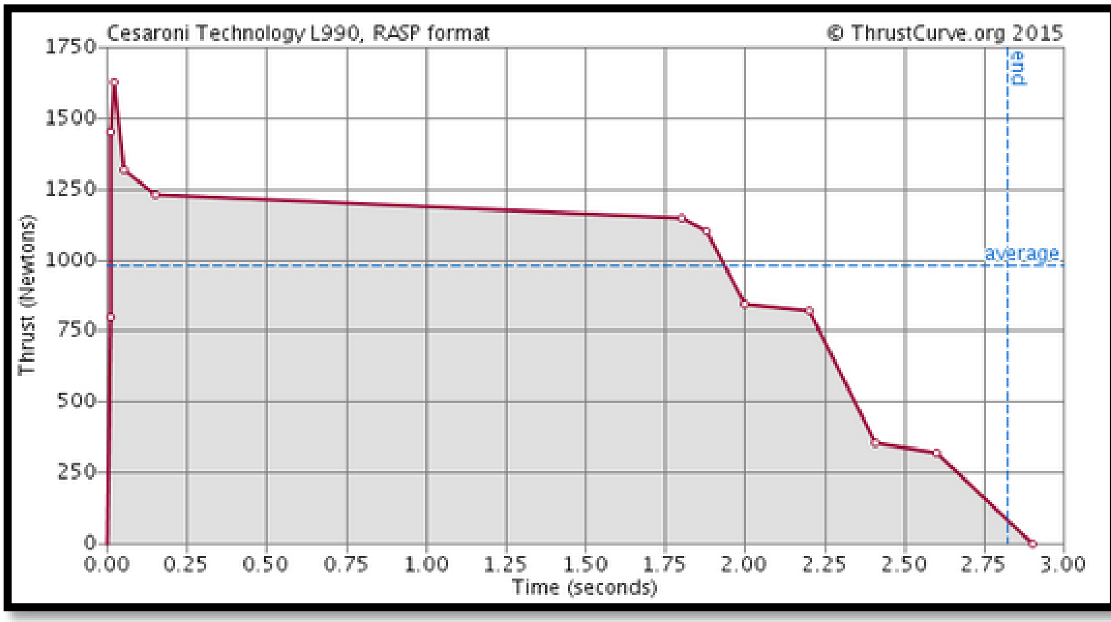



**Figure 11: Thrust curve of L990 motor.**

This motor selection will launch the vehicle to an altitude of 5,852 ft. Although higher than the target altitude, this preliminary altitude will allow for a 10% error in altitude of the simulation, accounting for changes in aerodynamic qualities and weight increases of the launch vehicle.

# 4) Retractable Door for Payload Insertion

**Overview**

To keep the AGSE and launch vehicle systematically autonomous, a retractable door will be incorporated into the launch vehicle. The door, when activated via on-board electronics, will begin in the opened position. The payload can be inserted into the payload bay. Once the payload is in place, the door will be closed via a signal sent to a servo motor, which will actuate the door into the closed position.

**Design**

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

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

Once the design of the payload capture device is finalized, the overall dimensions necessary for the launch vehicle's door shall be established. The designed door is to be

6 inches in length with an arc length of 3.5 inches. The team has experience with wound fiberglass tubing and has previously designed and tested a rocket with similar dimensions cut out of the airframe. Due to this experience, the team is confident that even with the reduction in structural integrity of the airframe, a structural failure will not occur.

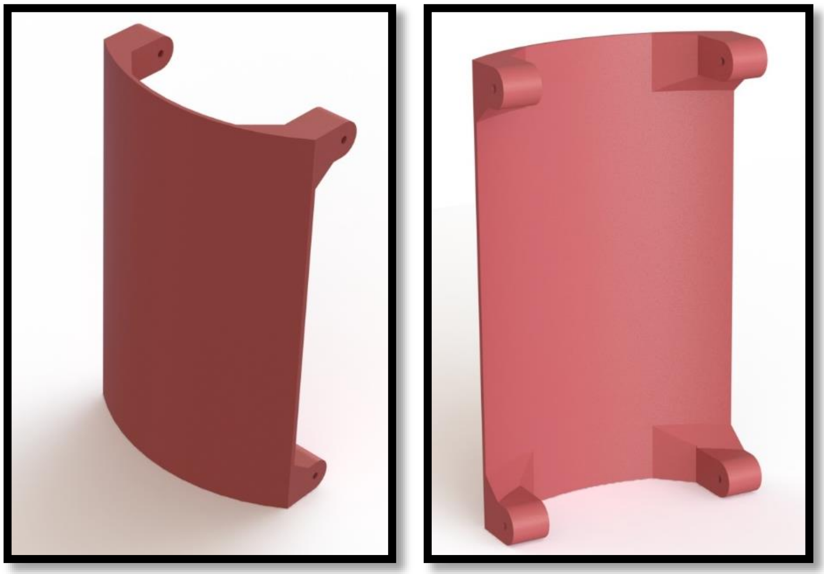


**Figure 12: Front and rear view of the preliminary door design.**

The door is designed to be manufactured on a 3D printer, printing ABS plastic. Because of this manufacturing method, density may be increased or decreased to provide the desired rigidity. Further structural analysis will be performed to determine the minimum density which can be used with a factor of safety of 1.5. A silicone rubber gasket will be designed and cut on a Universal Laser Systems laser cutter to create a hermetically sealed bay for the Payload.

The door is designed to actuate linearly along 3D printed guides. Each standoff on the door shall be outfitted with a shoulder screw and Delrin standoff. These standoffs and screws will guide the door along the tracks, ensuring a smooth closure of the door. One guide shall be outfitted with a straight rack gear, which will allow the servo motor to actuate the door into the closed position.

**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 8.

| Challenges | Solutions |
|---|---|
| Design the door such that the payload and payload capture device will fit during payload insertion. | Proper dimensional analysis will be conducted to ensure no clearance issues are present throughout the design and revision of any payload containment and insertion systems. |
| The door shall be autonomously closed. | On-board computer electronics will work hand in hand with ASGE systems to synchronize payload insertion and door actuation movements. |
| The door shall remain airtight when closed. | A custom silicone gasket will be designed and integrated into the door system to create a hermetic seal around the edges of the door. |
| The door shall not be allowed to open during flight. | Using the proper servo motor, the door system can be "locked" shut to be certain the door will not back itself through the guides during flight. |

**Table 8. Solutions to various door design challenges.**

# 5) Statement of Work Verifications

Designing an efficient high powered launch vehicle presents its own inherent challenges. To ensure safety and vehicle performance the team will focus on tackling various design challenges with multiple and varying solutions. Furthermore, the team must make sure the overall design stays within the constraints laid out in the Statement of Work. The various challenges and their related solutions are detailed in Table 9 below.

| 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 L990 six grain Xtra-Long Blue Streak motor for its full scale launch vehicle. The team has never had a motor failure in the past while using Cesaroni motors. |
| The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class). | The total impulse of the Cesaroni L990 six grain Xtra-Long Blue Streak motor is 2,771.0 Newton-seconds. |
| Pressure vessels on the vehicle shall be approved by the RSO and shall meet the criteria laid out in the Statement of Work. | The current design of the launch vehicle and AGSE does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met. |
| All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model. | The team will design a 1:2 scaled model of the full scale launch vehicle. The subscale launch vehicle will be used to test stability and integration of various systems seen in the full scale launch vehicle. |

**Table 9: Solutions to various challenges set out by the statement of work.**

# Section 5. Technical Design: Recovery

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

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

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

**Design**

In order to acquire the payload safety, the rocket will separate into two sections. The sequence at which this occurs is shown in Table 10.

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

**Table 10: 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. By reducing the overall length of the rocket, the team will be able to decrease the size of the launch platform while providing a larger buffer on the volume and weight requirements for the Autonomous Ground Station Equipment (AGSE).

The parachute will be stored in the upper airframe and appropriately sized to ensure that the both sections of the rocket land with a minimum kinetic energy of 75 ft-$lb_f$.

Calculations will be made to ensure the shock from opening the parachute doesn't prematurely release the reefed line. The main parachute will be held inward via the center of the parachute while tethered to device similar to a tender descender shown below in Figure 13.

Due to the teams experience in rocketry a custom device will be designed in order to withstand the high tension forces seen by the reefing system during flight.

**Figure 13: Tender descender.**

The electronics bay for the recovery system will deploy out of the upper stage at apogee where the tender descender will be attached via U-bolt below in Figure 14. The parachute shroud lines will be evenly disturbed among two eyebolts on top of the electronics bay as seen in Figure 14. At 800 feet, the tender descender will discharge, de-reefing the parachute to allow full inflation.

**Figure 14: Recovery electronics bay.**

For the deployment of the parachute and discharging of the tender descender, electronics will be separated from all other systems. Due to the past success with the PerfectFlite Stratologger, shown in Figure 15, two units will be placed in each avionics bay. A set of PerfectFlite Stratologger's will be placed in the recovery electronics bay and de-reefing system to ignite black powder charges during flight and the tender descender.


**Figure 15: PerfectFlite Stratologger.**

The PerfectFlite Stratologger altimeter records its altitude at a rate of 20Hz with a 0.1% accuracy. In previous testing, the altimeter was found to be accurate to ±1 foot. The StratoLogger can be configured to provide a constant serial (UART) stream (9600 baud rate ASCII characters) of the device's current altitude over ground. Each StratoLogger will be powered by an individual Duracell 9V battery. Duracell batteries have been selected due to their reliability and the feature that their leads are internally soldered.

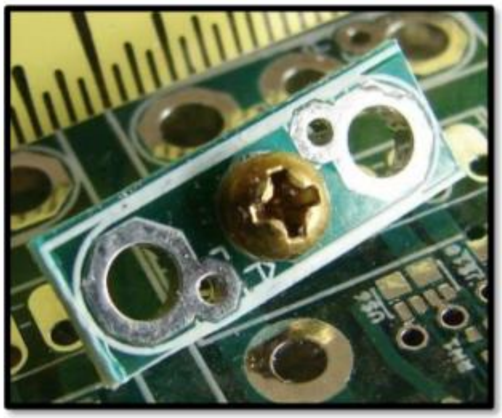


**Figure 16: Featherweight screw switch.**

Each altimeter will be locked into the on position through use of a Featherweight screw switch, shown above in Figure 16. The switches allow for easy arming of altimeters while the rocket is upright in the AGSE. Access holes will be drilled and marked to allow for arming.

To satisfy the GPS requirement, a Garmin Astro DC 40 will be positioned in the nose cone.

### 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 drag coefficient unknown, combining both drogue and main. | Testing will take place to determine drag coefficient and reliability of reefing system. |

**Table 11: Recovery challenges.**

# Section 6. Technical Design: AGSE

## 1) Autonomous Ground Support Equipment

**Overview**

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

1. Team must position launch vehicle horizontally on the AGSE.
2. Weight limit of 150 pounds.
3. Volume requirements including height of 12 feet, width of 10 feet, and length of 12 feet.
4. No use prohibited technologies, including:
    a. Sensors that rely on Earth's magnetic field
    b. Ultrasonic or other sound-based sensors
    c. Earth-based or Earth orbit-based radio aids
    d. Open circuit pneumatics
    e. Air breathing systems

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

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

To achieve the above requirements, the AGSE has been divided into sub-systems described in Table 12.

| 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 12: AGSE sub-systems.**

A rendering of the entire AGSE is shown in Figure 17.

**Figure 17: AGSE in launch orientation.**

The approximate overall AGSE dimensions are show in Table 13.

| Mass ($lb_m$) | Width (in) | Horizontal orientation | | Launch orientation | |
|---|---|---|---|---|---|
| | | Height (in) | Length (in) | Height (in) | Length (in) |
| 120.00 | 53.74 | 33.11 | 137.12 | 128.31 | 100.87 |

**Table 13: Overall AGSE dimensions.**

The approximate mass shown above is an estimation of the maximum weight of the system. The competition limit for overall weight of the AGSE is 150 pounds. The team is utilizing 125 pounds as a design limit to ensure that once the AGSE is manufactured it will be under the weight requirement. There are also multiple design optimization opportunities with each sub-system that will be explored throughout the design cycle. Each design optimization opportunity will be described later in their respective sub-system sections.

### System Timeline

Per the SOW, the AGSE has 5 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 18.

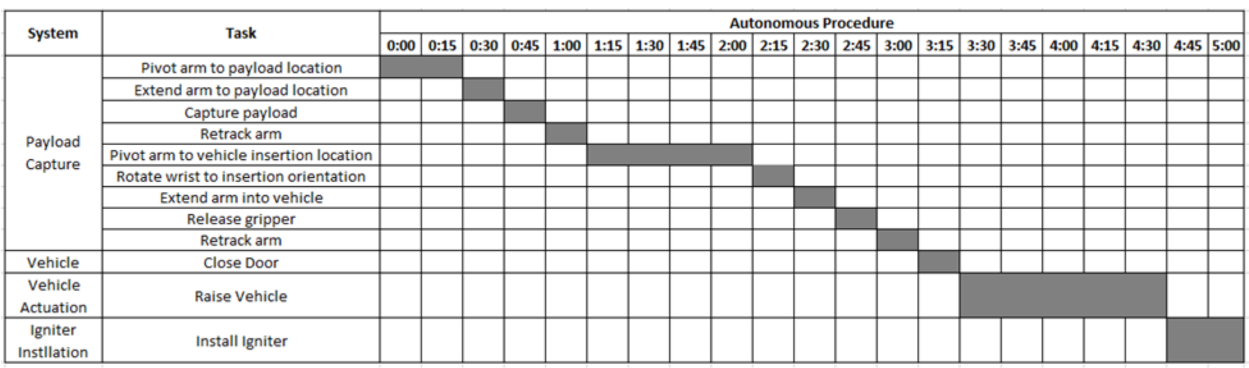



**Figure 18: AGSE process timeline.**

### Analysis Guidelines

The AGSE has multiple opportunities for analysis to be completed to optimize specific components. Throughout the design process a safety factor of 1.5 will be pursued for all components. However, designs under a factor of safety of 1.5 but over 1.0 will be considered at the team leadership's discretion.

## 2) Launch Platform

**Overview**

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

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

The overall approximate dimensions of the launch platform are show in Table 14.

| Mass ($lb_m$) | Optimization opportunity ($lb_m$) | Width (in) | Height (in) | Length (in) |
|---|---|---|---|---|
| 46.51 | 10.00 | 20.00 | 22.50 | 120.25 |

**Table 14: Launch platform general dimensions.**

A rendering of the launch tower assembly is shown in Figure 19.

**Figure 19: Launch tower assembly.**

**Design**

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

*Rails*

The purpose of the rails is to guide the launch vehicle as it is gaining velocity. Each rail will be constructed from a 10 foot piece of 6061-T6 aluminum rectangular structural tubing. The tubing will be a 1"x2" tube with 1/8" wall thickness. The length of the rails will be based on the minimum safe rail exit velocity of the launch vehicle. The current approximation for rail length was made based on fact that the team's previous guide tower launch platforms have had rail lengths at or below 10 feet. The final length of these rails will be determined after further design analysis is completed on the launch vehicle.

*Rings*

A rendering of a ring assembly is shown in Figure 20.

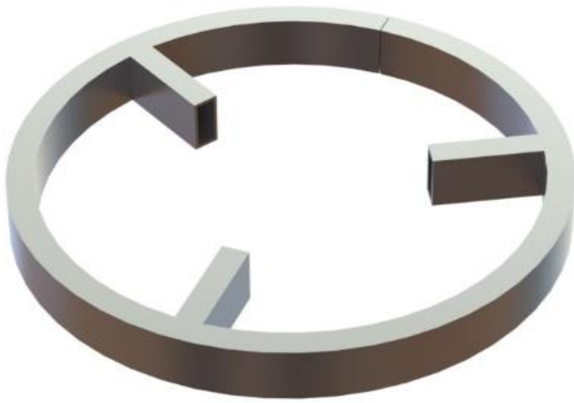


**Figure 20: Ring assembly rendering.**

Each ring will be used to stabilize the rails of the launch platform. The rings will be constructed from a rolled piece of 6061-T6 aluminum rectangular structural tubing. The tubing will be a 1"x2" tube with 1/8" wall thickness. The ring will be rolled to an internal diameter of 18 inches. The rings will also contain three standoffs that will interface with the rails. The standoffs will be made from the same structural tubing as the rings.

*Base*

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

*Pivots*

The lowest ring will also serve as the lower pivot point for the launch platform. The pivot point will be attached to the bottom of the ring when the launch platform is in the horizontal orientation. This pivot is shown in Figure 21.

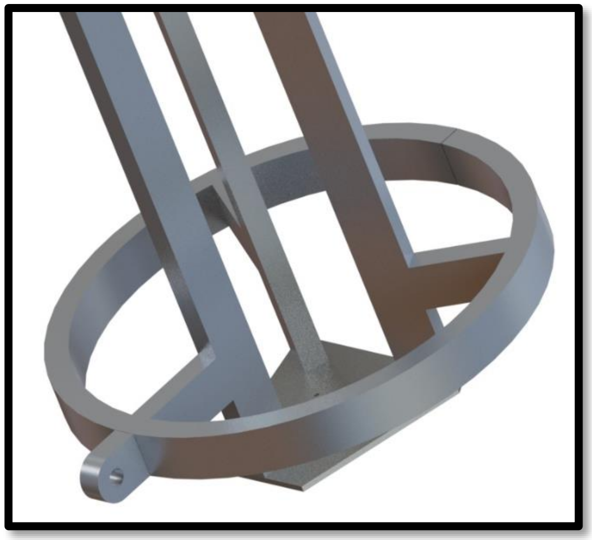


**Figure 21: Launch platform lower pivot point.**

The pivot's location was selected to provide mechanical advantage during the actuation of the launch platform. As the launch platform actuates from the horizontal to vertical orientation, the center of gravity will cross the pivot point, creating a mechanical advantage.

