NASA Student Launch

2016-2017 Proposal

September 30, 2016

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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 2016-2017

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/Integration Lead, Name: Kevin Compton
Contact Information: kckev101@gmail.com **or** (847) 977-9471

Kevin is currently a senior mechanical engineering student at the University of Louisville's J.B. Speed School of Engineering. This is Kevin's fourth season competing in NASA's student launch project and second year as co-captain of River City Rocketry. After contributing to his team's second place overall victory over the past two seasons, Kevin has been busy working with the aircraft structures division at UPS airlines. Throughout the years of competition Kevin has acquired important knowledge in design, fabrication, manufactural integration, and problem solving. With these skills he hopes to end up in the field of aerospace after graduation.

Team Captain/Electrical Lead Name: Ben Stringer
Contact Information: ben.stringer@gmail.com **or** (270) 779-3075

Ben is a Junior at the J.B. Speed School of Engineering and is majoring in electrical engineering. This is his second season with River City Rocketry and is excited to see the team accomplish its ambitions this year. Ben will be bringing experience gained from his co-op at Raytheon Missile Systems to both the positions of Co-captain and electrical lead. He is particularly interested in control theory, configurable logic, and microcontrollers and looks forward to employing these skills in the aerospace industry upon 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. In order to support the technical efforts on the project, the team consists of students from the mechanical engineering, electrical and computer engineering, and computer engineering and computer science departments (CECS). Additionally, the team has recruited other STEM disciplines from across the university in order to support the team, specifically with the intent of enhancing our educational outreach.

This project has been broken up by technical design and the following sub-team leads 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 to the launch vehicle.
- *Electrical* - responsible for the electrical design, prototyping, and manufacturing of all electrical payload systems. Additionally, oversees any extra electrical or CECS projects that enhance the overall product.
- *Integration* – responsible for ensuring all sub-teams work together, communicate, and integrate all systems together on a mechanical and electrical level. Also responsible for the design and manufacturing of test parameters to verify the success of each sub-team.

Each of the lead positions described above were assigned based on that member's experience, knowledge in the field, and leadership abilities. We are confident that the personal selected to uphold these leadership positions have the technical know-how and dedication to have their sub-team produce an innovative system that'll be showcased at the end of the season.

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

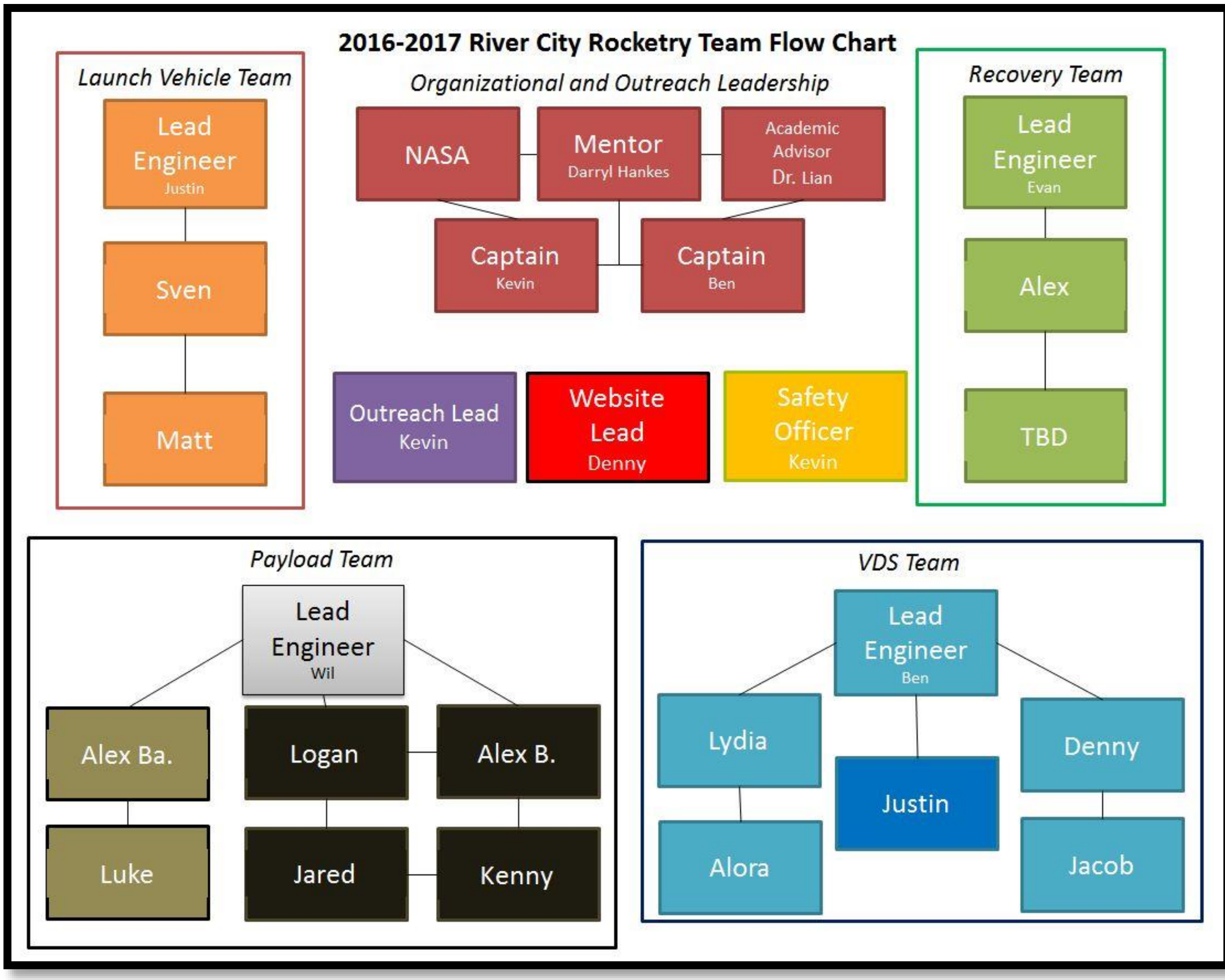


Figure 1: 2016-2017 NASA Student Launch team structure.

