NASA Student Launch

2017-2018 Proposal

September 20, 2017

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1 General Information

1.1 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:	River City Rocketry 2017-2018

1.2 Team Officials

Advisor Name: Dr. Younsheng 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 21 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: Maria Exeler
Contact Information: msexel01@louisville.edu **or** (859) 912-3547

Maria is currently a senior mechanical engineering student at the University of Louisville's J.B. Speed School of Engineering. This is Maria's second year in NSL and her first year as co-captain of River City Rocketry. After contributing to last year's successful season, Maria is looking forward towards improving on the team's safety while continuing to lead the team through new challenges. Maria plans to bring her experiences from working at GE Aviation to her position as co-captain and as safety officer. Throughout last year Maria gained valuable knowledge in fabrication, integration, and problem solving, and she hopes to both pass this knowledge down and employ these skills at GE Aviation following graduation.

Team Captain/Outreach Lead
Name: Gabriel Collins
Contact Information: gdcoll01@gmail.com **or** (502) 457-8829

Gabriel is currently a senior mechanical engineering student at the University of Louisville's J.B. Speed School of Engineering. This is Gabriel's third year in NSL and his first year as co-captain of River City Rocketry. After contributing to last year's success, Gabriel is looking forward towards improving on the team's integration while continuing to take the team to new heights. Gabriel plans to bring his experiences from working at PIA to his position as co-captain and Outreach Lead. Throughout this experience Gabriel has gained valuable knowledge in design, communication, and project optimization, and he hopes to both pass this knowledge down along with employing these skills in the aerospace industry following graduation.

1.3 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.

1.4 Team Members and Organization

The University of Louisville's team this year will consist of approximately 22 students coming from a variety of backgrounds. 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 to support the team, specifically with the intent of enhancing our educational outreach.

This project has been broken up by technical design and the following sub-teams are as follows:

- *Launch Vehicle* – responsible for design, testing, 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. Main responsibility is to ensure a safe landing for the launch vehicle while maintaining the kinetic energy requirement.
- *Payload* – responsible for the development, design, construction, and integration of the payload into the launch vehicle.
- *Variable Drag System* – responsible for the electrical design, prototyping, and manufacturing of all electrical vehicle systems. This includes the continued refinement of our variable drag system (VDS).

Each of these sub-teams has an assigned lead position which has been assigned based on that member's experience, knowledge in the field, and leadership abilities. We are confident that the personnel selected to uphold these leadership positions have the technical knowledge and dedication to have their sub-team produce an innovative system that will be showcased at the end of the season.

Other leadership roles that must be upheld are outreach lead and safety officer which have also been selected based on their knowledge of the subject. These members also have experience and the skills required to successfully execute the required tasks.

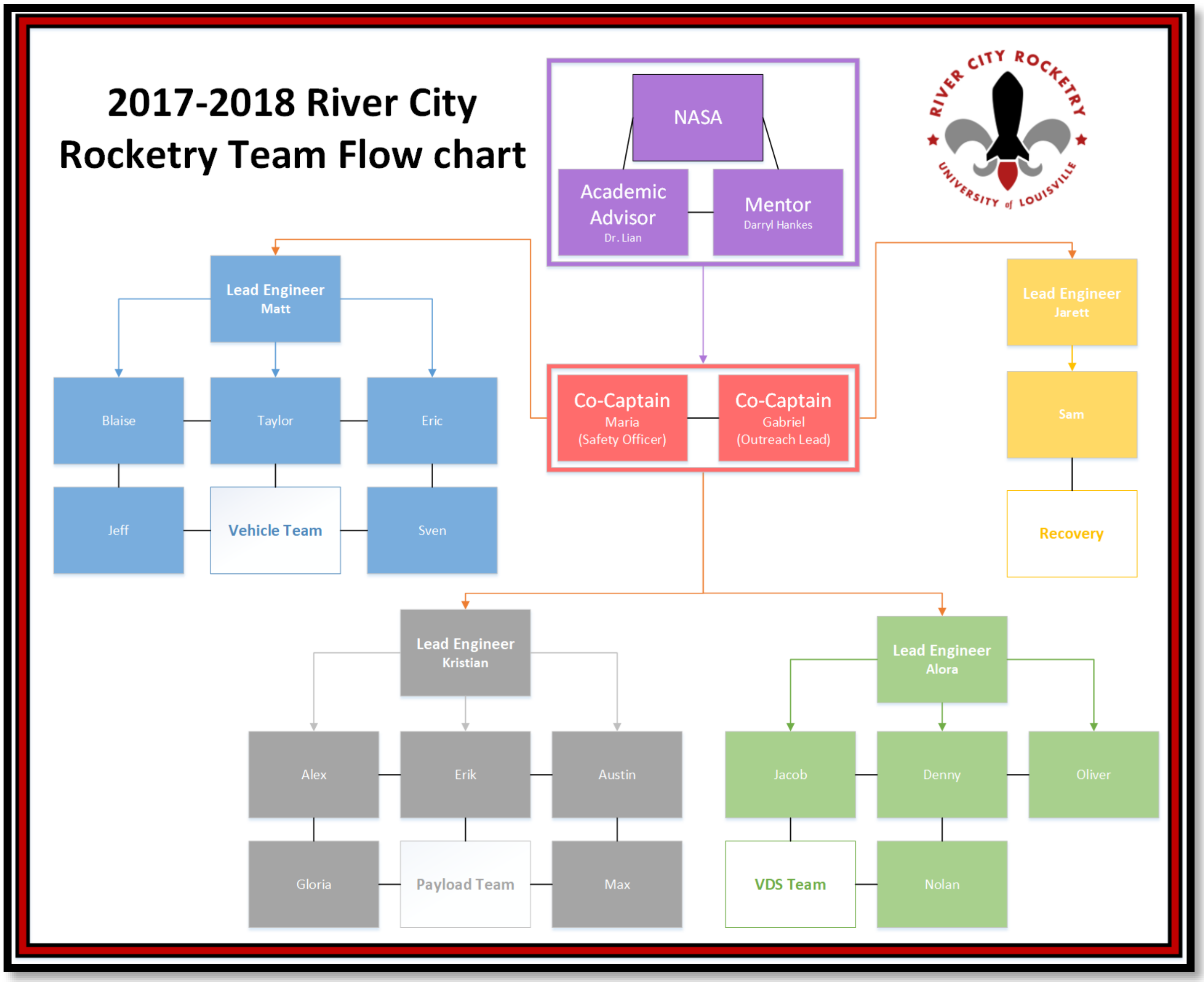


Figure 1: 2017-2018 NASA Student Launch team structure as of project proposal.

2 Facilities and Equipment

2.1 Facilities

2.1.1 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 this facility which is shown in Figure 2. This facility is available 24 hours a day, 7 days a week. Major equipment items include:

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

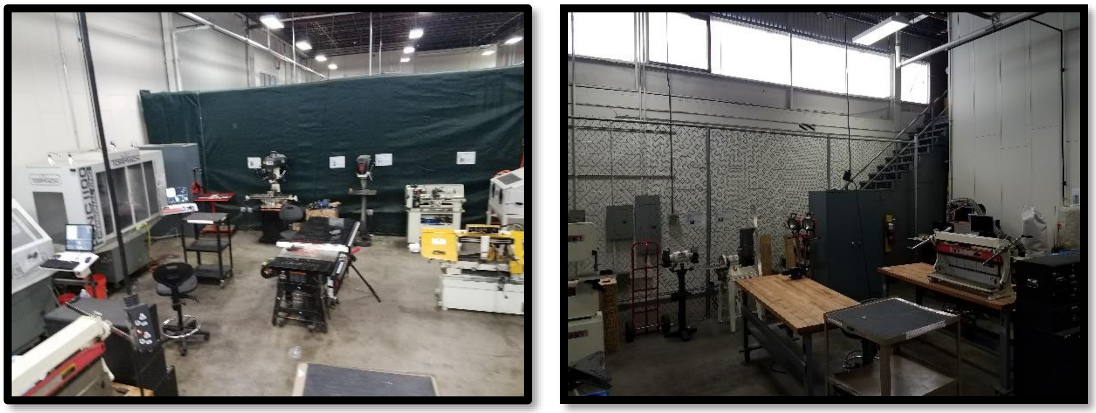


Figure 2: Engineering Garage machining equipment.

Included in the Engineering Garage the university has provided River City Rocketry with a storage and work space, shown in Figure 3. This part of the Engineering Garage is open 24 hours a day, 7 days a week. The team stores tools, hardware, and materials in this area.

Figure 3: River City Rocketry cage.

2.1.2 FirstBuild

Formed by GE Appliances, Local Motors, and the University of Louisville, FirstBuild is a microfactory and a place for builders, makers, and hackers to come together to bring their ideas to life. The building is shown in Figure 4. 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.

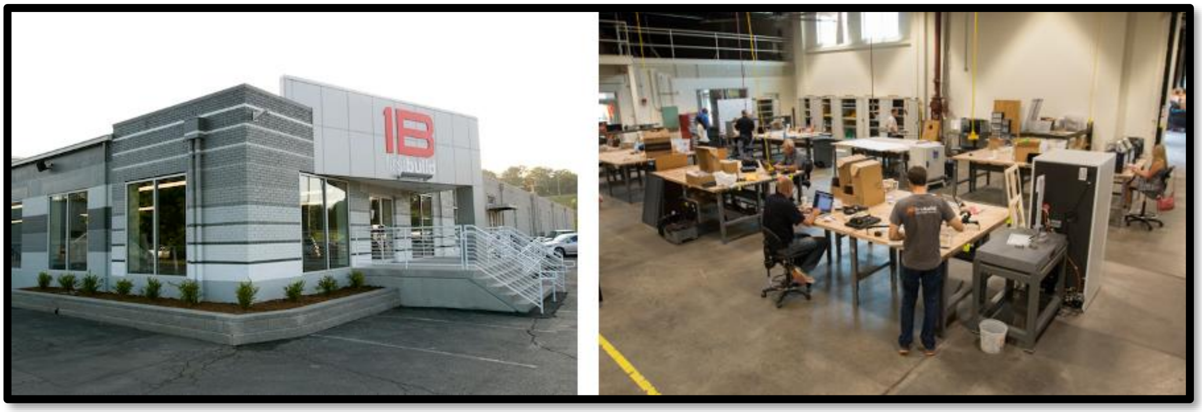


Figure 4: Part of FirstBuild's open workspace shown here (right).

With the proper training, each member of River City Rocketry is allowed access to the machine shop area. Major equipment items include:

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

- Vertical Band Saw
- 2 Metal Lathes
- Miter Saw
- Drill Press
- Surface Grinders
- 4 MakerBot 3D Printers
- Laser Printer
- PrinterPrinter
- 50 Ton Press
- Various Hand Tools
- Drills
- Soldering Equipment
- Air Compressor
- Objet 3D Printer
- Injection molding
- MIG/TIG welders

2.1.3 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.

2.1.4 University of Louisville Sackett Hall, Machine Shop

A staple in River City Rocketry's manufacturing resources is a Machine Shop provided by the University of Louisville. Located in Sackett Hall, this work area is shared with SAE Baja and Formula 1 teams. The University provides 24 hour access to the work space. Sackett serves as a second work place if the Engineering Garage is inaccessible with some machines shown in Figure 5 and Figure 6.

Figure 5: HAAS CNC Mill.

Figure 6: Chevrolets Manual Mill

The newly renovated, 1600 square foot machine shop provides access to the following machinery and tools:

- HAAS CNC Mill
- SHARI Manual Lathe
- Bridgeport Vertical Mill
- MakerBot 3D Extruder Printer
- Chevalier Vertical Mill
- Vertical Bandsaw
- 2x Horizontal Bandsaw
- 2x Drill Press

- Pneumatic Tool System
- Hydraulic Press
- Bench Grinder
- Belt Sander

2.1.5 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 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.

2.2 Supporting Airfields

The surrounding NAR and TRA chapters have given permission to River City Rocketry team to utilize their airfields. The team will be utilizing multiple fields throughout the season. The local chapters also have monthly launches at their fields with FAA clearance to fly at or above Level 2 altitudes. In the Table 1 are listed the fields the team is utilizing and the status of the team.

Field Location	Status	Team Objective
Elizabethtown, Kentucky	1) Pending on waiver approval up to 7,000 ft. 2) Less than an hour of travel 3) Moderate field size	1) Ideal field for test flights (possible main launch field) 2) Ideal for travel 3) Ideal for 0-20mph
Bowling Green, Kentucky	1) Pending on waiver approval up to 6,000 ft. 2) Less than two hours of travel 3) Moderate field size	1) Ideal field for test flights (possible main/backup launch field) 2) Moderate for travel 3) Ideal for 0-20mph
Manchester, Tennessee	1) Operational to 10,000 ft. 2) Only available part of the fall and spring semesters 3) Over 3 hours away 4) Large field size	1) Ideal field for test flights 2) Moderately inconvenient due to travel 3) Ideal for 0-20mph

Memphis, Tennessee	1) Operational to 5,000 ft. 2) Available almost every weekend 3) Over 5 hours of travel 4) Small field size	1) To utilize this field as a backup field 2) Not ideal for launches due to travel 3) Ideal for 7mph winds or lower

Table 1: Supporting airfields and team criteria.

2.3 Computer Software

2.3.1 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.

2.3.2 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 2016 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

2.3.3 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.

2.4 Website Compliance

The team website is http://www.rivercityrocketry.com/. 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.
- Showcase a project overview of the intended competition launch vehicle
- 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.
- A responsive and interactive layout to serve devices of various size and resolution

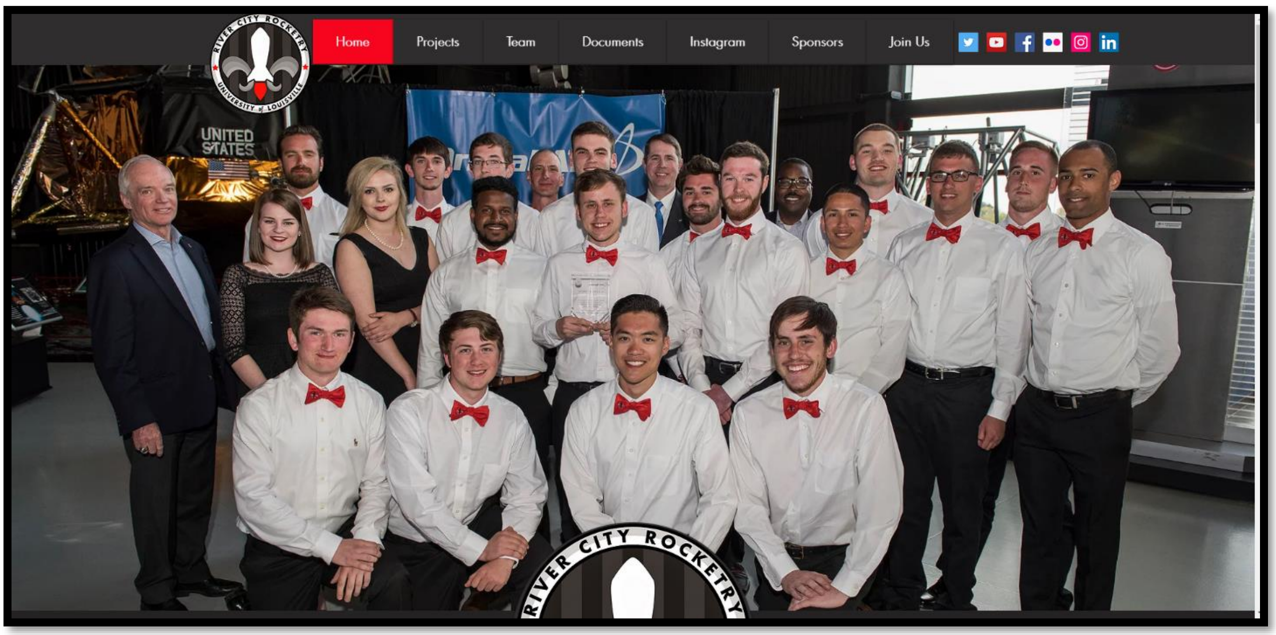


Figure 7: Website front page on www.riverctyrocketry.com/home/.

The website displayed in Figure 7 will be hosted on Wix servers that we gained access to from an online access portal. This allows the website to be more collaborative and engaging by allowing the team to more easily post updates.

3 Safety

3.1 Safety Plan

Maria Exeler is the safety officer for River City Rocketry during the 2017-2018 season. As safety officer, she is responsible for ensuring the overall safety of the team and public along with ensuring the team's compliance with all local and federal laws and regulations. These responsibilities include the following:

- Provide the team with a safety manual, which includes hazards, safety plans and procedures, PPE requirements, MSDS sheets, machine operation manuals, FAA laws, NAR and TRA regulations.
- Enforce the proper use of Personal Protective Equipment (PPE) during construction, ground tests, and test flights of the rocket.
- Verify that all team members understand, sign, and comply with the team safety manual regulations.
- Develop and inform the team of the safety plan for the various environments, materials and tests that will occur during rocket construction.
- Actively oversee the design, construction, and testing of the rocket to identify and quickly mitigate possible safety hazards or violations that may arise.
- Develop a risk matrix that determines the risk level of each hazard the team may encounter based on the severity of an occurrence and the probability that an occurrence may happen.
- Provide both digital and physical copies of all MSDS sheets and operator manuals to ensure ease of access at all times.
- Provide a comprehensive plan for proper purchasing, storing, transporting, and use of all energetic devices.
- Ensure team compliance with all local, state and federal laws.
- Ensure adherence to all NAR and TRA regulations.
- Ensure the safety of all educational outreach participants, teach the importance of safety, and provide proper PPE when necessary.

Maria will update the team safety manual that each member must review and sign, agreeing to comply with the rules and regulations. The safety manual includes hazards, proper safety plans and procedures, PPE requirements, MSDS sheets, FAA laws, NAR, and TRA regulations. The safety manual will be a floating document that will continually be reviewed and updated throughout the season. Maria is responsible for making sure each member has read and understood the safety manual and its updates. She will enforce all of the statements in the safety manual. The updated safety manual will be posted on the website to be accessible to all team members.

3.1.1 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 value through the use of a risk assessment matrix, found in Table 4 by evaluating the severity of the hazard and the probability that the hazard will occur. A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. 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. These criteria are outlined below in Table 2.

Severity		
Description	**Value**	**Criteria**
Catastrophic	1	Could result in death, significant irreversible environmental effects, complete mission failure, or monetary loss of $5k or more.
Critical	2	Could result in severe injuries, significant but reversible environmental effects, partial mission failure, or monetary loss of $500 or more but less than $5k.
Marginal	3	Could result in minor injuries, moderate environmental effects, complete failure of non-mission critical system, monetary loss of $100 or more but less than $500.
Negligible	4	Could result in insignificant injuries, minor environmental effects, partial failure of non-mission critical system, monetary loss of less than $100.

Table 2: Severity value criteria.

A probability value between 1 and 5 has been assigned to each identified 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 with the following conditions considered:

- 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 safety manual.
- Personal Protective Equipment (PPE) is used properly as indicated by the safety lab manual and MSDS.
- All procedures were correctly followed during the construction of the rocket, testing, pre-launch preparations, and during the launch.
- All components were thoroughly inspected for damage and fatigue prior to any test or launch.

The criteria for the selection of the probability value is outlined below Table 3.

Probability		
Description	**Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance that the mishap will occur.

Likely	2	Between 50% and 90% chance that the mishap will occur.
Moderate	3	Between 25% and 50% chance that the mishap will occur.
Unlikely	4	Between 1% and 25% chance that the mishap will occur.
Improbable	5	Less than a 1% chance that mishap will occur.

Table 3: Probability value criteria.

Through the combination of the severity level and the probability level, an appropriate risk level has been assigned using the risk assessment matrix found in Table 4. The matrix identifies each combination of severity and probability values as wither 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 as a low risk level will be readdressed through redesign, additional safety regulations, or other measures as required. Risk levels may also be reduced through verification systems.

Risk Assessment Matrix				
Probability Level	**Severity Level**			
	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)	4- Moderate	6- Low	7- Low	8- Low
Improbable (5)	6- Low	7- Low	8- Low	9- Low

Table 4: Risk Assessment Matrix.

Preliminary risk assessments have been completed for possible hazards that have been identified at this stage in the design. Identifying the hazards now brings attention to the components as failure mechanisms. As the design advances, the team will design surrounding components with these possible features in mind. The team will work to mitigate the hazards throughout the design phase. The identified hazards can be found in the hazard matrices located in the appendix.

Some identified risks are 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

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus labs. The hazards assessed in Table 30 are risks present from working with machinery, tools, and chemicals in the lab.

Stability and Propulsion Risk Assessment

The hazards outlined in Table 31 are risks associated with stability and propulsion. The team plans to have 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 32 are risks associated with the recovery. Since there are two recovery systems onboard, many of the failure modes and results will apply to all the systems but will be stated only once for conciseness.

Vehicle Assembly Risk Assessment

The hazards outlined in Table 33 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 34 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 35 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 will 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 maintain organization and prepares the team for a quick and efficient launch preparation on launch day. Each subsystem checklist must be 100% complete and 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.

3.2 NAR/TRA Procedures

3.2.1 NAR Safety Code

Table 5 describes each component of the High Power Safety Code, as provided by NAR, and how the team will comply with each component. This table is included in the team safety manual that all team members are required to review and acknowledge compliance.

NAR Code	Team 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.	Motor certified team members or Darryl, the team mentor, are permitted to pack or 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 Vehicle and Payload sub-teams will select appropriate materials for the rocket while considering structure and weight.
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.	The motors will be purchased from Chris' Rocket Supplies and will be stored and handled only by certified members. The entire team will understand the motor safety portion of the safety manual.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch	All launches will be conducted at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues. There will be arming switches for the altimeters that will inhibit premature activation of firing circuits that will not be armed before the rocket is on the launch pad. These arming switches may include screw switches, key switches, or pull pins.

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 battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The safety officer will remind the team of this rule prior to the 5-second countdown. The safety captain will communicate any precautions given by the Range Safety Officer the day of the launch.
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 1127.7.	The safety officer will sound an air horn prior to the 5-second countdown to ensure spectator awareness. The team will comply with this rule and any other rules given by the Range Safety Officer the day of the launch.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	The team will comply with this rule by launching out of the same rails provided by NAR at competition.

8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9,208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	The team will comply to this rule when designing the rocket and selecting an appropriate motor.
9. **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.	Wind gauge and weather assessment will be conducted prior to launch. Adequate FAA Waivers and notice will be in place before the launch occurs. The team will comply to any determination made by the Range Safety Officer on the day of the launch.
10. **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 1,500 feet, whichever is greater, or 1,000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1,500 grams, and a maximum expected altitude of less than 610 meters(2,000 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.
11. **Launcher Location.** My launcher will be 1,500 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.
12. **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	The Recovery team will be responsible for designing, constructing, and testing a safe recovery system for the rocket. A clear recovery checklist will be followed on the launch day to ensure that all critical steps in

will use only flame-resistant or fireproof recovery system wadding in my rocket.	preparing and packing the recovery components are completed.
13. **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. If necessary, professionals will be contacted for rocket retrieval.

Table 5: NAR High Power Rocket Safety Code Compliance.

3.3 Team Safety

A team safety meaning will be held prior to the construction, testing, or launch of the rocket to ensure that every team member is fully aware of all team 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, the safety captain will ensure that team members are up to date and compliant with any changes in 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
- Las specific rules

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

Prior to each launch, a briefing will be held to review potential hazards and accident avoidance strategies. Only team members that are present for the briefing will be allowed to attend the launch. In order to prevent an accident, thorough safety checklists will be created for each subsystem, the overall assembly, and "at the launch pad" and reviewed on launch day. Once all subsystem checklists are completed, a final checklist must be completed and then approved by the safety officer and captains. The safety officer has the right to call off a launch at any time if anything is determined to be unsafe or at a high risk level.