*Control Feedback*

An accelerometer will be installed on the launch platform to provide position feedback to the central processor. This feedback will be used to raise the launch vehicle to an angle 5 degrees from vertical even if the sub-frame is not level.

**Optimization Opportunities**

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

*Material Selection*

The rails and rings for the launch platform are both components where weight savings could be achieved by changing materials. In the 2014-2015 NSL season, the team's guide tower utilized t-slotted aluminum extrusions. The weight savings from switching materials is summarized in Table 15.

| 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 15: Material performance comparisons.**

The deflection for each material was calculated using

$$\delta = \frac{PL^3}{3EI} \quad (1)$$

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

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

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

Additional optimization can be achieved by comparing different tubing for each rail. Each rail will see a different loading case, therefore, optimizing the tubing for each individual rail could produce additional savings.

*Material Removal*

The rails are also candidates for material removal. Structural analysis will need to be performed to determine the impact of removing material from these members. An example of a material removal pattern and associated finite element analysis is shown in Figure 22. This pattern would result in a weight savings over a 10 foot length of 2.61 pounds. Optimization will be done to select the most weight efficient material removal pattern while maintaining the structural integrity of the member.

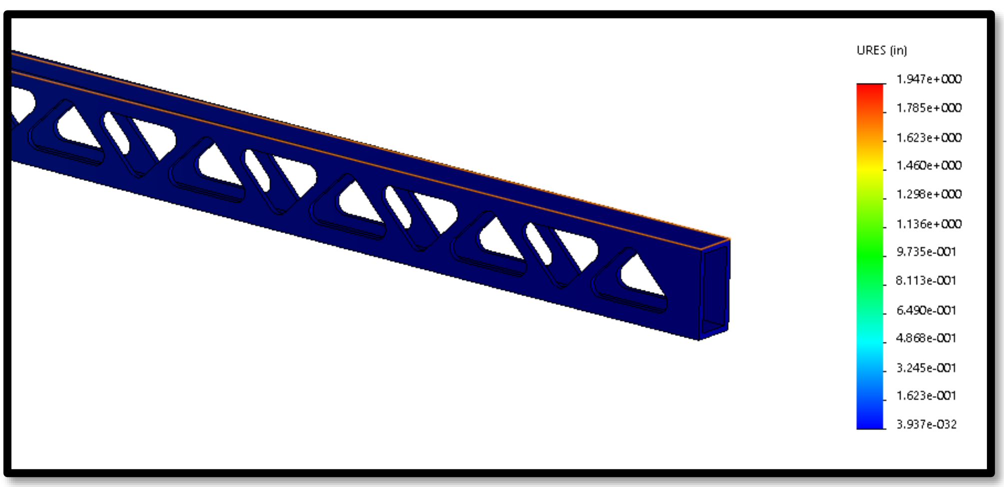



**Figure 22: Launch rail material removal example pattern.**

*Rail Length*
The current rail length is an approximation of the minimum rail length based on the launch vehicle's minimum rail exit velocity. Reducing the rail length would reduce the weight of the launch platform by 2.40 pounds per foot. Also, reducing the rail length will lower the AGSE center of gravity therefore requiring less material on the sub-frame.

*Fastener Selection*
Fasteners add a significant amount of weight to the system. Analysis and research will need to be performed to determine adequate fastening techniques for each connection in the launch platform. Some optimization opportunities include switching to small standard fasteners (10-32 UNC-2A bolt instead of a ¼"-20 UNC-2A), using pop rivets, using threaded holes, or welding the connections.

*Rail Button Configuration*
If design optimizations in other areas do not produce the expected weight savings, an additional option would be to change the launch platform configuration .Switching from a guide tower configuration to a rail button configuration would remove two launch rails and the stability rings. This change would reduce the weight of the AGSE by approximately 30 pounds.

# 3) Vehicle Actuation

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

1. Actuate launch platform from horizontal to 5 degrees of vertical.
2. Hold vehicle steady during pre-launch procedures including raising of the launch vehicle, installation of igniter, and arming of recovery systems.
3. Upon power failure, system pause, reaching desired orientation, or other motion interruption the system shall maintain the launch vehicle orientation.
4. Stabilize launch vehicle during launch.
5. Be reusable.

The overall approximate dimensions of the vehicle actuation device are show in Table 14.

| Mass ($lb_m$) | Optimization opportunity ($lb_m$) | Width (in) | Height (in) | Length (in) |
|---|---|---|---|---|
| 45.36 | 3.00 | 7.50 | 8.00 | 85.52 |

**Table 16: Vehicle actuation device general dimensions.**

A rendering of the vehicle actuation device is shown in Figure 23.

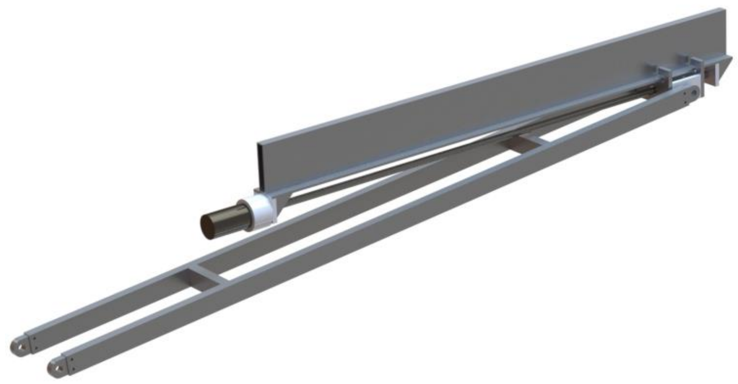


**Figure 23: Vehicle actuation device.**

### Design

The vehicle actuation device will consist of a track and carriage system which will be mounted on the upper section of the launch platform. An actuation arm assembly will connect the carriage to sub-frame at a stationary articulation point. Each component of the vehicle actuation device has been described in more detail below.

*Track*

A rendering of the track is shown in Figure 24.

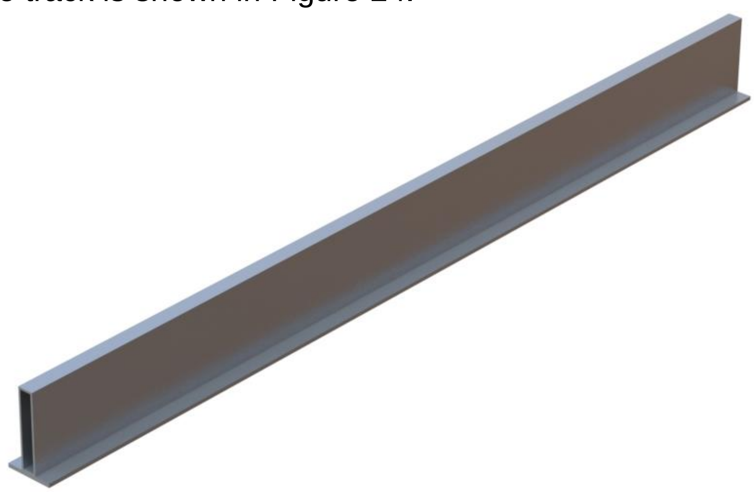


**Figure 24: Vehicle actuation track.**

The track will be constructed from a 60” long 5” x 1” 1/8” wall 6061-T6 aluminum structural tube and a 3” x 60” ¼” 6061-T6 aluminum plate. The tube will be centered on top of the aluminum plate and welded across the entire length of the track. The track will also be equipped with two limit switches to provide a high and low limit feedback to the central processor to prevent jamming the carriage.

*Carriage*
A rendering of the carriage assembly is shown in Figure 25.

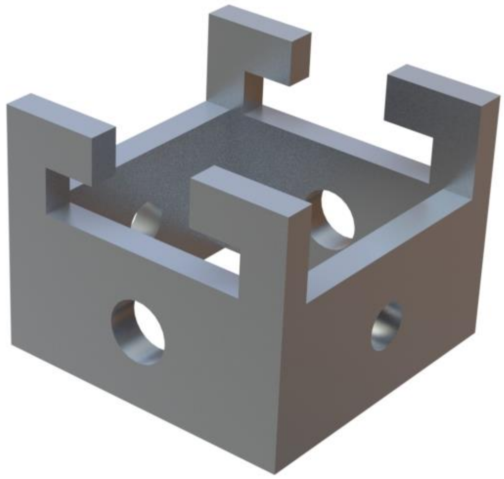


**Figure 25: Rendering of carriage assembly.**

The carriage will be constructed from four ¼" aluminum plates. Two aluminum plates will wrap around the lower track plate. The opening in these plates will be covered with 3D printed ABS sliders which will lower the frictional coefficient between the carriage and the track. These sliders will also prevent the carriage from jamming during actuation of the launch platform.

*Actuation Arms*
A rendering of the actuation arms is shown in Figure 26.

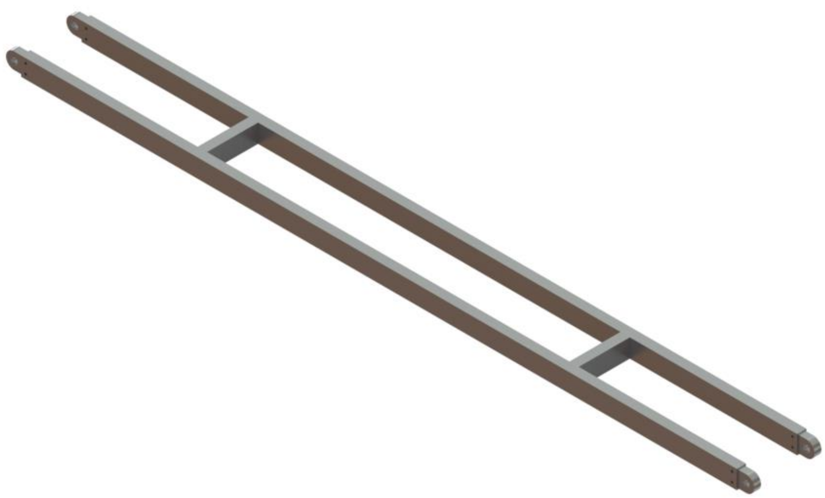


**Figure 26: Actuation arms rendering.**

The actuation arms will be constructed from two 1"x2" tube with 1/8" wall thickness 6061-T6 aluminum structural tubes. Each tube will be capped at both ends with a solid aluminum pivot point made from ¾" 6061-T6 aluminum bar stock. Both actuation arms will be connected by two cross members made from the same structural tubing as the arms.

*Ball Screw*

The carriage will be actuated the length of the track using a ball screw. The ball screw will be anchored at each end using a bearing assembly. One end of the ball screw will include a thrust and radial bearing configuration. This will ensure that the gearbox sees minimal loading and can operate properly. The opposite end of the screw will have only a radial bearing assembly. Analysis will be performed to determine the minimum diameter screw that can be used for this assembly.

*Motor*

The vehicle actuation device will be powered using a 2.5" CIM motor combined with an AndyMark GEM500 multi-stage planetary gearbox. The performance curve for the motor is shown in Figure 27. Each stage of the gearbox has a reduction of 3.67:1. Two stages will be used on the gearbox for the vehicle actuation.

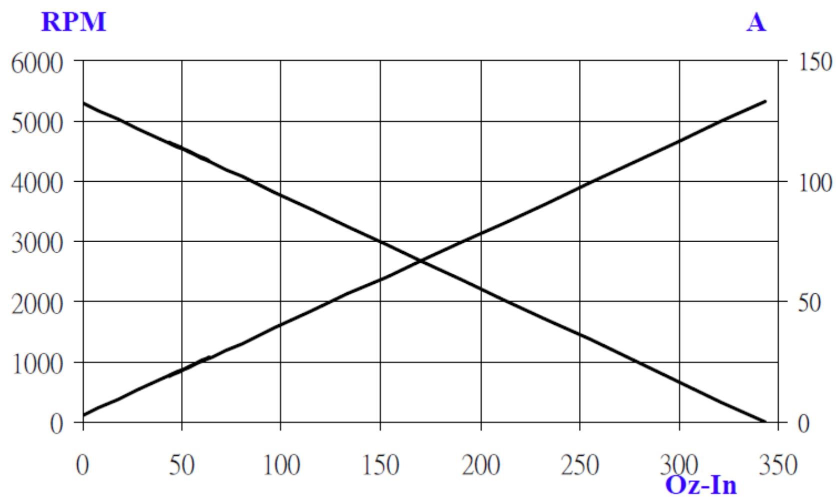



**Figure 27: CIM motor performance curve.**

## Optimization Opportunities

*Material Selection*

The track will be further analyzed to ensure the optimal materials are chosen for the system. The track must be spaced off the launch rail to clear the rocket, requiring a large extrusion to fill the gap. The material must also have adequate strength to handle the full load of the launch vehicle during actuation. Other extrusions or material combinations may result in a stronger and lighter option. Analysis will be performed to determine the most optimum material.

The materials used in the carriage will also be analyzed to determine the proper material selection. Different materials, as well as different geometries and thicknesses will be analyzed using Finite Element Analysis to determine the optimum material for this application.

*Material Removal*

The current tubing for the track and the actuation arms are both areas where material removal could further optimize the design. Cutting patterns similar to those discussed for the launch platform rails could be used on the vehicle actuation components to cut weight.

*Fastener selections*

Welding was decided to be used on the track based on the assumption that it would be stronger and lighter. Analysis will be completed to determine if this assumption is accurate or if other fastening methods are optimal.

Fasteners in the carriage will also be analyzed to determine the minimum size and quantity of fasters required to assemble this component.

# 4) Payload Capture

**Overview**

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

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

The approximate overall dimensions of the payload capture device are shown in Table 14.

| Mass ($lb_m$) | Optimization opportunity ($lb_m$) | Width (in) | Height (in) | Length (in) |
|---|---|---|---|---|
| 7.37 | 0.40 | 4.00 | 3.41 | 40.82 |

**Table 17: Payload capture device general dimensions.**

A rendering of the payload capture device is shown in Figure 28.

**Figure 28: 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.

*Telescopic extension arm*

A rendering of the telescopic arm is shown in Figure 29.

**Figure 29: Telescopic extension arm (outer tube transparent for clarity).**

The telescopic arm will consist of two 1/16" wall 6061-T6 aluminum structural tubes. The inner tube will be ¾" and the outer tube will be 1.25". The telescopic motion allows the arm to reach the payload in its initial position 12 inches away from the AGSE. The inner tube will have four Delrin sliders mounted exteriorly at the bottom of the tube. The outer tube will have four additional sliders mounted internally at the top of the tube. These sliders will ensure the inner tube slides freely in and out but will not allow side to side movement. The telescopic arm will be actuated using an internal ACME screw that will be powered using a gearmotor. The gearmotor will be located inside the outer tube at the base of the telescopic arm. An analog encoder will be attached to the telescopic arm to provide position feedback to the central processor.

To manage control signals and power distribution to the wrist and gripper assemblies a retractable wire spool will also be installed on the outer tube of the telescopic arm. The wire spool is shown in Figure 30.

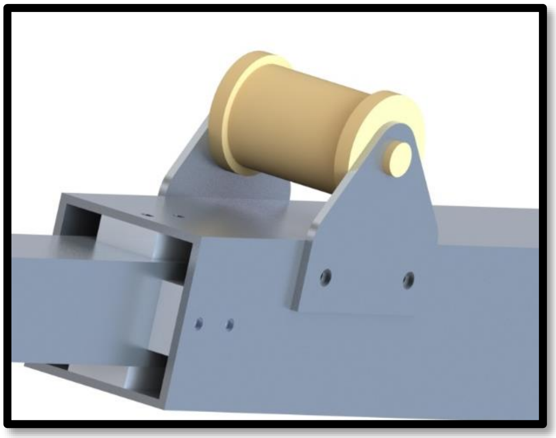


**Figure 30: Payload arm wire spool.**

This spool will be spring loaded to keep the wires taunt, reducing the risk of the wires tangling in other components. The spool will also have a slip ring installed similar to the one shown in Figure 31. This will allow the spool to rotate and still maintain electrical connectivity in each wire.

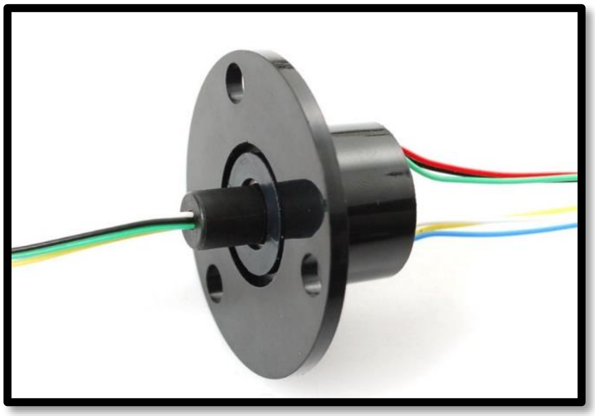


**Figure 31: Electrical slip ring.**

*Base Pivot*

The bottom of the telescopic arm will be connected into an actuated pivot point. The telescopic arm will interface with a custom machined hex axle. The pivot point will be actuated using a worm gearbox as shown in Figure 32. This gearbox will be paired with a gearmotor and an analog encoder. The encoder will provide position feedback to the central processor. The worm gearbox allows the telescopic arm to be stopped at any angle and limits the stall load on the motor. Attempting to hold a specific angle with only a motor or standard gearbox could cause damage to the motor while it is stalled.