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

Figure 2: Engineering garage major equipment.

Included in the Engineering Garage the University has provided River City Rocketry with a storage and work space. This part of the Engineering Garage is open 24 hours a day, 7 days a week and consists of numerous hand and power tools.

Figure 3: River City Rocketry cage.

2.1.2 FirstBuild

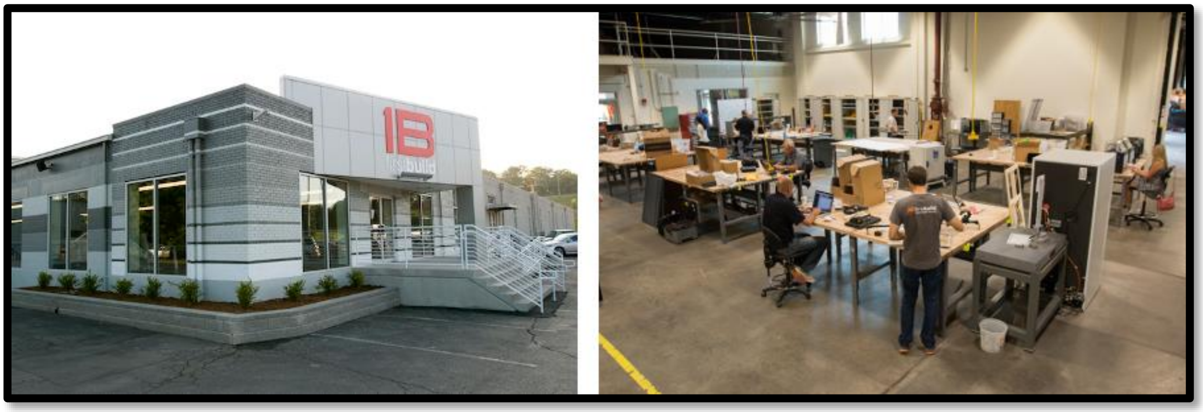


Figure 4: Part of FirstBuild's open workspace shown here (right).

Formed by GE Appliances, Local Motors, and the University of Louisville, FirstBuild, a microfactory, is a place for builders, makers and hackers to come together to bring their ideas to life. Having ties with the University, FirstBuild is excited to engage the team members in professional manufacturing practices and allowing them to use their equipment to build any necessary components. 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
- Vertical Band Saw
- Haas CNC Lathe
- Sheet Metal Brakes
- Various Hand Tools
- 24”x48” Universal Laser Cutter
- 50 Ton Press

- 2 Metal Lathes
- Miter Saw
- Drill Press
- Surface Grinders
- 4 MakerBot 3D Printers
- AMADA CO_2 Laser
- 3DP 3D Platform Printer
- Various Hand Tools
- Drills
- Soldering Equipment
- Air Compressor
- Objet 3D Printer
- Injection molding
- MIG/TIG welders

2.1.3 LVL1

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

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

2.1.4 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.

2.1.5 University of Louisville Sackett Hall, Machine Shop

Figure 5: Haas 3-axis CNC machine.

Figure 6: Manual 3-axis Chevrolet mill.

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 when the Engineering Garage is inaccessible. The newly renovated, 1600 square foot machine shop provides access to the following list of machinery and tools:

- HAAS CNC Mill
- Bridgeport Vertical Mill
- Vertical Bandsaw
- 2x Drill Press
- Hydraulic Press
- SHARI Manual Lathe
- Chevalier Vertical Mill
- 2x Horizontal Bandsaw
- Bench Grinder

2.1.6 Lutz Micro/Nano Technology Center

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

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

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

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

- Keep public up to date on the project with project updates.
- 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