3.4 Local/State/Federal Law Compliances

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.

3.5 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.

3.6 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.

4 Technical Design: Variable Drag System

At the beginning of the 2016-2017 competition season, River City Rocketry developed and implemented a target detection system which we called the "Variable Drag System" (VDS). In previous years, a ballast system was utilized, however the uncertainty and lack of precision in such a system was not optimal for River City Rocketry's systematic design, leading to the development of the VDS. This system, through extensive testing, has proven to have a precision of ±31 ft. (9.4 m.) from the target altitude. The system is shown below in Figure 8.

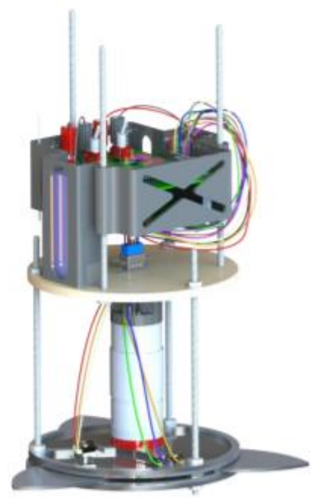


Figure 8: Variable Drag System.

The VDS alters the drag force of the rocket through dynamic actuation of three blades from the body of the vehicle at the heel of the burn phase. It does this by utilizing software which allows the system to calculate the trajectory of the rocket throughout the coast phase in order to account for in-flight variable conditions, and adjust the drag force accordingly with the blades. Each blade is able to increase the area of the vehicle by a factor of 1.28, and increase the coefficient of drag by an estimated factor of 1.35.

Design Overview

Through the course of the 2016-2017 competition season, River City Rocketry was able to optimize the VDS for peak performance. The electrical hardware consists of two printed circuit boards, which utilize one shared Teensy 3.6 microcontroller, the data acquisition system (DAQ) is made up by a BMP280 barometric pressure and altitude sensor, a BNO055 nine degrees of freedom (9DOF) velocity/acceleration vector sensor, a BTN7960 motor driver circuit, as well as DC motor encoder and two limit switches. The software consists of a program written in C/C++ which controls the sensors data acquisition and prediction to motor control, to the physical actuation of the drag blades, as shown in Figure 9. The mechanical and electrical systems will be described in the forthcoming sections.

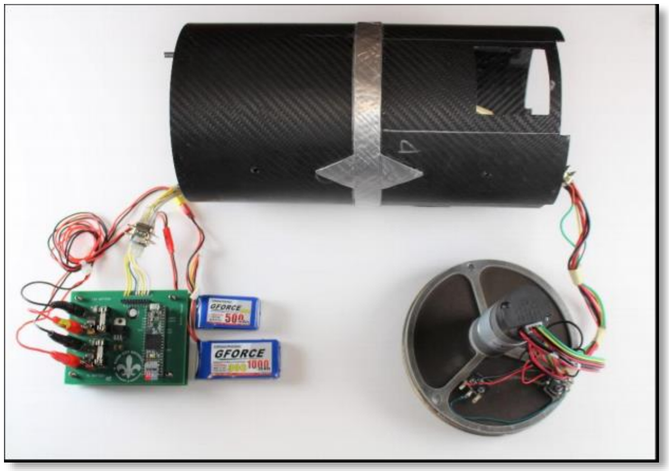


Figure 9: Exploded view of VDS software.

4.1 Control Theory

The vital function of the VDS is its ability to autonomously determine its variable actuation, however this poses a unique challenge to the software architect to employ a decision-making software. This autonomous software is what determines the rate and timing of the actuation of the drag blades throughout the flight – it does this by continually comparing its real time vertical velocity to a predetermined ideal flight at and correcting for deviations (The set point path).

The control theory of the VDS can be divided in to three categories: control scheme, system modelling, and experimental verification.

4.1.1 Applicable equations

Through developing the control scheme of the VDS, River City Rocketry derived several vital equations in order to calculate and model its behavior. These VDS applicable model equations are derived from the coast deceleration equation

$$\boldsymbol{a = -g - cv^2} \tag{1}$$

where *v* represents the vertical component of velocity, and the constant *c* represents the vehicle's unique drag characteristics. The unique drag characteristic is calculated using

$$\boldsymbol{c = \frac{C_d \rho A}{2m}} \tag{2}$$

where A is the cross-sectional area of the vehicle, C_d is the coefficient of drag of the vehicle, and m is the mass of the vehicle after burn. The density of air, ρ, is taken to be a constant 1.225 [kg/m^3] despite that it changes with altitude. These changes were taken to be negligible and ignored for computational efficiency. Other forms can be derived from the coast phase deceleration equation such as the velocity WRT height form. This form is shown below.

$$\boldsymbol{v(h) = -e^{-hc}\sqrt{\frac{g}{c}e^{2K_2C} - e^{-2hc}}} \tag{3}$$

Calculating the Coefficient of Drag

The primary function of the variable drag system is to increase the area of the rocket and therefore increasing drag on the vehicle, creating a controlled slowing of its path. The process of determining the coefficient of drag in this system posed a unique challenge to the team, and therefore had to be determined experimentally instead of analytically. Within the system there exists two separate coefficients; C_r, the coefficient of the vehicle itself, and C_{r+b}, and the coefficient for the vehicle with the air brakes deployed. Through simulations run with data from prototype launches, these were determined to be 0.4 and 0.4494, respectively. These numbers were determined using the onboard accelerometer data to fit a curve to axial acceleration of the vehicle using

$$a_a = -g\,\frac{C_d \rho A_r v_a^2}{2m} \tag{4}$$

where a_a is representative of the axial acceleration of the vehicle, g represents the component of gravitational acceleration in the direction of the vehicle's roll axis, C_d is the coefficient of drag, ρ is the air density, A_r is the cross-sectional area of the rocket, v_a is the axial velocity of the vehicle, and m is the mass. The curve fitting with full-scale launch data can be seen below in Figure 10.

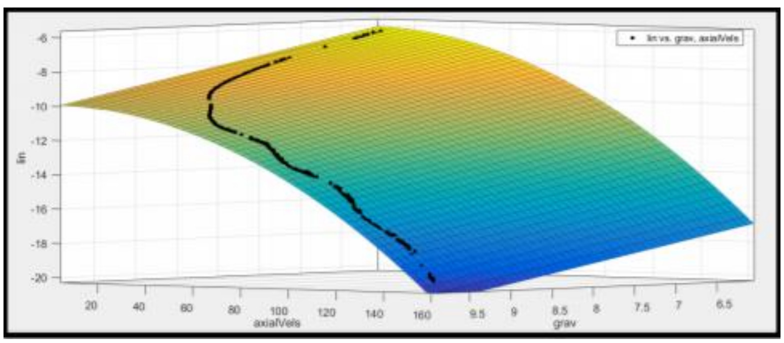


Figure 10: Full scale curve fitting.

The curve-fitting tool was used to solve for the average coefficient of drag that fit this data with the least error-squared. The resulting curve fit the data model with an R-square value of 0.9989 and had a sum-squared-error value of 0.1012, indicating a satisfactory fit.

4.1.2 Control Scheme

In order to achieve a controlled apogee altitude, the VDS employs a control scheme, which is the decision making process which controls how and when the VDS actuates its blades in order to reach a target apogee altitude of 5280 feet (1609.34 m). The program is constructed in *Visual Studio* using a C/C++ code structure with pop out GUIs for interfacing with the test system, running on a puTTY interface.

Setpoint Path

The setpoint path (SPP) is an equation of velocity as a function of altitude, $V_{spp}(h)$. It is derived from the coast phase deceleration equation and has an altitude axis (h) intercept equal to 1609 [m] (1 mile). The SPP is given below.

$$V_{spp} = \begin{cases} -e^{h\bar{c}}\sqrt{\dfrac{g}{\bar{c}}e^{2K_2\bar{c}} - e^{-2h\bar{c}}}\left[\dfrac{m}{s}\right] & , v > 125\left[\dfrac{m}{s}\right] \\ -e^{-hc_{min}}\sqrt{\dfrac{g}{c_{min}}e^{2K_2c_{min}} - e^{-2hc_{min}}}\left[\dfrac{m}{s}\right] & , v < 125\left[\dfrac{m}{s}\right] \\ 0\left[\dfrac{m}{s}\right] & , h > 1609\ [m] \end{cases} \quad \mathbf{(5)}$$

The piecewise SPP displayed above is shown in three parts. The first part, where h >125 [m], is calculated using an average drag characteristic constant to facilitate a smooth transition to the minimum drag characteristic path. The second part follows the minimum drag characteristic path to the target altitude. The third part where V_{spp}= 0 for h >1609 [m] ensures that the VDS will deploy the brakes if it surpasses its target altitude. The calculated set path point is shown in

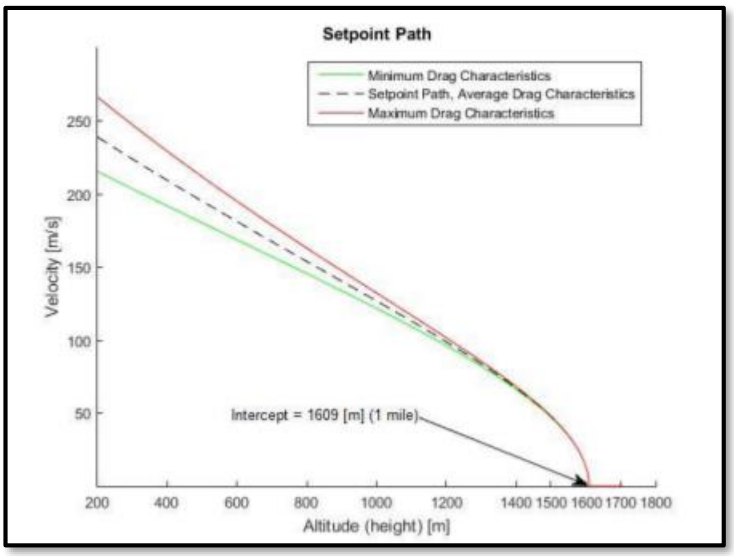


Figure 11: Setpoint path.

Each variation of the plot is found through substituting the minimum, maximum, and average values of the constant c to describe the various drag scenarios. The most optimal plot is displayed by the average value of c, as the vehicle is able to follow its ideal path when the value of c is at its most balanced state. The VDS uses its data acquisition system to feed its actual position data to the software, and adjusts the velocity through actuation of the blades, to match this SPP as closely as possible.

In order for this adjustment effect to occur, these must be a closed feedback loop that compensates for any deviation from the SPP. This occurs through the effect that the VDS corrects for any deviation from the SPP with a magnitude proportional to that deviation – this is called proportional compensation. This effect was chosen as it has been able to be finely tuned to the specificity of the weather conditions and the sensitivity of the DAQ system.

4.1.3 System modeling

Through the process of optimizing and validating the design and accuracy of the VDS, a simulation has been developed to describe the entirety of the control system. This simulation has been generated using Mathworks Simulink, and incorporates the kinematics of the coast phase, the responses of the control scheme, and the mechanics of the VDS's actuators seen in Figure 12.

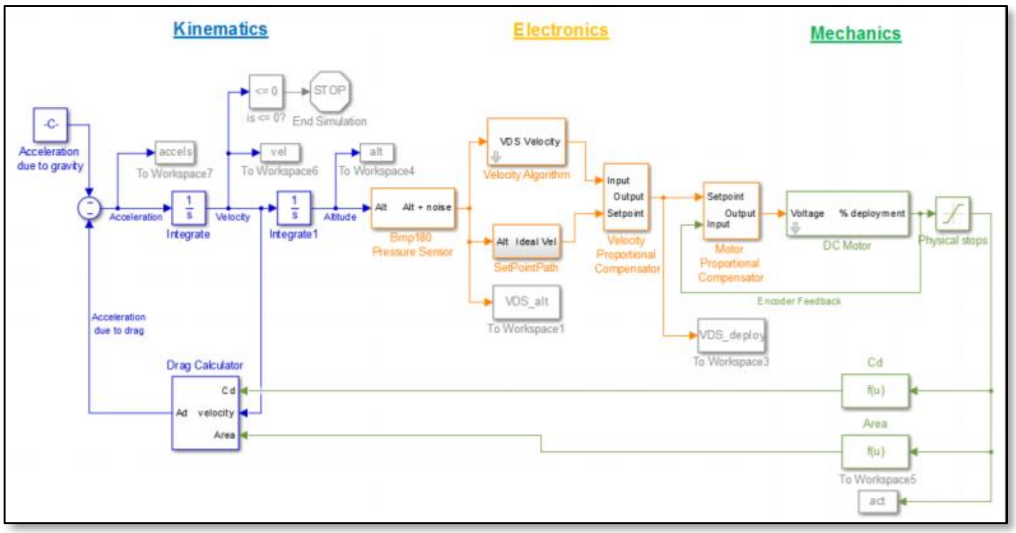


Figure 12:VDS schematic simulation.

The simulation has the ability to predict flight behavior considering factors such as noise in the data, data frequency, motor response time, different drag coefficients, and particular motor selections. Throughout the season, River City Rocketry will create simulations in Mathworks Simulink as well as in OpenRocket in order to analyze different conditions based off of improvements and changes that are made on the VDS.

In addition to this overall simulation, another exists solely for the existence of a Kalman filter as shown in Figure 13. The Kalman filter is an algorithm programmed custom to the VDS, which actively detects noise in the data and creates a plot based off of collected data and calculated path points. This is included in order to generate the most accurate picture of what flight path the DAQ system underwent in comparison with what the sensors read. This piece of the data analysis is crucial for filtering noise from the sensory input, to distinguish accurate readings from error in the data.

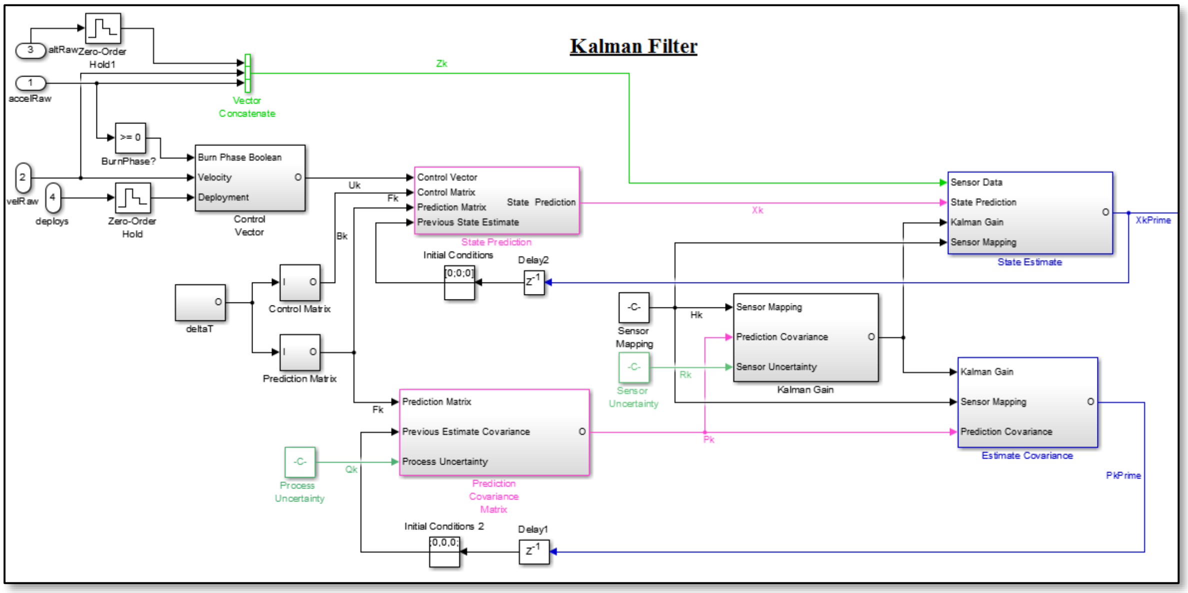


Figure 13: Kalman filter.

4.1.4 Electrical Hardware

Multiple electrical configurations have been tested and adjusted throughout the life of the VDS. The goal of the hardware system is to achieve simplicity and ease of use and in doing so, minimizing the threshold for error. The current design is composed of a dual stacked configuration of printed circuit boards, of which the top board is the controls board, which houses fuses, LED lights, battery connectors, switches, as well as the connectors to the external hardware components of the VDS and the Teensy 3.6: The bottom board is the logic and embedded systems board, which contains the sensors, and motor drivers. They share the microcontroller through header pins and a connection header piece, but are powered individually by 7.4V and 11.1V batteries, respectively. The printed circuit boards, as shown in Figure 14, are manufactured by Advanced Circuits, and are harnessed within the rocket by custom designed 3D printed electronics sleds. The components in which the embedded firmware interacts directly on the PCB are annotated as;

1. Teensy 3.6
2. Fuse (Amperage required contingent on current pulled from testing)
3. BMP280 Pressure Sensor
4. BNO055 9DOF
5. BTN7960 Motor Driver
6. DSUB connector to motor encoder and blade configuration

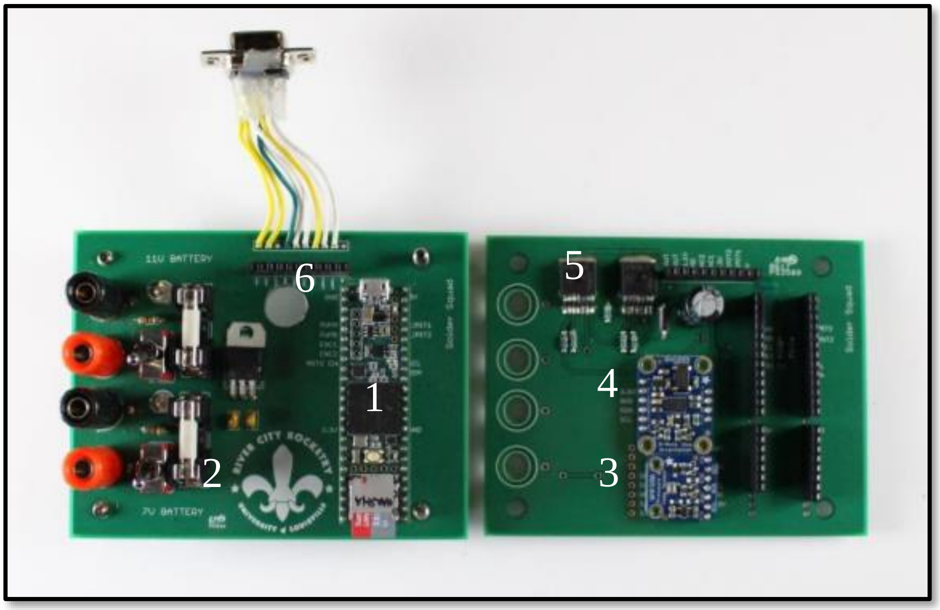


Figure 14: Printed circuit boards for VDS Hardware.

Sensory upgrades

Because of a reoccurring issue with sensor noise (which is discussed in further sections), we plan to upgrade the DAQ system from lower grade commercially available sensors, to aerospace grade sensors. While research and development of the particular product is still underway, it is anticipated that this will require a new PCB configuration as well as a new microcontroller interface. This is being done to mitigate past issues experienced solely because of high margins of error on the lower quality sensors that were being used. This will be implemented in further designs to come.

Experimental Verification

Throughout the 2016-2017 competition season, a total of nine successful full scale launches, including last season's competition flight, a full control flight, and a full break flight, were completed. The following data in Table 6 validates that the aforementioned control theory and system modelling is accurate and that the variable drag system is a viable and justified target altitude system.

Launch Name	Date	Launch Summary	Apogee Altitude	Burnout*
Control launch 1	5-28-16	No brakes were deployed during this flight. This launch was intended to characterize the drag effects of the vehicle on its own as well as to exercise the VDS Electronics data collection and velocity algorithms.	**Target**: None **AIM**: x **VDS**:4809 ft. (1466.05 m)	[x,x]

VDS prototype; Active launch 1	8-6-16	The brakes were deployed during this flight. This launch was intended to exercise the control scheme as well as to characterize the drag effects of the brakes.	**Target:** 4593.18 ft (1400.00 m) **AIM:** 4625.98 ft (1410.00 m) **VDS:** 4625.85 ft (1409.96 m)	$h0$=628.48 ft (191.56 m) $v0$=593.27 ft/s (180.83 m/s)
VDS prototype; Active launch 2	8-27-16	The brakes were deployed during this flight. Like the previous launch, this test was intended to exercise the control scheme as well as to characterize the drag effects of the brakes.	**Target**: 4265.09 ft (1300 m) **AIM:** 1330 [m] **VDS**: 4294 ft 1(309.5 [m])	$h0$ =826.44 ft (251.9 m) $v0$ =527.66 ft/s (160.83 m/s)
VDS prototype Full deploy launch	9-10-16	The brakes were fully deployed directly after burnout. This was intended to more comprehensively characterize the drag effects of the brakes.	**Target:** None **AIM:** 4225.72 ft (1288 m) **VDS**: 4173.56 ft (1272.1 m)	$h0$ =679.13 ft (207 m) $v0$ =564.01 ft/s (171.91 m/s)
VDS V2 control launch (2)	2-18-17	Full scale launch of fully optimized, full version manufactured VDS, air brakes were not deployed – control launch to determine natural apogee altitude of rocket in full weight without target detection. AIM had error during flight	**Target:** 5300 ft **AIM: x** **VDS:** 6049.6 ft (1844.5 [m])	$h0$ =668.5.13 ft/s (203.75 m) $v0$ =572.03 ft/s (174.35 m/s)
VDS V2 full break control launch	2-26-17	Brakes were in full deployment of launch beginning in coast phase, meaning that the control scheme was not in place – the purpose of this launch was to determine the maximum amount of drag produced by the optimized mechanical VDS design. This data was heavily altered by suboptimal weather conditions and pressure anomalies.	**Target:** 5280±33 ft ft **VDS:** 5538.7 ft (1688.2 m)	$h0$ =632.4 ft (192.7 m/s) $v0$ =586.3 ft/s (178.7 m/s)
VDS V2 Typhon official launch	3-24-17	First full scale launch of fully optimized, full version manufactured VDS in which brakes were deployed, and	**Target:** 5280±33 ft ft **VDS:**	$h0$ =680.6 ft (207.5 m/s) $v0$ =564.6 ft/s (172.09 m/s)

		control scheme actuation was in use.	4921 ft (1500 m)	
VDS V2 Typhon official launch 2	4-2-17	Airbrake launch after CATO event – brakes were in full use and deployed directly after burnout in coast phase.	**Target:** 5280±33 ft ft **VDS:** 5187 ft (1581 m)	$h0$ =675.73 ft (205.9 m/s) $v0$ =577.09 ft/s (175.8 m/s)
2017 NSLA official competition launch – Typhon	4-8-17	Full scale competition launch 2017 – full control scheme actuation. Most ideal launch to date.	**Target:** 5280±33 ft ft **VDS:** 5302.9 ft (1616.4 m)	$h0$ =679.9 ft (207.2 m/s) $v0$=567.12ft/s (172.85 m/s)

Table 6:VDS launch data.

*Altitude based on AIM extra flight computer

There are several points that should be noted in the table above. Firstly, despite having thrown the same prototype launch vehicle with the same weight and the same motor, there was a standard deviation in burnout altitude of 25.6 [m] (84 [ft]) and a standard deviation in burnout velocity of 66.9 [m/s] (220 [ft/s]). This provides an affirmation that an adaptive altitude control system necessary to overcome the large variation in motor to motor output in order to reach the design goal of ±10 [m]. A passive ballast system would have been subject to these variations and the variance would have been reflected in the resulting apogee altitude. Additionally, the altitude of the rocket during the control launches verifies that without said adaptive altitude control, the apogee would be vastly (769 ft) above target altitude. Comparatively, the breaking power is evident in relating the control launch to the 'full deploy' launch where the brakes are fully deployed without actuation throughout launch there is a difference in altitude of 193.95 [m] (636 [ft]).