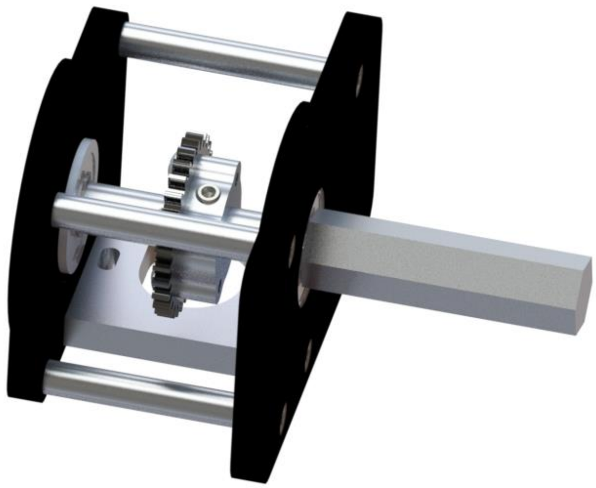


**Figure 32: Telescopic arm pivot gearbox.**

*Removable Gripper*

The payload will be captured using a deformation gripper. The gripper will be 3D printed using ABS plastic. The gripper will be designed to allow the arms of the gripper to deflect when the gripper is pressed over the payload. This will lock the payload into the gripper arms. Analysis will be completed to determine the appropriate geometry for the gripper to ensure there is adequate compression on the payload so the payload isn't dropped during insertion into the launch vehicle. The current gripper design is shown in Figure 34.

**Figure 33: Payload capture device gripper.**

Once the payload and gripper have entered the rocket, a 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 34.

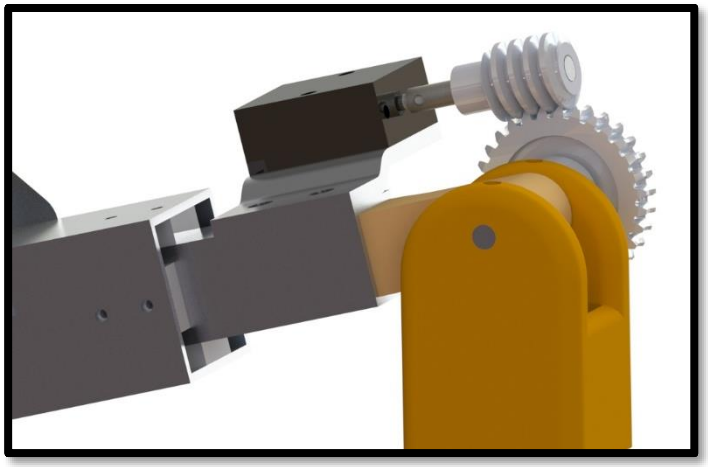


**Figure 34: Payload capture device wrist.**

The wrist will attach the gripper to 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 micro gearmotor. The worm gear configuration was chosen also chosen to avoid stall loading on the motor when attempting to lock the wrist into a specific location. The wrist connection will be made from 3D printed ABS plastic. The wrist will also include an analog encoder to provide position feedback to the central processor.

### Optimization Opportunities

*Material Selection*

Additional analysis will be completed on the telescopic arm to determine if aluminum structural tubing is the optimal material to use for this component. The telescopic arm will see very small loads, so a plastic may be sufficient to support the payload. Deflection calculations similar to those discussed for the Launch Platform rails and Finite Element Analysis will be used to determine the optimal material.

## 5) Igniter Installation

### Overview

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

1. House and protect the igniter from damage during the actuation of the launch vehicle.
2. Raise the igniter to the top of the interior of the launch vehicle motor.
3. Hold igniter in position until motor ignition and liftoff has been achieved.
4. Be reusable.

The overall approximate dimensions of the igniter installation device are show in Table 14.

| Mass ($lb_m$) | Width (in) | Height (in) | Depth (in) |
|---|---|---|---|
| 3.42 | 3.25 | 6.32 | 3.25 |

**Table 18: Igniter installation device general dimensions.**

**Figure 35:  Igniter installation device.**

### Design

The igniter installation device will be mounted at the base of the launch platform and will primarily consist of 3D printed components.  The device can be broken down into four basic components: the housing, belts, tensioner, and cable spool.

*Housing*

The igniter installation device housing will be made of 3D printed ABS as shown in Figure 36.

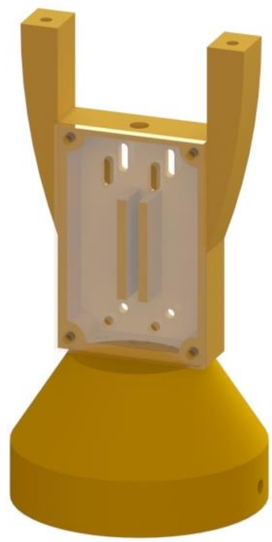


**Figure 36: Igniter installation housing.**

The housing will have a clear acrylic cover and will contain the drive belts. Both belts will be driven by the same motor using spur gears on the lower pulleys to transfer rotational energy between the two belts. Two belt guides protrude from the rear of the housing to ensure constant contact between the belts and the igniter during installation. Two #10-32 threaded holes are located at the top of the housing and will be used to interface with the bottom plate of the launch platform. The base of the housing will also include a funnel that will help guide the igniter into the device and serve as a mounting point for the cable spool.

*Belt geometry*

As shown in Figure 37, the belts will have a center groove to help guide the igniter into the motor of the launch vehicle. These belts will either be custom printed or will be purchased and machined to the correct dimensions. Research will be conducted to determine the best option for the belts.

**Figure 37: Igniter installation belt.**

*Tensioner*

The tension will be 3D printed out of ABS and will include two ¾" 10-32 UNC-2A socket head aluminum cap screws. The cap screws will provide an adjustment point for the tensioner. The tensioner will wrap over the igniter installer and connect directly to the top two belt pulley axles. The top two belt pulleys axles will be constrained in slots that allow the adjustment of the tensioner. The tensioner assembly is shown in Figure 38.

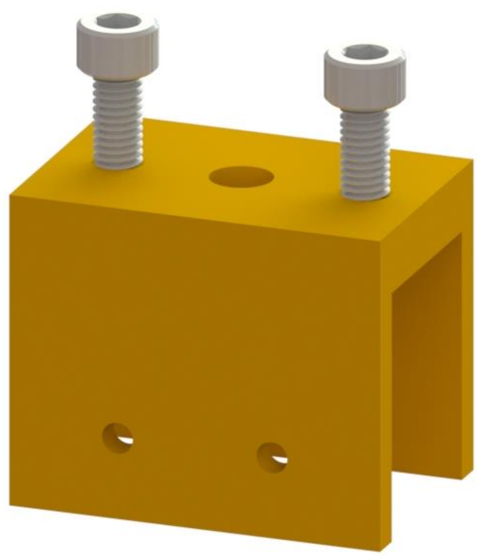


**Figure 38: Igniter installation tensioner.**

*Cable spool*
The cable spool will also be 3D printed out of ABS and is shown in Figure 39.

**Figure 39: Igniter installation cable spool.**

A dampener will be connected to the spool to control the maximum velocity that the spool can spin. This will keep tension on the igniter and will assist in straightening the igniter. One end of the spool will include a slip ring similar to the one used on the payload capture device. An encoder will be attached to opposite side so the system can verify the igniter has been fully inserted.

# 6) Sub-Frame

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

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

The approximate overall dimensions of the sub-frame are shown in Table 14.

| Mass ($lb_m$) | Width (in) | Height (in) | Length (in) |
|---|---|---|---|
| 17.34 | 53.74 | 12.63 | 100.87 |

**Table 19. Sub-frame general dimensions.**

A rendering of the sub-frame is shown in Figure 40.

**Figure 40: AGSE sub-frame assembly.**

### Design

The sub-frame's primary purpose is to provide stability for the AGSE and integration points for all sub systems. The tubing on the sub-frame will be 1"x2" 1/8" wall 6061-T6 aluminum structural tubing. This tubing will be connected using 1/8" thick sheet metal 6061-T6 gussets. Below, the critical components and concepts of the sub-frame have been described in detail.

*Pivot points*

The final location of the pivot points for the launch platform actuation will be determined based on a force analysis. These locations will be optimized based on the force and the carriage travel distance required to raise the launch platform. The design of the pivot points will also be analyzed and appropriate bearings or busing will be selected for each pivot.

*Stability*

Stability will be continually analyzed throughout the design cycle of the AGSE. The final footprint of the AGSE and sub-frame will be determined based on the AGSE center of gravity. Lowering the center of gravity will reduce the footprint area required for a stable AGSE. If it is determined that a larger footprint is required, the Y shaped support structure will be extended to increase the size of the footprint. The current approximate center of gravity location is represented in Figure 41 as the yellow sphere.

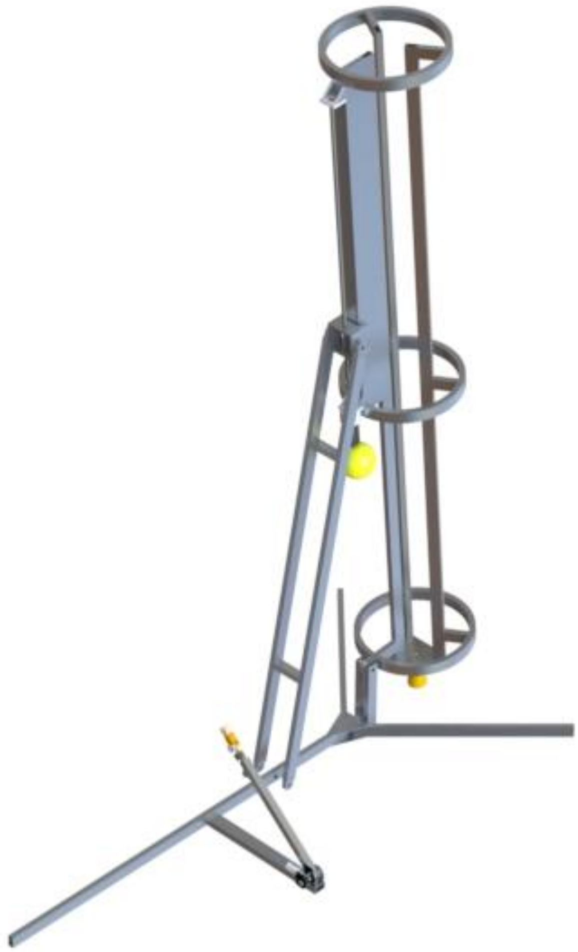


**Figure 41: AGSE center of gravity location.**

# 7) Electronics

The Autonomous Ground Support Equipment will perform the proposed tasks without human interaction. The entire system will operate off of a single 12 volt, 18 amp hour lead acid battery. The electronics system will primarily include a central processor, human machine interface, motor controllers, and custom circuitry.

*Central Processor*

The Arduino Mega was selected as the primary processor because of its versatility with multiple shield options and multiple I/O pins. The AGSE will require six pulse width modulation (PWM) outputs, four analog inputs, and seven digital input/outputs as allocated in Table 20.

The Mega will meet these requirements with 54 digital ports, 16 analog pins and 14 of the digital parts having PWM capabilities.

| Function | I/O Type | I/O Direction |
|---|---|---|
| Payload arm pivot position feedback | Analog | Input |
| Telescopic arm position feedback | Analog | Input |
| Vehicle actuation accelerometer feedback | Analog | Input |
| Wrist position feedback | Analog | Input |
| Igniter spool encoder feedback, pole 1 | Discrete | Input |
| Igniter spool encoder feedback, pole 2 | Discrete | Input |
| Pause switch | Discrete | Input |
| Vehicle actuation high limit | Discrete | Input |
| Vehicle actuation low limit | Discrete | Input |
| All systems go indicator | Discrete | Output |
| Pause indicator | Discrete | Output |
| Gripper release servo | PWM | Output |
| Igniter installation motor control | PWM | Output |
| Payload arm pivot motor control | PWM | Output |
| Telescopic arm motor control | PWM | Output |
| Vehicle actuation motor control | PWM | Output |
| Wrist motor control | PWM | Output |

**Table 20: AGSE input and output requirements.**

*Human Machine Interface*

A human machine interface (HMI) panel will be included onboard the AGSE sub-frame. The interface panel will contain the master power switch, master power indicator, pause switch, pause indicator, all systems go indicator, and a touch screen interface. The touch screen interface will be connected to a Raspberry Pi processor. The Raspberry Pi will act as a data server, storing active system status information. The Raspberry Pi will then access the data server to feed the touch screen with current system information. The main purpose of the touch screen will be to give additional diagnostic data to any operator.

The Raspberry Pi and Arduino will communicate directly utilizing a two way communication protocol. Currently, $I^2C$ and Ethernet/IP communication are being considered for this communication. Analysis will be completed to determine which protocol will be used.

A remote HMI is also being planned that will utilize a wireless communication method to transmit status information form the ground station back to the team at the launch viewing area. Status information will be displayed on a handheld tablet.

*Motor Controllers*

To control the motors, the Arduino Mega will communicate to motor controllers using PWM signals. The primary motor controller on the AGSE will be the Talon SRX Speed

Controller. The Talon SRX Speed Controller is shown in Figure 42. The talon has a surge current rating of 100 amps, and a continuous current rating of 60 amps. Other smaller motor controllers will explored for low load applications, such as the igniter installation device motor.


**Figure 42: Talon SRX speed controller.**

*Circuitry*

All low voltage and low current signal connections will be made utilizing RJ45 connections and CAT-5e cable. This will help with wire management and provide a quick disconnect for all sensors.

Many sensors will be located a significant distance from the central processor. Relays and amplifiers will be used to ensure the signals are not lost between any sensor and the central processor.

A custom printed circuit board will be manufactured to organize connections to the central processor and human interface. This circuit board will make the direct connections to the processors and will terminate at screw terminals, terminal blocks, or RJ45 female connections for later connections to field devices. Additional circuit boards will be manufactured at each sub-system interface. These circuit boards will include an RJ45 female connection and will break out each conductor to a termination point.

# Section 7. 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.

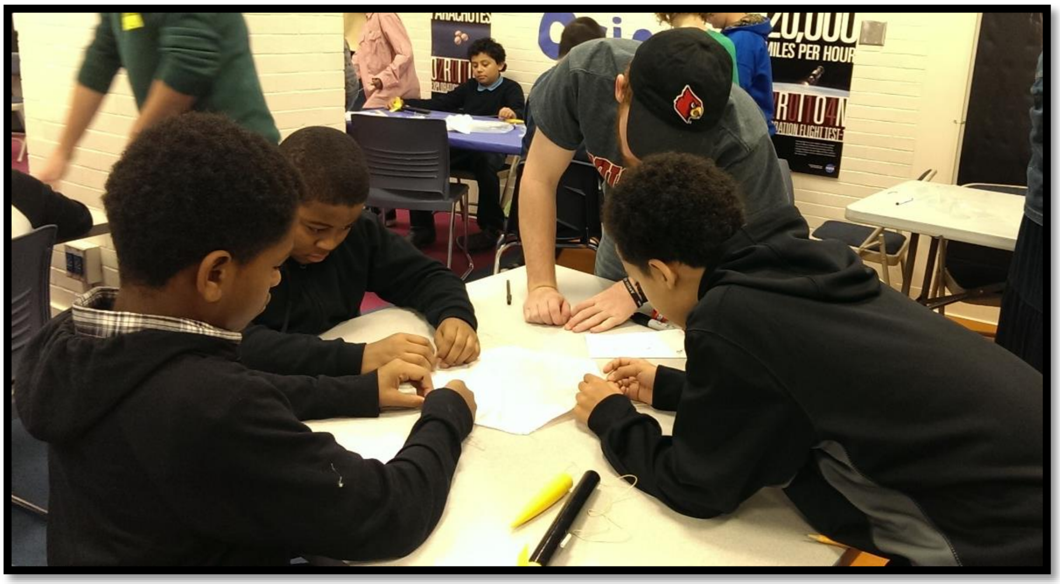



**Figure 43: Ross assisting students in assembling their parachute.**

## 8) 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 44: 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 45: 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.