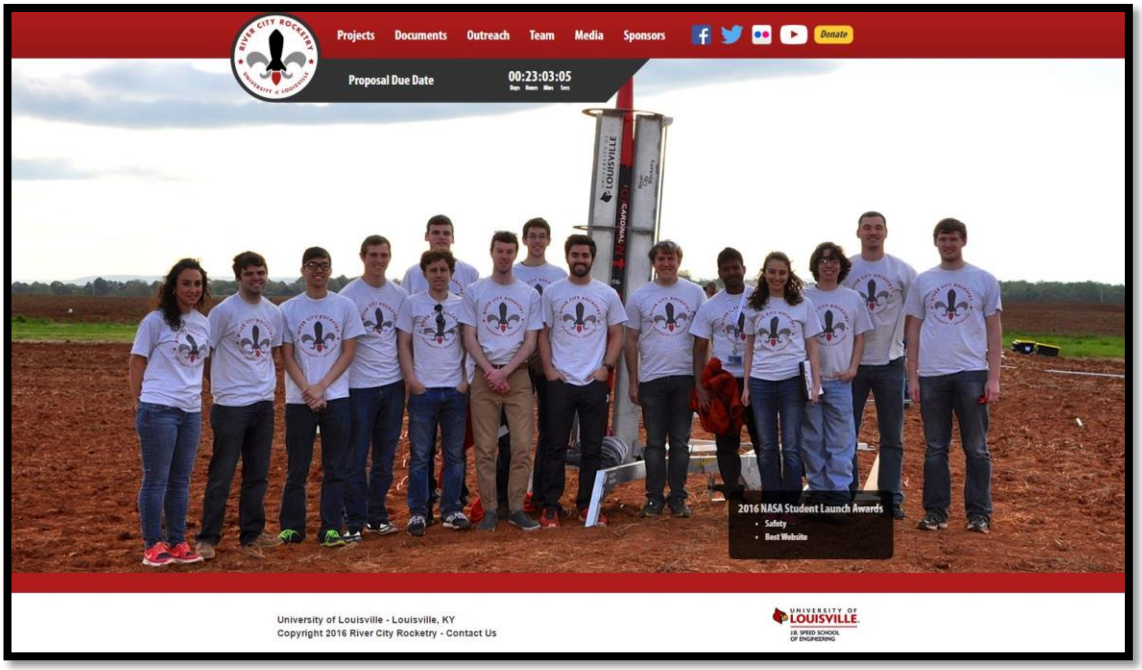


Figure 7: Website front page on www.riverctyrocketry.org/home/.

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

3 Safety

3.1 Safety Plan

Safety Officer Responsibilities

Kevin Compton is the safety officer for the River City Rocketry team during the 2016-2017 season. He is responsible for ensuring the overall safety of the team, students and public throughout all team activities, as well as assuring compliance with all laws and regulations. The following are the Safety Officer's specific responsibilities:

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

Kevin has written a team safety manual that each team member is required to review and sign indicating compliance. The document includes hazards, proper safety plans and procedures, PPE requirements, MSDS sheets, FAA laws, and NAR and TRA regulations. The manual will be a floating document and constantly revised throughout the season. Kevin is responsible for making sure that each team member has read and acknowledged the safety manual and will continue to enforce all statements in the safety manual.

3.1.1 Hazard Analysis

Risk Assessment Matrix

Throughout the season the team will review each human interaction, environment, rocket system and component, along with testing procedures to ensure hazards have been accounted for and continually brought to the team's attention. Each hazard has been assigned a risk level through the use of a risk assessment matrix, found in Table 4 by evaluating the severity of the hazard and the probability that the hazard will occur.

A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. In order to determine the severity of each hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, and damage to the rocket and/or equipment. This criterion is outlined below in Table 2**.**

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

Table 2: Severity value criteria.

A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being most likely. The probability value was determined for each hazard based on an estimated percentage chance that the mishap will occur given the following:

- All personnel involved have undergone proper training on the equipment being used or processes being performed.
- All personnel have read and acknowledged that they have a clear understanding of all rules and regulations set forth by the latest version of the safety manual.
- Personal Protective Equipment (PPE) is used as indicated by the safety lab manual and Material Safety Data Sheets (MSDS).
- All procedures were correctly followed during construction of the rocket, testing, pre-launch preparations, and the launch itself.
- All components were thoroughly inspected for damage or fatigue prior to any test or launch.

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

Probability		
Description	**Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance that the mishap will occur.
Likely	2	Between 50% and 90% chance that the mishap will occur.
Moderate	3	Between 25% and 50% chance that the mishap will occur.
Unlikely	4	Between 1% and 25% chance that the mishap will occur.
Improbable	5	Less than a 1% chance that mishap will occur.

Table 3: Probability value criteria.

Through the combination of the severity value and probability value, an appropriate risk level has been assigned using the risk assessment matrix found in Table 4. The matrix identifies each combination of severity and probability values as either a high, moderate, or low risk. The team's goal is to have every hazard to a low risk level by the time of the competition launch. Those that are not currently at a low risk level will be brought down through redesign, new safety regulations, or any other measures seen fit to reduce risk. Risk levels will also be reduced through verification of systems.

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

Table 4: Risk assessment matrix.

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

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

A brief overview of each risk assessment the team must be aware throughout the course of the season is indicated below.

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

VDS Actuation Risk Assessment
The hazards outlined in this section discuss the risks associated during testing and flight of the variable drag system. The VDS interfaces with the main structure of the vehicle, with potential risks in tools, manufacturing, and installment. This can be found in Table 38.

Payload Landing Risk Assessment
The hazards outlined in this section discuss the risks associated with the payload, which includes the upper half of the nose cone, landing upright. Since the payload separates from the vehicle it will encounter environmental hazards. This can be found in Table 42.

Payload Deployment Risk Assessment
The hazards outlined in this section will discuss the risks associated with the deployment of the payload from the vehicle. The payload deployment interfaces with multiple systems, making it prone to hazards. This can be found in Table 41.

Stability and Propulsion Risk Assessment
The hazards outlined in are risks associated with stability and propulsion. The team has multiple members of the team with certifications supporting that they can safely handle motors and design stable rockets of the size that the team will be working with. This area is considered a low risk for the team, but it is still important to address any potential problems that the team may face throughout the project. This can be found in Table 39.

Recovery Risk Assessment
The hazards outlined in Table 40 are risks associated with the recovery. Since there two recovery systems onboard, many of the failure modes and results will apply to all of the systems but will be stated only once for conciseness.