Sensor Noise

While analyzing the data from all 8 of the test flights of the VDS, a consistent error pattern arose throughout these data acquisitions that is in the process of mitigation. The data taken from the altimeter derived barometer displayed some questionable 'blips' in the coast phase, which indicated a flight pattern that is not probable or even possible, as seen in Figure 15 from the launch on April 2nd, 2017.

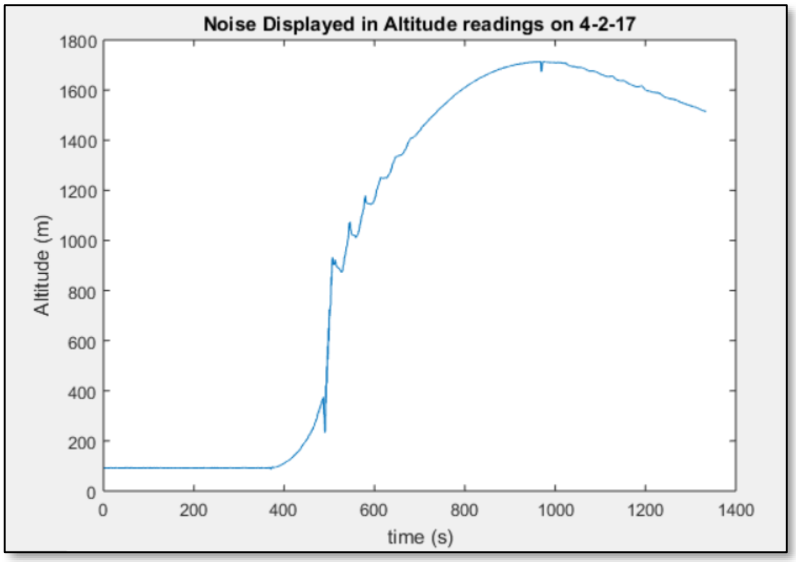


Figure 15: Noise in VDS data.

This strange data pattern prompted River City Rocketry to do further analysis into the cause of this anomaly. It was hypothesized that, because the electrical harness is not in a vacuum, nor airtight from the blade configuration, the actuation of the blades from the electronics bay was causing a pressure differential to form within the rocket as air was scooped from the outside of the vehicle into the bay. This was found to be a plausible hypothesis too near in time to the date of the competition flight to make any significant changes to the vehicle, so a temporary system was put into place. An alternative BMP280 was placed, in its own individual PCB and harness, in the nose cone of the rocket to prevent any pressure buildup within the bay – this configuration was wired through USB connection down through the vehicle to the booster section, containing the primary VDS electronics. River City Rocketry has acknowledged that this is an issue that will be mitigated in the coming vehicle through proper installation and air tight fitting of the VDS blade configuration into the vehicle. Additionally, separation of the electronics bay from this mechanical configuration will be verified. This idea is still in the research and development phase, and the next prototype of the rocket will contain an experiment that will verify whether the new configuration will be effective in mitigating this noise problem in the future.

4.2 Mechanical Design

The mechanical design for the VDS was optimized for volume, actuation speed, mass, and drag area during the 2016-2017 season. For the 2017-2018 season, River City Rocketry will primarily focus on improving the previous mechanical design with respect to the following aspects:

1. Gear design
2. Integration

The previous VDS mechanical assembly and the current assembly are shown below in Figure 16: Previous VDS assembly (left) and current VDS mechanical assembly rendering (right).Figure 16.

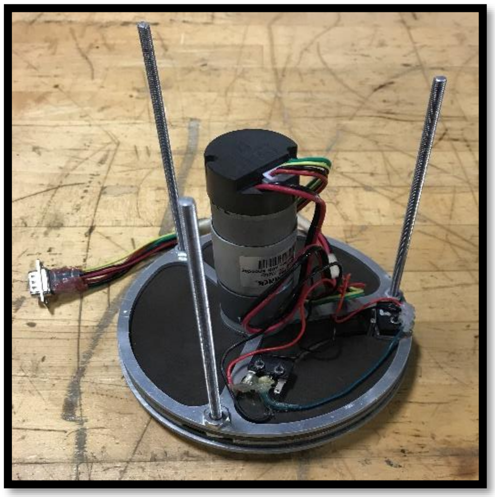


Figure 16: Previous VDS assembly (left) and current VDS mechanical assembly rendering (right).

4.2.1 Design Overview

The VDS was designed to actuate the drag inducing blades perpendicularly to the airflow in order to minimize the volume of the design. This prevents the motor from having the counteract the drag force on the blades, allowing for a smaller motor and increased actuation speed. The entire VDS, including the electronics, is able to fit inside a single 6in. by 12in. carbon fiber coupler, which allows the VDS to be inserted and removed from the launch vehicle.

4.2.2 Actuation

The VDS was designed so that three drag inducing blades are actuated perpendicularly to the vehicle's airframe simultaneously by a single central gear press fit to the shaft of an AndyMark NeveRest DC 40 Motor. The AndyMark NeveRest DC 40 Motor was chosen during the 2016-2017 season after verifying that the torque requirement for the motor was 125.2 oz-in. The motor specifications are shown in Table 7.

Gearbox Output Power	14W
Stall Torque	350 oz-in.
No-Load Speed	160 rpm
Weight	0.75 lb

Table 7. AndyMark NeveRest motor specifications.

By radially actuating the blades, the drag force on the blades is transferred primarily to the support plates rather than directly to the motor. Each blade is fit with a set of radial gear teeth that mesh with the central spur gear. To meet the team's goal of improving the gear assembly of the VDS, the central spur gear and the radial gear teeth of each drag blade have been redesigned, and will be improved to reduce stress concentrations in the gear teeth. The drag blade assembly with the central spur gear is shown in Figure 17.

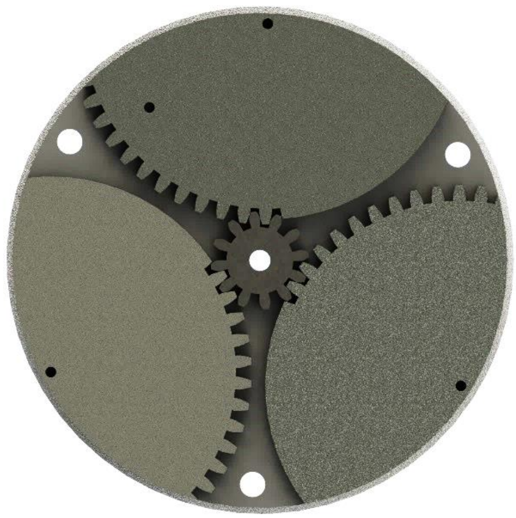


Figure 17: Drag Blade Assembly.

Similar to the 2016-2017 design, each drag blade will rotate about a 1/8” dowel pin. At full actuation, approximately ½ of each blade will protrude into the airflow surrounding the vehicle and the other half will remain supported by the VDS assembly. The VDS assembly is shown before and after drag blade actuation in Figure 18.

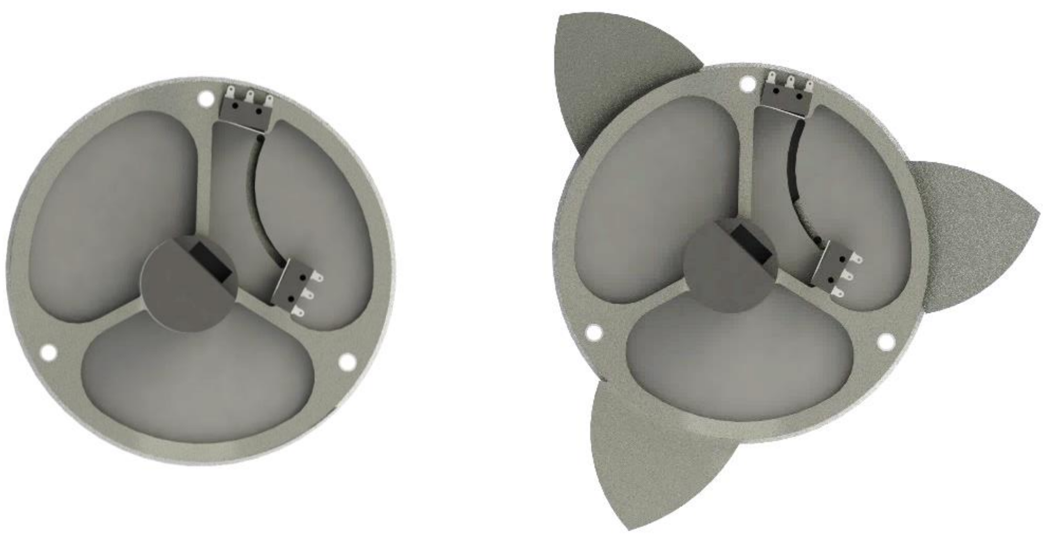
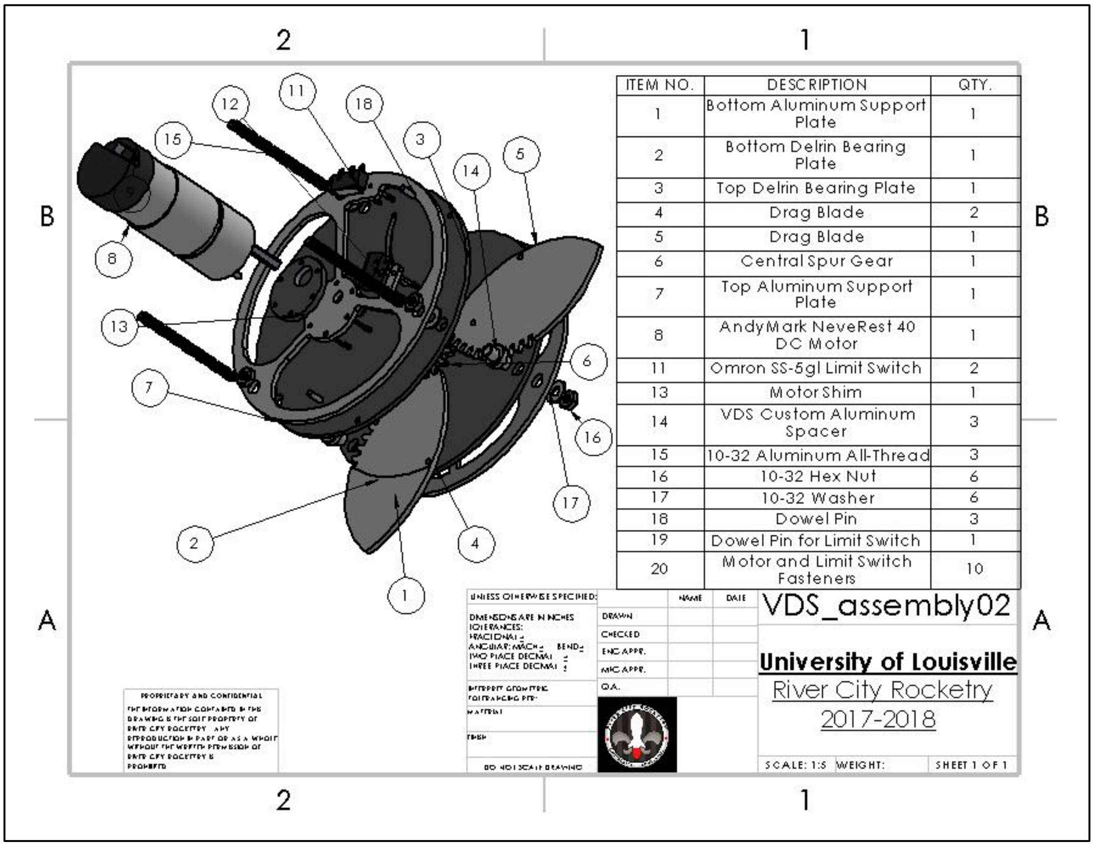


Figure 18. VDS top view before blade actuation (left) and after blade actuation (left).

4.2.3 Components

A bill of materials of the mechanical VDS assembly is show below in Figure 19.



ITEM NO.	DESCRIPTION	QTY.
1	Bottom Aluminum Support Plate	1
2	Bottom Delrin Bearing Plate	1
3	Top Delrin Bearing Plate	1
4	Drag Blade	2
5	Drag Blade	1
6	Central Spur Gear	1
7	Top Aluminum Support Plate	1
8	AndyMark NeveRest 40 DC Motor	1
11	Omron SS-5gl Limit Switch	2
13	Motor Shim	1
14	VDS Custom Aluminum Spacer	3
15	10-32 Aluminum All-Thread	3
16	10-32 Hex Nut	6
17	10-32 Washer	6
18	Dowel Pin	3
19	Dowel Pin for Limit Switch	1
20	Motor and Limit Switch Fasteners	10

Figure 19. VDS bill of materials.

Each of the three drag blades are water jet from 1/8” 6061-T6 aluminum using a Maxiem 450 Water Jet. 6061-T6 aluminum was chosen for the drag blades due to its rigidity and low weight. The drag blades rest between two 1/8” Delrin bearing plates. Delrin was chosen because of its low coefficient of friction with aluminum, which is rated at 0.3. Three custom machined aluminum spacers are set between the two Delrin plates. This allows for proper alignment of the assembly and prevents the plates from being overtightened on the drag blades.

Two aluminum support plates are also water jet from 1/8” 6061-T6 aluminum using a Maxiem 450 Water Jet. The plates will take on the majority of the force transferred from the drag blades during flight. Renderings of the top and bottom support plates are shown in Figure 20.

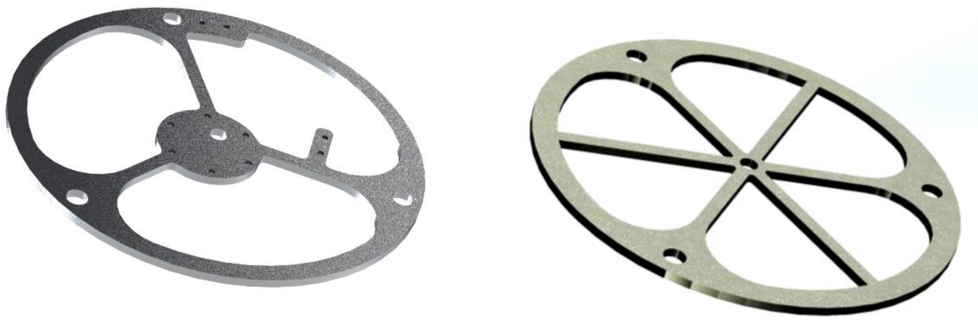


Figure 20. Top (left) and bottom (right) aluminum support plate renderings.

During the 2016-2017 season, the team corrected over actuation of the drag blades which caused the gearbox of the DC motor to fail by installing Omcron SS-5GL limit switches to the top aluminum support plate. The limit switches are triggered by a 1/8" dowel pin that is press fit into one of the drag blades. The dowel pin is free to slide along a radial slot cut into the top Delrin bearing plate during actuation and triggers one of the limit switches upon full actuation or retraction. The end of the radial slot also serves as a stopper to the dowel pin should the motor attempt to actuate the drag blades past maximum actuation.

4.2.4 Integration

A rendering of the custom printed sled used during the 2016-2017 season is shown in Figure 21.

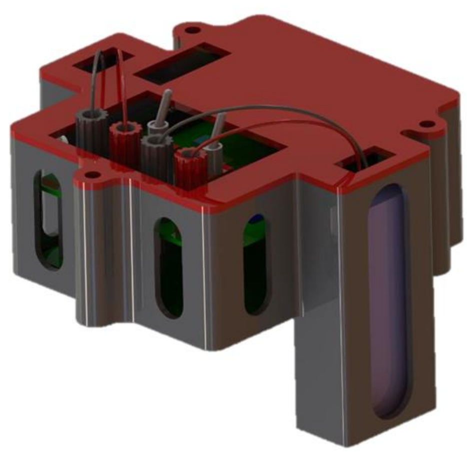


Figure 21. Custom printed VDS electronics sled.

The team is currently working to improve the sled design to provide a more modular and protective housing for the VDS electronics components. The two primary goals for the VDS integration into the launch vehicle is to ensure that the VDS can be inserted into and removed from the vehicle independently of all other subsystems within the vehicle, and to provide an adequate seal for all VDS sensors from any disturbances caused by the drag inducing blade actuation. Secondary goals set for the integration of the VDS are to eliminate or reposition the VDS limit switches, and to reduce excess wiring in the final assembly.

4.3 Conclusion

Through experimental and analytical data, the Variable Drag System has proven to be a reliable method for River City Rocketry to target an apogee altitude by increasing drag on the vehicle. It will be fully implemented in this season's rocket with upgrades to the electrical hardware for noise reduction, physical integration for ease of installment, and mechanical design for more reliability in the blade actuation. We anticipate that it will exceed its previous standard of ±31 ft. (9.4 m.) from target altitude with reaching an updated predicted precision of ±20 ft. (6.09 m) from target altitude.

5 Technical Design: Launch Vehicle

5.1 Formulas

To assess the performance of the rocket in flight, three main values are calculated: peak altitude, center of gravity, and center of pressure of the rocket. Calculating peak altitude requires a specific sequence of equations. First, average mass of the rocket before burnout is calculated using

$$\boldsymbol{m_a = m_r + m_e - \frac{m_p}{2}} \tag{6}$$

in which m_r is the mass of the rocket, m_e is the mass of the motor, and m_p is the propellant mass. Then the rocket's aerodynamic drag coefficient (kg/m) is calculated using

$$\boldsymbol{k = \frac{1}{2}\rho C_D A} \tag{7}$$

where ρ is air density (1.22kg/m^3), C_D is the drag coefficient, and A is the rocket's cross-sectional area (m^2). Burnout velocity coefficient (m/s) is calculated using

$$\boldsymbol{q_1 = \sqrt{\frac{T - m_a g}{k}}} \tag{8}$$

where T is the motor thrust and g is the gravitational constant (9.81 m/s^2). The rocket's burnout velocity delay coefficient (1/s) is calculated using

$$\boldsymbol{x_1 = \frac{2kq_1}{m_a}} \tag{9}$$

The burnout velocity (m/s) is calculated using 1010101010

$$\boldsymbol{v_1 = q_1 \frac{1 - e^{-x_1 t}}{1 + e^{-x_1 t}}} \tag{10}$$

where t is the motor burnout time (s). The rocket's altitude at motor burnout can then be computed using

$$\boldsymbol{y_1 = \frac{-m_a}{2k} \ln\left(\frac{T - m_a g - k v_1^2}{T - m_a g}\right)} \tag{11}$$

After the altitude at burnout is calculated, the rocket's coasting distance must then be calculated. Comparable to burnout altitude, rocket mass must be calculated first. The coasting mass is calculated using

$$\boldsymbol{m_c = m_r + m_e - m_p} \tag{12}$$

Using coasting mass, the coasting velocity coefficient is calculated using

$$\boldsymbol{q_c = \sqrt{\frac{T - m_c g}{k}}} \tag{13}$$

Also using coasting mass, the coasting velocity delay coefficient was calculated using

$$x_c = \frac{2kq_c}{m_c} \tag{14}$$

The rocket's coasting velocity is then found using

$$v_c = q_c \frac{1 - e^{-x_c t}}{1 + e^{-x_c t}} \tag{15}$$

The coasting distance is found using

$$y_c = \frac{m_c}{2k} \ln\left(\frac{m_c g + k{v_c}^2}{T - m_c g}\right) \tag{16}$$

The peak altitude of the rocket can then be found using

$$PA = y_1 + y_c \tag{17}$$

The rocket's center of gravity location is calculated using

$$\boldsymbol{cg = \frac{d_n w_n + d_r w_r + d_b w_b + d_e w_e + d_f w_f}{W}} \tag{18}$$

where W is the total weight of the rocket and d is the distance between the denoted rocket section's center of gravity (nose, body, rocket, body, engine, and fins, respectively) and the aft end. The rocket's center of pressure measured from the nose tip is computed using

$$\boldsymbol{X = \frac{(C_N)_N X_N + (C_N)_F X_F}{(C_N)_N + (C_N)_F}} \tag{19}$$

where C_{NN} is the nose cone center of pressure coefficient (2 for conical nose cones). X_N is calculated using

$$\boldsymbol{X_N = \frac{2}{3} L_N} \tag{20}$$

where L_N is the nose cone's length. Variable C_{NF} of equation 14 is defined by the fin center of pressure coefficient calculated using

$$\boldsymbol{(C_N)_F = \left[1 + \frac{R}{S + R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_f}{C_R + C_T}\right)^2}}\right]} \tag{21}$$

where R is the cross-sectional radius of the rocket 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, and C_T is the fin tip chord length. X_F is calculated using

$$\boldsymbol{X_F = X_B + \frac{X_R(C_R + 2C_T)}{3(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right]} \tag{22}$$

where X_B is the distance from the nose tip to the leading edge of the fin root chord, X_R is the distance between the fin root leading edge and the fin tip leading edge measured parallel to the rocket body. Equations 14 through 17 are also known as the Barrowman Equations (The Theoretical Prediction of the Center of Pressure, 1966).

Note that Equation 14 makes use of a simplified form because the rocket makes no transition in the rocket body diameter, thus the transitional terms have been omitted. These equations are used to verify the OpenRocket simulation conducted of the full-scale launch vehicle.

5.2 Design

5.2.1 Launch Vehicle:

The launch vehicle was designed to be as efficient as possible while also being able to safely fly to an apogee of exactly 5,280ft AGL. To do this, the launch vehicle was designed primarily with the open-source software OpenRocket as well as the student edition of Solidworks 2017. An OpenRocket model is shown in Figure 22.

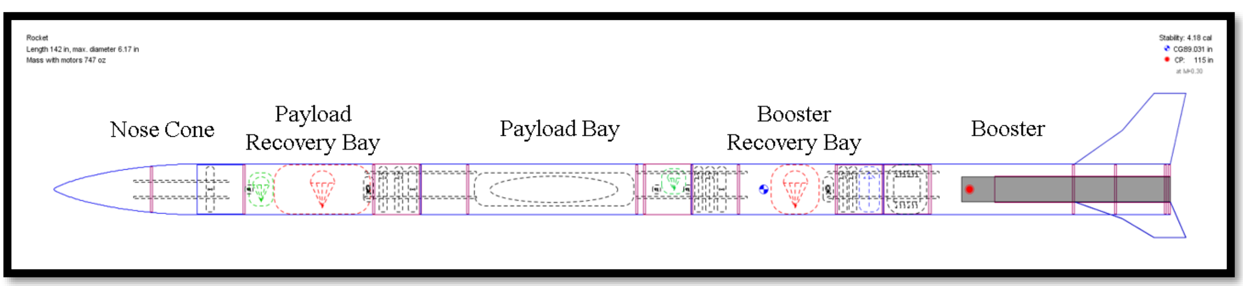


Figure 22: OpenRocket model of launch vehicle.

The launch vehicle consists of the booster, booster recovery bay, payload bay, payload recovery bay, and the nose cone. Each section will be connected to the next via 6 in. diameter carbon fiber couplers, 12 inches in length. The separating sections of the launch vehicle will be joined to their respective coupler using three nylon 4-40 socket head cap screw shear pins. Each section that will not be separating will be joined to its respective coupler with three 6-32 button head socket cap screws. The couplers will house VDS and recovery electronics that are secured to ¼-20 aluminum threaded rods that extend beyond the coupler's bulkplate. The couplers will be capped with carbon fiber bulkplates on both ends. The length and mass of each section of the launch vehicle is shown in Table 8.

Section of Launch Vehicle	Length of section (in)	Weight (lb)
Booster	36	56.7 oz

Booster Recovery Bay	24	37.8 oz
Payload Bay	34	52.7 oz
Payload Recovery Bay	28	43.4 oz
Nose Cone	18	19.6 oz

Table 8: Launch vehicle overall dimensions.

5.2.2 Airframe

The airframe of the launch vehicle will be constructed from 6K carbon fiber filament and Aeropoxy PR2032 epoxy. The airframe will be helically wound onto a 6-inch diameter aluminum mandrel using the team's 4 axis X-Winder Filament Winder. The X-Winder can be seen below in **Figure 23**.