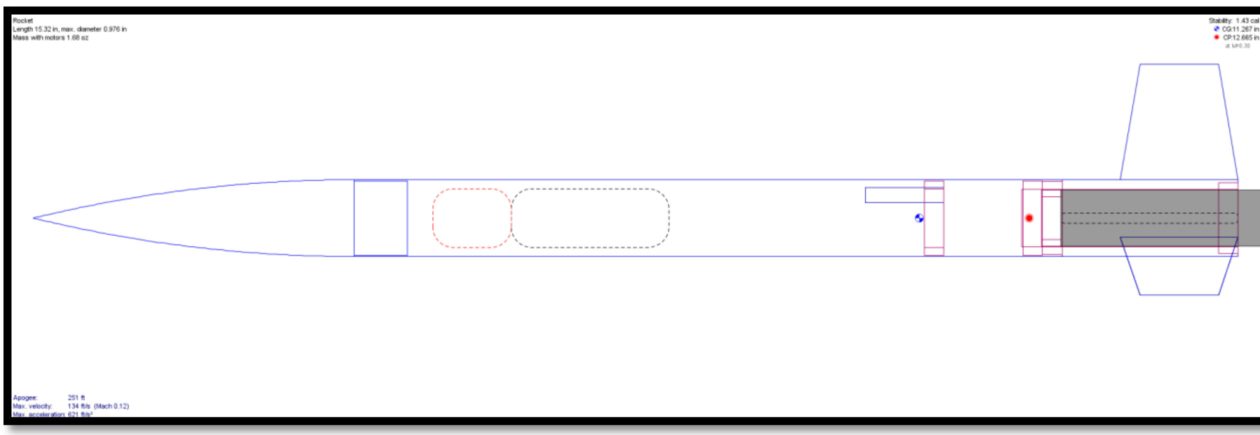



**Figure 46: OpenRocket simulation created by students.**

*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 47: Carlos helping student prepare her rocket for launch.**

Six Week Exploring Rocketry and Engineering Program

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

*Day One: Programming*

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

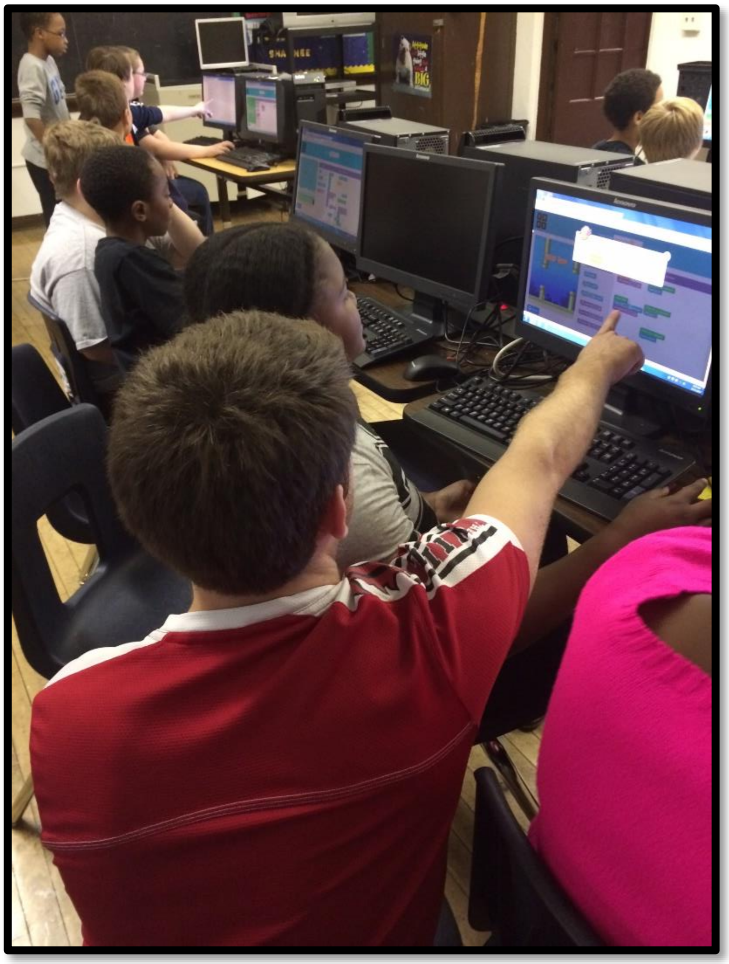


**Figure 48: David teaches students how to program a game on code.org.**

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.

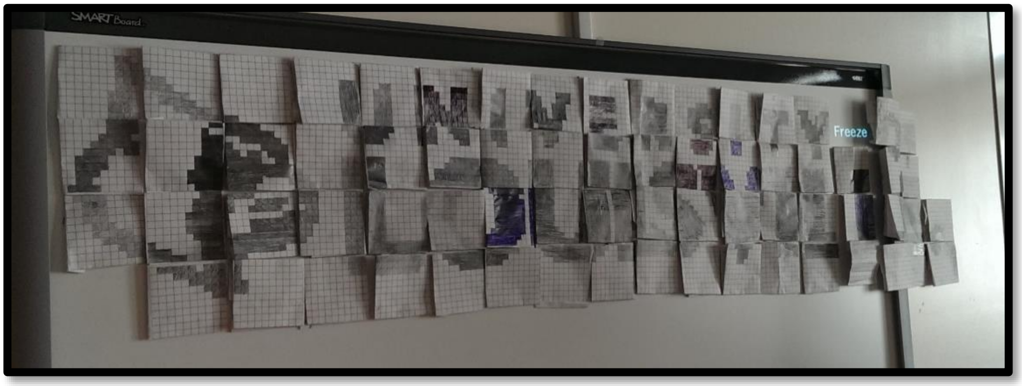


**Figure 49: The satellite message that students decoded.**

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.

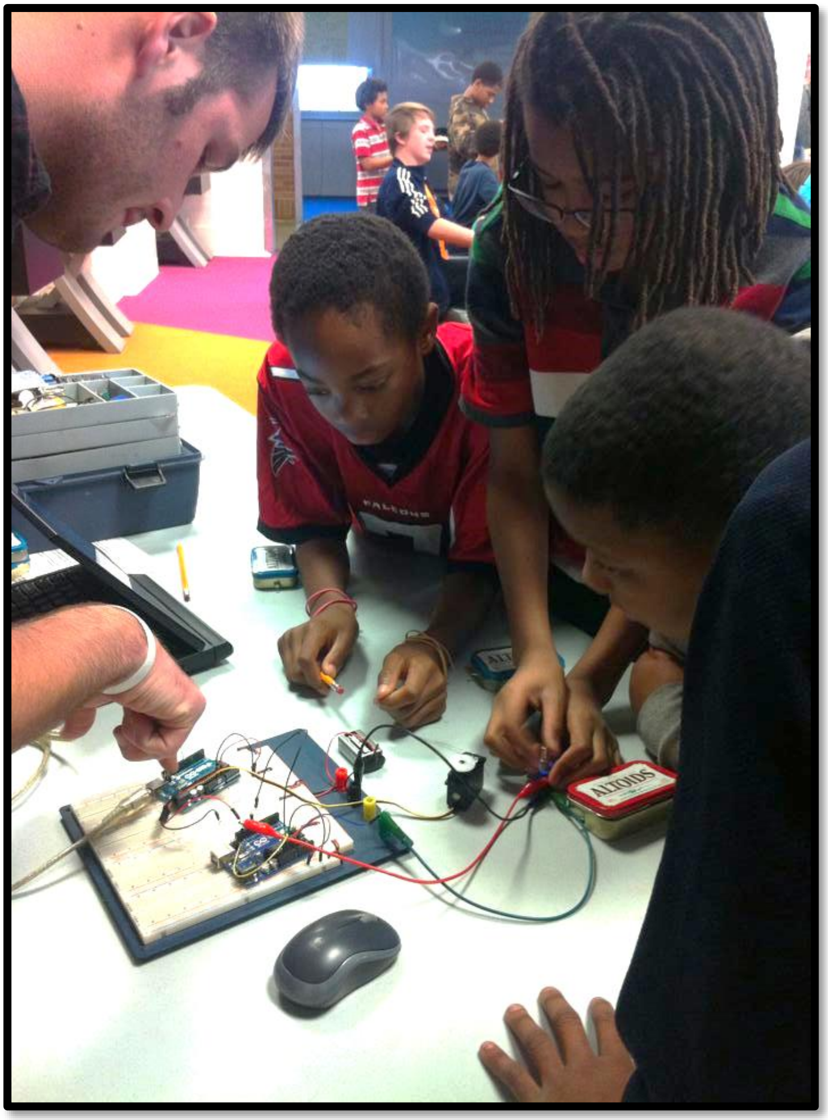



**Figure 50: Sherman shows students a circuit that he built and how it works.**

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.

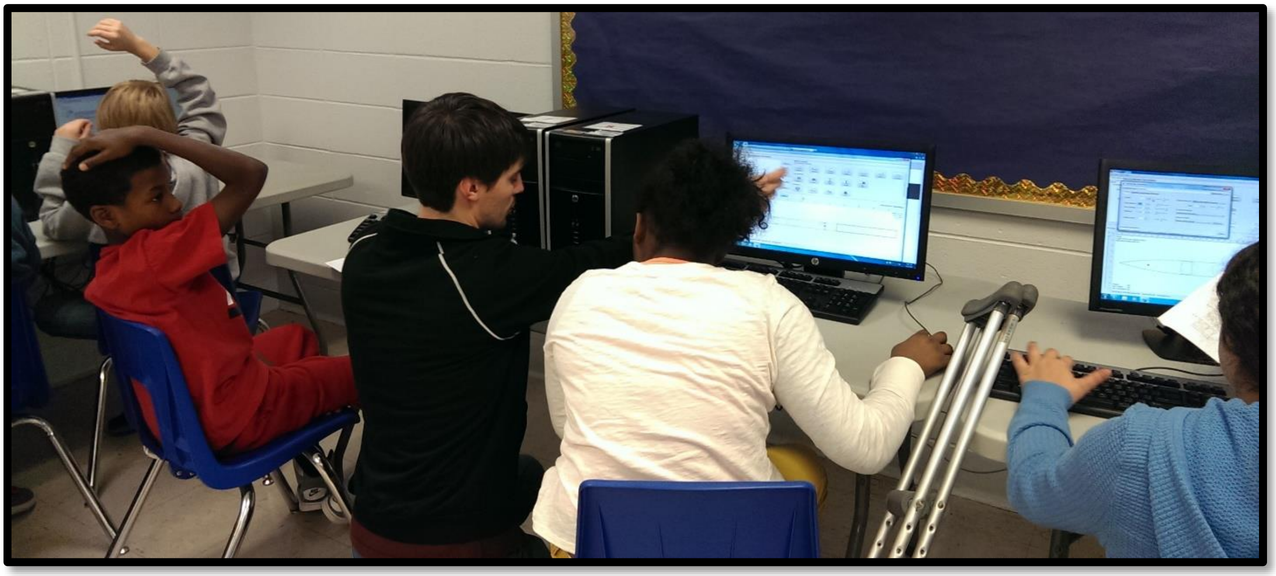


**Figure 51: Gregg helps student with her OpenRocket simulation.**

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.

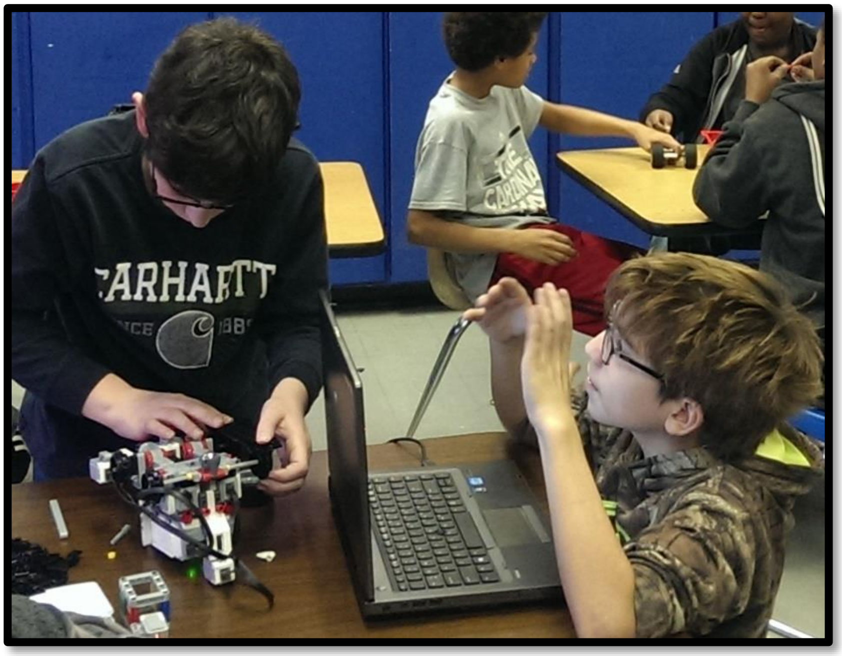


**Figure 52: Students discuss designs and modifications to their program.**

# 9) 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 53: Three students launch a water bottle rocket that they built themselves while at the annual E-Expo.**

In addition to the water rocket competition, the team will host a paper rocket station for people of all ages. This has been the most popular station at the exposition in the past and are looking to continue to build up that reputation.

**Boy Scouts and Cub Scouts:**

In the past, the University of Louisville River City Rocketry Team has worked with local Boy Scout and Cub Scout troops to assist the earning of the Space Exploration merit badge. The team has assisted in developing a program that meets the requirements to earn the merit badge. The scouts get to learn about the history of space, current space endeavors, and build and launch an Estes rocket. The team has plans to continue to work with these groups throughout the year.

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

**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 54: 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 am opportunity to talk to the community about our project and what it does. This is an informal setting which is perfect for interacting with visitors and answering their questions about the project, what the team does, and about rocketry in general.

**FIRST Lego League Competition**

The team initially become involved with the FIRST Lego League Competition during the 2014-2015 season. This was such a successful event that River City Rocketry has been invited back to participate for the second year in a row! The FIRST Lego League competition is an all-day event and the team performs several activities throughout the day. Throughout the majority of the day, the team has a display set up so that when students are in between events, the team can talk to them about the previous year's project. This is a good way to show the students how programming can be applied into something beyond their Lego Mindstorm robots.

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

**Figure 55: Sherman talking with FIRST Lego League participant about how the team has previously developed a hazard detecting rover.**

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

**Louisville Astronomical Society**

The team has been invited to be the guest speaker at a Louisville Astronomical Society (LAS) meeting. This event is for both those that are members of LAS as well as the public. This is 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 will allow 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.

# Section 8. Project Plan

## 1) Timeline

Master Schedule

| ID | | Task Mode | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|
| 1 | | | **NASA Competition Deadlin** | **174 days** | **Fri 9/11/15** | **Wed 5/11/16** |
| 1 | | | PDR Due | 1 day | Fri 9/11/15 | Fri 9/11/15 |
| 2 | | | Awarded proposals announ | 1 day | Fri 10/2/15 | Fri 10/2/15 |
| 3 | | | Kickoff and PDR Q&A | 1 day | Wed 10/7/15 | Wed 10/7/15 |
| 4 | | | Team web presence establi | 1 day | Wed 9/23/15 | Wed 9/23/15 |
| 5 | | | PDR Due | 1 day | Fri 11/6/15 | Fri 11/6/15 |
| 6 | | | PDR video teleconferences | 10 days | Mon 11/9/15 | Fri 11/20/15 |
| 7 | | | CDR Q&A | 1 day | Fri 12/4/15 | Fri 12/4/15 |
| 8 | | | CDR Due | 1 day | Fri 1/15/16 | Fri 1/15/16 |
| 9 | | | CDR view teleconferences | 9 days | Tue 1/19/16 | Fri 1/29/16 |
| 10 | | | FRR Q&A | 1 day | Wed 2/3/16 | Wed 2/3/16 |
| 11 | | | FRR Due | 1 day | Mon 3/14/16 | Mon 3/14/16 |
| 12 | | | FRR video teleconferences | 13 days | Mon 3/14/16 | Wed 3/30/16 |
| 13 | | | **Competition Week** | **4 days** | **Wed 4/13/16** | **Sun 4/17/16** |
| 19 | | | PLAR | 1 day | Fri 4/29/16 | Fri 4/29/16 |
| 20 | | | Winning team announced | 1 day | Wed 5/11/16 | Wed 5/11/16 |
| 2 | | | **General Team Buisness** | **174 days** | **Mon 8/24/15** | **Thu 4/21/16** |
| 1 | | | **Team Meetings** | **8 days** | **Tue 8/25/15** | **Thu 9/3/15** |
| 2 | | | Kickoff/brainstorming me | 1 day | Tue 8/25/15 | Tue 8/25/15 |
| 3 | | | Brainstorming Meeting # | 1 day | Fri 8/28/15 | Fri 8/28/15 |
| 4 | | | Team Meeting | 1 day | Thu 9/3/15 | Thu 9/3/15 |
| 5 | | | Team Lead Meeting | 1 day | Thu 8/27/15 | Thu 8/27/15 |
| 6 | | | **Recruiting/Team Developm** | **94 days** | **Mon 8/24/15** | **Thu 12/31/15** |
| 7 | | | Speed School Society Pic | 1 day | Mon 9/14/15 | Mon 9/14/15 |
| 8 | | | Mechanical Engineering S | 1 day | Fri 9/4/15 | Fri 9/4/15 |
| 9 | | | RSO Fair | 2 days | Tue 8/25/15 | Wed 8/26/15 |
| 10 | | | **Speed School Student Council Meeting** | **166 days** | **Thu 9/3/15** | **Thu 4/21/16** |
| 45 | | | Individual PDR sections due | 1 day | Mon 1/4/16 | Mon 1/4/16 |
| 46 | | | Individual FRR sections due | 1 day | Mon 3/7/16 | Mon 3/7/16 |
| 47 | | | Individual CDR sections due | 1 day | Fri 1/8/16 | Fri 1/8/16 |
| 48 | | | Subscale test #1 | 1 day | Sat 12/12/15 | Sat 12/12/15 |
| 49 | | | Subscale test #2 | 1 day | Sat 12/19/15 | Sat 12/19/15 |
| 50 | | | Backup subscale test | 1 day | Sat 1/9/16 | Sat 1/9/16 |
| 51 | | | Full scale test #1 | 1 day | Sat 2/20/16 | Sat 2/20/16 |
| 52 | | | Full scale test #2 | 1 day | Sat 2/27/16 | Sat 2/27/16 |
| 53 | | | Full scale backup launch | 1 day | Sat 3/5/16 | Sat 3/5/16 |
| 54 | | | Individual proposal sections | 1 day | Thu 9/10/15 | Thu 9/10/15 |
| 3 | | | **Educational Outreach** | **127 days** | **Fri 9/18/15** | **Mon 3/14/16** |
| 1 | | | Louisville Astonomical Socie | 1 day | Fri 9/18/15 | Fri 9/18/15 |
| 2 | | | Louisville Mini Maker Faire | 1 day | Sat 9/19/15 | Sat 9/19/15 |
| 3 | | | FIRST Lego League Regional | 1 day | Sat 11/14/15 | Sat 11/14/15 |
| 4 | | | Goal: Reach 750 students | 1 day | Thu 12/31/15 | Thu 12/31/15 |