Payload Redundant Recovery Risk Assessment
The hazards outlined in this risk assessment is associated with the redundant recovery that monitors the state of the payload pre-deployment and during flight. This assessment is strictly dealt with the electronical side that is monitoring and watches a pre-determined set of criteria that will deploy a backup parachute if any of the criteria were to be made true. Please refer to the recovery risk assessment for the deployment of the backup parachute. This can be found in Table 41.

Vehicle Assembly Risk Assessment
The hazards outlined in Table 43 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 44 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 45 are risks that construction, testing or launching of the rocket can pose to the environment.

Launch Procedures

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

The checklists are broken up into checklists for each subsystem for pre-launch day as well as launch day. This allows the team to keep organized and ensures a quick and efficient launch prep on launch day. Each subsystem checklist must be 100% complete and be signed by a representative of that subsystem and reviewed by one of the two captains. 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

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

NAR Code	Compliance
1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only Darryl, the team mentor, and certified team members are permitted to handle the rocket motors.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The Mechanical Engineering team will be responsible for selecting the appropriate materials for construction of the rocket.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Motors will be purchased through commercially rocket motor vendors such as Aerotech, Cesaroni, and Loki will only be handled by certified members of the team who are responsible for understanding how to properly store and handle the motors. Additionally, there is a portion on motor safety in the team lab manual that the entire team is responsible for understanding.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its batter and	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.

will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	The team will comply with this rule by launching out of the rails provided by NAR at competition.
8. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	
9. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams and a maximum expected altitude of less than 610 meters (2000 feet).	All team launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any rocketry safety issues.
10. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will comply with this rule and any determination the Range safety Officer makes on launch day.
11. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The Recovery team will be responsible for designing and constructing a safe recovery system for the rocket. A safety checklist will be used on launch day to ensure that all critical steps in preparing and packing the recovery system and all necessary components into the rocket are completed.
12. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

Table 5: NAR safety code compliance.

3.3 Team Safety

A team safety meeting will be held prior to any construction, tests, or launches in order to ensure that every team member is fully aware of all team safety regulations as detailed in the team safety manual. Each team member is required to review and acknowledge the safety manual. As revisions are made and released, team members are responsible for remaining up to date with team safety regulations. The team safety manual covers the following topics:

- Lab workshop safety
- Material safety
- Personal Protective Equipment regulations
- Launch safety procedures
- Educational engagement safety
- MSDS sheets
- Lab specific rules

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

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

3.4 Local/State/Federal Law Compliance

The team has reviewed and acknowledged regulations regarding unmanned rocket launches and motor handling. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 "Code for High Power Rocket Motors"

3.5 Motor Safety

Darryl Hankes, 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 of a 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

In past years River City Rocketry has utilized a ballast system to achieve its target apogee altitude. While a ballast system is simple, it is subject to variability in motor impulse, rail friction, and weather conditions. As a result, ballasted vehicles often cannot achieve a level of precision in their apogee altitudes greater than ± 167 ft (51 m).[1] In order to improve the consistency with which the team can achieve its target apogee, River City Rocketry has begun the development of the Variable Drag System (VDS).

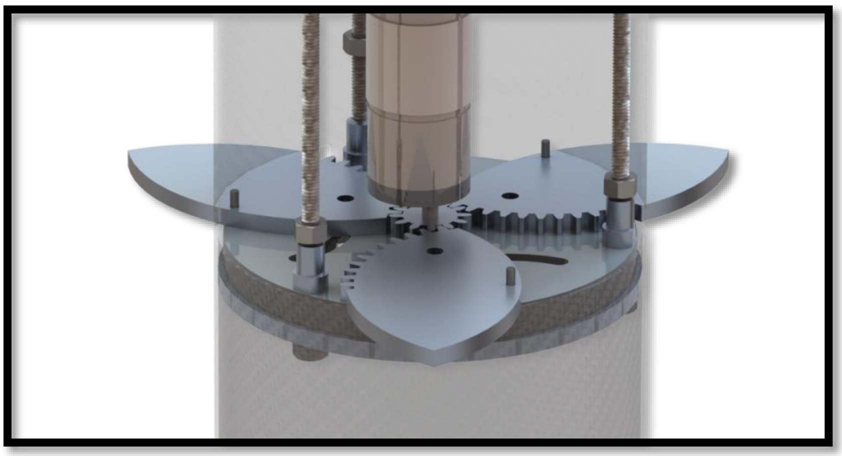


Figure 8: Variable Drag System (VDS) rendering (airframe transparent).

The VDS is set to replace the ballast system as the system responsible for determining the vehicle's apogee altitude and will be able to achieve a target apogee with ± 10 [m] accuracy. This will be achieved by dynamically changing the drag force of the rocket during the coast phase, allowing the VDS to compensate for the variations in burn phase flight characteristics. The VDS varies the drag force on the vehicle by projecting three flat blades into the airstream surrounding the rocket. With the flat faces of the blades perpendicular to the airstream, the VDS is able to increase the projected area of the vehicle by a factor of 1.28 and the coefficient of drag by an estimated factor of 1.35.

Project Status

As of 9/30/2016, the VDS project has completed an initial prototype phase and entered a design revision phase. The prototype phase, which began in May 2016, consisted of an accelerated design/build schedule and four full-scale test launches with the prototype installed in the launch vehicle. The purpose of the launches during the prototype phase was to provide a strong proof of concept for the project, and to provide data that will be used to make well-informed improvements and optimizations to the system. This document will discuss the results of this

[1] 95% confidence interval based on 27 samples from the NSL 2015-2016 competition flights

prototype phase and use them to justify the proposed improvements that will be a part of the new design.