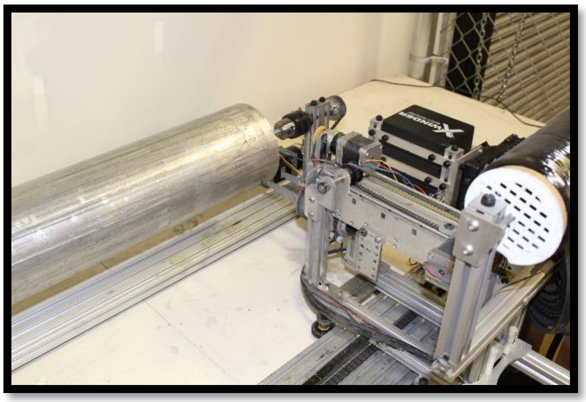


Figure 23: X-Winder filament winder.

The winding angles of the filament greatly affect the overall strength of the airframe. During flight, the airframe will experience mainly axially compressive loads. In the event of an accident such as a parachute failure, the airframe would most likely land horizontally, experiencing high tangential loads. To account for both scenarios, with more emphasis on the axially compressive loads, the airframe will be wound in four layers at alternating angles of 45° and 55° from horizontal.

Following the completion of the winding process, the airframe will be wrapped in Dunstone Hi-Shrink Tape and placed in an oven used for powder coating to cure. Shrink tape is applied to the airframe to remove excess resin and improve surface finish. In the past, the team had used a vacuum-bagging method to accomplish this, but during last season it was discovered that shrink tape drastically improved surface finish and was a much easier process than vacuum-bagging. The couplers will be made of carbon fiber and purchased from a supplier. Carbon fiber was chosen due to its low mass and high strength. Each coupler will be capped with a carbon fiber bulkplate.

5.2.3 Booster

The booster will consist of a removable fin system (RFS), motor mount tube, and the motor. To reduce weight and remove epoxy joints, the RFS has been designed for the launch vehicle. This system eliminates the possibility of damaging fins or epoxy joints during transportation of the launch vehicle or during the landing of the launch vehicle. Additional fins will be readily available at launch, allowing for any damaged fin to immediately be replaced. Along with having the ability to replace damaged fins before a launch, the RFS also allows different fin designs to be utilized during test launches to account for mass changes throughout the year. A rendering of the assembled booster is shown below in Figure 24.

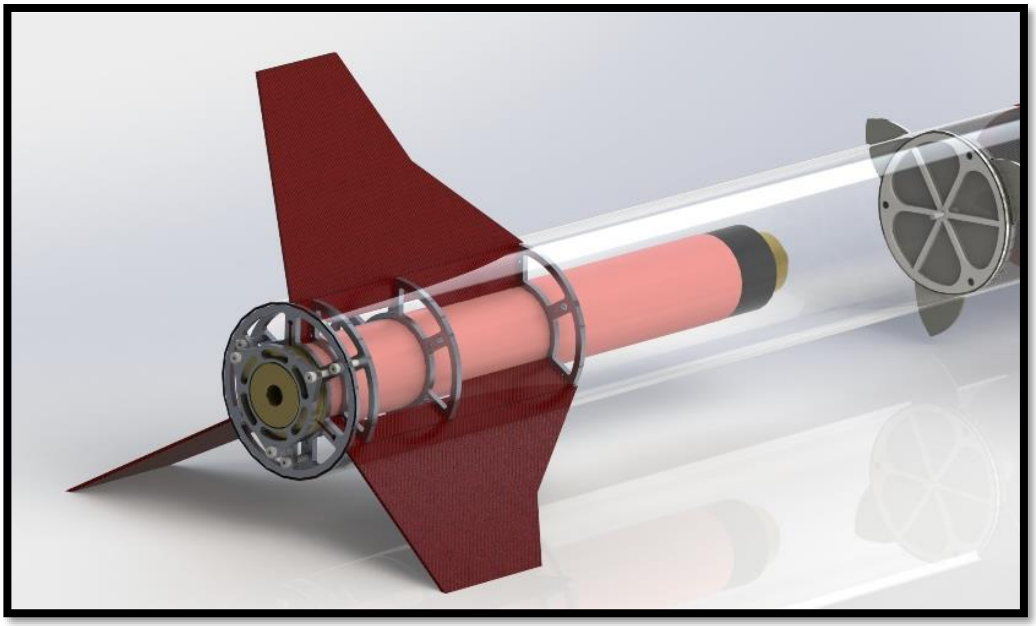


Figure 24: Booster with RFS, motor mount, and motor retainer shown.

The booster will utilize three centering rings cut from ¼ in. 6061-T6 aluminum. The centering rings will have three 1/8 in. wide slots radially separated 120° to insert the three fins into the booster. The fins are held in place by placing the specified fin tab into their proper slots in each centering ring. The fins are locked into place with the fin retainer mounting to the aft centering ring via three #10-32 UNF-3A socket head cap screws 1in. in length.

The motor is installed into the booster via the motor mount tube, three 6061-T6 aluminum centering rings, and a 6061-T6 aluminum motor retainer. With the motor installed into the motor mount tube, the motor retainer mounts to the fin retainer via three #10-32 UNF-3A shoulder screws 1 in. in length. All fasteners in the system are made from 18-8 stainless steel.

Models of the motor retainer and fore centering ring are shown below in Figure 25 and Figure 26.

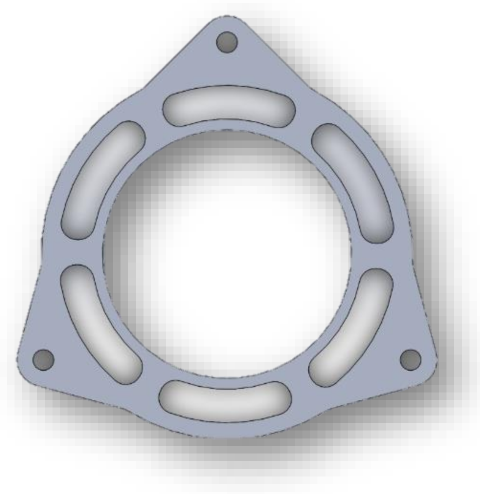


Figure 25: Motor retainer.

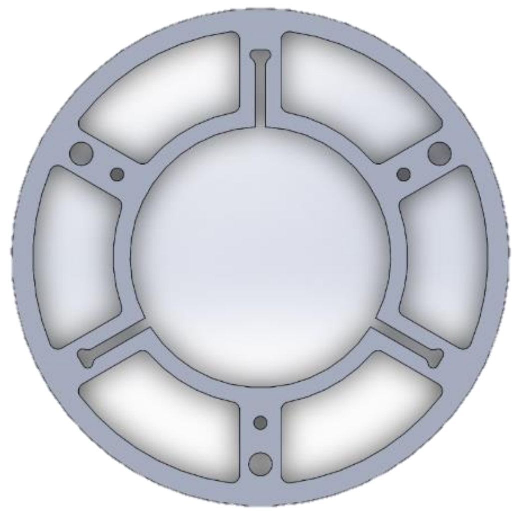


Figure 26: Fore Centering ring.

5.2.4 Motor Selection

To choose a motor that will deliver the launch vehicle to the desired altitude, many factors had to be considered. The VDS is most effective at higher velocities, therefore, a motor with a high impulse was chosen that would also burn long enough to deliver the vehicle above 5,280ft AGL with an inactive VDS. Several OpenRocket simulations were run with different motors selected. Upon analyzing the simulation results, the launch vehicle will utilize an Aerotech L2200G-PS rocket motor. With the L2200G-PS, the current configuration of the launch vehicle would reach an apogee altitude of 5,481ft AGL with an inactive VDS. Referencing the performances of the VDS last year, the VDS will be able to brake enough to bring the apogee altitude down to the 5,280ft target. The L220G-PS specifications can be seen in Table 9.

Characteristics	Specification
Diameter	75 mm
Length	68.1 cm
Total Weight	4,783 g
Propellant Weight	2,518 g
Average Thrust	2,200 N
Maximum Thrust	3,104 N
Total Impulse	5,104 Ns
Burn Time	2.3 sec

Table 9: Aerotech L2200G-PS characteristics.

5.2.5 Variable Drag System

The VDS will be housed in a 12-in long coupler, separated into two halves via a wooden bulkplate, directly above the booster recovery bay. The VDS is placed into the bottom half of the VDS coupler via three 10-32 aluminum threaded rods and secured via 10-32 hex nuts. The electronics for the VDS will be secured in the top half of the VDS coupler via a custom designed 3D printed sled. Above the VDS coupler is the booster recovery bay which will house a main parachute further outlined in the recovery section.

5.2.6 Payload bay

The payload bay will house the rover payload. The rover and the Rover Orientation Correction System is further outlined in section 7.3. Above the payload bay will be the payload recovery bay and nose cone. The three sections will separate from the booster recovery bay at apogee which is further outlined in section 6.2.

5.2.7 Stability

To ensure a safe flight, the launch vehicle was designed to have a stability margin greater than 2.0 cal at rail exit. With an overall weight of 47lbs, the current configuration of the launch vehicle has a stability margin of 2.32 cal at rail exit. This stability margin was calculated using OpenRocket and verified using the formulas in section 5.1. The projected altitude of 5,481ft. was calculated using an OpenRocket simulation and also verified using the formulas in section 5.1. The conditions for the launch were set to include 10mph winds and the launch vehicle was launched from a 144in. rail. Characteristics regarding the launch vehicle's flight are shown in Table 10.

Characteristic	Value
Stability margin at rail exit	2.32 cal.
Exit rail velocity	95.7 ft/s
Projected apogee altitude AGL	5,481 ft.
Max velocity	709 ft/s
Max acceleration	460 ft/s

Table 10: Characteristics of the launch vehicle's flight.

5.2.8 Nose cone

The nose cone will be a LD Haack series nose cone with a 3:1 fineness ratio. This nose cone design was chosen for its minimal coefficient of drag at the velocities at which the launch vehicle will be experiencing. The nose cone will be constructed using a positive mold cut from medium density fiberboard (MDF) with a ShopBot. The positive mold will then be wrapped in fiberglass fabric impregnated with epoxy resin to create a negative mold. The negative mold with then have epoxy saturated carbon fiber fabric laid onto it and will be left to cure overnight. Upon completion of the curing process, the fiberglass mold will be cut away revealing the completed carbon fiber nose cone. A model of the nose cone is shown below in Figure 27.

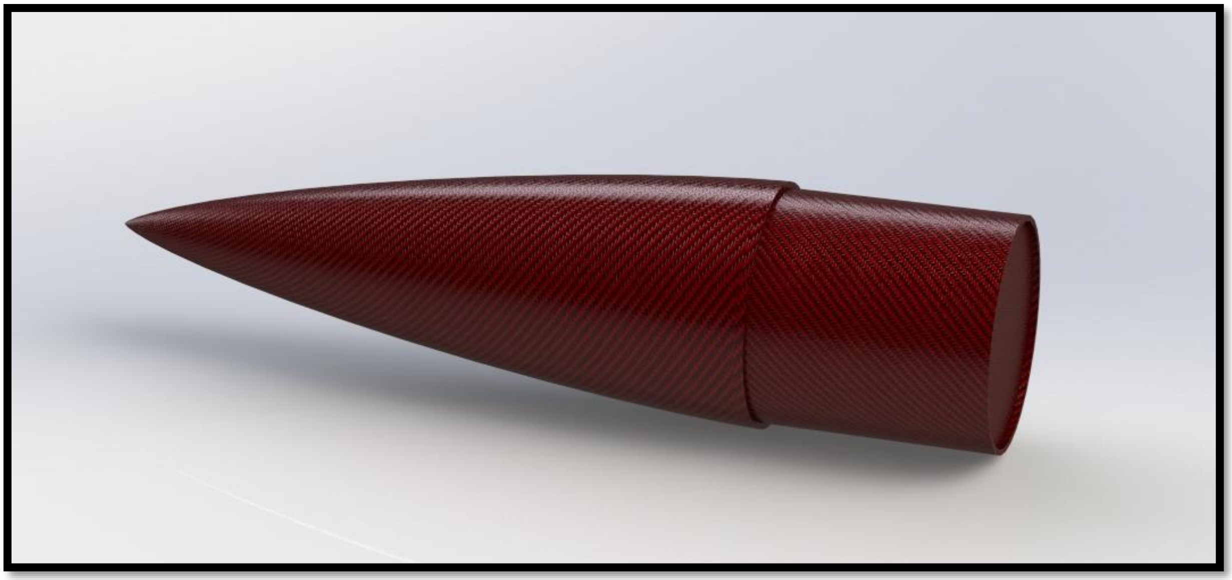


Figure 27: LD-Haack nose cone model.

5.2.9 Fins

The launch vehicle will use three swept fins designed to maximize the stability, efficiency, and reusability of the launch vehicle. The three fins will be cut from carbon fiber sheet 0.125 inches in thickness using an Maxiem 450 Waterjet available for use at FirstBuild. The carbon fiber sheet will either be purchased from a supplier or manufactured on campus with the help of mechanical engineering professor Dr. Roger Bradshaw. A model of the fin design is shown in Figure 28.

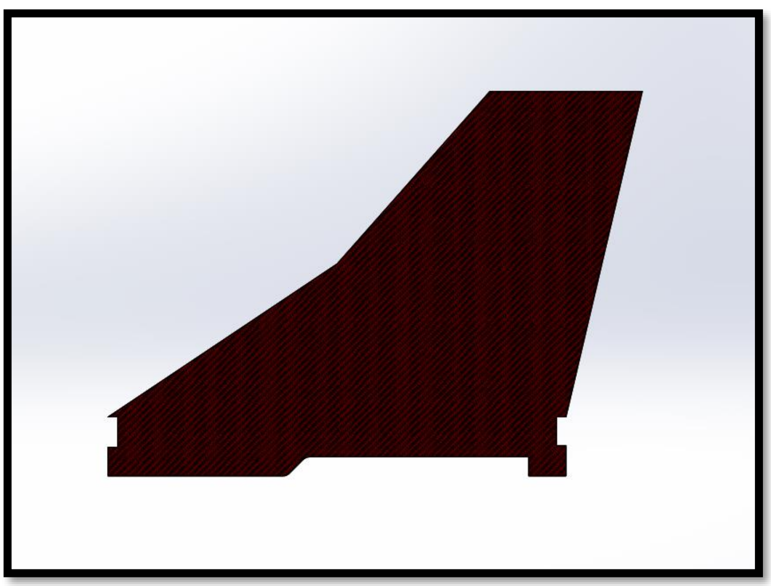


Figure 28: Swept fin design.

5.3 Requirements

The launch vehicle has been designed to meet all of the requirements laid out in the statement of work. Each requirement, and it's solution, is shown in Table 11.

Requirement	Solution
2.1. The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	The launch vehicle will be efficiently documented and all material and component masses will be recorded throughout the design and manufacturing. Accurate OpenRocket simulations and hand calculations will be maintained to ensure correct motor selections. The VDS will be optimized and thoroughly tested to minimize deviation of apogee altitude of 5,280 feet.
2.2. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	The launch vehicle will descend under a single recovery system, using a drogue and main parachute. A Perfectflite StratoLoggerCF altimeter will be used to record the apogee altitude for the competition. For complete redundancy, a secondary backup altimeter shall be included as well.
2.3. Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Each altimeter will have a screw switch that is accessible via a small hole drilled in the airframe.
2.4. Each altimeter will have a dedicated power supply.	Each altimeter will use a commercially available 9-volt Duracell battery.
2.5. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The screw switches used will be tightened to their maximum extent on the launch pad.
2.6. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The parachutes will be designed to ensure every section of the launch vehicle lands with a kinetic energy below the maximum kinetic energy laid out in the Statement of Work. Through 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

2.7. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The launch vehicle will be comprised of three independent sections: the booster section, payload bay, and the nose cone.
2.8. The launch vehicle will be limited to a single stage.	The launch vehicle is designed to utilize a single stage to reach the target altitude of 5,280ft AGL.
2.9. The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.	The launch vehicle and payload is designed with ease of integration in mind. Before launch day the team will practice assembling the launch vehicle and payload to ensure an appropriate assembly time. A comprehensive launch procedure check-list will be compiled prior to launch day to ensure nothing is overlooked during the assembly process.
2.10. The launch vehicle will 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 components.	All electronics will carry their own power source capable of remaining in launch-ready configuration for the required amount of time. Electronics will be tested ahead of launch day for their maximum run time in launch-ready configuration.
2.11. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	The launch vehicle will utilize proven launch igniters purchased from Wildman Rocketry. The igniters are designed to ignite the vehicle's motor by use of a standard 12-volt direct current firing system.
2.12. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	The launch vehicle will not require external circuitry or special ground support equipment to initiate launch.
2.13. The launch vehicle will 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 an Aerotech L2200G-PS motor for its full-scale launch vehicle.
2.14. Pressure vessels on the vehicle will be approved by the RSO.	The launch vehicle will not utilize any pressure vessels.

2.15. The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	The team will use an Aerotech L2200G-PS motor with 5,104 Newton-seconds for its full-scale launch vehicle.
2.16. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	In the current configuration of the launch vehicle, the static stability margin is 2.32 and the rail exit velocity is 95.7 fps.
2.17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	In the current configuration of the launch vehicle, the rail exit velocity is 95.7 fps.
2.18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	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.
2.19. All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.).	The team plans to conduct several full-scale test flights throughout the season to test the rigidity and effectiveness of the VDS and payload design.
2.20. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	The only structural protuberance on the launch vehicle are the drag blades in the VDS. The launch vehicle was designed to place the VDS as furthest aft of the center of gravity as possible. As a result, all structural protuberances are located aft of the burnout center of gravity.

Table 11: Launch Vehicle Requirements and Solutions.

5.4 Potential Challenges and Their Solutions

5.4.1 Nose Cone Construction

The construction of the nose cone and nose cone mold could prove to be challenging for the team. During the construction of last year's nose cone, the MDF the mold was constructed from chipped while being cut to shape. This resulted in holes in the mold which later affected the surface finish of the final nose cone. We are currently researching the use of different materials and different cutting methods to help mitigate this issue.

Last year's nose cone construction method resulted in uneven thickness across the body of the nose cone as well. This was a result of using rectangular pieces of carbon fiber fabric that overlapped each other at the tip of the nose cone mold. The excess mass from this overlapping made the nose cone tip thicker, and more massive than necessary. To solve this issue, we will cut precise shapes from the carbon fiber fabric that will mate precisely will the inside of the nose cone mold.

5.4.2 Airframe Surface Finish

Our current airframe manufacturing method uses heat shrink tape to squeeze excess epoxy from the filament and reduce the overall mass of the airframe. A side effect of this is that ridges are formed from the pressure on the airframe from the tape shrinking. In the past, we used a heat gun to heat the tape to the point of shrinkage. This year we will use a different grade of shrink tape and an oven to get a constant uniform temperature across the entire airframe which will result in a more uniform compressive force from the shrink tape. This will hopefully mitigate the issue of ridges forming on the airframe.

5.4.3 Payload Integration

During last year's competition, payload integration was the most challenging part of launch days. This year's launch vehicle will be designed with integrating the rover payload seamlessly at the top of the team's priorities. To accomplish this, the rover payload will be designed in such a way that allows the payload to be removed from the payload bay easily. The payload sub-team will then be able to work on the rover while the vehicle sub-team gets the launch vehicle ready for launch.

6 Technical Design: Recovery

6.1 Requirements

The recovery system will be designed to fulfill the following criteria outlined in the statement of work:

Requirements	**Solutions**
1. The launch vehicle will 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. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	The team will obey this rule and the RSO will have the final say in determining the safety of the system.
2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	Both sub-scale and full-scale separation tests will be conducted until a completely successful separation is observed.
3. At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	Parachutes will be tailored correctly to ensure kinetic energy requirements are met.
4. The recovery system electrical circuits will be completely independent of any payload electrical circuits.	All StratoLogger's will be independent on any surrounding electronics and will rely on their own power supply.
5. All recovery electronics will be powered by commercially available batteries.	Duracell 9V batteries will be used for all recovery related electronics.
6. The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Each main parachute and drogue parachute system will utilize two redundant PerfectFlite StratologgerCF's for all separation and deployment events.
7. Motor ejection is not a permissible form of primary or secondary deployment.	The aforementioned PerfectFlite StratologgerCF's will use a black powder or CO_2 ejection method.
8. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Three 4-40 socket head cap screw shear pins will be used for each bay intended to separate.
9. Recovery area will be limited to a 2,500 ft. radius from the launch pads.	Drift calculations will require a drift radius of less than 2,500 ft. in less than favorable winds. (~10mph)
10. An electronic tracking device will be installed in the launch vehicle and will	A GPS device will be placed in each independent non-tethered section.

transmit the position of the tethered vehicle or any independent section to a ground receiver.	
11. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	PerfectFlite StratologgerCF's will maintain sufficient distance from any electronics emitting electromagnetic radiation.

6.2 Vehicle Recovery

The recovery system will serve the purpose of ensuring a soft landing for both the booster half and payload half of the rocket separately, where all independent sections of the vehicle will be equipped with GPS tracking devices. A separation of the nose cone and deployment of a single drogue will take place at apogee and a main separation event will free the booster section, payload section, and nose cone to land under kinetic energy requirements under two main toroidal parachutes and a cruciform drogue, respectively.

6.2.1 Deployment Procedure

For the single-bay dual deployment of the payload segment of the main vehicle, the recovery system will consist of a drogue and main parachute in the same recovery bay. There will be one recovery bay for each respective half of the rocket, where the booster main recovery bay will be contained by a coupler until it is separated. The payload segment recovery system will use an Advanced Retention and Release Device (ARRD) to anchor the shock cord of the drogue to the bulkplate underneath the main deployment bag. The ARRD in Figure 29 is an assembly that serves as a load bearing connection point until a black powder charge forces a piston inside to release the attachment point out of the assembly, freeing it. This will ensure that the drogue does not act as the main pilot chute until the main deployment event. The black powder charge will be ignited by an electronic-match routed into the device.

Figure 29: ARRD.

In order for the vehicle to be recovered safely and in a reusable state, two deployment events will have to occur. The sequence is detailed below in Table 12, a separation event occurs between the booster recovery bay and the payload bay, splitting the rocket into two segments. For the top section, the ARRD disengages drogue shock cord, engaging the lanyard attached to the main toroidal deployment bag. The main parachute deploys with drogue now acting as pilot chute, pulling the main from the recovery bay. The drogue becomes the main parachute for the nose cone as it separately lands under kinetic energy requirements.

Event	Altitude (ft.)	Phase	Description
1	5,280	Drogue Phase	Launch vehicle separates the nose cone via black powder charge and shear pin configuration and begins drogue descent as a main section and a tethered nose cone.
2	1,000	Payload Section Main Deployment and Separation Event	A separation event occurs between the booster recovery bay and the payload bay, splitting the rocket into two segments. For the top section, the ARRD disengages drogue shock cord, engaging the lanyard attached to main toroidal deployment bag. Main deploys with drogue now acting as pilot chute, pulling the main from the recovery bay. The drogue becomes the main parachute for the nose cone as it separately lands under kinetic requirements separately.
3	1,000	Booster Drogue Phase	Immediately at separation, the drogue for the booster section is deployed for a drogue decent phase lasting approximately 400 ft.
4	600	Booster Main Deployment	After the approximate 400 ft. decent the coupler with drogue attached will separate, opening the main recovery bay. The drogue and coupler will remain tethered to the main booster segment as the main parachute is deployed.

Table 12: Recovery procedure.

As seen below in Figure 30, the ARRD provides a temporary connection point for the drogue parachute to the bulkhead of the launch vehicle. This connection maintains slack in the shock cord that runs from the toggle to the top of the main deployment bag, tethering the drogue to the top of the main deployment bag.

Figure 30: ARRD assembly.