Page 1

**Figure 56: Task list view of team schedule. Page 1.**

Master Schedule

| ID | | Task Mode | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|
| 5 | | | Goal: Reach 1,500 Students | 1 day | Mon 3/14/16 | Mon 3/14/16 |
| 4 | | | **AGSE** | **146 days** | **Mon 8/24/15** | **Mon 3/14/16** |
| 1 | | | **Launch Platform** | **120 days** | **Mon 8/24/15** | **Fri 2/5/16** |
| 1 | | | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | | | Preliminary design | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | | | Peer review design | 5 days | Mon 10/26/15 | Fri 10/30/15 |
| 4 | | | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 5 | | | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 6 | | | Rail deformation | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | | | Rail weight optimizatic | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | | | Joint analysis | 8 days | Mon 9/14/15 | Wed 9/23/15 |
| 9 | | | **Fabrication/Assembly** | **56 days** | **Mon 11/16/15** | **Mon 2/1/16** |
| 10 | | | Mill rail | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 11 | | | Roll rings | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 12 | | | Assemble rings | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 13 | | | Waterjet baseplate | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 14 | | | Mill fastening brackets | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 15 | | | Complete launch platf | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 16 | | | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 17 | | | Deflection testing | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 18 | | | Rocket integration | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 19 | | | Complete launch platf | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 2 | | | **Vehicle Actuation Device** | **120 days** | **Mon 8/24/15** | **Fri 2/5/16** |
| 1 | | | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | | | Preliminary design | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | | | Bearing assebmly desi | 15 days | Mon 9/14/15 | Fri 10/2/15 |
| 4 | | | Peer review design | 5 days | Mon 10/26/15 | Fri 10/30/15 |
| 5 | | | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 6 | | | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 7 | | | Track material selectio | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | | | Track joining method | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | | | Weight optimization o | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | | | Carraige load analysis | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | | | Carriage weight optimi | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 12 | | | Articulating arm asser | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 13 | | | Articulating arm weigh | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 14 | | | Ball screw sizing | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 15 | | | Motor/gearbox sizing | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 16 | | | **Fabrication/Assembly** | **56 days** | **Mon 11/16/15** | **Mon 2/1/16** |
| 17 | | | Mill track | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 18 | | | Assemble track | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 19 | | | Water jet carriage com | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 20 | | | 3D print carriage comp | 56 days | Mon 11/16/15 | Mon 2/1/16 |

Page 2

**Figure 57: Task list view of team schedule. Page 2.**

Master Schedule

| ID | Indicators | Task Mode | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|
| 21 | | | Mill/waterjet carriage | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 22 | | | Assemble articulating a | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 23 | | | Final assembly of vehic | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 24 | | | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 25 | | | Deflection testing | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 26 | | | Rocket integration | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 27 | | | Complete launch platfo | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 3 | | | **Payload Capture Device** | **120 days** | **Mon 8/24/15** | **Fri 2/5/16** |
| 1 | | | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | | | Preliminary design | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | | | Peer review design | 5 days | Mon 10/26/15 | Fri 10/30/15 |
| 4 | | | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 5 | | | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 6 | | | Motor torque calculati | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | | | Telescopic arm deflect | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | | | ACME screw buckling | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | | | ACME screw torque | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | | | Gripper clamping force | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | | | **Fabrication/Assembly** | **56 days** | **Mon 11/16/15** | **Mon 2/1/16** |
| 12 | | | Machine pivot axel | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 13 | | | Machine ACME thread | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 14 | | | Mill telescopic arm tub | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 15 | | | 3D print gripper and w | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 16 | | | Assemble payload capt | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 17 | | | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 18 | | | Verify gripper clamping | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 19 | | | Verify pivot range | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 20 | | | Verify payload capture | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 4 | | | **Subframe** | **120 days** | **Mon 8/24/15** | **Fri 2/5/16** |
| 1 | | | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | | | Preliminary design | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | | | Peer review design | 5 days | Mon 10/26/15 | Fri 10/30/15 |
| 4 | | | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 5 | | | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 6 | | | Stability analysis | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | | | Deflection analysis | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | | | Structural analysis of p | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | | | **Fabrication/Assembly** | **56 days** | **Mon 11/16/15** | **Mon 2/1/16** |
| 10 | | | Mill structural tubing | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 11 | | | Waterjet gusset plates | 56 days | Mon 11/16/15 | Mon 2/1/16 |
| 12 | | | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 13 | | | Structural testing | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 5 | | | Final assembly of AGSE | 6 days | Fri 2/5/16 | Fri 2/12/16 |

Page 3

**Figure 58: Task list view of team schedule. Page 3.**

Master Schedule

| ID | | Task Mode | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|
| 6 | | | Test ability to raise launch p | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 7 | | | Verify stability | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 8 | | | Full system test | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 5 | | | **Recovery** | **109 days?** | **Fri 9/11/15** | **Wed 2/10/16** |
| 1 | | | **Design** | **46 days?** | **Fri 9/11/15** | **Fri 11/13/15** |
| 2 | | | Preliminary design | 32 days | Fri 9/11/15 | Mon 10/26/15 |
| 3 | | | Sizing of parachute | 32 days? | Fri 9/11/15 | Mon 10/26/15 |
| 4 | | | Sizing of suspension lines | 32 days? | Fri 9/11/15 | Mon 10/26/15 |
| 5 | | | Sizing of harnesses | 32 days | Fri 9/11/15 | Mon 10/26/15 |
| 6 | | | Peer review design | 32 days | Fri 9/11/15 | Mon 10/26/15 |
| 7 | | | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 8 | | | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 9 | | | Drift calculations | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | | | Kinetic energy calculatior | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | | | Shock force calculations | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 12 | | | **Fabrication/Assembly** | **18 days** | **Mon 1/18/16** | **Wed 2/10/16** |
| 13 | | | Cut templates for fullscal | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 14 | | | Cut and number all gores | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 15 | | | Hem all gores | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 16 | | | Secure lines into gores | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 17 | | | Construct deployment ba | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 18 | | | Assemble reefing bulkpla | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 19 | | | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 20 | | | Ground test tender desce | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 21 | | | Ground test parachute | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 22 | | | Verify proper deploymen | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 6 | | | **Launch Vehicle** | **123 days?** | **Mon 8/24/15** | **Wed 2/10/16** |
| 1 | | | **Design** | **60 days?** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | | | Preliminary design | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | | | Detailed design of payloa | 32 days? | Fri 9/11/15 | Mon 10/26/15 |
| 4 | | | Detailed design of remov | 32 days? | Fri 9/11/15 | Mon 10/26/15 |
| 5 | | | Peer review design | 5 days | Mon 10/26/15 | Fri 10/30/15 |
| 6 | | | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 7 | | | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 8 | | | Fluid analysis of airframe | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | | | Fin flutter analysis | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | | | Structural analysis of pay | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | | | Structural analysis of bull | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 12 | | | OpenRocket Simulation | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 13 | | | Structural analysis of rem | 8 days | Mon 9/14/15 | Wed 9/23/15 |
| 14 | | | **Fabrication/Assembly** | **18 days** | **Mon 1/18/16** | **Wed 2/10/16** |
| 15 | | | Measure fiberglass thickr | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 16 | | | Measure and cut airfram | 18 days | Mon 1/18/16 | Wed 2/10/16 |

Page 4

**Figure 59: Task list view of team schedule. Page 4.**

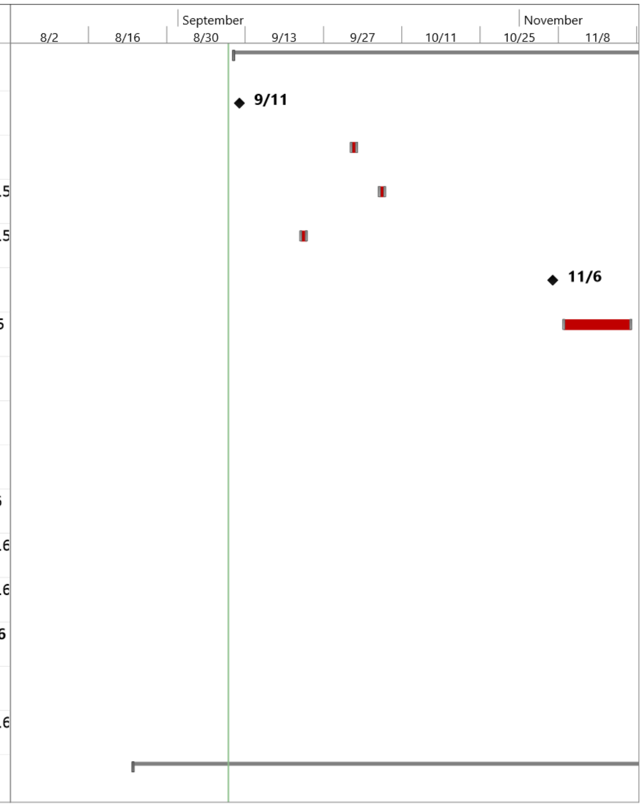
Master Schedule

| ID | | Task Mode | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|
| 17 | | | Waterjet fins | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 18 | | | Waterjet centering rings | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 19 | | | Construct fin slot jig | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 20 | | | Epoxy centering rings | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 21 | | | Review fitment of fins in | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 22 | | | Laser cut bulkheads | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 23 | | | 3D print electronics sleds | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 24 | | | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 25 | | | Test flight altimeters | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 26 | | | Ejection charge testing | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 27 | | | Verify payload door actu: | 1 day | Mon 2/1/16 | Mon 2/1/16 |

Page 5

**Figure 60: Task list view of team schedule. Page 5.**

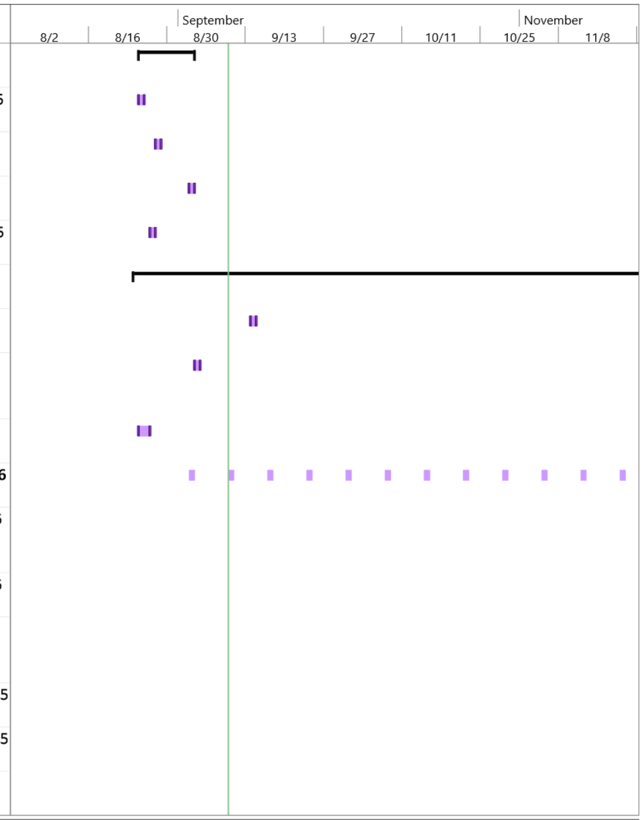
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **NASA Competition Deadlines** | **174 days** | **Fri 9/11/15** | **Wed 5/11/16** |
| 1 | PDR Due | 1 day | Fri 9/11/15 | Fri 9/11/15 |
| 2 | Awarded proposals | 1 day | Fri 10/2/15 | Fri 10/2/15 |
| 3 | Kickoff and PDR Q& | 1 day | Wed 10/7/15 | Wed 10/7/15 |
| 4 | Team web presence | 1 day | Wed 9/23/15 | Wed 9/23/15 |
| 5 | PDR Due | 1 day | Fri 11/6/15 | Fri 11/6/15 |
| 6 | PDR video teleconf | 10 days | Mon 11/9/15 | Fri 11/20/15 |
| 7 | CDR Q&A | 1 day | Fri 12/4/15 | Fri 12/4/15 |
| 8 | CDR Due | 1 day | Fri 1/15/16 | Fri 1/15/16 |
| 9 | CDR view teleconfe | 9 days | Tue 1/19/16 | Fri 1/29/16 |
| 10 | FRR Q&A | 1 day | Wed 2/3/16 | Wed 2/3/16 |
| 11 | FRR Due | 1 day | Mon 3/14/16 | Mon 3/14/16 |
| 12 | FRR video teleconfe | 13 days | Mon 3/14/16 | Wed 3/30/16 |
| 13 | **Competition Week** | **4 days** | **Wed 4/13/16** | **Sun 4/17/16** |
| 19 | PLAR | 1 day | Fri 4/29/16 | Fri 4/29/16 |
| 20 | Winning team annc | 1 day | Wed 5/11/16 | Wed 5/11/16 |
| 2 | **General Team Buisness** | **174 days** | **Mon 8/24/15** | **Thu 4/21/16** |




Page 1

**Figure 61: Project timeline page 1.**

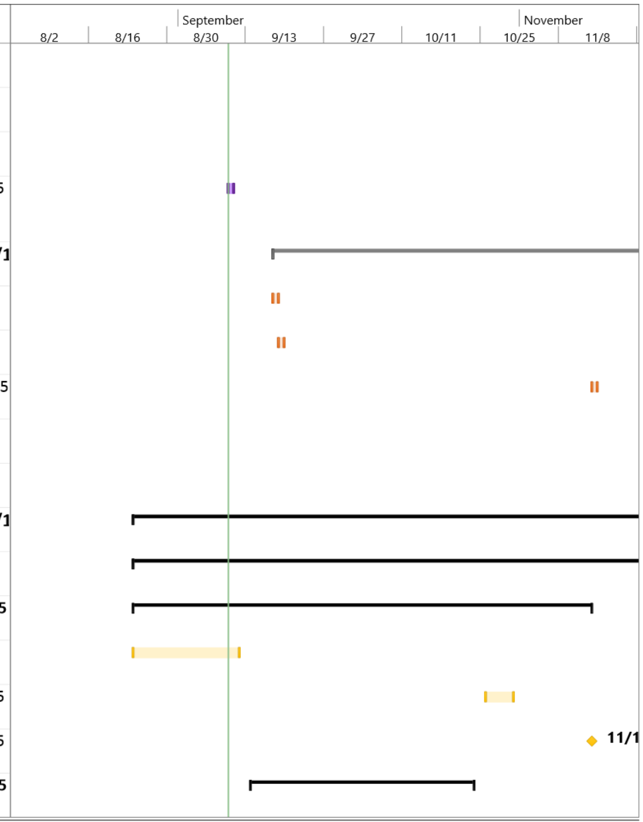
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **Team Meetings** | **8 days** | **Tue 8/25/15** | **Thu 9/3/15** |
| 2 | Kickoff/brainstor meeting | 1 day | Tue 8/25/15 | Tue 8/25/15 |
| 3 | Brainstorming Meeting #2 | 1 day | Fri 8/28/15 | Fri 8/28/15 |
| 4 | Team Meeting | 1 day | Thu 9/3/15 | Thu 9/3/15 |
| 5 | Team Lead Meet | 1 day | Thu 8/27/15 | Thu 8/27/15 |
| 6 | **Recruiting/Team Development** | **94 days** | **Mon 8/24/15** | **Thu 12/31/15** |
| 7 | Speed School Society Picnic | 1 day | Mon 9/14/15 | Mon 9/14/15 |
| 8 | Mechanical Engineering Student Lunch | 1 day | Fri 9/4/15 | Fri 9/4/15 |
| 9 | RSO Fair | 2 days | Tue 8/25/15 | Wed 8/26/15 |
| 10 | **Speed School Student Council** | **166 days** | **Thu 9/3/15** | **Thu 4/21/16** |
| 45 | Individual PDR sections due to captains | 1 day | Mon 1/4/16 | Mon 1/4/16 |
| 46 | Individual FRR sections due to | 1 day | Mon 3/7/16 | Mon 3/7/16 |
| 47 | Individual CDR sections due to captains | 1 day | Fri 1/8/16 | Fri 1/8/16 |
| 48 | Subscale test #1 | 1 day | Sat 12/12/15 | Sat 12/12/15 |
| 49 | Subscale test #2 | 1 day | Sat 12/19/15 | Sat 12/19/15 |
| 50 | Backup subscale te: | 1 day | Sat 1/9/16 | Sat 1/9/16 |