Several improvements include the VDS Electronics sensor array, the reduction of the signal-noise ratio, a focus on improving the user-interface, an increase in blade actuation speed, and a reduction in mass. Each of these design goals was formed through the observation of issues and faults during testing.

Design Overview

The VDS will be a custom system. The primary components of the VDS are manufactured using Delrin Acetal Resin and 6061-T6 Aluminum. The control scheme will be tuned and modeled in a custom simulation and will be implemented in Python source code written from scratch. The electronics, a Raspberry Pi microcomputer, Bmp180 barometric pressure sensor, Bno055 ~~9DOF~~ 9 Degrees of Freedom sensor (9DOF), and an H-bridge circuit will all be designed into a custom printed circuit board (PCB). The documentation of the design–divided into control theory, mechanical design, and electrical design–will be discussed in the following sections.

4.1 Control Theory

The ability to vary the drag force on the rocket is an important requirement in the success of the VDS. However, the unique challenge of achieving a consistently precise apogee is in the design of the autonomous decision-making this system must employ to achieve its objective. The autonomous control theory, is what determines how much/when the VDS changes the drag force on the vehicle.

The VDS's control theory is divided into three sections: control scheme, system modeling, and experimental verification. These sections delve into the details of the VDS's control feedback loop, how it is modeled, and how the model has been verified in experimental launches.

4.1.1 VDS Applicable Equations

There are several important equations that model the behavior of the vehicle during the coast phase. These equations are used to design the VDS, used to simulate its behavior, and have been verified experimentally. Each of these applications will be discussed in further detail.

The VDS model equations are derived from the coast phase deceleration equation.

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

Where a is the vertical component of acceleration, g is the acceleration due to gravity, and v is the vertical component of velocity. The constant c represents the vehicle's unique drag characteristics.

$$c = \frac{C_d \rho A}{2m} \qquad (2)$$

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. ρ, the density of air, is taken to be a constant 1.225 $[\frac{kg}{m^3}]$ despite that it changes with altitude. These changes were taken to be negligible and ignored for the purpose of 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.

$$\mathrm{v(h)} = -\mathrm{e}^{-hc}\sqrt{\frac{\mathrm{g}}{\mathrm{c}}\mathrm{e}^{2K_2c}} - \mathrm{e}^{-2hc} \qquad (3)$$

4.1.2 Control Scheme

The control scheme is the autonomous decision-making process that the VDS performs during flight to achieve its goal of an exact apogee altitude. It does this by continually comparing its real-time vertical velocity to a predetermined ideal flight path and correcting for any deviations. This ideal flight path, or ‘set point path’, leads the rocket to a velocity of 0 m/s at the target altitude AGL of 1609.34 [m] (1 mile).

The 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).

Another important characteristic of the SPP is that it is calculated with drag characteristics equal to a weighted balance of the maximum drag characteristics and minimum drag characteristics. The ‘maximum drag characteristics’ meaning the constant ‘c’ calculated as though the brakes are fully deployed and the ‘minimum drag characteristics’ meaning the constant ‘c’ calculated as though the brakes are fully retracted. The constant ‘c’ calculated as a weighted average of these two scenarios shown below.

$$c_{spp} = \frac{\rho(\mathrm{w}A_{\mathrm{r}} + (1-\mathrm{w})A_{\mathrm{r+b}})(\mathrm{w}C_{\mathrm{r}} + (1-\mathrm{w})C_{\mathrm{r+b}})}{2\mathrm{m}} \qquad (4)$$

where A_r is the cross-sectional area of the vehicle, A_{r+b} is the cross sectional area of the rocket and brakes, C_r is the coefficient of drag of the vehicle, and C_{r+b} is the coefficient of drag of the rocket and brakes. ‘w’ is the weighting which must be a number between zero and one.

Calculating the SPP results in a plot shown below in Figure 9.