During main event, the shock cord is freed from the ARRD, allowing the drogue to now act as a pilot chute for the main, pulling the deployment bag and main parachute from the recovery bay as seen in Figure 31.

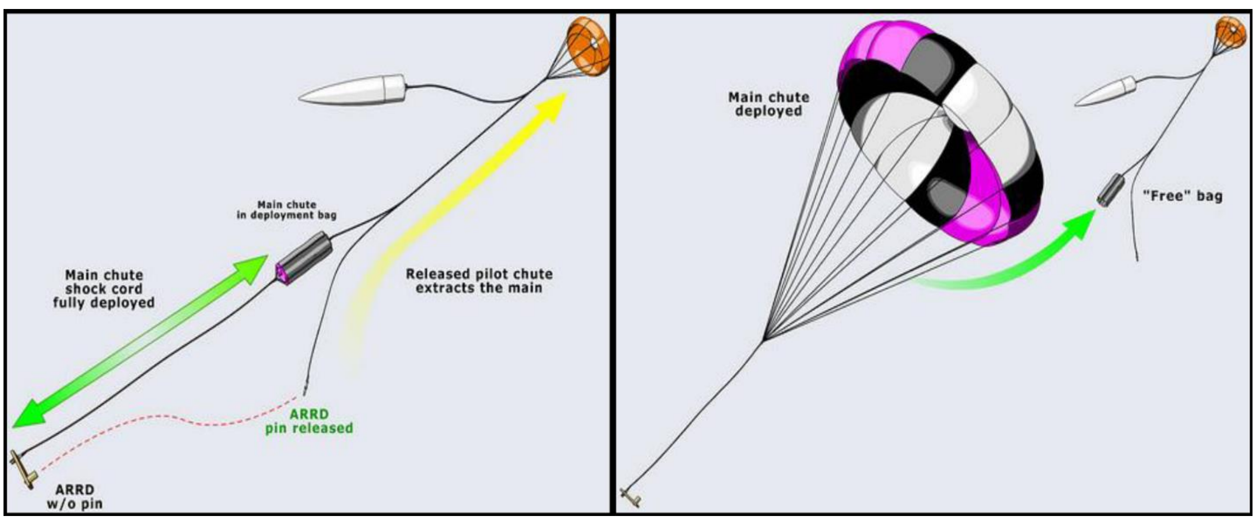


Figure 31: Payload recovery deployment.

Each deployment will be triggered by a redundant set of two PerfectFlite StratologgerCF's for each recovery bay. The PerfectFlite StratologgerCF's altimeter records its altitude at a rate of 20Hz with 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 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.

6.2.2 Toroidal Parachute Design

The main parachute's toroidal design was chosen to decrease mass, volume, and complexity while also having an increase in drag properties. This choice was made and implemented during the 2016-2017 NSL season and has numerous successful previous flights onboard the team's 2016-2017 Typhon Heavy launch vehicle. The toroidal design uses a more shallow curve compared to that of a hemispherical parachute as seen in Figure 32, resulting in a 19% drop in material use. This allows for a smaller packed size and less mass. The toroidal parachute also has a recorded coefficient of drag of roughly 1.4 compared to a hemispherical which has been documented as 0.62 to 0.77. This allows for smaller inflated diameters, less mass, and less volume.

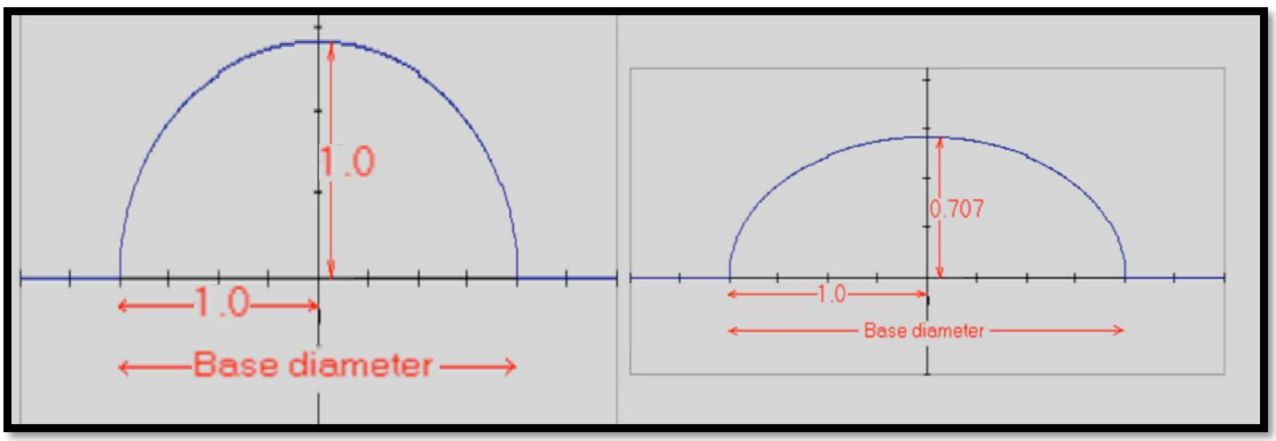


Figure 32: Hemispherical vs. toroidal parachute.

6.2.3 Opening Force Dampener

An 89 in. toroidal main parachute was manufactured by the team during the previous season and flown on every flight of Typhon Heavy as the booster recovery system. It can be seen in Figure 33. This parachute saw excessive opening forces due to its geometry and high drag coefficient. During the 2016-2017 season, two of the toroidal parachutes were fitted with these reefing rings in order to prevent the lines from snapping during deployment. This proved successful and eliminated the problem. The 89 in. parachute was fitted with a reefing ring as seen in Figure 34 and drop tested to observe the opening process. The reefing ring is slipped over the shroud lines of a parachute to cinch the canopy closed and to cause slight friction during opening resulting in a slower opening and a more gradual opening shock force.

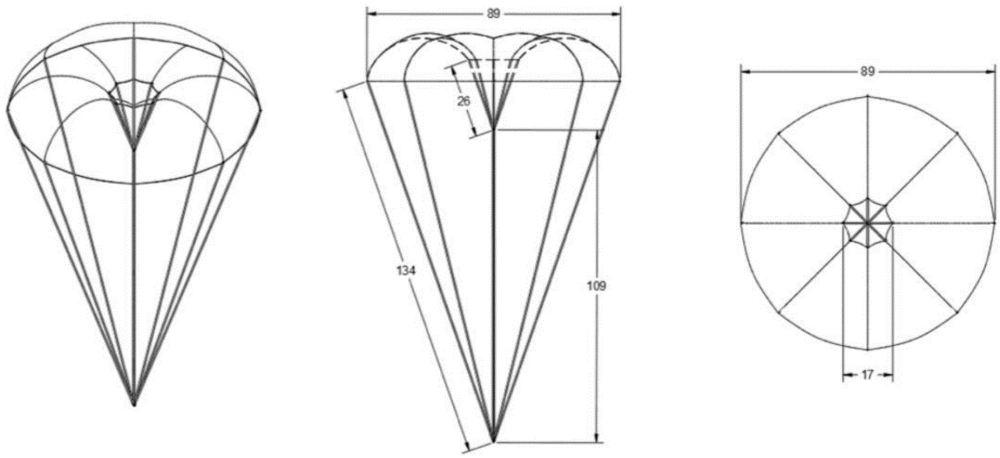


Figure 33: Toroidal parachute.

Figure 34: Reefing ring.

Tests proved successful in noticeably slowing the opening of the deployed parachute and lessening the intense opening force that is caused. This will prove useful in reducing damage to electronics or sensitive payload equipment during main deployment events.

6.2.4 Separation Experimentation

The payload is sensitive to the black powder charge separation event occurring between the payload bay and booster recovery bay on decent. To solve the problem of residue coating the instruments or the concussive properties of the black powder damaging sensors, three precautionary methods were chosen. The first of which was the use of a shield which would see a force, in blue, from the black powder separation charge and act as a bulkplate for the payload section, then separate with the bottom half of the rocket as it falls away by being tethered to the top of the drogue, seen in red, in Figure 35. This also doubles as a mechanism for ensuring deployment of the drogue parachute. This is the most mechanically complex system and is unfavorable for that reason.

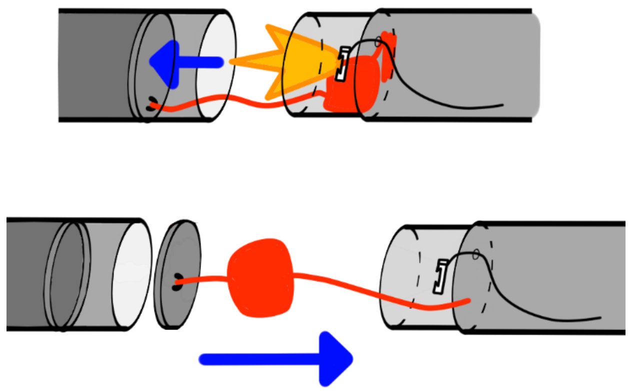


Figure 35: Shield system.

The second proposed method is to use a CO_2 separation method, which has been previously researched and developed. The system, as seen in Figure 36, consists of a pair of redundant cold gas canisters that expel their contents into the intended bay for separation in place of black powder charges. This eliminates the need of a shield, however, the pressure spike will still affect the sensors located on the payload. This effect is not substantial when the lack of residue expelled into the payload bay is considered.

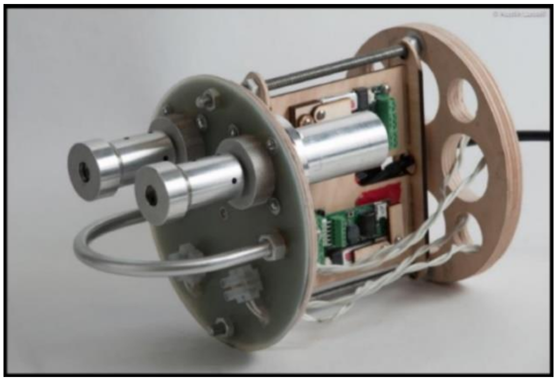


Figure 36: CO_2 Separation system.

The third and simplest solution is to encase the black powder charges in directional tubes to expel the contents away from fragile equipment, seen in Figure 37 while still producing a pressure change. This again includes the high-pressure spike in the payload bay, but the explosive heat and residue effects are less significant.

Figure 37: Commercially available charge wells.

7 Technical Design: Payload

7.1 Payload Requirements

The experiment selected is the Deployable Rover with foldable solar cell panels. The payload will be designed to meet the following criteria:

1. The rover must be capable of being activated remotely upon landing.
2. The rover must be able to drive autonomously a distance of 5 feet away from the payload bay.
3. Upon reaching 5 feet, the rover will stop moving and deploy foldable solar panels.

Multiple design ideas were considered to accomplish these tasks as well as the task of ensuring that the orientation of the rover prior to deployment is ideal. Trade studies were performed to determine the design ideas that we will pursue and are shown in their respective section.

The results of the trade studies have determined that a tank style rover with solar panels that will be raised from their stowed configuration by a tether and deployed by a rotating mechanism will most reliably be able to accomplish these tasks. A trade study also determined that mounting the rover on a sled that is free to rotate inside the payload bay is the optimal solution to ensuring proper orientation prior to deployment. Upon reaching its final destination, the rover will use the power generated by the solar array to take pictures of the surrounding area. These pictures will then be posted to River City Rocketry's social media accounts following recovery of the vehicle.

The rover will be entirely contained within the payload bay of the rocket until receiving the deployment signal upon landing at which point it will exit the payload bay to perform its mission. Designs for the rover are still under consideration and subject to change. The rover in its flight configuration is shown below in Figure 38.

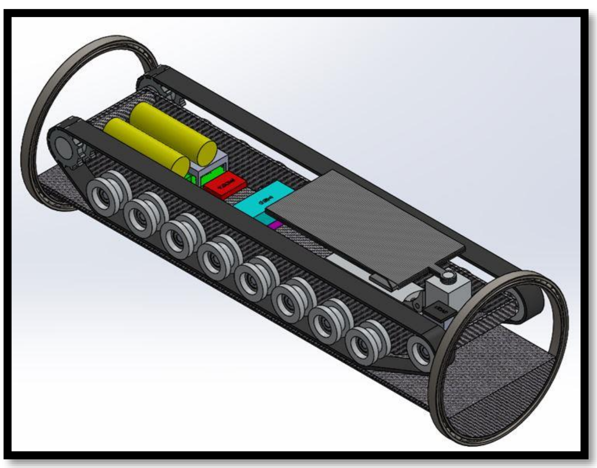


Figure 38: Rover flight configuration.

The primary design goal of the payload is to reliably complete the three tasks outlined above regardless of environmental conditions. The payload will be organized into multiple subsystems in order to organize the design tasks. Table 13 depicts the payload subsystems and their purposes.

Payload Subsystem	Description
Deployment Station	Transmitter station and receiver for payload activation.
Rover Orientation Correction System	System responsible for ensuring proper orientation of the rover prior to deployment from the payload bay.
Solar Array Structure	Mechanical structure to raise and deploy the solar panels upon reaching 5 feet.
Control System	System responsible for driving the rover's motors as well as deploying the solar panels
Rover Body	Systems responsible for supporting all electronic controls, drive mechanisms, and solar array structure.

Table 13: Payload subsystems.

The secondary design goal of the payload is ease of integration. This will be achieved by designing each system for compactness and weight reduction. In addition to this, each system will be independently removable from each other and from the payload bay. This will provide easy access to every system of the payload as well as reducing time to integration time by simply inserting the payload in the airframe section and locking it with set screws. The preliminary rover dimensions for the stowed and deployed configurations are shown below in Table 14.

Configuration	Weight (lb)	Width (in.)	Length (in.)	Height (in.)
Stowed	6	4.61	16	2.53
Deployed	6	12	16	5

Table 14: Approximate dimensions.

These dimensions and weight are approximates based on datasheets for components and size of structural systems.

7.2 Deployment Station

The deployment station of the payload is the system that will send the deployment signal to the rover after landing. The system will consist of a transmitter module, held by a team member behind the flight line, and a paired receiver module inside the payload bay. The transmitter-receiver pair will be two HC-12 433 SI4463 Wireless Serial Radio Modules. A pushbutton located on the transmitter will be used to send the deployment signal. The justifications for this remote radio module are stated below.

7.2.1 Deployment Station Hardware

HC-12 433 SI4463 Wireless Serial Radio Module

This module has a maximum open field range of 1 km which exceeds the recovery range for the field. This range will be verified by ground testing prior to use. The package size of the module is 15mm x 28mm allowing for easy integration of the receiver into the airframe. This system uses RX/TX communication which will be linked to the control electronics of the rover. The radio module mounted in the vehicle will receive power from the rover's microcontroller board and sends data to software serial ports that will be created. The wireless module is shown below in Figure 39.

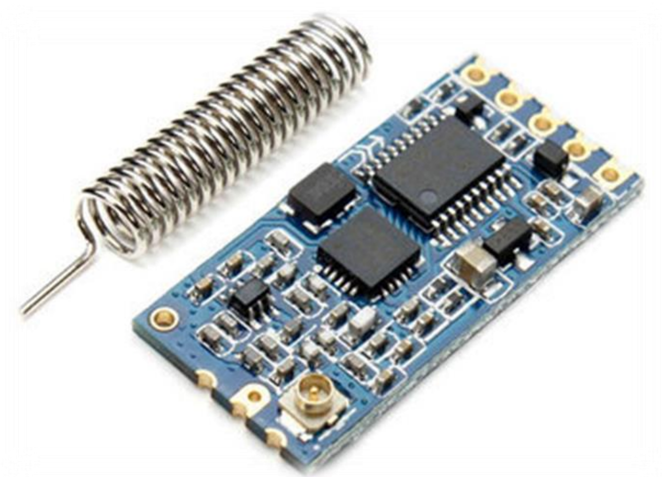


Figure 39: HC-12 wireless serial radio module.

Upon receiving the signal from the deployment station and confirming upright orientation, the rover will drive away from the deployment station, disconnecting the male/female jumper connection between them. This allows the wireless module to remain fixed to the airframe eliminating the need for removable antennas or a moving antenna assembly to deploy the rover.

The orientation and shape of the antennas will be determined through experimentation. To avoid orientation problems with the rover body being on top of the antenna, multiple antennas will be used. Multiple antennas connecting together creates complex interactions and interference. For this reason, using multiple receiver modules is being considered.

7.3 Rover Orientation Correction System

The Rover Orientation Correction System (ROCS) will ensure proper orientation of the rover prior to deployment using a system of bearings and a sled to support the rover. This system will perform during four phases of the mission. These phases as well as the operation of the ROCS is detailed below in Table 15.

Phase	Operation
Preflight Integration	The rover will be secured to the ROCS and upper recovery bulkplate using a locking mechanism. The entire payload will then be integrated into the payload bay and secured using set screws.
During Flight	The ROCS and its locking mechanism will keep the rover from being damaged during ascent and from falling out of the payload bay during descent.
Landing	The ROCS will allow the rover to roll freely and independently as the payload bay comes to rest on the ground.
Deployment	Signal will be sent to deploy the payload at which time the locking mechanism will disengage allowing the rover to begin its mission.

Table 15: ROCS phases and operation.

This system is being designed with the intent that the entire assembly is completely removable from the payload bay. This will allow for more efficient integration prior to the launch of the vehicle as well as recovery of the system.

7.3.1 ROCS Trade Study

A trade study determined that a system utilizing bearings capable of rotating a sled holding the rover around the interior of the airframe is the optimal solution for this system. Other designs considered in the study involved bearings integrated into the body of the rover allowing it to rotate around a central rod and linear actuator that would roll the payload bay into the desired orientation prior to deployment of the rover. The trade study results can be seen below in Figure 40.

Orientation Correction Trade Study							
Options:		Center Bearings		Perimeter Bearings		Actuators	
Mandatory Requirements							
Achievable within 1 season		Yes		Yes		Yes	
System will ensure correct orientation of rover		Yes		Yes		Yes	
Categories	**Weights**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Integration	20.00%	6	1.2	9	1.8	3	0.6
Simplicity of Design	15.00%	7	1.05	9	1.35	2	0.3
Manufacturability	15.00%	8	1.2	10	1.5	1	0.15
Affordability	10.00%	10	1	5	0.5	2	0.2
Possible Affect on Ascent Attitude	10.00%	10	1	10	1	3	0.3
Payload Weight	10.00%	8	0.8	6	0.6	2	0.2
Team Member Interest	5.00%	3	0.15	9	0.45	10	0.5
Uniqueness	5.00%	3	0.15	5	0.25	10	0.5
Impact on Size of Rover	10.00%	7	0.7	4	0.4	10	1
Total Score	**100%**		72.50%		78.50%		37.50%

Figure 40: ROCS trade study.

The categories scored for the trade study as well as their meaning are outlined below in Table 16.

Category	Description
Integration	Ease of integration into the launch vehicle with the rover.
Simplicity of Design	The lack of complex mechanisms that could lead to project failure.
Manufacturability	The ability to manufacture the design with the resources at our disposal.
Affordability	The cost effectiveness of the design.
Possible Effect on Ascent Attitude	Possible effect on the flight of the launch vehicle during ascent.
Payload Weight	Effect of the design on the overall weight of the payload.
Team Member Interest	Interest level of the team members involved in designing and manufacturing the system.
Uniqueness	Rating based on the commonality of the design.
Impact on Size of Rover	Impact that the ROCS design dimensions would have the maximum rover dimensions.

Table 16: ROCS trade study categories.

7.3.2 ROCS Sleeves and Bearings

A set of two carbon fiber sleeves with outer diameters slightly smaller than the inner diameter of the payload bay will be used for securing a set of two large diameter bearings inside the payload bay. A shoulder will be epoxied to each sleeve on both sides of the bearings to mitigate potential damage to the bearings due to high G forces at launch and landing. The shoulders will extend to the edge of the inner diameter of the bearings to provide maximum support and reduce slop. One locating triangle will be cut out of the forward sleeve with a corresponding triangle being epoxied to the interior of the payload bay. This will ensure that the sleeve is integrated in the same orientation every time. Set screws will secure the sleeves, and thus the outer ring of the bearings, in the payload bay.

7.3.3 ROCS Sled

A sled will be mounted to the inner ring of both bearings. A male T-slot protruding from the top of the sled will be matched with a female T-slot on the under-side of the rover's body securing the rover to the sled in all directions except along the axis of the rocket. This allows the rover to roll independent of the payload bay while keeping the rover from being damaged by hitting the interior walls of the payload bay. The sled will be made of carbon fiber and the male T-slot will be made out of aluminum. The preliminary model of the ROCS is shown below in

Figure **41** with a cross section of the system shown in Figure 42.

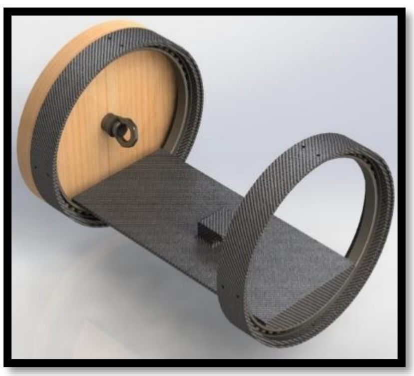


Figure 41: Preliminary ROCS ISO view.

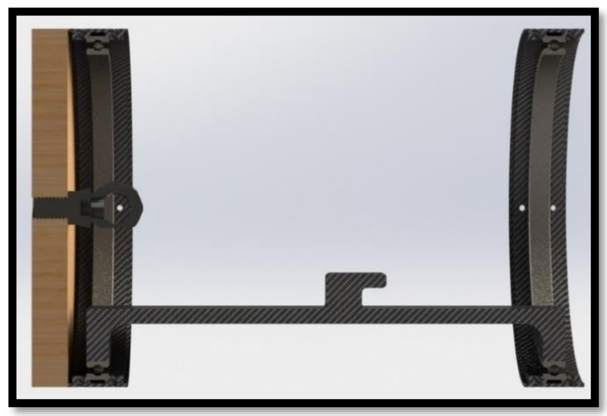


Figure 42: Preliminary ROCS section view.

The male T-slot on the sled and female T-slot on the rover can be seen below in Figure 43.

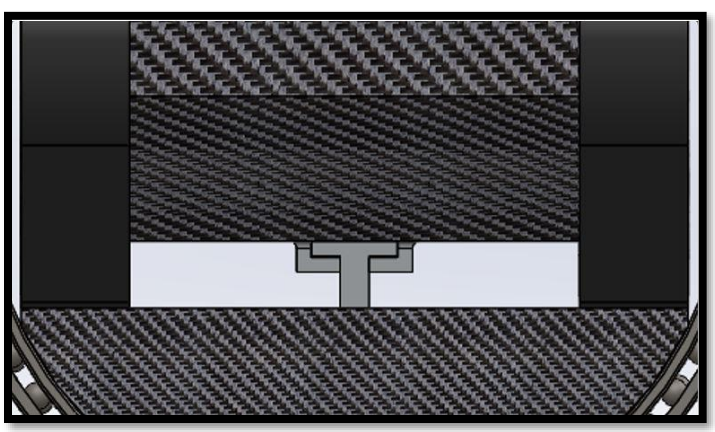


Figure 43: T-slot design.

7.3.4 Rover Locking Mechanism

Two designs for the Rover Locking Mechanism (RLM) are being considered at this time. Further research and testing will determine which design is chosen to pursue further. The two design ideas being considered are explained below.

ARRD Mounted on Rover

The first of these designs is to mount an ARRD to the rear of the rover. The shackle on the ARRD will be tethered to an eye bolt in the recovery bulkplate that is forward of the ROCS. This will keep the rover secured along the axis of the launch vehicle. Upon landing, a small black powder charge inside the ARRD will be ignited by the control electronics. This will release the shackle and allow the rover to drive itself off the sled. ARRDs have been tested to withstand two tons which greatly exceeds the maximum forces expected to be seen by the system.