Page 2

**Figure 62: Project timeline page 2.**

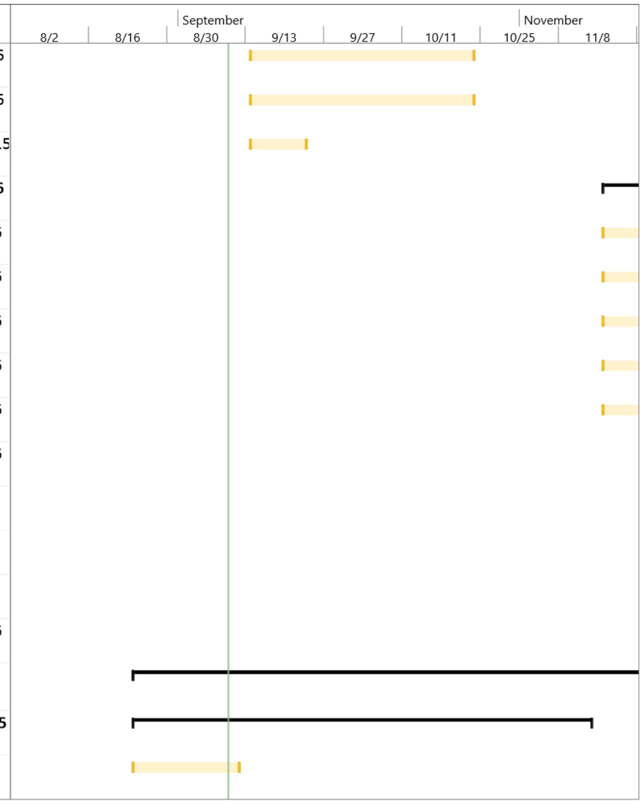
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 51 | Full scale test #1 | 1 day | Sat 2/20/16 | Sat 2/20/16 |
| 52 | Full scale test #2 | 1 day | Sat 2/27/16 | Sat 2/27/16 |
| 53 | Full scale backup launch | 1 day | Sat 3/5/16 | Sat 3/5/16 |
| 54 | Individual proposal sections due to captains | 1 day | Thu 9/10/15 | Thu 9/10/15 |
| 3 | **Educational Outrea** | **127 days** | **Fri 9/18/15** | **Mon 3/14/1** |
| 1 | Louisville Astonomical | 1 day | Fri 9/18/15 | Fri 9/18/15 |
| 2 | Louisville Mini Maker Faire | 1 day | Sat 9/19/15 | Sat 9/19/15 |
| 3 | FIRST Lego League Regional | 1 day | Sat 11/14/15 | Sat 11/14/15 |
| 4 | Goal: Reach 750 students | 1 day | Thu 12/31/15 | Thu 12/31/15 |
| 5 | Goal: Reach 1,500 Students | 1 day | Mon 3/14/16 | Mon 3/14/16 |
| 4 | **AGSE** | **146 days** | **Mon 8/24/1** | **Mon 3/14/1** |
| 1 | **Launch Platform** | **120 days** | **Mon 8/24/1** | **Fri 2/5/16** |
| 1 | **Design** | **60 days** | **Mon 8/24/1!** | **Fri 11/13/15** |
| 2 | Preliminary de | 15 days | Mon 8/24/1! | Fri 9/11/15 |
| 3 | Peer review de | 5 days | Mon 10/26/1 | Fri 10/30/15 |
| 4 | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 5 | **Analysis** | **30 days** | **Mon 9/14/1!** | **Fri 10/23/15** |




Page 3

**Figure 63: Project timeline page 3.**

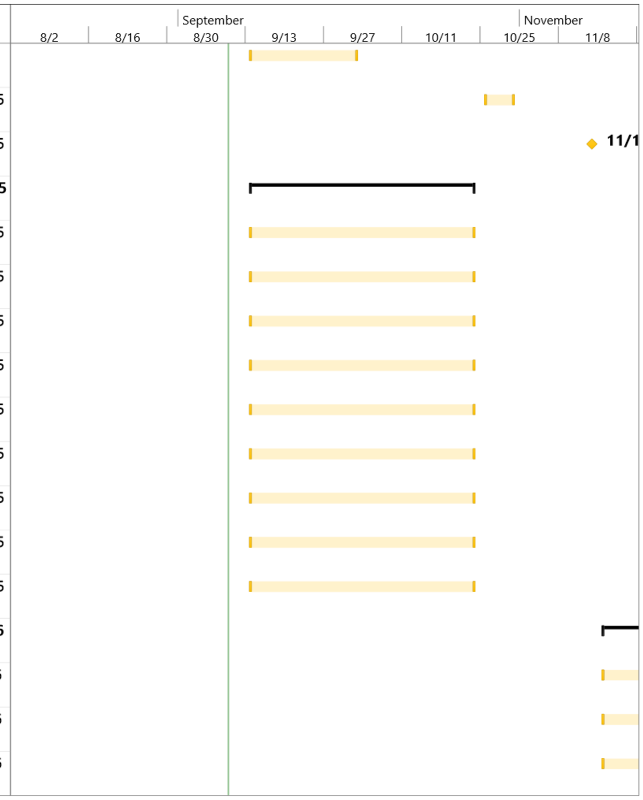
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 6 | Rail deformati | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | Rail weight op | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | Joint analysis | 8 days | Mon 9/14/15 | Wed 9/23/15 |
| 9 | **Fabrication/Asse** | **56 days** | **Mon 11/16/1** | **Mon 2/1/16** |
| 10 | Mill rail | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 11 | Roll rings | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 12 | Assemble ring | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 13 | Waterjet base | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 14 | Mill fastening | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 15 | Complete laun | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 16 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 17 | Deflection test | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 18 | Rocket integra | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 19 | Complete laun | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 2 | **Vehicle Actuation** | **120 days** | **Mon 8/24/15** | **Fri 2/5/16** |
| 1 | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | Preliminary de | 15 days | Mon 8/24/15 | Fri 9/11/15 |




Page 4

**Figure 64: Project timeline page 4.**

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 3 | Bearing assebr | 15 days | Mon 9/14/15 | Fri 10/2/15 |
| 4 | Peer review de | 5 days | Mon 10/26/1 | Fri 10/30/15 |
| 5 | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 6 | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 7 | Track material | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | Track joining n | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | Weight optimi | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | Carraige load a | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | Carriage weigh | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 12 | Articulating ar | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 13 | Articulating ar | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 14 | Ball screw sizir | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 15 | Motor/gearbo | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 16 | **Fabrication/Asse** | **56 days** | **Mon 11/16/1** | **Mon 2/1/16** |
| 17 | Mill track | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 18 | Assemble tracl | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 19 | Water jet carri | 56 days | Mon 11/16/1 | Mon 2/1/16 |



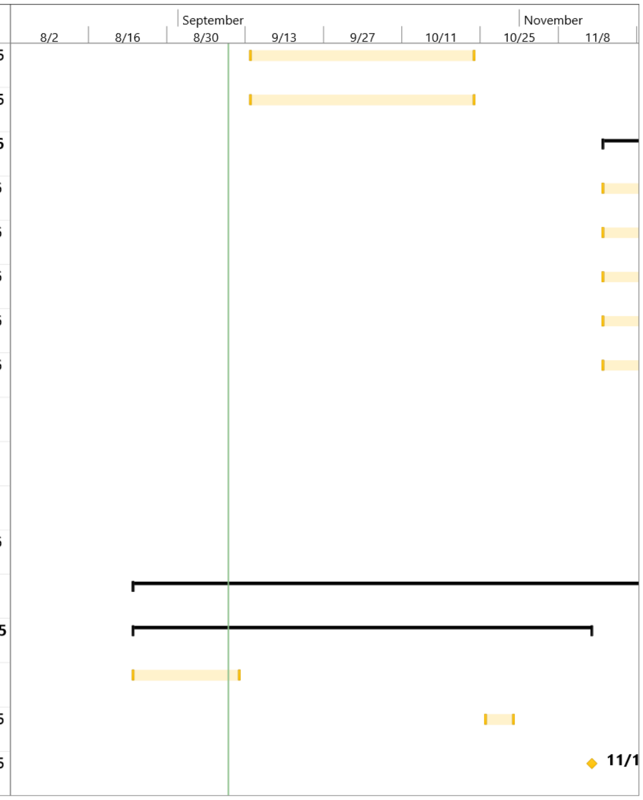

Page 5

**Figure 65: Project timeline page 5.**


| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 20 | 3D print carria | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 21 | Mill/waterjet c | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 22 | Assemble artic | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 23 | Final assembly | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 24 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 25 | Deflection test | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 26 | Rocket integra | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 27 | Complete laun | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 3 | **Payload Capture Device** | **120 days** | **Mon 8/24/15** | **Fri 2/5/16** |
| 1 | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | Preliminary de | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | Peer review de | 5 days | Mon 10/26/1 | Fri 10/30/15 |
| 4 | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 5 | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 6 | Motor torque | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | Telescopic arm | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | ACME screw b | 30 days | Mon 9/14/15 | Fri 10/23/15 |

**Figure 66: Project timeline page 6.**

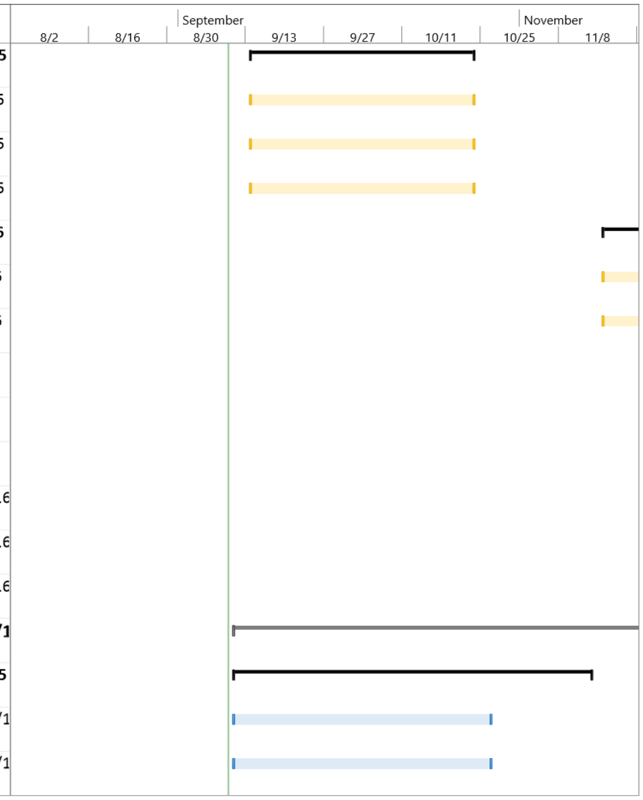
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 9 | ACME screw tc | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | Gripper clamp | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | **Fabrication/Asse** | **56 days** | **Mon 11/16/1** | **Mon 2/1/16** |
| 12 | Machine pivot | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 13 | Machine ACMI | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 14 | Mill telescopic | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 15 | 3D print grippe | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 16 | Assemble payl | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 17 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 18 | Verify gripper | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 19 | Verify pivot ra | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 20 | Verify payload | 1 day | Mon 2/1/16 | Mon 2/1/16 |
| 4 | **Subframe** | **120 days** | **Mon 8/24/1** | **Fri 2/5/16** |
| 1 | **Design** | **60 days** | **Mon 8/24/15** | **Fri 11/13/15** |
| 2 | Preliminary de | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | Peer review de | 5 days | Mon 10/26/1 | Fri 10/30/15 |
| 4 | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |




Page 7

**Figure 67: Project timeline page 7.**

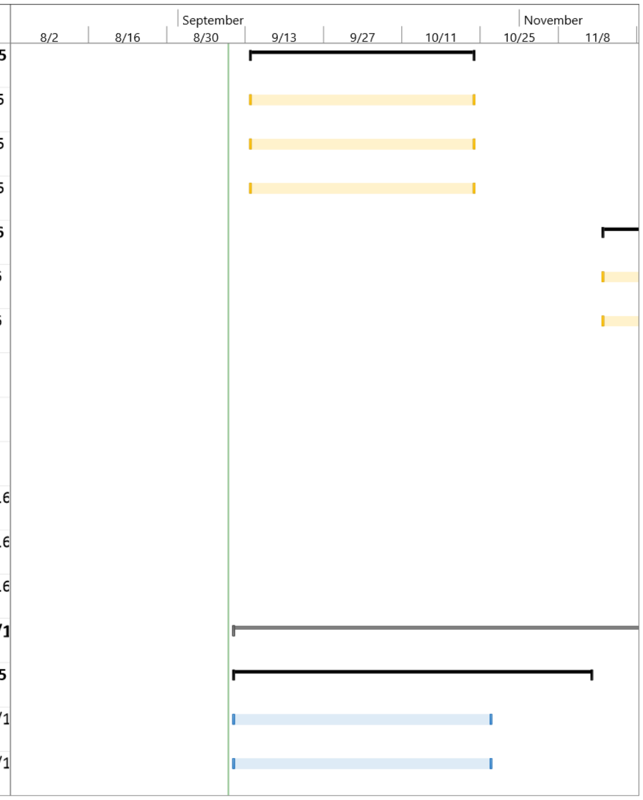
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 5 | **Analysis** | **30 days** | **Mon 9/14/15** | **Fri 10/23/15** |
| 6 | Stability analy: | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | Deflection ana | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | Structural anal | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | **Fabrication/Asse** | **56 days** | **Mon 11/16/1** | **Mon 2/1/16** |
| 10 | Mill structural | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 11 | Waterjet guss | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 12 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 13 | Structural test | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 5 | Final assembly of A | 6 days | Fri 2/5/16 | Fri 2/12/16 |
| 6 | Test ability to raise | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 7 | Verify stability | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 8 | Full system test | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 5 | **Recovery** | **109 days?** | **Fri 9/11/15** | **Wed 2/10/1** |
| 1 | **Design** | **46 days?** | **Fri 9/11/15** | **Fri 11/13/15** |
| 2 | Preliminary desig | 32 days | Fri 9/11/15 | Mon 10/26/1 |
| 3 | Sizing of parachu | 32 days? | Fri 9/11/15 | Mon 10/26/1 |




Page 8

**Figure 68: Project timeline page 8.**

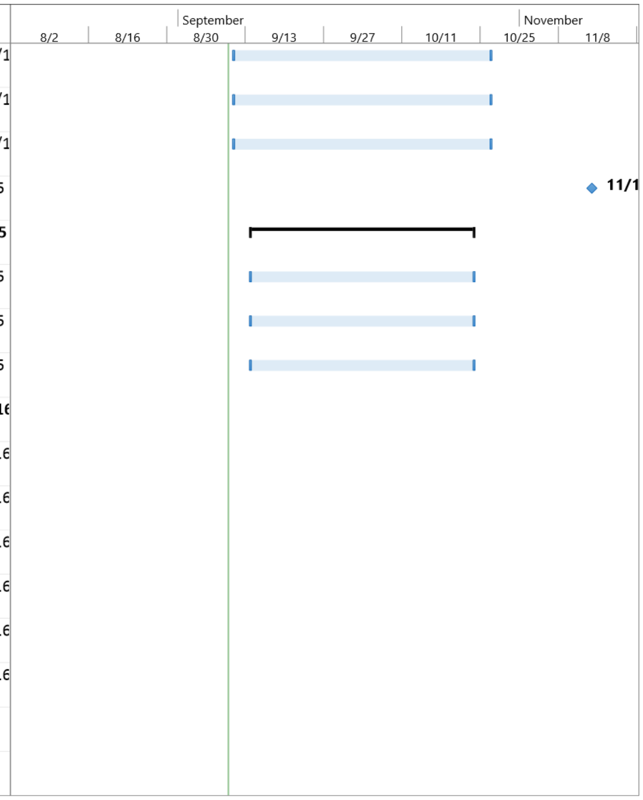
| ID | Task Name | Duration | Start | Finish |
| --- | --- | --- | --- | --- |
| 5 | **Analysis** | **30 days** | **Mon 9/14/1** | **Fri 10/23/15** |
| 6 | Stability analy | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 7 | Deflection ana | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 8 | Structural anal | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | **Fabrication/Asse** | **56 days** | **Mon 11/16/1** | **Mon 2/1/16** |
| 10 | Mill structural | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 11 | Waterjet guss | 56 days | Mon 11/16/1 | Mon 2/1/16 |
| 12 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 13 | Structural test | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 5 | Final assembly of A | 6 days | Fri 2/5/16 | Fri 2/12/16 |
| 6 | Test ability to raise | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 7 | Verify stability | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 8 | Full system test | 22 days | Fri 2/12/16 | Mon 3/14/16 |
| 5 | **Recovery** | **109 days?** | **Fri 9/11/15** | **Wed 2/10/1** |
| 1 | **Design** | **46 days?** | **Fri 9/11/15** | **Fri 11/13/15** |
| 2 | Preliminary desig | 32 days | Fri 9/11/15 | Mon 10/26/1 |
| 3 | Sizing of parachu | 32 days? | Fri 9/11/15 | Mon 10/26/1 |