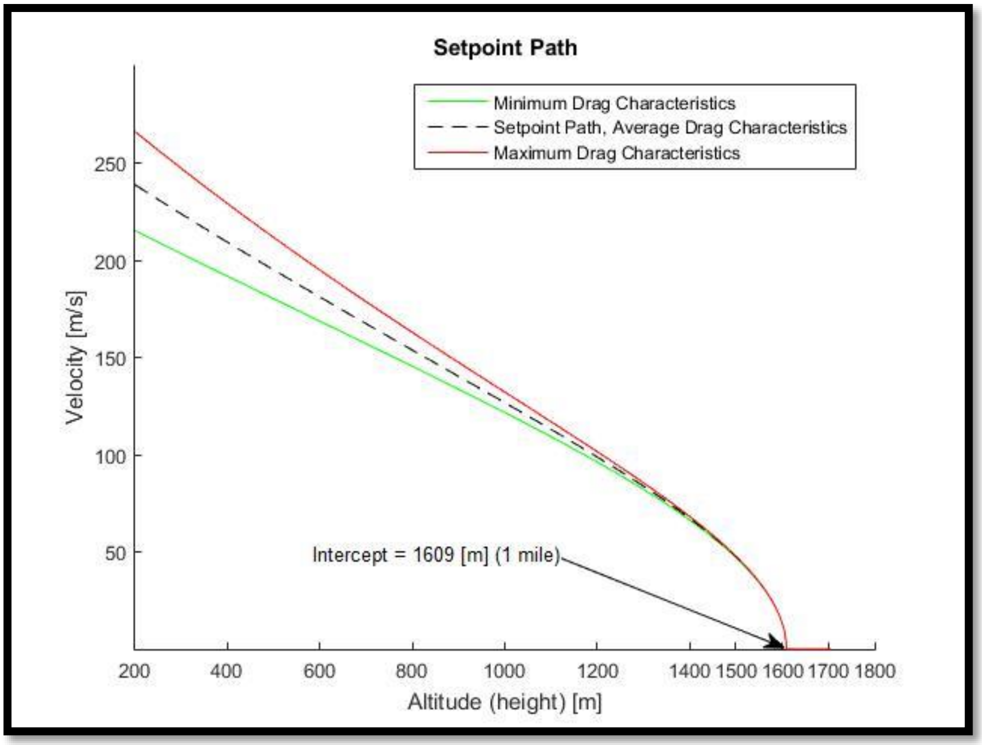


Figure 9: Setpoint Path.

Each of the plots shown above are of the form v(h). The different variations shown above are found by substituting the maximum, minimum, and average values of the constant 'c' to describe different drag characteristics. An average value of 'c' is ideal because it is comfortably balanced in the middle of the drag that the VDS is capable of producing. In other words, the vehicle will be most able to follow the SPP if 'c' is balanced. Another advantage of choosing an average value of 'c' is that it distributes the braking over the course of the majority of the coast phase rather than all at once.

The SPP describes the ideal flight path for the vehicle. The vehicle will follow this flight path by continually comparing its SPP velocity to its real-time velocity and compensating for any deviations.

Compensation

In order for the vehicle to follow the SPP it must have a closed feedback loop that compensates for any deviation from the SPP. This is done with simple proportional compensation where the VDS corrects for any deviation from the SPP with a magnitude proportional to that deviation. Proportional compensation was chosen for its simplicity and robustness but future versions may use a more finely-tuned method. Research into more advanced compensation methods will take place following an improvement in signal noise reduction.

4.1.3 System Modeling

In order to verify and optimize the design of the control scheme, a simulation has been developed that incorporates the kinematics of the coast phase, the responses of the control scheme, and the mechanics of the VDS prototype's actuators. This simulator predicts flight behavior before test launches and allows for the tuning of parameters such as the SPP weighting, w and proportional compensation constant, K_p. The Mathworks Simulink blocks for the simulation are shown below in Figure 10.

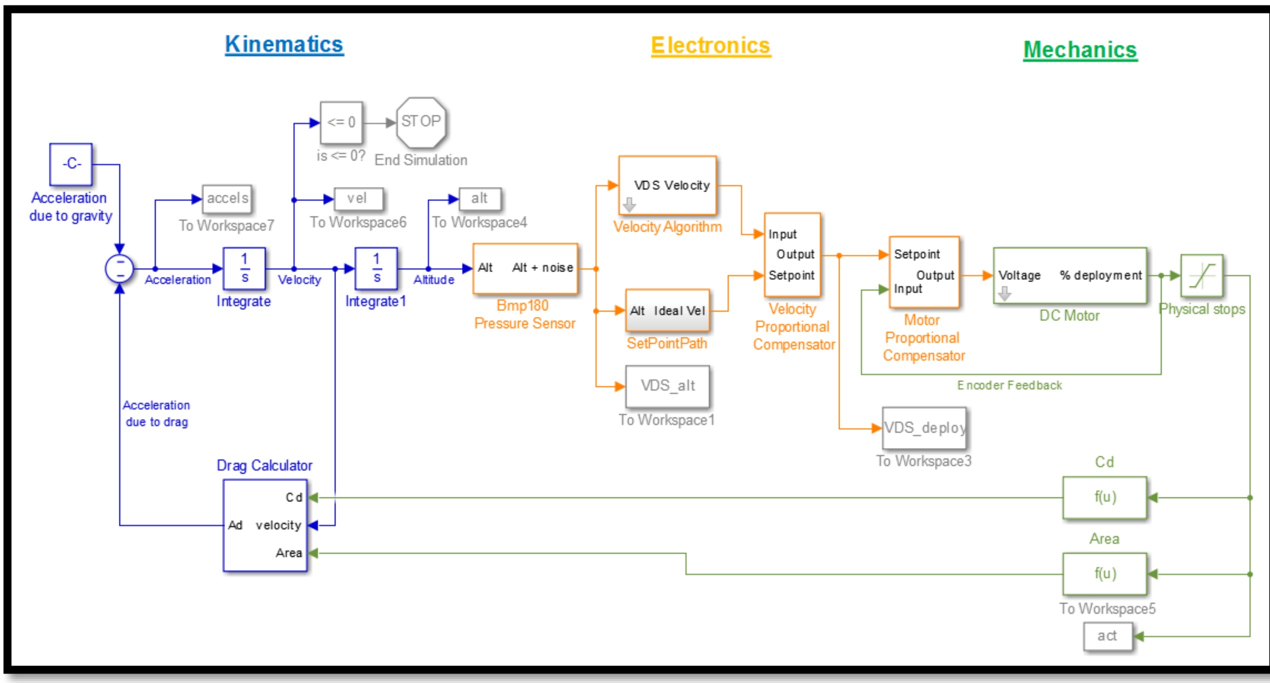


Figure 10: VDS Prototype Simulation.

This simulation can predict flight behavior and includes factors such as noise, data frequency, motor response time, different drag coefficients, and different motor selections. The ability to simulate these factors in a new and unexplored system before test launches has been an invaluable tool in reducing risk and cost. It has enabled this project and will continue to be developed as the VDS evolves. The VDS simulator will be updated to include new noise reduction methods such as the addition of new sensors and the addition of a Kalman filter. The simulation will also be used to explore the effects of faster blade actuation.