In order to ensure safety of all team members, this design will require that the system be initiated after the rocket is upright on the launch pad.

Solenoid Lock

A small push-pull solenoid will be mounted to the rear of the rover. The armature will be extended through two bushings. One bushing connected to the rover body and the other bushing connected to the sled will take any loads off of the armature of the solenoid mitigating risk of damage to the coil. The configuration will be such that the rover is locked in while the coil is not energized as a safety measure. Upon landing, the control electronics will retract the armature of the solenoid allowing the rover to drive itself off the sled.

This system does not require black powder to be used meaning that the rover’s control electronics can be powered on prior to integration.

7.3.5 Solar Array Structure

The Solar Array Structure (SAS) will support and protect the solar panels during flight and deployment of the rover. When the rover reaches a distance of five feet from the vehicle’s payload bay, this system will raise the solar panels giving them clearance from the rest of the rover. The panels will then be deployed from their stowed configuration using a motor mounted inside the structure’s base. The SAS is shown in its stowed and deployed configurations below in Figure 44 and Figure 45.

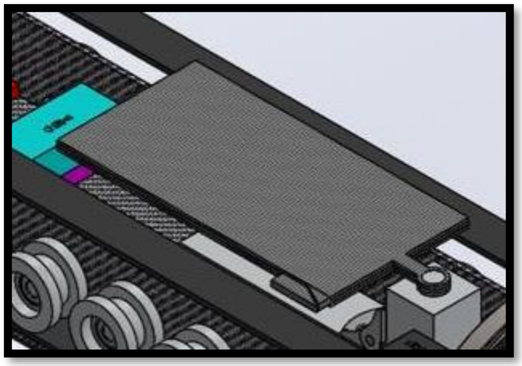


Figure 44: SAS Stowed.

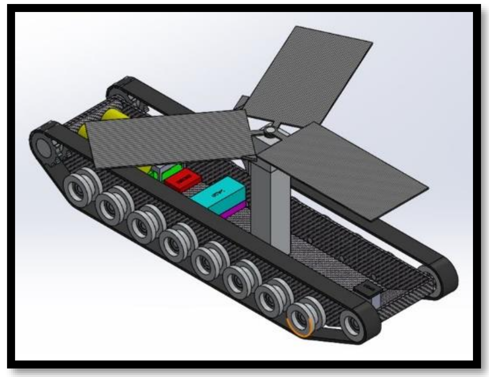


Figure 45: SAS Deployed.

7.3.6 SAS Lower Section

The lower section of the SAS will be tethered to the payload bay. During the flight of the launch vehicle, this section will be locked in its stowed configuration by a solenoid. Upon receiving the deployment signal, this solenoid lock will disengage. After the rover has reached the 5-foot threshold, the tether connecting this structure to the airframe will be at full length. The hinge on the lower section of the structure will allow this tether to pull the tower upright while the rover continues forward. When the lower section of the SAS raises to its final position, a locking pin will keep it raised and a limit switch will be activated stopping the rover's drive motors. This limit switch will also be used by the electronic controls to begin deployment of the solar panels via a small motor mounted inside the SAS lower section.

7.3.7 SAS Upper Section

The upper section of the SAS which will support the panels consists of three thin leaves stacked on top of each other. These leaves will be connected to a central shaft. The shaft will be connected to the motor in the lower section of the SAS at this stage. The motor will begin to spin which will separate the leaves from each other bringing them to their final positions. The motor will then stop rotating and hold the panels in place while energy is collected by the panels.

This leafed design was chosen from a field of four design candidates as the result of a trade study. The results of this study are displayed below as Figure 46.

Solar Array Trade Study									
Options:		180 Degree Flip		Tower Rotate		Tent Style/Origami		Zig Zag	
Mandatory Requirements									
Achievable within 1 season		yes		yes		yes		yes	
Satisfies NASA requirement of Foldable		yes		yes		yes		yes	
Categories	**Weights**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Integration	20.00%	10	2	6	1.2	5	1	8	1.6
Solar Array Area	15.00%	6	0.9	7	1.05	10	1.5	6	0.9
Simplicity of Design	15.00%	8	1.2	7	1.05	5	0.75	7	1.05
Affordability	15.00%	8	1.2	6	0.9	4	0.6	6	0.9
Uniqueness	15.00%	1	0.15	10	1.5	9	1.35	4	0.6
Payload Weight	10.00%	8	0.8	6	0.6	7	0.7	7	0.7
Team Member Interest	5.00%	0	0	10	0.5	10	0.5	3	0.15
Availability of Useable Panels	5.00%	10	0.5	10	0.5	10	0.5	10	0.5
Total Score	**100%**	67.50%		73.00%		69.00%		64.00%	

Figure 46: Solar array trade study.

Many of the categories used to perform this trade study are the same categories that were used for the Orientation Correction Trade Study. For this reason, refer to Table 16 for repeated category descriptions. Other category descriptions are listed below in Table 17.

Category	Description
Solar Array Area	Total surface area of all solar panels.
Availability of Useable Panels	The availability of commercial solar panels that could be used for each design.

Table 17: Solar array trade study categories.

7.3.8 Solar Panels

There will be a total of three thin flexible solar panels mounted on the three leaves of the SAS. After deployment, these panels will harvest energy. Justifications for the panels are stated below.

PowerFilm Solar MPT3.6-150 Solar Panels

These panels were chosen for their minimal thickness while maintaining a large surface area. The overall dimensions of the panels are 5.75 in. x 2.91 in. x 0.00866 in. Three panels will provide a total of 50.2 in.^{2} of operational area generating 1.08 Watts. The MPT3.6-150 is shown below in Figure 47.

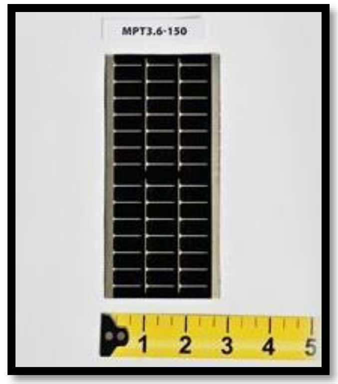


Figure 47: MPT3.6-150 solar panel.

7.3.9 Control System

The Control System of the rover consists of the hardware and software involved with the autonomous driving of the rover, deployment of the solar panels, data logging, and pictures. This system will receive the deployment signal from the Deployment Station, release the locking mechanism, control all sensors and motors, and finally take pictures. The components and functions involved in the Control System are outlined below.

7.3.10 Control System Electronics Hardware

Adafruit Feather M0 Bluefruit LE Microcontroller

The Bluefruit version of the Feather M0 microcontroller will be used to run all of the software for the payload. The board is supported by the Arduino IDE and relevant libraries. This controller contains 20 GPIO pins, is compatible with I2C devices, and has on-board battery charging making it ideal for operating a system with multiple sensors and outputs. This Feather has built-in Bluetooth and app building capability for testing purposes. The Feather Bluefruit is shown below in Figure 48.

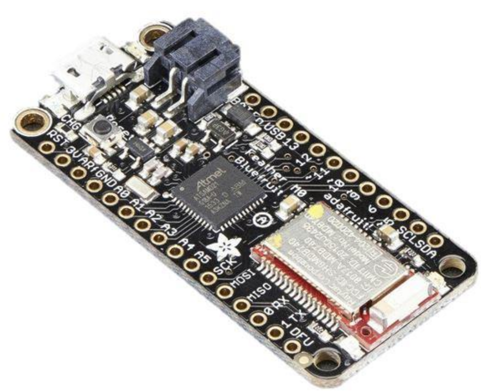


Figure 48: Adafruit Feather M0 Bluefruit LE.

7.3.11 Adafruit FeatherWing Motor Shield

This motor shield acts as a driver for the motors on the rover. The shield was designed as an add on to the Feather microcontroller family with a stackable design. This greatly reduces the size of the controls while still being capable of driving the two DC drive motors and the one DC solar panel deployment motor from the same shield. The device is shown below in Figure 49.

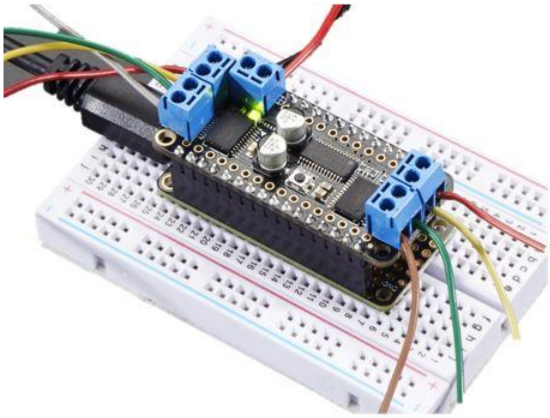


Figure 49: Adafruit FeatherWing motor shield.

Adafruit FeatherWing Adalogger

The FeatherWing Adalogger is a stackable add-on to the motor shield and Feather M0 microcontroller listed above. This device will be used for the purposes of logging data as well as images taken by the rover. A battery backed real time clock (RTC) provides accurate time stamps for logging of data on the board's removable microSD card. The device is shown below in Figure 50.

Figure 50: FeatherWing Adalogger.

Adafruit BNO055 9DOF IMU

The BNO055 IMU will be used to accurately measure the absolute orientation of the rover prior to deployment. This IMU runs at an output data rate of 100Hz providing very accurate measurements. If the ROCS has not performed appropriately and the payload is not oriented correctly, the rover will not detach from the sled to avoid damage to any of the components and systems on the rover. The sensor is shown below in Figure 51.

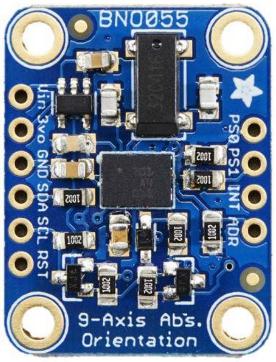


Figure 51: BNO055 9DOF IMU.

VL53L0X Time of Flight Distance Sensor

The VL53L0X will be used to determine an optimal path for the rover after exiting the payload bay. This sensor has an operating detection range of 1.18 in. to 39.4 in. This will be mounted to the front of the rover and swept horizontally by a servo motor. Each sweep of the area in front of the rover will be used to determine if a large object that cannot be overcome by the rover is in its driving path. If this is the case, the rover will be maneuvered around the object. The VL53L0X is shown below in Figure 52.

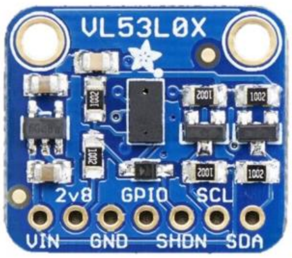


Figure 52: VL53L0X Distance Sensor.

ArduCAM Mini Camera Module

This mini camera will be mounted on the rear of the rover facing forward. Upon the rover reaching its final position, the camera will use the power generated by the solar array to take pictures of the rover and the area around it at a resolution of 1600x1200. The module has a 5-megapixel camera that can be controlled by a microcontroller via I2C and SPI protocol. The module is shown below in Figure 53.

Figure 53: ArduCAM Mini Camera Module.

7.3.12 Motors

Tower Pro SG92R Micro Servo

The SG92R Micro Servo will be used to sweep the distance sensor horizontally in order for the sensor to provide data on the terrain in front of the rover. The motor is low power and capable of being mounted on the front of the rover. The SG92R is shown below in Figure 54.

Figure 54: SG92R Micro Servo motor.

Actobotics Planetary Gear Motors

Two planetary gear drive motors will be used to move the rover out of the airframe and to its final position 5 feet away. These motors will be capable of 52 RPM and 1.52 ft.*lb of torque which will be capable of managing the load of the rover while maintaining very small dimensions. Bevel gears will be mounted on the shaft and connected to the drive gear of the rover’s treads. The motor is shown below in Figure 55.

Figure 55: Planetary gear drive motor.

Pololu 1000:1 Micro Metal Gearmotor

This small motor will be mounted inside the lower section of the SAS and will be used to unfold the solar panels. The motor is capable of 32 RPM and 0.65 ft.*lbs of torque allowing it to unfold the panels and hold them steady in their final position. This motor was chosen due to its low power consumption and high torque relative to its small size. The motor is shown below in Figure 56.

Figure 56: Micro Metal Gearmotor.

7.3.13 Solenoid

Small Push-Pull Solenoid

A small solenoid will be used to lock the lower section of the SAS during the flight of the launch vehicle. This solenoid has a 5.5 mm throw in the push and the pull. The armature will be retracted to unlock the SAS in order to reduce the amount of power that the solenoid draws and to ensure safety in the case of an electronics failure. The solenoid is shown below in Figure 57.

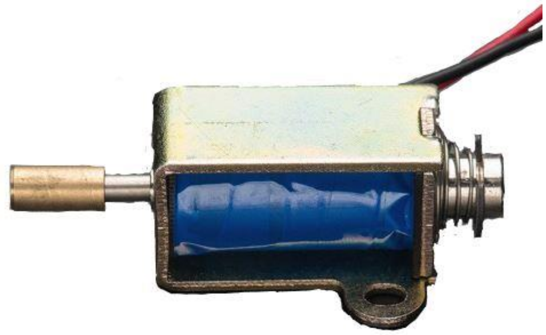


Figure 57: Push-Pull Solenoid.

7.3.14 Control System Batteries

Motor Battery

The battery to be used to power the two drive motors and one solar panel deployment motor will be an 11.1V 400mAh 3S-50C rechargeable LiPo battery. This will provide over 30 minutes of continuous running of the two drive motors. Verification of battery life will be performed through testing. The battery is shown below in Figure 58.

Figure 58: 11.1V 400mAh LiPo.

Controller Battery

The battery to be used to power the microcontroller will be a 3.7V 500mAh rechargeable LiPo battery. This battery is recommended by Adafruit to be used with the Feather microcontroller. The built-in recharging feature of the Feather will provide easy charging of the battery. The 500mAh of battery life will be sufficient to keep the board powered throughout the flight of the rocket and operation of the rover. Battery life will be verified through testing. The battery is shown below in Figure 59.

Figure 59: 3.7V 500mAh LiPo.

These components will all be integrated in the most compact configuration to ensure that the rover will easily fit within the payload bay and be able to exit the airframe under its own power.

7.4 Rover Body

The rover body will be made of carbon fiber to minimize its weight while maximizing space for electronics and durability. The rover body will serve as the bay for the electronics and the deployable solar panels. The rover body will be secured using the RLM. The expected dimensions of the rover body are listed below in Table 18.

Width (in.)	Length (in.)	Height (in.)
4.61	16	2.53

Table 18: Rover Body Dimensions.

7.4.1 Wheel Design

A trade study was done to determine the best style of wheels for the rover. The study determined that regular wheels were the best option, but after more research tank style tracks were chosen. Tank style tracks will offer the most traction and stability for the environment the rover will be in. On the ends of the rover the tracks will be angled upward to improve climbing ability. Two motors will drive the two tracts separately so the rover can maneuver around obstacles if needed. The drive wheels will be the rear-most wheels. More research and testing will be done to ensure the optimal wheel design. The trade study and a visual of the track design can be seen below in Figure 60 and Figure 61.

Wheels Trade Study									
Options:		Augers		Standard Tires		Tank Treds		Treds/Tires Combo	
Mandatory Requirements									
Achievable within 1 season		yes		yes		yes		yes	
Categories	**Weights**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Integration	30.00%	8	2.4	9	2.7	7	2.1	7	2.1
Drive Controls/Mechanism Simplicity	30.00%	9	2.7	10	3	8	2.4	4	1.2
Team Member Interest	20.00%	3	0.6	4	0.8	8	1.6	5	1
Terrain Handling	20.00%	8	1.6	6	1.2	10	2	10	2
Total Score	**100%**		73.00%		77.00%		81.00%		63.00%

Figure 60: Wheels trade study.

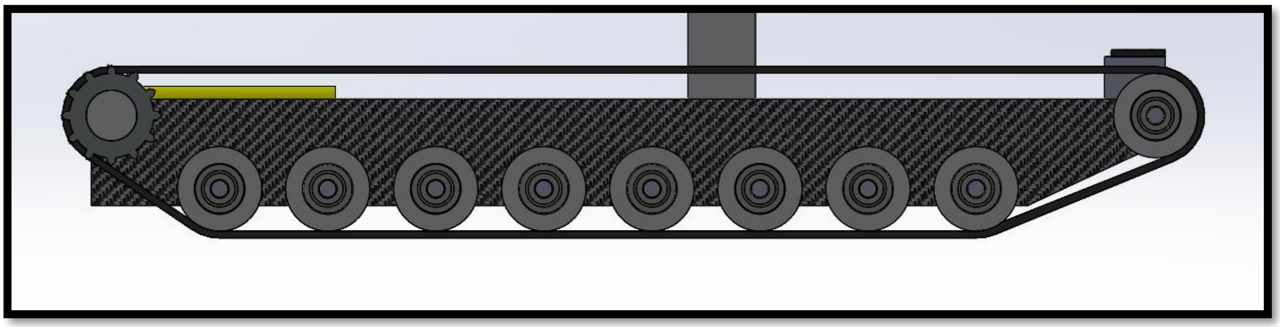


Figure 61: Wheel design.

Passive Wheel Design

The non-driven wheels will be passive and will be machined out of aluminum. These will have bearings connected to their shaft to allow them to rotate freely. The wheels will have a circumferential groove in the middle that will align the track. The passive wheel design is shown below in Figure 62.

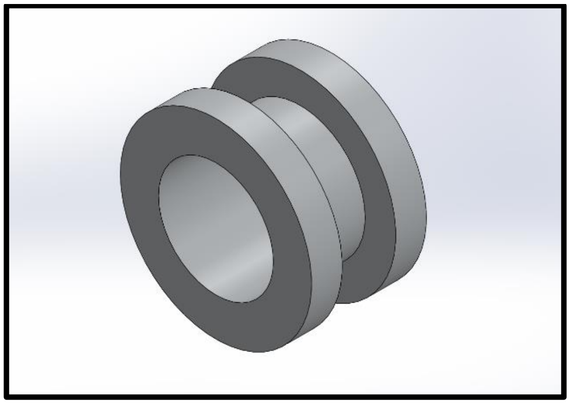


Figure 62: Passive wheel design.

7.4.2 Electronics Bay

The cavity of the rover body will serve as the electronics bay. The motors will be mounted on top of the batteries at the back of the rover. The feather and shield will be mounted on top of each other directly forward of the motors. The distance sensor will be mounted on top of the servo and that assembly will be mounted at the front of the rover to insure the sensors field of view will not be obstructed. A basic layout of the electronics can be seen below in Figure 63.

ITEM NO.	PART	QTY.
1	Rover Chassis	1
2	Driven wheel	2
3	Rover wheels	18
4	Rover Track	2
5	60355K44	18
6	Passive Wheel Axil	18
7	Rover wheel axis	2
8	BNO055	1
9	controller battery	1
10	Feather	1
11	Lidar	1
12	motor battery	1
13	servo	1
14	shield	1
15	Rover Motor Mount	1
16	Tower Panel Assembly	1
17	91251A243	4
18	Motor Mock	2
19	Motor Shaft	2

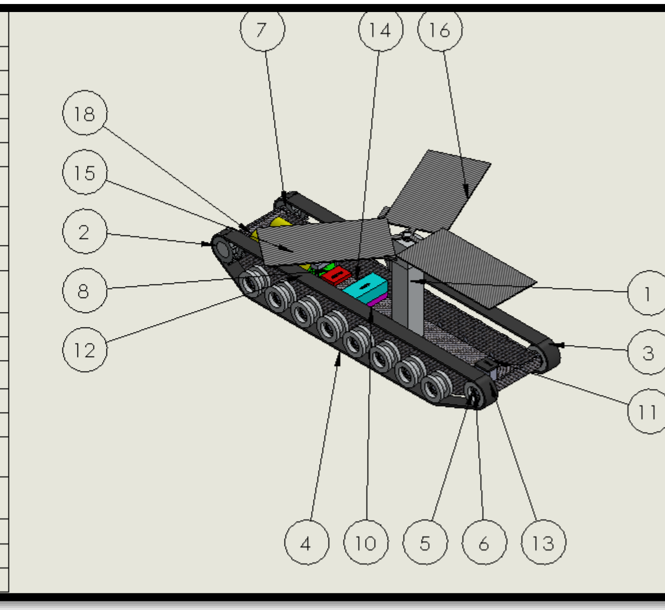


Figure 63: Electronics layout.

7.4.3 Drive System

After the activation of the rover, the two motors will be powered and begin turning the tracks. Two bevel gears per motor will transfer the rotational motion of the motor to the drive shaft. Bevel gears were chosen for their ability to transfer rotational motion 90 degrees. A visual representation of these gears is shown in Figure 64.

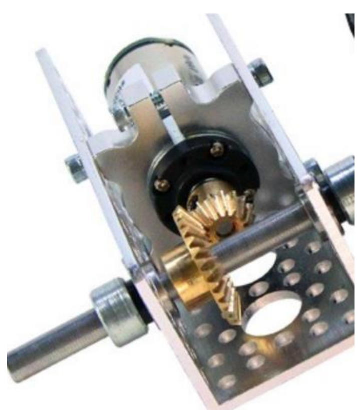


Figure 64: Bevel gears.

7.4.4 Future Testing and Analysis

Parameters to be tested with regard to the rover's design and description are listed below in Table 19.

Parameter	Description
Rover Wheels	Tests will be performed to ensure the wheels and tracks of the rover remain functional after vibrations experienced during flight.
Motors	The motors will be tested with the rover on multiple terrains to ensure they have the required torque to accomplish the mission.
Treads	Different style treads will be tested to determine the best design for an all-terrain rover. These different styles include rubber and metal treads.
Rover Body	Test will be conducted to ensure the rover body will remain in place on the sled during flight.

Table 19: Future testing and analysis.

7.5 Statement of Work Verification

The SOW verifications are listed below in Table 20.

Challenges	Solutions
The rover must be capable of being activated remotely upon landing.	The payload bay will contain a receiving radio module with a corresponding transmitting module behind the flight with a team member. The receiving module will be linked with the control electronics for the rover allowing for remote activation.
The rover must be able to drive autonomously a distance of 5 feet away from the payload bay.	The control electronics of the rover will operate without any team member control. These electronics will be responsible for controlling the two main drive motors as well as any other components on the rover.
Upon reaching 5 feet, the rover will stop moving and deploy foldable solar panels.	A set of solar panels will be mounted on the rover's body that will deploy upon reaching a distance of 5 feet from the payload bay. Energy harvested by these panels will be used to take pictures of the rover and the area around it.

Table 20: Challenges and solutions.

8 Project Plan

8.1 2017-2018 Timeline

The project timeline is shown below in Figure 65.