Page 8

**Figure 69: Project timeline page 8.**

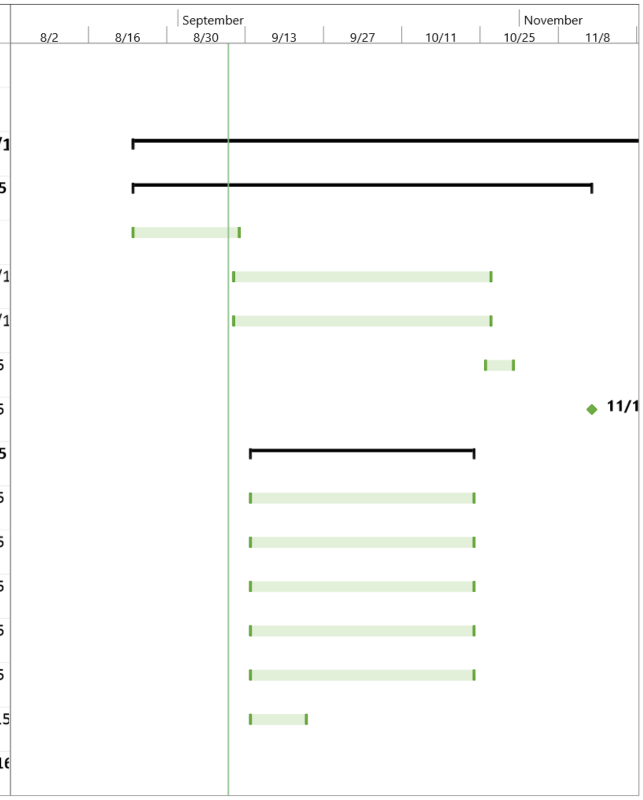
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 4 | Sizing of suspens | 32 days? | Fri 9/11/15 | Mon 10/26/1 |
| 5 | Sizing of harness | 32 days | Fri 9/11/15 | Mon 10/26/1 |
| 6 | Peer review desi | 32 days | Fri 9/11/15 | Mon 10/26/1 |
| 7 | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 8 | **Analysis** | **30 days** | **Mon 9/14/1** | **Fri 10/23/15** |
| 9 | Drift calculations | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | Kinetic energy ca | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | Shock force calcu | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 12 | **Fabrication/Assem** | **18 days** | **Mon 1/18/1** | **Wed 2/10/1** |
| 13 | Cut templates fo | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 14 | Cut and number | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 15 | Hem all gores | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 16 | Secure lines into | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 17 | Construct deploy | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 18 | Assemble reefing | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 19 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 20 | Ground test tend | 5 days | Mon 2/1/16 | Fri 2/5/16 |




Page 9

**Figure 70: Project timeline page 9.**

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 21 | Ground test para | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 22 | Verify proper de | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 6 | **Launch Vehicle** | **123 days?** | **Mon 8/24/1** | **Wed 2/10/1** |
| 1 | **Design** | **60 days?** | **Mon 8/24/1** | **Fri 11/13/15** |
| 2 | Preliminary desig | 15 days | Mon 8/24/15 | Fri 9/11/15 |
| 3 | Detailed design c | 32 days? | Fri 9/11/15 | Mon 10/26/1 |
| 4 | Detailed design c | 32 days? | Fri 9/11/15 | Mon 10/26/1 |
| 5 | Peer review desi | 5 days | Mon 10/26/1 | Fri 10/30/15 |
| 6 | Finalize design | 1 day | Fri 11/13/15 | Fri 11/13/15 |
| 7 | **Analysis** | **30 days** | **Mon 9/14/1** | **Fri 10/23/15** |
| 8 | Fluid analysis of | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 9 | Fin flutter analys | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 10 | Structural analys | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 11 | Structural analys | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 12 | OpenRocket Sim | 30 days | Mon 9/14/15 | Fri 10/23/15 |
| 13 | Structural analys | 8 days | Mon 9/14/15 | Wed 9/23/15 |
| 14 | **Fabrication/Assem** | **18 days** | **Mon 1/18/1** | **Wed 2/10/1** |




Page 10

**Figure 71: Project timeline page 10.**

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 15 | Measure fibergla | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 16 | Measure and cut | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 17 | Waterjet fins | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 18 | Waterjet centeri | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 19 | Construct fin slot | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 20 | Epoxy centering | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 21 | Review fitment o | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 22 | Laser cut bulkhea | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 23 | 3D print electron | 18 days | Mon 1/18/16 | Wed 2/10/16 |
| 24 | **Testing** | **5 days** | **Mon 2/1/16** | **Fri 2/5/16** |
| 25 | Test flight altime | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 26 | Ejection charge t | 5 days | Mon 2/1/16 | Fri 2/5/16 |
| 27 | Verify payload dc | 1 day | Mon 2/1/16 | Mon 2/1/16 |


Page 11

**Figure 72: Project timeline page 11.**

## 2) Comprehensive Budget

| Full Scale Vehicle Budget | | | |
|---|---|---|---|
| Description | Quantity | Per Unit Cost | Total Cost |
| 6" FG Von Karman Noseone | 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 (Alumium) (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 Nomac | 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** |
| Orbit 1" 24V Electronic Valve | 3 | $12.97 | $38.91 |
| 7/8" Tire Valve (pkg of 2) | 2 | $2.09 | $4.18 |
| 1 NPT Pipe Size Threading Bushing (Brass) | 3 | $7.70 | $23.10 |
| 2-1/2" Tube ID x 1/2 Male Pipe Size Barbed Fitting (Brass) | 3 | $4.66 | $13.98 |
| 2-1/2" Male x 1 NPT Female Bushing (PVC) | 3 | $2.80 | $8.40 |
| 7/32" to 5/8" Hose Clamp (pkg of 10) | 1 | $5.87 | $5.87 |
| 1/4" Wide x 14 Yards Teflon Tape | 1 | $5.19 | $5.19 |
| 2 Pipe Size x 4' Length (PVC) | 1 | $36.94 | $36.94 |
| 2 Pipe Size Cap (PVC) | 3 | $0.94 | $2.82 |
| Plastic Pipe Cement | 1 | $12.94 | $12.94 |
| 3/4 Male Adapter to Female Slip (PVC) | 6 | $0.30 | $1.80 |
| 3/4 Pipe End male x 1/2 Female Bushing (PVC) 3 | 3 | $0.36 | $1.08 |
| 3/4 Pipe Size x 5' Length (PVC) | 1 | $3.25 | $3.25 |
| 1/2 Pipe Size x 4' Length (PVC) | 1 | $9.08 | $9.08 |
| 2 Pipe End Male x 3/4 Female Slip Bushing (PVC) | 3 | $1.57 | $4.71 |
| 6mm, SPDT-NO Push Button Switch | 3 | $6.18 | $18.54 |
| 15" Length Red Nylon Cable Tie (pkg of 25) | 1 | $6.12 | $6.12 |
| 9V Battery (pkg of 12) | 1 | $14.36 | $14.36 |
| 9V Battery Snap, I-Style | 6 | $0.68 | $4.08 |
| 24 GA 25' Stranded Wire (Black) | 1 | $3.18 | $3.18 |
| 24 GA 25' Stranded Wire (Red) | 1 | $3.18 | $3.18 |
| Gnome Rocket Bulk Pack (pkg of 24) | 2 | $123.99 | $247.98 |
| 1/2A3-4T Engine Bulk Pack (pkg of 24) | 2 | $57.79 | $115.58 |
| Scotch Tape (pkg of 3) | 40 | $4.74 | $189.60 |
| BristleBot Kit | 20 | $19.99 | $399.80 |
| | | **Overall Cost** | **$1,174.67** |

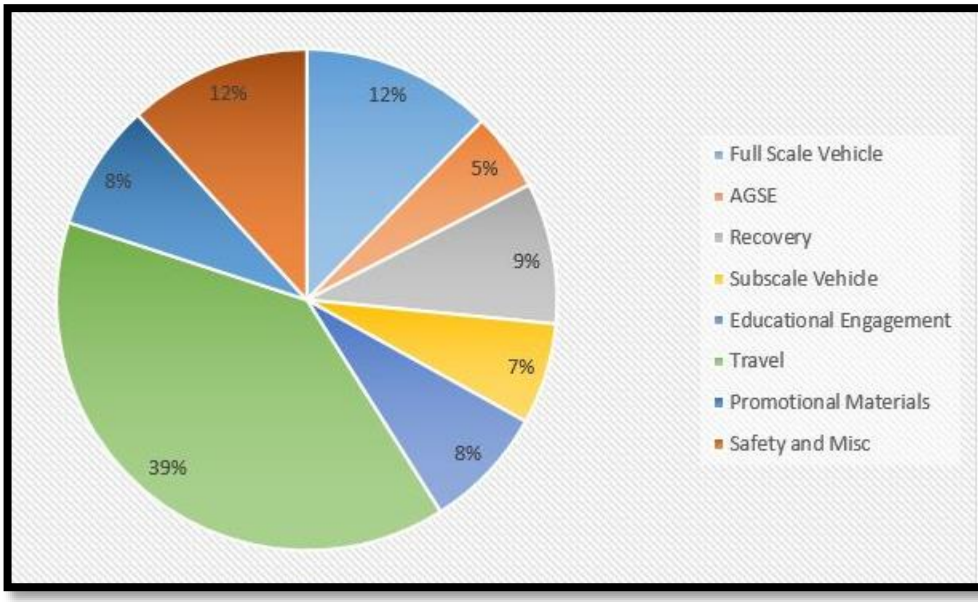
| Travel Expenses Budget | | | |
|---|---|---|---|
| **Description** | **Quantity** | **Per Unit Cost** | **Total Cost** |
| Hotel (Competition in Huntsville, AL) | N/A | N/A | $4,000.00 |
| Hotel (Testing at Thunderstruck in Ash Grove, IN) | N/A | N/A | $500.00 |
| Gas (Competition in Huntsville, AL) | 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 | 75 | $8.00 | $600.00 |
| Stickers | 750 | $0.15 | $112.50 |
| Miscellaneous Marketing | N/A | N/A | $500.00 |
| | | **Overall Cost** | **$1,212.50** |

| Safety and Misc Budget | | | |
|---|---|---|---|
| **Description** | **Quantity** | **Per Unit Cost** | **Total Cost** |
| 3M 20-Pack Sanding Respirators | 3 | $19.97 | $59.91 |
| Latex Disposable Gloves (100 Count) | 1 | $8.92 | $8.92 |
| Loctite Instant Mix 5 min. Epoxy | 20 | $4.70 | $94.00 |
| Rocket Poxy | 2 | $38.25 | $76.50 |
| Misc Hardware | 1 | $500.00 | $500.00 |
| Additional Parts Bank | 1 | $1,000.00 | $1,000.00 |
| | | **Overall Cost** | **$1,739.33** |

| Ground Station 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 | TBD | $0.00 |
| Igniter Installation Device Motor | 1 | TBD | $0.00 |
| | | **Overall Cost** | **$746.40** |

| Overall Tentative Budget | |
|---|---|
| **Budget** | **Total Cost** |
| Full Scale Vehicle | $1,822.49 |
| AGSE | $746.40 |
| Recovery | $1,346.88 |
| Subscale Vehicle | $962.30 |
| Educational Engagement | $1,174.67 |
| Travel | $5,750.00 |
| Promotional Materials | $1,212.50 |
| Safety and Misc | $1,739.33 |
| **Overall Cost** | **$14,754.57** |




## 3) Funding

***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 21.

| 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, 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. |

**Table 21: 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.

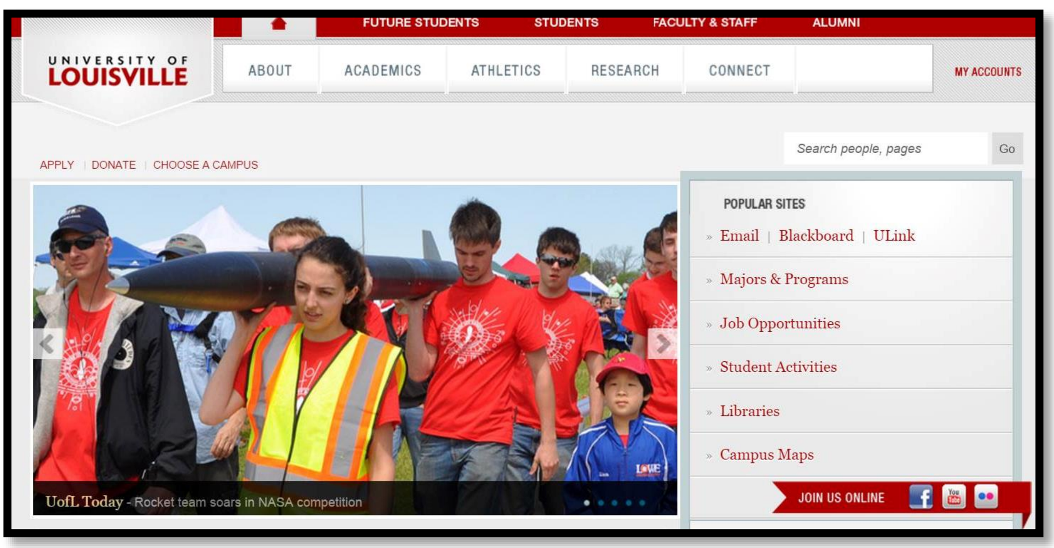



**Table 22: River City Rocketry on the front page of the University of Louisville website.**

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 23: 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 9. Conclusion

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

# Appendix I – Leadership Resumes

## Austin

**OBJECTIVE**
Professional Mechanical Engineering Position

**EDUCATION**
Masters of Engineering in Mechanical Engineering — *Expected Graduation Spring 2016*
B.S. Mechanical Engineering — *MEng GPA: 4.0*
*J.B. Speed School of Engineering UofL, Louisville, KY* — *BS Graduation GPA: 3.8*

**Technical Experience**
- SolidWorks **&** SolidWorks Simulation
- AutoCAD
- Additive Manufacturing
- Machining (Waterjet, Lathe, and Mill)
- Competitive Robotics
- High Powered Rocketry
- Engineering Measurements
- Microsoft Office, Access, SQL Server, & VBA
- Allen Bradley Automation Equipment
- PHP, HTML, CSS, C programming

**Applied Experience**
*NASA Student Launch - River City Rocketry:* Work with a team of fellow students to design, fabricate, test, and launch a high powered rocket. Served as a sub team lead for the autonomous ground support equipment team. The team finished the 2015 season ranked 2nd nationally and received awards for best presentation and documentation, best vehicle design, and the safety award.

*FIRST Robotics Team (Mentor)* – For three seasons have organized and taught CAD training courses for students to use during the building process. Worked with students to help facilitate the design process. Training program, including instructional videos, is still in place and is being facilitated by new students.

*First Robotics Team (Student)* – Worked to design, build, and program a robot for competition alongside industry professionals in in six weeks. Team Captain 2010-2011: managed schedules, the design process, and 10+ students.

**Employment**
Nucor Steel Gallatin – Ghent, KY — Summer 2015
*Utilities Engineering Co-op*
- Developed and retrofitted Human Machine Interfaces (HMI).
- Managed multiple retrofitting projects including determining material requirements, verifying received equipment, and other prep work.
- Assisted in troubleshooting day to day production sensitive issues.

Altec Industries – Elizabethtown, KY — Spring 2013, Fall 2013, Summer 2014
*Applications Engineering Co-op*
- Created detailed models, sales drawings) to convey customer specifications using SolidWorks.
- Lead the transition from 2D AutoCAD environment to SolidWorks environment for sales drawings.
- Conducted virtual customer product preview meetings using SolidWorks.
- Designed new mounting frame interface plates with goal of reducing variations between exiting parts.
- Design and implemented devices to aid production using SolidWorks.

Altec Industries – Elizabethtown, KY — Fall 2013
*Manufacturing Engineering Co-op*
- Designed fixtures to assist manufacturing with material handling.
- Conducted quality control testing and analysis to improve paint adhesion and durability.
- Developed and implemented database systems to increase efficiency.

**Honors**
- 4.0 GPA in ME Department
- UofL Dean's List
- 2010 Kentucky Governor Scholar (Bellarmine Campus)

*References furnished upon request*

# Emily

**EDUCATION**

**J.B. Speed School of Engineering, University of Louisville, Louisville, KY**
**B.S. Mechanical Engineering** — **May 2015**
GPA 3.899/4.0

**M.S. Mechanical Engineering** — **Expected May 2016**
GPA 4.0/4.0

**SKILLS/ COURSEWORK**

- Additive Manufacturing
- Composites
- Aircraft Structures
- Probability and Statistics
- Fundamentals of GD&T
- Machine Shop Experience
- Measurements & Lab
- Mechanics of Materials & Lab
- Creo
- SolidWorks
- ANSYS
- Fluids I/II
- Material Science

**APPLIED EXPERIENCE**

**River City Rocketry (NASA Student Launch Projects):**
*2012-2013 Season – Stability and Propulsion Team, Member*
- Developed and designed a reusable rocket with a scientific payload to launch exactly one mile above ground level.
- Wrote technical reports detailing all systems which were submitted, reviewed, and approved by a panel of NASA engineers at each milestone.

*Accomplishments:*
- 2nd place nationally
- Best Vehicle Design Award
- Best Educational Outreach Award

*2013-2014 Season – Mechanical Design Team, Safety Officer, Educational Lead*
- Designed, built, and tested an innovative rocket with a deployable rover.
- Performed hazard analysis and risk mitigation to ensure safety to personnel and success of the mission.
- Developed and taught three engaging STEM related classes a week to middle school students.