An example output of this simulation is shown below in Figure 11.

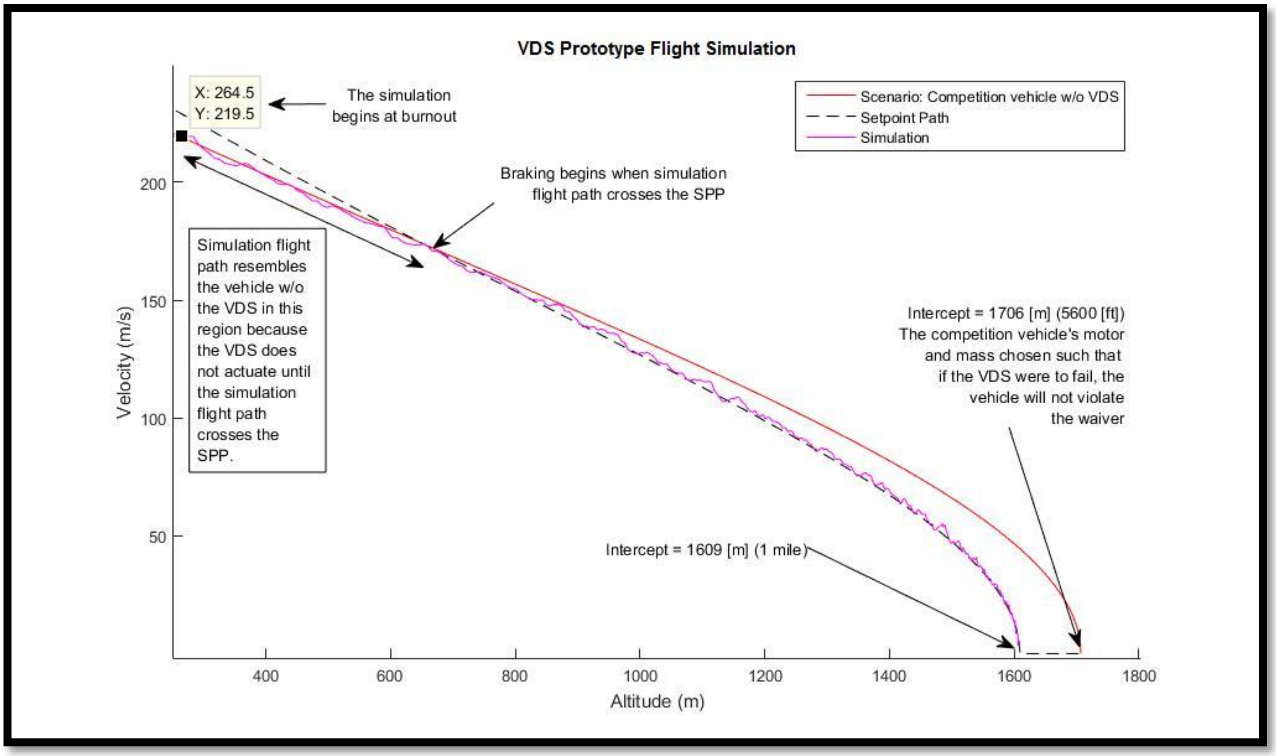


Figure 11: VDS prototype flight simulation.

4.2 Electrical Design

The need for a suitable upgrade to the VDS Electronics initiated the transition to the next stage of development.

The new VDS Electronics design will build upon the simplicity of the VDS Electronics prototype while also improving the precision and fidelity of the sensors. This will be achieved with the inclusion of sensors that will provide data that is superior in quality to merely having a barometric pressure sensor.

The original VDS Electronics prototype was designed to meet preliminary system objectives that consisted of a facilitation of flight test timelines, establishment of base-line data sets, and overall system operation. The electronics prototype was successful in demonstrating a proof of concept of an air-braking system. The components that were used in the prototype are listed below:

- Arduino Pro Mini
- BMP180 Barometric Pressure Sensor
- LM7805 Linear 5V Regulator
- Micro SD card module
- Mega Moto Motor Control Arduino shield

- Rotary Encoder

In addition to the aforementioned intended improvements, the electrical design will be optimized in order to increase processing performance, optimize power consumption, user access to the electronics. The new version of the VDS Electronics will be designed with an inherent focus on precision.

To facilitate the new design, the VDS Electronics will be executed with Python source code on a Raspberry Pi 3 running the Raspbian operating system. It will collect data using a barometer, accelerometer, gyroscope, and magnetometer. These sensors will manage a full range of positional information of the rocket, permitting the rocket to collect a greater quantity and quality of data to predict an expected flight trajectory. The VDS Electronics will manage a DC motor through an H-bridge circuit, and a power conversion circuit will be implemented to power the new electronics. A VDS control panel will be accessible from the outside of the vehicle, streamlining the process of servicing the electronics, and further reducing assembly and preparation time.

Justification for Raspberry Pi 3

Many different controllers and computers were considered for the new VDS Electronics. The device necessitated to be capable to support multiple sensors, interface with a data storage device, perform high fidelity floating point arithmetic, and had to have enough flash memory to store the VDS software. The various platforms that were considered are shown below in Table 6.