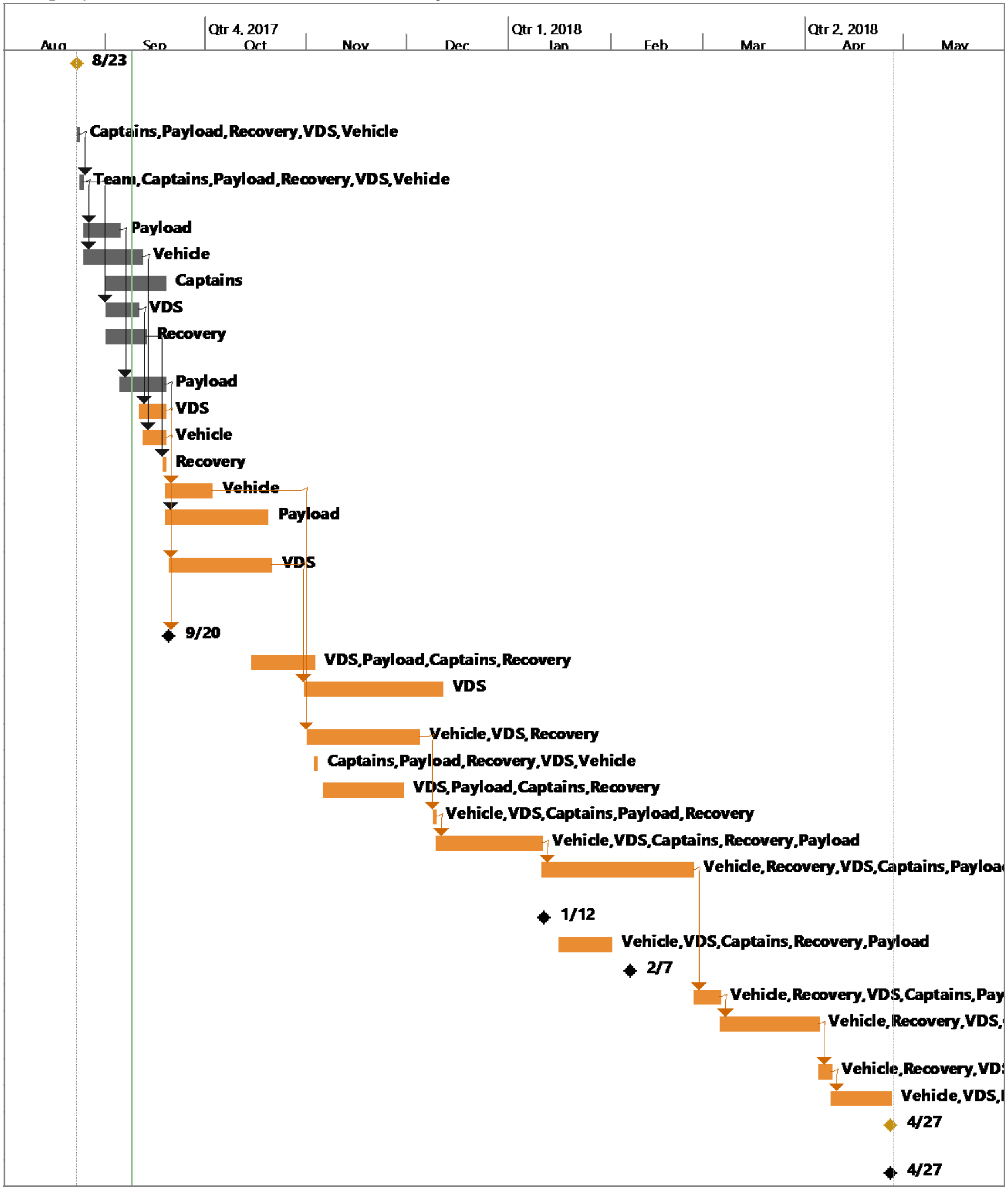


Figure 65: 2017-2018 Timeline.

8.2 Proposal Timeline

The proposal timeline is shown below in Figure 66.

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Physical % Complete
1			NASA Student Launch Mission Statement Release	0 days	Wed 8/23/17	Wed 8/23/17		Vehicle,VDS,P:	100%
2			RCR Mission Statement Release	1 day	Wed 8/23/17	Wed 8/23/17		Captains,Paylo	100%
3			Team Decision and Season Kickoff	1 day	Thu 8/24/17	Thu 8/24/17	2	Team,Captains	100%
4			Payload Concepting	7 days	Fri 8/25/17	Mon 9/4/17	3	Payload	100%
5			Vehicle Concepting	12 days	Fri 8/25/17	Mon 9/11/1	3	Vehicle	100%
7			Safety Proposal	12 days	Fri 9/1/17	Mon 9/18/1		Captains	50%
10			VDS Concepting	6 days?	Fri 9/1/17	Sun 9/10/17	3	VDS	100%
24			Recovery Concepting	8 days?	Fri 9/1/17	Tue 9/12/17		Recovery	90%
8			Payload Proposal	10 days	Tue 9/5/17	Mon 9/18/1	4	Payload	50%
11			VDS Proposal	6 days?	Mon 9/11/1	Mon 9/18/1	10	VDS	50%
9			Vehicle Proposal	5 days?	Tue 9/12/17	Mon 9/18/1	5	Vehicle	50%
25			Recovery Proposal	1 day?	Mon 9/18/1	Mon 9/18/1	24	Recovery	5%
12			Vehicle Designing	10 days?	Tue 9/19/17	Mon 10/2/1	9	Vehicle	0%
13			Payload Design and Testing	24 days?	Tue 9/19/17	Thu 10/19/17	8	Payload	0%
14			VDS sensor integration and reworking	24 days?	Wed 9/20/17	Fri 10/20/17	11	VDS	0%
29			Proposal Due	0 days	Wed 9/20/1	Wed 9/20/1	8,11,9	Captains,Paylo	0%

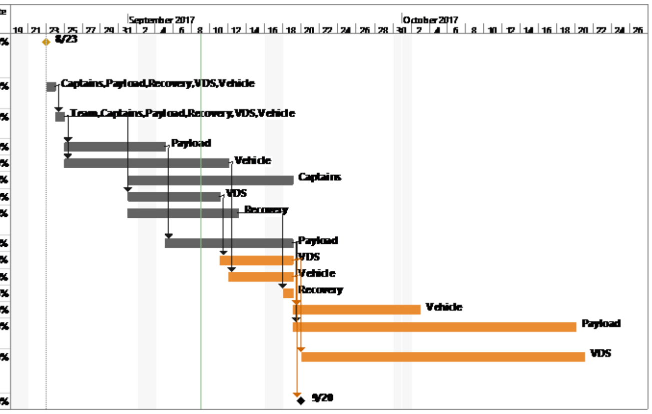


Figure 66 : Proposal Timeline.

8.3 PDR Timeline

The PDR timeline is shown below in Figure 67.

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Physical % Complete
15			PDR	16 days?	Sun 10/15/1	Thu 11/2/17		VDS,Payload,C	0%
17			VDS Data Acquisition	32 days?	Tue 10/31/17	Mon 12/11/17	14	VDS	0%
18			Subscale Build	24 days?	Wed 11/1/1	Mon 12/4/1	12	Vehicle,VDS,R	0%
30			PDR Due	1 day	Fri 11/3/17	Fri 11/3/17		Captains,Paylo	0%

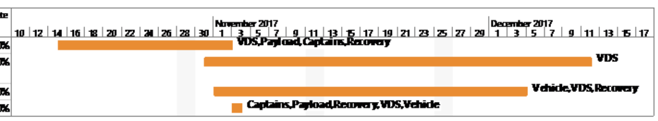


Figure 67: PDR Timeline.

8.4 CDR Timeline

The CDR timeline is shown below in Figure 68.Figure 65

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Physical % Complete
19			Subscale Flight	1 day?	Sat 12/9/17	Sat 12/9/17	18	Vehicle,VDS,C	0%
20			CDR	24 days	Sun 12/10/1	Wed 1/10/1	19	Vehicle,VDS,C	0%
22			Full scale Build and Flights	33 days?	Thu 1/11/18	Sun 2/25/18	20	Vehicle,Recov	0%
31			CDR Due	0 days	Fri 1/12/18	Fri 1/12/18		Captains,Paylo	0%
21			CDR Presentation	12 days?	Tue 1/16/18	Wed 1/31/1		Vehicle,VDS,C	0%

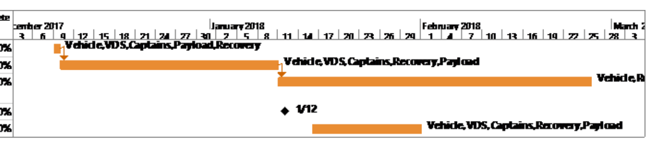


Figure 68: CDR Timeline.

8.5 FRR Timeline

The FRR timeline is shown below in Figure 69.

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Physical % Complete
23			FRR	6 days?	Mon 2/26/1	Mon 3/5/18	22	Vehicle,Recov	0%
32			FRR Due	0 days	Mon 3/5/18	Mon 3/5/18		Captains,Paylo	0%
26			Test Flights and Refinement	22 days?	Tue 3/6/18	Wed 4/4/18	23	Vehicle,Recov	0%
27			Competition	3 days?	Thu 4/5/18	Sun 4/8/18	26	Vehicle,Recov	0%
28			PLAR	14 days?	Mon 4/9/18	Thu 4/26/1	27	Vehicle,VDS,R	0%
33			PLAR	0 days	Fri 4/27/18	Fri 4/27/18		Vehicle,VDS,P	0%
6			Season Ended	0 days	Sat 4/28/18	Sat 4/28/18		Captains,Paylo	0%

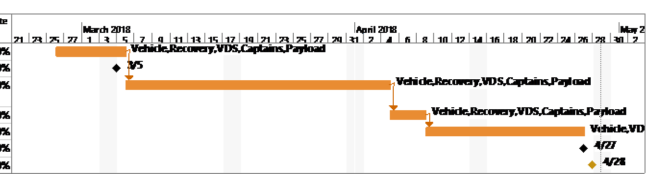


Figure 69: FRR Timeline.

8.6 Timeline Overview

The project timeline overview is shown in Table 21.

Task Name	Duration	Start	Finish	Predecessors	Resource Names	Physical % Complete
NASA Student Launch Mission Statement Release	0 days	Wed 8/23/17	Wed 8/23/17		Vehicle,VDS,Payload,Captains,Recovery	100%
Team Decision and Season Kickoff	1 day	Thu 8/24/17	Thu 8/24/17	2	Team,Captains,Payload,Recovery,VDS,Vehicle	100%
Payload Concepting	7 days	Fri 8/25/17	Mon 9/4/17	3	Payload	100%
Vehicle Concepting	12 days	Fri 8/25/17	Mon 9/11/17	3	Vehicle	100%
Safety Proposal	12 days	Fri 9/1/17	Mon 9/18/17		Captains	100%
VDS Concepting	6 days?	Fri 9/1/17	Sun 9/10/17	3	VDS	100%
Recovery Concepting	8 days?	Fri 9/1/17	Tue 9/12/17		Recovery	100%
Payload Proposal	10 days	Tue 9/5/17	Mon 9/18/17	4	Payload	100%
VDS Proposal	6 days?	Mon 9/11/17	Mon 9/18/17	10	VDS	100%
Vehicle Proposal	5 days?	Tue 9/12/17	Mon 9/18/17	5	Vehicle	100%
Recovery Proposal	1 day?	Mon 9/18/17	Mon 9/18/17	24	Recovery	100%
Vehicle Designing	10 days?	Tue 9/19/17	Mon 10/2/17	9	Vehicle	0%
Payload Design and Testing	24 days?	Tue 9/19/17	Thu 10/19/17	8	Payload	0%
VDS sensor integration and reworking	24 days?	Wed 9/20/17	Fri 10/20/17	11	VDS	0%
Proposal Due	0 days	Wed 9/20/17	Wed 9/20/17	8,11,9	Captains,Payload,Recovery,VDS,Vehicle	0%
PDR	16 days?	Sun 10/15/17	Thu 11/2/17		VDS,Payload,Captains,Recovery	0%
VDS Data Acquisition	32 days?	Tue 10/31/17	Mon 12/11/17	14	VDS	0%
Subscale Build	24 days?	Wed 11/1/17	Mon 12/4/17	12	Vehicle,VDS,Recovery	0%
PDR Due	1 day	Fri 11/3/17	Fri 11/3/17		Captains,Payload,Recovery,VDS,Vehicle	0%
PDR Presentation	18 days?	Mon 11/6/17	Wed 11/29/17		VDS,Payload,Captains,Recovery	0%
Subscale Flight	1 day?	Sat 12/9/17	Sat 12/9/17	18	Vehicle,VDS,Captains,Payload,Recovery	0%
CDR	24 days	Sun 12/10/17	Wed 1/10/18	19	Vehicle,VDS,Captains,Recovery,Payload	0%
Full scale Build and Flights	33 days?	Thu 1/11/18	Sun 2/25/18	20	Vehicle,Recovery,VDS,Captains,Payload	0%
CDR Due	0 days	Fri 1/12/18	Fri 1/12/18		Captains,Payload,Recovery,VDS,Vehicle	0%
CDR Presentation	12 days?	Tue 1/16/18	Wed 1/31/18		Vehicle,VDS,Captains,Recovery,Payload	0%
FRR	6 days?	Mon 2/26/18	Mon 3/5/18	22	Vehicle,Recovery,VDS,Captains,Payload	0%
FRR Due	0 days	Mon 3/5/18	Mon 3/5/18		Captains,Payload,Recovery,VDS,Vehicle	0%
Test Flights and Refinement	22 days?	Tue 3/6/18	Wed 4/4/18	23	Vehicle,Recovery,VDS,Captains,Payload	0%
Competition	3 days?	Thu 4/5/18	Sun 4/8/18	26	Vehicle,Recovery,VDS,Captains,Payload	0%
PLAR	14 days?	Mon 4/9/18	Thu 4/26/18	27	Vehicle,VDS,Recovery,Captains,Payload	0%
PLAR	0 days	Fri 4/27/18	Fri 4/27/18		Vehicle,VDS,Payload,Captains,Recovery	0%

Season Ended	0 days	Sat 4/28/18	Sat 4/28/18		Captains,Payload,Recovery,VDS,Vehicle	0%

Table 21: Project timeline overview.

8.7 Educational Engagement

Throughout the last five years University of Louisville River City Rocketry has reached over 8,000 members of the local community. Through our outreach, we have been able to give back to the state of Kentucky by educating our youth about engineering, math, and technology all while sharing our passion and knowledge for rocketry. Throughout the years we have worked to build and maintain relationships with organizations in our community while continuing to find new and innovative ways to reach people in our community. We aim to continually improve the quality of education we provide to our community.

8.7.1 Education Curriculum

River City Rocketry has developed an educational program that will be incorporated in this year's outreach program. Many of these activities have been used in the past and will continue to be done due to the success we have had.

Middle School Rocket Team mentorship

River City Rocketry has partnered with a local middle school team that is starting up. Following an introduction through our academic advisor, we will teach the students about the science behind rocket building and work with them about learning how to build up their team and to foster a successful program.

Lego Mindstorms Programming

Every year, local students work in teams on building and programming Lego Mindstorms 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. Students from a Lego team are shown in Figure 70.

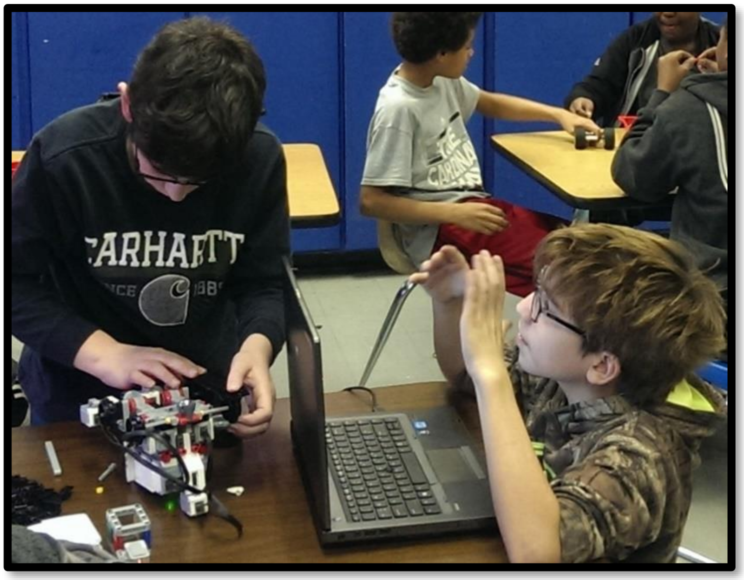


Figure 70: Students discuss designs and modifications to their robot.

8.8 Outreach Opportunities

8.8.1 Engineering Exposition (E-Expo)

Since 2006, the J.B. Speed School of Engineering Student Council has hosted the largest student-run event on the University of Louisville's campus called the 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 U of L'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 sixth 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 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 voiced interest in continuing their involvement so we are looking for our best turnout yet this year. A previous paper rocket E-Expo event is shown in Figure 71.

Figure 71: Team member, Denny, building rockets with students at E-Expo 2016.

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 we are looking to continue to build up that reputation.

8.8.2 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 with one event already scheduled for September 30th, 2017.

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 scout troops in educating the kids about the fundamentals of rocketry, while also giving them the opportunity to build and launch their own paper rockets.

8.8.3 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 Back to School Event for kids that had not yet been paired with a mentor through the program, shown in Figure 72. 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 72: Big Brothers Big Sisters Back to School Event (2017).

8.8.4 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 variety of people attend this event ranging from small children to adults with experience in the field. This gives the team an opportunity to talk to the community about our project and what it does. This is an informal setting which is perfect for interacting with visitors and answering their questions about the project, what the team does, and about rocketry in general.

8.8.5 Kentucky Science Center

During the 2015-2016 season, the team first came in contact with Andrew Spence, manager of public programs and events, that assisted in several events in the Louisville area. For this season the team will participate in the Youth Science Summit, Advanced Manufacturing, and National Engineers' Week at Kentucky Science Center. The team will be able to reach out to hundreds of young rocketeers and teach them about rocketry, engineering, and skills needed to succeed as an engineer.

The 2016-2017 competition rocket will be permanently featured in the Kentucky Science Center paper rocket exhibit.

8.9 Comprehensive Budget

The VDS budget is shown in Table 22.

VDS Budget			
Description	**Qty.**	**Price**	**Total**
¼ in. Thick 12 in. x 48 in. Delrin	1	$85.22	$85.22
1/8 in. Dowel Pins 3/4 in. Length (pkg of 25)	2	$10.63	$21.26

M3-16 mm Socket Head Cap Screws (pkg of 50)	1	$10.20	$10.20
SD/microSD 8Gb	2	$9.95	$19.90
Short Feather Male Headers - 12-pin and 16-pin Male Header Set	20	$0.50	$10.00
GPS	1	$39.95	$39.95
banana to alligator clip cables	1	$3.95	$3.95
Hall effect encoder cable	1	$5.00	$5.00
10-Pin Connector w/ Header, 0.1 in. Spacing	2	$2.90	$5.80
Encoder Cable	2	$1.11	$2.22
Male D-Sub Connector	2	$0.81	$1.62
Female D-Sub Connector	2	$0.87	$1.74
Power Switch	2	$2.11	$4.22
MegaMotor	1	$49.99	$49.99
Break Away Headers - 40-pin Male (Long Centered, PTH, 0.1 in.)	2	$0.75	$1.50
Teensy Header Kit	2	$1.50	$3.00
10 Pin Header	6	$0.50	$3.00
7.4V Lipo Battery	2	$5.20	$10.40
11.1V Lipo Battery	2	$26.90	$53.80
12 in. x 24 in. 6061 Aluminum plate .125 in. thick	1	$48.55	$48.55
Quick Lock Seals	1	$18.00	$18.00
AndyMark Neverest 40 DC Motor	2	$28.00	$56.00
10 Pin Receptacle	2	$0.54	$1.08
10 Pin Insurance	2	$0.19	$0.38
Standoff	10	$0.53	$5.30
Copper PCB sheets	2	$6.00	$12.00
teensy header pin	10	$0.66	$6.58
Banana Plug Post (Black)	2	$0.35	$0.70
Banana Plug Post (Red)	2	$0.35	$0.70
Protoboard	2	$12.49	$24.98
Vectornav 100 IMU	2	$530.00	$1,060.00
Break Away Headers - 40-pin Male (Long Centered, PTH, 0.1 in.)	2	$0.75	$1.50
Miscellaneous	1	$450.00	$450.00
TOTAL			**$2,018.54**

Table 22: VDS budget.

The Vehicle budget is shown in Table 23.

Vehicle Budget			
Description	**Qty.**	**Price**	**Total**
6k Carbon fiber tow, 4lbs	4	$57.68	$230.72

Epoxy	3	$141.95	$425.85
6061-T6 Aluminum sheet	1	$160.72	$160.72
¼ in. -20 threaded rod	4	$4.46	$17.84
1/4 in. -20 Hex Nuts	1	$6.74	$6.74
1/4 in. plywood	1	$12.60	$12.60
4-40 Black Nylon Shear Pins	1	$5.42	$5.42
18-8 Stainless Steel Shoulder Screw, 1 in. Long Shoulder, 1/4 in. -20 Thread	9	$6.06	$54.54
18-8 Stainless Steel Shoulder Screw, 1/ in. Diameter in. Long Shoulder, 10-32 Thread	9	$2.65	$23.85
Aerotech L2200G-PS	6	$249.99	$1,499.94
6 in. X 12 in. Carbon Fiber coupler	5	$110.00	$550.00
Featherweight screw switches	8	$5.00	$40.00
Paint-job/wrap	1	$400.00	$400.00
Glenmarc G5000 Epoxy	2	$69.99	$139.98
Stratologger CF	4	$49.46	$197.84
Rail buttons	3	$10.00	$30.00
E-Matches	2	$15.79	$31.58
Ejection Charge Canisters	50	$0.50	$25.00
Sub-scale Blue Tube (3 in. diameter, 48 in. length)	2	$29.95	$59.90
Sub-scale Blue Tube coupler	1	$9.95	$9.95
Sub-scale motor	2	$50.00	$100.00
Sub-scale motor retainer	1	$31.95	$31.95
Carbon fiber sheet 24 in. x 48 in. x 0.125 in. thick	1	$422.00	$422.00
MDF for nose cone mold	1	$15.99	$15.99
7781 x 5 in. 8.9oz Fiberglass Prepreg Fabric	1	$47.05	$47.05
Shoulder Length Poly Gloves - 35 in. Clear	1	$17.00	$17.00
Shipping	1	$500.00	$500.00
Miscellaneous	1	$500.00	$500.00
Potential replacement parts	1	$750.00	$750.00
Heat shrink tape	2	$17.86	$35.72
Total			**$6,342.18**

Table 23: Vehicle budget.

The Recovery budget is shown in Table 24.

Recovery Budget			
Material	**Qty.**	**Cost**	**Total**
Large Spool of Thread	4	$30.00	$120.00
Reefing Rings	6	$3.00	$18.00
Silver Sharpies (36)	1	$29.00	$29.00
Sewing Machine Repair	1	$160.00	$160.00

Stronger Shockcord (ft.)	200	$0.55	$110.00
Spectra Line	4	$30.00	$120.00
Possible CO2 deployment	4	$174.00	$696.00
Total			**$1,253.00**

Table 24: Recovery budget.

The Payload budget is shown in Table 25.

Payload Budget			
Description	**Qty.**	**Price**	**Total**
Adafruit Feather M0 Bluefruit LE	2	$29.95	$59.90
Adafruit FeatherWing Motor Shield	2	$19.95	$39.90
3.7V 500mAh LiPo	2	$7.95	$15.90
Planetary Gear Drive Motor	2	$27.99	$55.98
11.1V 400mAh LiPo	2	$14.90	$29.80
BNO055 9DOF IMU	1	$34.95	$34.95
VL53L0X Distance Sensor	2	$13.95	$27.90
HC-12 433MHz Radio Module	3	$7.55	$22.65
PowerFilm Solar Panel	8	$9.29	$74.32
Micro Metal Gear Motor	2	$24.95	$49.90
Small Throw Push-Pull Solenoid	2	$9.95	$19.90
Large Throw Push-Pull Solenoid	2	$14.95	$29.90
Carbon Fiber Sheet	1	$1,000.00	$1,000.00
4mm 90 Degree Gear	8	$5.99	$47.92
ArduCAM Mini Camera Module	2	$39.99	$79.98
Adafruit FeatherWing Adalogger	2	$8.95	$17.90
Large Diameter Bearings	2	$300.00	$600.00
Miscellaneous	1	$1,000.00	$1,000.00
TOTAL			**$3,206.80**

Table 25: Payload budget.

The Outreach budget is shown in Table 26.