*Accomplishments:*
- 3rd place nationally
- Safety Award

*2014-2015 Season-Team Captain, Recovery Lead, Safety Officer, Educational Lead*
- Lead the team to design, build, test, and launch a rocket and integrated ground station with autonomous functionalities.
- Aligned the team to ensure technical deadlines and goals were met.
- Organized STEM outreach programming for one thousand students.

*Accomplishments:*
- 2nd place nationally
- Best Vehicle Design Award
- Project Review Award
- Safety Award

**EMPLOYMENT HISTORY**

**Raytheon Missile Systems, Tucson AZ** — **January 2013-May 2013**
*Mechanical Engineering Junior Co-op, Mechanical Subsystems Directorate*
- Redesigned components when problems arose in production.
- Developed test plan to verify redesigned components were acceptable.
- Collaborated with suppliers to ensure complete understanding of GD&T and to improve drawings.

**Raytheon Missile Systems, Tucson, AZ** — **August 2013-December 2013**
*Mechanical Engineering Senior Co-op, Mechanical Subsystems Directorate*
- Troubleshot designs while working on assembling first delivery product.
- Completed quality reports for assembly procedures.

- Modified models and drawings in Pro-E to present proposed improvements to Engineering Review Board and Change Control Board.

**Raytheon Missile Systems, Tucson, AZ** **June 2014-August 2014**
*Mechanical Engineering Senior Co-op, Mechanical Subsystems Directorate*

- Managed company priority project to mitigate torque tolerance risk.
- Supported critical tolerance and structural analyses.
- Gathered and organized information to update warhead specifications and technical data package.

**Raytheon Missile Systems, Tucson, AZ** **June 2015-August 2015**
*Mechanical Engineering Post-Grad Intern, Mechanical Subsystems Directorate*

- Managed design modifications to maintain production schedule.
- Efficiently implemented cost saving changes to product.
- Collaborated with suppliers to determine the most cost efficient solutions.

**HONORS**

- Raytheon: Team Achievement Award (2013)– First Delivery Team
- ASME Student Section Award (2013)
- Mechanical Engineering Department: Academic Achievement Award – Senior (2015) highest cumulative GPA of the graduating class.
- University of Louisville: Dean's Scholar (2011-2015)

UNIVERSITY OF LOUISVILLE.

J.B. SPEED SCHOOL OF ENGINEERING

# Kevin

**OBJECTIVE** First Mechanical Engineering co-op position **August 24 – December 18, 2015**

**EDUCATION**

**B.S. in Mechanical Engineering** Expected January 2017
*J.B. Speed School of Engineering, U of L, Louisville, KY* GPA 2.8 / 4.0
Date Transferred 1/2015 Hours Completed: 75

**Associate in Engineering Science** December 2014
*William Rainey Harper College, Palatine, IL* GPA 3.0/4.0

**SKILLS/ COURSEWORK**

- **AutoCAD**
- **Autodesk Inventor**
- Dynamics
- MIG Welder
- Microsoft Office
- **Solid Works**
- Statistics
- Thermodynamics

**APPLIED EXPERIENCE**

**NASA student launch project** – Nation-wide competition held by NASA requiring teams to design, construct, and launch high-powered rockets, scientific payloads, and ground stations by using the same criteria as NASA engineers:

- **River City Rocketry** (University of Louisville; 2014-2015): **Placed Second** overall out of thirty-five teams. Received additional awards for best vehicle design, project review, and safety.
- **Provectus Automata** (Harper College; 2012-2013): Placed **fourth** overall and runner-up for rookie of the year.

**Educational Outreach –** Taught fourth to sixth graders about aerodynamics by designing and fabricating a wind tunnel.

**Backyard Engineering –** Enhanced basic transportation vehicles by modifying an engine to fit on each vehicle.

- Adapting a chainsaw engine to friction drive the rear tire of a bicycle
- Customized a mini snowmobile by utilizing a bicycle frame, snow blower tank tread, and a snow blower five and a half horse power engine

**EMPLOYMENT HISTORY**

**DLZ (Architects, Engineers, Planners, Surveyors),** Chicago, IL
*Engineering Assistant* May – August 2013
- Collected and analyzed surveying data
- Data used to construct new layout for the north side of Lake Shore Drive walkway

**University of Louisville,** Louisville, KY
*Student Worker, Co-Op Office* January 2015 - Present
- Create, input, organize, and retrieve data stored in excel worksheets
- Ensure that student's co-op reports are complete
- Maintain overall statistics of confidential co-op reports

**Mariano's Fresh Market,** Palatine, IL
*Grocery Team Leader,* August 2012 – October 2014
- Maintained inventory by regularly updating stock
- Provided excellent customer service through transactions and answering inquiries
- Trusted as department lead to properly close the store
- Manual and power jack certified

**ACTIVITIES HONORS**

- **Team lead** on high mileage car project (High School)
- Three year competitor of battle bots (High School)

UNIVERSITY OF LOUISVILLE. J.B. SPEED SCHOOL OF ENGINEERING

**Zach**

**EDUCATION**

**B.S. in Mechanical Engineering** — Expected May 2016
*J.B. Speed School of Engineering, UofL, Louisville, KY*
Dates attended 8/2012 - Present — Hours Completed: 106

**Core 40 Academic Honors Diploma** — May 2012
*Floyd Central High School, Floyd Knobs, IN*

**SKILLS/ COURSEWORK**

- Statics
- AutoCAD
- Scratch rocket construction and design
- Python programming
- Fluid Mechanics/Dynamics
- Microsoft Office
- C Programming
- Solid Edge / SolidWorks
- Siemens NX
- AutoDesk Inventor /Project Falcon
- MatLab

**APPLIED EXPERIENCE**

**NASA USLI Team:** Autonomous Rocket Project– Worked as a sub team lead to design and create autonomous ground station, robotic arm, and high powered rocket with payload. Used standard shop mills, laser cutter, water jet, and 3D printer to fabricate parts. Last year the team placed third in a national competition sponsored and judged by NASA and ATK.

**EMPLOYMENT HISTORY**

**Samtec Inc.**, New Albany, IN — May 2015 – Present
*Discrete Wire Product/Tooling Engineer*
- Design and modify tooling for product assembly
- Analyze product to mitigate tolerance errors
- Design and develop new electronic connectors

**Rockwell Collins**, Cedar Rapids, IA — January 2014 – May 2014
*Platforms System Engineer Co-op* — August 2014 – December 2014
- Perform and edit functional tests for FMS(Flight Management Systems)
- Troubleshoot functional problems during functional Qualification Testing
- Development of Aerial Refueling camera system
- Develop and fabricate test equipment

**University of Louisville**, Louisville, KY
*Undergraduate Teaching Assistant* — August 2013 – December 2013
- Assist and instruct students during time spent in the lab
- Supplemental Instruction leader
- Tutoring of students upon request of professor

**Boy Scouts of America**, Charlestown, IN
*Webelos Resident Camp Staff* — June 2007 – August 2012
- Fishing Area Director
- Scout Skills Lead Program Instructor
- Shooting Sports Assistant Director

**ACTIVITIES & HONORS**

- University Honors Scholar
- Eagle Scout project of the year
- Trustees Scholar
- Level 2 High powered rocketry certification
- Tripoli Rocketry Association Member

**REFERENCES** Furnished upon request

# Appendix II – Safety Risk Assessments

| Lab and Machine Shop Risk Assessment | | | | | | |
|---|---|---|---|---|---|---|
| **Hazard** | **Cause/ Mechanism** | **Outcome** | **Severity Value** | **Probability Value** | **Risk Level** | **Mitigation** |
| Using power tools and hand tools such as blades, saws, drills, etc. | 1. Improper training on power tools and other lab equipment. | 1a. Mild to severe cuts or burns to personnel.<br>1b. Damage to rocket or components of the rocket.<br>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.<br>1. Safety glasses must be worn at all times.<br>1. Sweep or vacuum up shavings to avoid cuts from debris. |
| Sanding or grinding materials. | 1. Improper use of PPE.<br>2. Improper training on the use of a Dremel tool. | 1a. Mild to severe rash.<br>1b. Irritated eyes, nose or throat with the potential to aggravate asthma.<br>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.<br>1b. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required.<br>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 due to inhalation of toxic fumes, or chemical spills | 1. Chemical splash.<br>2. Chemical fumes. | 1. Mild to severe burns on skin or eyes.<br>2. Lung damage or asthma aggravation due to inhalation of fumes, | 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.<br>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.<br>1. Safety goggles are to be worn at all times when handling chemicals.<br>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<br>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.<br>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.<br>2. Leaving soldering iron too long on plastic could cause plastic to melt producing toxic fumes. | 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.<br>2. Team members will be informed of appropriate soldering techniques, avoiding contact of the soldering iron to plastic materials for extended periods of time. |
| 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.<br>2. Respiratory irritation. | 3 | 4 | Low | 1. Nitrile gloves and safety glasses are to be worn when applying grease.<br>2. When applying grease, it should be done in a well ventilated area to avoid inhaling fumes. |
| High voltage shock. | Improper use of welding equipment. | Death or severe injury. | 1 | 5 | Low | All team members are required to be trained on the equipment prior to use. Any time personnel is welding, there must be at least two people present. |
| Break bit on mill. | Spindle speed too high. | Injury to personnel and damage to equipment and/or part. | 2 | 5 | Low | All team members are required to be trained on the mill prior to use. If personnel is uncertain about the proper settings, they are to consult an experienced member prior to operation. |
| Metal shards. | Using equipment to machine metal parts. | Metal splinters in skin or eyes. | 2 | 5 | Low | Team members must wear long sleeves and safety glasses whenever working with metal parts. |

**Table 24: Lab and machine shop risk assessment.**

| AGSE -Launch Pad Functionality Risk Assessment | | | | | | |
|---|---|---|---|---|---|---|
| **Hazard** | **Cause/ Mechanism** | **Outcome** | **Severity Value** | **Probability Value** | **Risk Level** | **Mitigation** |
| Unstable launch platform | Un-level ground or improperly staked launch tower. | If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable. | 1 | 3 | Moderate | Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Ensure that the launch pad is stable and secure prior to launch. Outriggers will be added to increase the footprint of the launch platform providing increased stability. |
| Unleveled launch platform | Un-level ground or improperly leveled launch tower. | The launch tower could tip over during launch, making the flight of the rocket unpredictable. | 1 | 4 | Moderate | The launch pad should always be placed on a level surface. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Outriggers will be implemented to allow for fine adjustments on un-level terrain. |
| Rocket gets caught in launch tower or experiences high friction forces | Misalignment of launch tower joints | Rocket may not exit the launch tower with a high | 2 | 5 | Low | During setup, the launch tower will be inspected for a good fit to the rocket. A spare piece of airframe is taken out and 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, graphite is applied to each beam in order to reduce any frictional forces on the rocket. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sharp edges on the launch pad | Manufacturing processes. | Minor cuts or scrapes to personnel working with, around, and transporting the launch tower. | 4 | 3 | Low | Sharp edges of the launch pad should be filed down and de-burred. |
| Brush fire caused by rocket during launch | Dry launching conditions. | Small brush fire. | 4 | 3 | Low | Wait until the range safety officer has cleared personnel to approach the launch pad and extinguish any fires that have been started. The launch tower also has a blast deflector to prevent brush fires. |
| Loss of power during vehicle erection | Faulty circuit | Vehicle crashes back to horizontal position. | 1 | 4 | Moderate | The power screw geometry combined with the gearboxes resistance to back drive will prevent the tower from moving. To lower the vehicle the motors that drive the system must be run in reverse. |
| Lead screw shears during actuation | 1. Undersized screw selection.<br>2. Material failure. | Platform crashes back to horizontal position. | 1 | 4 | Moderate | All actuation devices will be analyzed and have a factor of safety of at least 2. |

**Table 25: AGSE - Launch pad functionality 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.<br>2. Delayed ignition.<br>3. Faulty e-match.<br>4. Disconnected e-match. | 1,3,4. Rocket will not launch.<br>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.<br>2. Motor impulse is too low.<br>3. High friction coefficient between rocket and launch tower. | 1,2. Unstable launch. | 1 | 5 | Low | Too low of a velocity will result in an unstable launch. Simulations are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in graphite prior to each launch in order to minimize friction. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fins shear during flight. | Insufficient adhesion during installation resulting in a failure in the epoxy. | Unstable rocket, causing the flight path to become unpredictable. | 1 | 5 | Low | Confirm all personnel are alert and at a distance allowed by the Minimum Distance Table as established by NAR. Examine external epoxy beads for cracks prior to launch. |
| Airframe buckles during flight. | Airframe encounters stresses higher than the material can support. | Rocket will become unstable and unsafe during flight. | 1 | 5 | Low | Through prediction models, appropriate material selection, and a secure factor of safety, this failure mode can be nearly eliminated. |
| Internal bulkheads fail during flight. | Forces encountered are greater than the bulkheads can support. | 1. Internal components supported by the bulkheads will no longer be secure.<br>2. Parachutes attached to bulkheads will be left ineffective. | 1 | 5 | Low | The bulkheads will be designed to withstand the force from the motor firing with an acceptable factor of safety.<br>1. Electrical components could be damaged and will not operate as intended during flight.<br>2. A catastrophic failure is likely. A portion of the rocket or the fairing would become ballistic. |

**Table 26: 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.<br>2. Coupling has too tight of fit. | 1,2. Rocket follows ballistic path, becoming unsafe. | 1 | 5 | Low | 1. The separation section of the rocket will be designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system.<br>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. 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.<br>2. Parachute lines become tangled. | 1,2. Rocket follows ballistic path, becoming unsafe. | 1 | 4 | Moderate | Deployment bags will be specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Should the rocket become ballistic, all personnel at the launch field will be notified immediately. |
| Rocket descends too quickly | Parachute is improperly sized. | The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged. | 2 | 5 | Low | The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design. |
| Rocket descends too slowly | Parachute is improperly sized. | The rocket will drift farther than | 3 | 3 | Low | The parachutes have each been carefully selected and designed to |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | intended, potentially facing damaging environmental obstacles. | | | | safely recover its particular section of the rocket. Should this be too large, the parachute will have to be resized. |
| Parachute has a tear or ripped seam | Parachute is less effective or completely ineffective depending on the severity of the damage. | The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged. | 2 | 5 | Low | Through careful inspection prior to packing each parachute, this failure mode should be eliminated. |
| 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 | Through careful packing and the appropriate use of Nomax material, this failure mode is unlikely. |
| Recovery system separates from the rocket | 1. Bulkhead becomes dislodged.<br>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. |

**Table 27: Recovery risk assessment.**

| Vehicle Assembly 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.<br>2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket. | 1 | 5 | Low | The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket. |
| Black powder charges go off prematurely | 1. Altimeters send a false reading.<br>2. Open flame sets off charge. | 1,2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket. | 1 | 5 | Low | All electronics will be kept in their OFF state for as long as possible during preparation. Open flames and other heat sources will be prohibited in the area. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Seized nut or bolt due to galling or cross threading | Repetitive uninstalling and reinstalling of parts made of materials prone to galling. | Component becomes unusable, potentially ruining expensive, custom machined parts. Amount of rework depends on the location and component that seized. | 2 | 4 | Low | Through proper choice in materials, appropriate pre-load, and proper installation, the risk of galling can be eliminated. |

**Table 28: 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.<br>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.<br>2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage. |

| | | | | | | |
|---|---|---|---|---|---|---|
| High winds | N/A | 1. Have to launch at high angle, reducing altitude achieved.<br>2. Increased drifting.<br>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.<br>2. Irretrievable rocket components. | 1 | 4 | Moderate | Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius. |
| Swampy ground | N/A | Irretrievable rocket components. | 1 | 4 | Moderate | With the potential of the salt flats being extremely soft, as well as local launch sites, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket. |
| Ponds, creeks, and other bodies of water. | N/A | 1. Loss of rocket components.<br>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.<br>2. Shrinking of fiberglass. | 1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events.<br>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.<br>2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch. |
| Humidity | N/A | Motors or black powder charges become moist and don't ignite. | 1 | 5 | Low | Motors and black powder should be stored in a location free from moisture to remove |
| UV exposure | Rocket left exposed to sun for long periods of time. | Possibly weakening materials or adhesives. | 4 | 4 | Low | Rocket should not be exposed to sun for long periods of time. If the rocket must be worked on for long periods of time, shelter should be sought. |

**Table 29: 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 | Toxic air emissions. | 4 | 1 | Moderate | Productions methods for fiberglass produces toxic air pollutants, particularly styrene, |

| | | | | | | |
|---|---|---|---|---|---|---|
| | design, fiberglass is manufactured by a second party. | | | | | 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.<br>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<br>2. Ground contamination | 4 | 1 | Low | The amount of vapor from the soldering process is at such a low quantities that no action will be needed. |
| Use of lead acid battery leakage. | Old or damaged housing to battery | 1. Acid will leak onto the ground and get into the water system.<br>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.<br>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 | 3 | 5 | Low | 1. All plastic material will be disposed of in proper waste receptacles. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | ingested by an animal.<br>2. Plastic could find its way down a drain and into the water system. | | | | |
| 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 30: Hazards to environment risk assessment.**