Outreach Budget			
Description	**Qty.**	**Price**	**Total**
StarhwakModel Rocket Kit (pkg of 25)	3	$149.67	$449.01
Estes Tandem Model Rocket Launch set	2	$26.18	$52.36
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	50	$19.99	$999.50
Pipe wrench	1	$14.98	$14.98
PVC Cement	1	$9.10	$9.10
plasticweld	1	$7.86	$7.86

Standard Tire Valve	1	$4.82	$4.82
10 ft. 6 in. PVC	2	$6.74	$13.48
2 in. slip fit t joint	1	$2.84	$2.84
2 in. end cap	2	$0.84	$1.68
Slim Wall Plug in 120 volt tire inflator	1	$19.99	$19.99
2 in. to 1 in. reducer bushing	1	$1.52	$1.52
1 in. to .5 in. reducer bushing	1	$1.09	$1.09
.5 in threaded male adapter	2	$0.44	$0.88
.5 in. x 2 ft. pvc pipe	1	$1.47	$1.47
sprinkler system valve	1	$15.27	$15.27
push button switch	1	$11.99	$11.99
battery lead 9v	1	$5.39	$5.39
Miscellaneous	1	$400.00	$400.00
Total			**$2,318.41**

Table 26: Outreach budget.

The Travel budget is shown in Table 27.

Travel Budget			
Description	**Qty.**	**Price**	**Total**
Competition Hotel	N/A	$4,500.00	$4,500.00
Competition Travel Gas	N/A	$600.00	$600.00
Trailer Rental	N/A	$150.00	$150.00
Test Launch Gas	N/A	$500.00	$500.00
Total			**$5,750.00**

Table 27: Travel budget.

The Merchandising budget is shown in Table 28.

Merchandising Budget			
Description	**Qty.**	**Price**	**Total**
Shirts	30	$18.00	$540.00
Polos	40	$28.00	$1,120.00
Stickers	1,000	$0.15	$150.00
Business Cards	2,500	$0.03	$75.00
Total			**$1,885.00**

Table 28: Merchandising budget.

The budget overview is shown in Table 29.

Overall Budget	
Budget	Total
VDS	$2,018.54
Vehicle	$6,342.18

Recovery	$1,253.00
Payload	$3,206.80
Outreach	$ 2,318.41
Travel	$ 5,750.00
Merchandising	$ 1,885.00
Total	**$22,773.93**

Table 29: Overall budget.

The budget overview pie chart is shown in Figure 73.

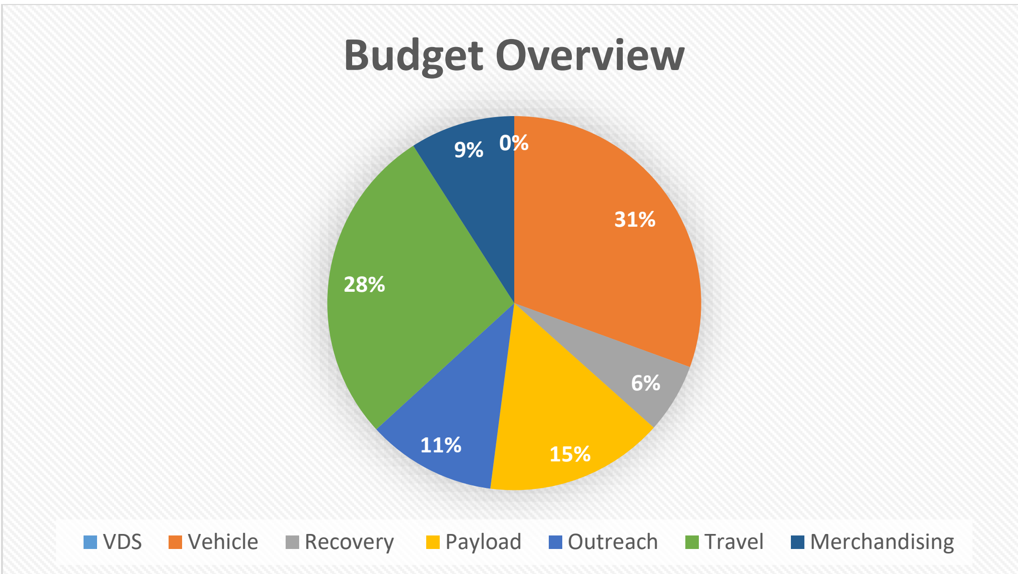


Figure 73 : Budget overview.

8.10 Funding and Community Support

Throughout the year River City Rocketry utilized their past success and community involvement to propose funding to local and commercial companies along with applying for grants throughout the year. Each year the team sets a goal of having an ending balance of $10,000. This money is then utilized for the team to do research and development over the summer along with providing the team with providing the team with a comfortable amount to kick off the next season. When new fundraising opportunities arise the team begins by initiating contact via email or face to face where we provide them with our sponsorship package. This package includes a general overview of NASA Student Launch project, the team's history including past results and accomplishments and a detailed budget outlining the expenses of the past season. The sponsorship packet can be found on our website (rivercityrocketry.com) and is updated annually.

The community has continually supported River City Rocketry over the years and besides grants and commercial sponsors, the following individuals have reached out to help the team achieve their goals.

8.10.1 Corporate and Organization Supporters

Community Outreach: River City Rocketry has enabled a donate button on rivercityrocketry.com to allow anyone in our community to donate and help support the team. This is a way for people to make small donations to support the team.

Wave 3 – MathMovesU: The event MathMovesU, which is more thoroughly discussed in the Education Outreach, brought in Wave 3 News where River City Rocketry got local television coverage throughout the duration of the event. This promotion allowed the team to gain additional popularity and allowed us to reach even more people.

Wave 3 – Team Interview: Following the end of the 2017 season, Wave 3 news came in and interviewed River City Rocketry along with showing the facilities that River City Rocketry works and the projects that have been completed. This promotion allowed the team to become more well-known and helped with the growth of the team along with team funding.

WHAS 11- Mini Maker Faire: River City Rocketry participated in the 2016 and 2017 Louisville Mini Maker Faire. WHAS 11 covered this event, which showcased the team on local television where the team demonstrated last year's rocket and payload design. The team further grew its support and received constant emails to either join or arrange an outreach event.

University of Louisville Magazine: After the success of the 2016-2017 season, River City Rocketry made an appearance in the University of Louisville Magazine where last year's awards are further showcased. This magazine expands the team's audience to all university alumni, especially those that contribute financially to the University of Louisville.

WDRB – Team Interview: At the end of last season's competition WDRB interviewed co-captains Kevin Compton and Ben Stringer to discuss the challenges and achievements that occur over the duration of a season. This was another local television network that further promoted the team's successes.

Louisville Cardinal – Team Interview: 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. Since becoming an RSO River City Rocketry has been able to significantly increase its recruiting and funding capabilities.

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.

Art's Rental Services: During the past seasons, Art's Rental Services has provided discounted trailer rentals to River City Rocketry which is has allowed the team to travel to competition with all the supplies necessary to be successful at competition.

Big Brothers Big Sisters Louisville (BBBS) : River City Rocketry has been partnered with BBBS for several years and together we have been able to organize successful outreach events, allowing us to reach students that we otherwise would be unable to reach.

Bro Ties: Bro Ties has been a partner of River City Rocketry since its foundation and has made it a tradition to donate the competition apparel to River City Rocketry to ensure that the team has a cohesive look for competition.

FirstBuild: FirstBuild has been one of River City Rocketry's top supporters. FirstBuild has provided River City Rocketry with raw materials along manufacturing equipment, support and training. The facilities that FirstBuild provides has been a major proponent of River City Rocketry's success.

Jefferson County Public Schools (JCPS): JCPS has been a major proponent of our outreach, by allowing us in their classrooms to teach about STEM and rocketry. The partnership has been one of River City Rocketry's most important in enabling to be the team in successfully completing outreach goals.

Lowes: Lowes has provided River City Rocketry tools and materials at a discounted rate. As the main materials and tools merchant for River City Rocketry, the discount provided has been a tremendous benefit and amounted to significant savings for the team

Metal Supermarkets: Metal Supermarkets is an excellent resource for small quantity metals and for that reason River City Rocketry has benefited greatly from partnering with Metal Supermarket, enabling us to receive our raw materials at a discounted rate.

8.10.2 Individual Supporters

Darryl Hankes: Since the foundation of the team Darryl has been a crucial part of the team. Being our rocket mentor for the last 5 years the team has often times relied on Darryl's rocket knowledge and experience to gain a better understanding of flight performances and how to improve future designs. Darryl has also been an excellent resource for discounted rocketry materials.

Dr. Yongsheng Lian: Dr. Lian has been River City Rocketry's advisor for the last 5 years. During this time Dr. Lian's role on the team has been to oversee the team budget, assist in campaigning for university funds and building and maintaining relationships with donors, industry and the university.

Dr. Roger Bradshaw: Dr. Bradshaw has been a major contributor to River City Rocketry as we continue to do more research and continue to use carbon fiber. As an expert in the behavior of polymer matrix composites, his expertise on testing and improving the strength and surface finish of our composites has been vital to the team's continued quest to improve.

Mike Miller: As the facility manager for the University's engineering department, including the building in which River City Rocketry is housed, Mike Miller has been an excellent resource. Mike has provided the team with the storage and workshop space needed along with machine shop equipment and the safety training and maintains required to ensure a safe working environment.

Gregg Blincoe: As a previous captain of River City Rocketry, Gregg has been a significant resource providing support with manufacturing processes along with insight from his own previous team leadership experiences.

Emily Robinson: As a previous captain of River City Rocketry, Emily has been a significant resource for River City Rocketry in assisting with safety, writing, and technical critic along with providing advice based on previous team leadership experience.

Austin Eschner: As a previous captain of River City Rocketry, Austin has been a significant resource for River City Rocketry in assisting with writing and technical critic along with providing advice based on previous team leadership experience.

Kyle Hord: As a previous recovery lead, Kyle has been a resource to provide knowledge and expertise on recovery design and manufacturing.

Nick Greco: As a previous captain, founder of the team, and vehicle designer for Blue Origin, Kyle has been a resource to provide knowledge and expertise on vehicle design and manufacturing along with team management.

Diane Jenne: Diane is the administrative assistant and runs the team's university account so the team can order all materials and components tax free.

Kari Donahue: Kari is in charge of communication and marketing for Speed School and helps the team receive exposure, promotes events and organizes press releases for the team

Gary Rivoli: Gary is speed school's Director of Outreach and as director he establishes connections with local schools for educational events and financially supports outreach events for River City Rocketry.

Dr. Clinton Kelly: Dr. Kelly, being a huge rocket enthusiast and an advisor to the Board of Trustees of the university, has been a major supporter and a generous donor for River City Rocketry.

8.11 Project Sustainability

Since the start of River City Rocketry, our end goal has always been to continue the tradition of success that is deeply rooted in every generation of the team. As we begin this season, the team will continue with that same expectation as we continue to develop community and financial support while continuing our tradition of success.

8.11.1 Local Exposure

River City Rocketry continues its exposure in a multitude of ways. Every year we continue to gain more exposure through the following facets.

- Educational Outreach Events
- Community Outreach Events
- Local news media
- University press releases

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

To further gain exposure the team has begun to put more emphasis on social media. With so many successful responses that the team received last year from the videos and other media that were posted on social media, the team realized that social media is a critical part about creating exposure and communicating the team objectives. As a result, we plan to continue to build an even larger internet presence and continue to post updates and content to keep our community informed and engaged. The team's Facebook page,https://www.facebook.com/rivercityrocketry/, is shown Figure 74.

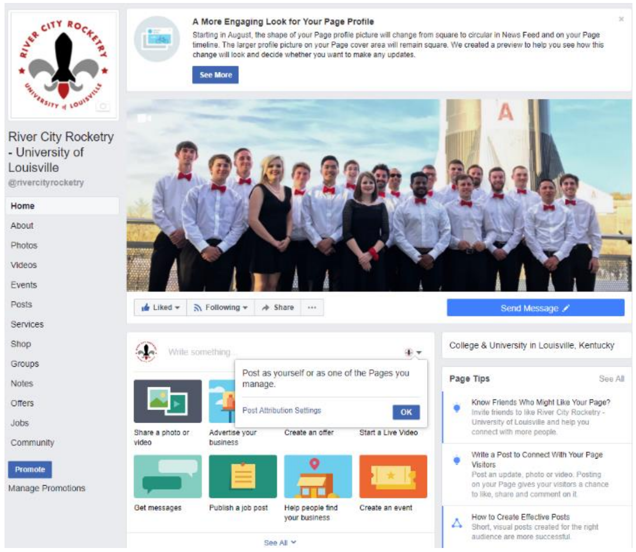


Figure 74: River City Rocketry Facebook page.

8.11.2 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. The team retains members interest by having a series of interest meetings on top of constant improvement of the team, for example the two-stage rocket with gas thrusters over the summer. This year to improve in this area River City Rocketry provided an opportunity for the new members to build their own level one rockets drastically improved retention and helped newer people get engaged early and begin learning rocket knowledge in a fun and enjoyable way, and was considered a great success for building the team with knowledgeable, excited students. To ensure the entire team maintains on the same page weekly meetings will take place where each sub-team lead will present a technical presentation of the progress they have made of a period of time and where they are headed. This assists in presentation practice as well as to mitigate design flaws by having the entire team to tag up. A recent RSO fair is shown in Figure 75.

Figure 75: Speed School Recruiting Event.

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 been brought in and mentored closely by former and current team members.

8.11.3 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.

9 Conclusion

River City Rocketry is returning as motivated as ever to continue participating in the NASA Student Launch competition and are striving to continue to meet our standard by setting the following goals:

- To improve upon and set a standard for safety for years to come
- To engage 1500+ students in STEM centered engaging outreach events, encouraging enthusiasm for rocketry and the larger STEM fields.
- To continue to improve on the Variable Drag System (VDS) design to set a new standard for apogee accuracy in NSL flights.
- To design a reliable payload system to deploy solar arrays and easily integrates into the vehicle.
- To grow the team; expanding the team's cumulative knowledge of rocketry and ensuring a sustained continuous improvement in the team's ability to achieve its goals.

10 Appendix I- Safety Risk Assessments

The following pages detail the current 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.	Improper training on tools and other lab equipment.	1. Mild to severe cuts or burns to personnel. 2. Damage to rocket or components of the rocket. 3. Damage to the 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. 2. Safety glasses must be worn whenever using power tools. 3. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE. 2. Improper training on the use of a Dremel tool.	1. Mild to severe rash. 2. Irritated eyes, nose or throat with the potential to aggravate asthma. 3. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	3	3	Low	1. Long sleeves should be worn whenever sanding or grinding materials. 2. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required. 3. 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.
Machining equipment including CNC, lathe, and saws.	Improper training on tools and other lab equipment.	1. Damage to the equipment. 2. Damage to materials being machined. 3. Potentially severe cuts or burns to personnel.	1	5	Low	The machining equipment available to the team requires safety training and certification for each team member. Each piece of equipment has a Job Safety and Sequence Instruction card that details task steps, safety instructions, and ergonomic reminders.

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 2.Chemical fumes	1. Mild to severe burns on skin or eyes. 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. Each member must acknowledge the hazards that accompany working with these chemicals. All chemical containers will be marked to identify appropriate precautions that need to be taken. Nitrile gloves are available and shall be used when handling hazardous materials.
Damage to equipment while soldering.	1. Soldering iron is too hot 2. Prolonged contact with heated iron	1.The equipment could become unusable. 2. Parts of the circuit get damaged and become inoperable.	3	3	Low	1. The temperature on the soldering iron will be controlled and set to a level that will not damage components. 2. For temperature sensitive components sockets will be used to solder ICs to.
Dangerous fumes while soldering.	1. Use of loaded solder can produce toxic fumes 2. Leaving soldering iron too long on plastic could cause plastic to melt producing toxic fumes	1. Inhalation of toxic fumes could make team members sick. 2. Lung irritation may occur.	3	3	Low	Team members will be trained how to solder and will follow all safety protocols related to soldering.
Potential burns to team members while soldering.	Team members do not pay attention while soldering.	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	Safety glasses shall be worn whenever machining metals.
Use of white lithium grease.	Used while installing motor and on ball screws.	1. Irritation to skin and eyes. 2. Respiratory irritation.	3	4	Low	1. Nitrile gloves and safety glasses are to be worn when applying grease. 2. When applying grease, it should be done in a well-ventilated area to avoid inhaling fumes.
High voltage shock.	Improper use of welding equipment.	Death or severe injury.	1	5	Low	All team members are required to be trained and certified on the equipment prior to use. Any time team members are welding, there must be at least two certified people present.
Bit breaks on mill.	Spindle speed set too high	Injury to personnel and damage to equipment and/or rocket component.	2	5	Low	All team members are required to be trained and certified 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, long pants, and safety glasses when machining metal parts.

Table 30: Lab and Machine Shop Risk Assessment.

Stability and Propulsion Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity Value	Probability Value	Risk Level	Mitigation
Motor fails to ignite.	1.Faulty motor 2. Delayed ignition. 3.Faulty e-match 4.Disconnected e-match.	1,3,4. Rocket will not launch. 2. Rocket fires at an unexpected time.	3	4	Low	Follow NAR safety code and wait a minimum of 60 seconds 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 or during ascent.	Faulty motor	Rocket and interior components significantly damaged.	1	5	Low	1. Alert all personnel at the launch field immediately. 2. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR to ensure that no one is hurt by flying debris. 3.Extinguish any fires that may have been started when it is safe to approach. 4.Collect all debris to eliminate any hazards created due to explosion.

						5.The team will only select motors from reliable suppliers. The team has only had one faulty motor.
Rocket doesn't reach high enough velocity before leaving the launch pad.	1.Rocket is too heavy 2.Motor impulse is too low 3.High coefficient of friction between rocket and launch tower	Unstable rocket 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.	1. Rocket will become unstable and unsafe during flight. 2. Flight may end prematurely and prevent proper recovery events from occurring.	1	5	Low	1. Through prediction models, appropriate material selection, and a secure factor of safety, this failure mode can be nearly eliminated. 2. If the rocket follows a ballistic path, all personnel at the launch field will be notified immediately.
Internal bulkheads fail during flight.	Forces encountered are greater than the	1. Internal components supported	1	5	Low	1.The bulkheads will be designed to withstand the force

	bulkheads can support.	by the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.				from the motor firing with an acceptable factor of safety. 2. Electrical components could be damaged and will not operate as intended during flight. If the rocket follows a ballistic path, all personnel at the launch field will be notified immediately.

Table 31: Stability and Propulsion Risk Assessment.

Recovery Risk Assessment						
Hazard	**Cause/Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket does not split to allow for recovery system deployment.	1. Not enough pressurization to break shear pins. 2. Coupling has too tight of fit.	Rocket follows ballistic path and becomes unsafe.	1	5	Low	1. The separation section of the rocket will be designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system. 2. The coupling between the sections will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight. If the rocket follows a ballistic path, all personnel at the launch field will be notified immediately.
Altimeter or e-match failure.	Parachutes will not deploy.	Rocket follows a ballistic path, becoming unsafe.	1	5	Low	Multiple altimeters and e-matches are included into systems for redundancy to eliminate this failure mode. If all altimeters or e-matches fail, the recovery system will not deploy and the rocket will follow a ballistic path. All

						personnel at the launch field will be notified immediately.
Parachute does not open.	1. Parachute gets stuck in the deployment bag. 2. Parachute lines tangle. 3. Parachute gets caught on an internal rocket component.	Rocket follows a 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. All internal structures will be adequately covered to prevent the parachute from catching on edges. If the rocket follows a ballistic path, 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 each specific 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 intended, potentially damaging environmental obstacles.	3	3	Low	The parachutes have each been carefully selected and designed to safely recover each specific section of the rocket. Should the selections be oversized, the parachutes will 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 following each launch and prior to packing each parachute, this failure mode should be eliminated.

Parachute or cords 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	The parachutes will be carefully packed. Appropriate use of fire-retardant materials like Nomax and No-Burn spray will make recovery materials less likely to burn.
Recovery system separates from the rocket.	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1. Parachute completely separates from the component, causing the rocket to become ballistic. 2. Parachute may not be found after launch.	1	5	Low	1. 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. 2. If the rocket follows a ballistic path, all personnel at the launch field will be notified immediately.

Table 32:Recovery Risk Assessment.

Vehicle Assembly Risk Assessment						
Hazard	**Cause/Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket drop (INERT)	Mishandling of the rocket during transportation.	Minimal damage and scratches to components of the rocket.	4	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and recovery. Careful handling should be practiced while transporting the rocket.
Rocket drop (LIVE)	Mishandling of the rocket during transportation.	1. Minimal damage and scratches to components of the rocket if no charges go off. 2. Charges prematurely go off, resulting in a serious	1	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and recovery. Careful handling will be practiced while transporting the rocket.

		safety threat to personnel in the area and significant damage to the rocket.				
Black powder charges go off prematurely	1. Altimeters send a false reading. 2. Open flame sets off charge.	Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	1. All electronics will be kept in their OFF state for as long as possible during preparation. 2. Open flames and other heat sources will be prohibited in the area. The onboard energetics and firing circuits will be disabled until after the rocket is on the launch pad. All personnel will be notified when the firing circuits and energetics are live.
Seized nut or bolt due to galling or cross threading.	Repetitive uninstalling and reinstalling of parts made of materials prone to galling.	1. Component becomes unusable, potentially ruining expensive, custom machined parts. 2. Large amounts of rework may be required depending 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 33: 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	Low	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not

						prohibit launching or testing the entire system.
Rain.	N/A	1. Unable to launch. 2. Damage to electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage.
High winds.	N/A	1. Must launch at high angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees.	N/A	1. Damage to rocket or parachutes. 2. Rocket components must be retrieved by professionals.	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 specific 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	The rocket should not be launched if there is swampy

						ground within the predicted drift radius.
Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.
Extremely cold temperatures.	N/A	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will not separate as easily.	1	5	Low	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. If the flight is delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.
Extremely high temperatures.	N/A	1. Prolonged heat exposure could reduce the performance of or degrade electronics, lead to over	1	5	Low	The 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.

		discharging, or cause an explosion in LiPo batteries. 2. Adhesives could degrade and lead to possible electrical malfunctions.				
Humidity.	N/A	Moisture in the motor or black powder charges may prevent them from igniting.	1	5	Low	Motors and black powder should be stored in a location free from moisture.
UV exposure.	N/A	Possibly weakening materials or adhesives.	4	4	Low	The 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 34: 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.
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.
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 toxins released will cause minimal degradation.
Production of styrene gas.	The fiberglass that is used in the vehicle body is manufactured by a second party.	Toxic air emissions.	4	1	Moderate	Productions methods for fiberglass produces toxic air pollutants, particularly styrene, which evaporate during the curing process. Due to the quantity of fiberglass utilized on the rocket, the amount of pollutants produced throughout manufacturing process will have a negligible effect on the environment.
Spray painting.	The rocket will be spray painted.	1. Water contamination. 2. Emissions to environment.	2	5	Low	All spray painting operations will be performed in a paint booth. This prevents any overspray from entering the water system or air.
Soldering wires.	All wires will be soldered together to retain strength and proper connection.	1. Air contamination 2. Ground contamination	4	1	Low	The amount of vapor from the soldering process is at such a low quantities that no action will be needed.

Use of lead acid battery leakage.	Old or damaged housing to battery	1. Acid will leak onto the ground and get into the water system. 2. Chemical reaction with organic material that could potentially cause a fire.	3	4	Low	1. We are using new batteries that have been factory inspected and tested. 2. Proper lifting and storing procedures in accordance with manufacturer's specifications will be adhered to.
Plastic waste material.	Plastic used in the production of electrical components and wiring.	1. Sharp plastic material produced when shaving down plastic components could harm animals if ingested. 2. Plastic may enter the water system through a drain.	3	5	Low	All plastic material will be disposed of in proper waste receptacles.
Wire waste material.	Wire material used in the production of electrical components.	Sharp bits of wire being ingested by an animal if improperly disposed of.	3	5	Low	All wire material will be disposed of in proper waste receptacles.
CO_2 emissions.	Travel to launch sites and competition.	Contribution to greenhouse effect and to global warming	4	1	Moderate	While the effects of CO_2 emissions cannot be reversed, the amount produced is negligible.

Table 35: Hazards to environment risk assessment.