	Overview	**Interface with multiple sensors (i2c and UART)**	**Data Storage > 1 Gb**	**Language**	**Adequate Program Storage Space**	**Floating Point Arithmetic**
Arduino	- Vastly documented, familiar platform -Simplistic microcontroller	-Yes -Well-supported libraries	-Must include external storage device such as micro SD card reader -Costs SPI I/O pins	-C/C++	-Only models above the Mega class meet this requirement	-No. Floating point hybrid not acceptable
Raspberry Pi	-Relatively familiar platform -GUI based microcomputer	-Yes -Well-supported libraries	-Data storage native to Raspbian, uses standard file IO	-Python	-Program storage space not fixed, can upgrade easily	-Yes

Field Programmable Gate Array (FPGA)	-Highly customizable/ optimizable -More obscure	-Yes -NO well-supported libraries,	-Must include external storage device such as micro SD card reader	-VHDL -Verilog	-Difficult to quantify given that the area/speed trade-off is up to the designer	-Yes

Table 6: VDS controller comparisons.

The Arduino platform, which was used for the prototype, was determined to be vastly simplistic and familiar but is largely overwhelmed by the complexities of the VDS software–which is largely limited by the lack of the Arduino's processing power–due to the inclusion of the several new sensors previously mentioned. The Field Programmable Gate Array (FPGA) was considered for its highly customizable nature and the fact that it is the premier computing technology in the aerospace industry. It was eliminated as an option due to its lack of support and the projected development time required to implement it. The Raspberry Pi 3 was selected for its balance of processing power, component support, and relative simplicity. It meets all the requirements set forth for this project and is highly documented. Its GUI-based operating system will greatly streamline the process of implementation.

Sensor Choice

The VDS Electronics prototype relied on a singular barometric pressure sensor to provide both altitude and velocity data. This posed several problems further outlined in the Experimental Results Section. The reliance on a single sensor proved problematic with the appearance of noise issues; these problems were further amplified in the velocity data, which relied on a least-squares fit method. For this reason, a 9 Degrees of Freedom (9DOF) sensor–featuring an accelerometer, gyroscope, and a magnetometer–will be added to diversify the data and aid in mitigating concerns.

Control Panel

The control panel is a user interface that will be installed on the rocket to access the electrical systems. Adding a control panel will provide the following capabilities: measure inputs/outputs, charge the battery, install troubleshooting peripherals, circuit protection, and signal indication. These features will increase troubleshooting efficiency and improve on-field operations.

The control panel will be removable in order to access the electronics housed inside of the rocket. The connections on the control panel will be labeled in accordance to naming conventions defining the signals/connections of the system. The indications will provide access to major circuit locations in order to assure successful operation of the electrical system. The picture below illustrates the section of the control panel.

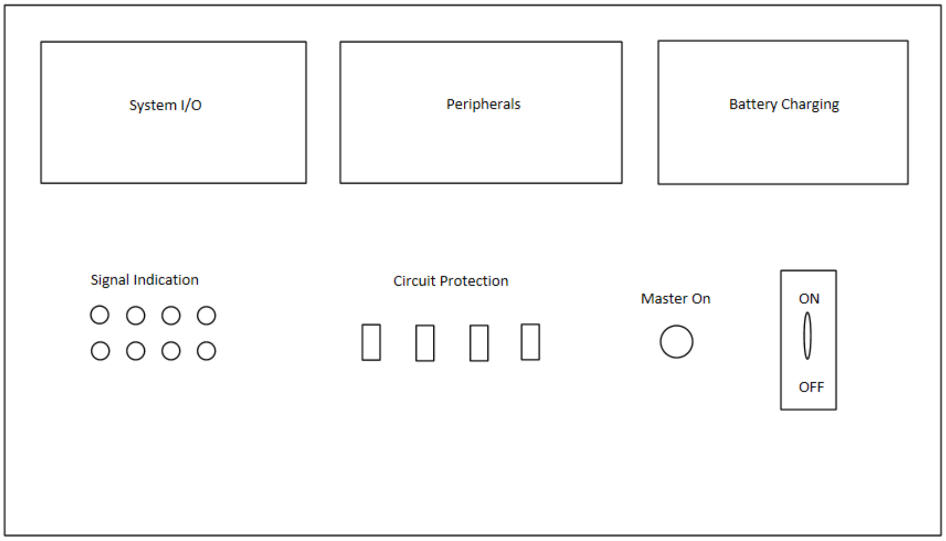


Figure 12: VDS control panel.

Electric Power Distribution

With the inclusion of a Raspberry Pi 3, along with several sensors, powering the electronics will be challenging due to the high current draw, and the limited space within the rocket. The Electric Power Distribution focuses on two main components: reducing thermal radiation and maximizing power efficiency.

The two power regulatory options that were considered are the linear regulator and the switching regulator. The power waste due to the linear regulator was calculated to be three times the amount of the switching regulator. Minimizing the power waste will prevent over heating of the electronics. It will also allow the electrical system to maximize space that would have been occupied by a linear regulator heat sink. The first equation below was used to calculate the power waste of the linear regulator; the second equation was used to calculate the power waste of the switching regulator.

$$P_{Linear\_Waste} = (V_{in} - V_{out}) * I_{load} \quad (5)$$

$$P_{Switching\_Waste} = P_{in} - P_{out} \quad (6)$$

4.3 Mechanical Design

In order for the VDS to be the most mechanically efficient system possible, several factors were taken into consideration for the mechanical design of the VDS:

1. Volume
2. Actuation speed
3. Mass
4. Drag area

The VDS assembly is shown below in Figure 13 and Figure 14.

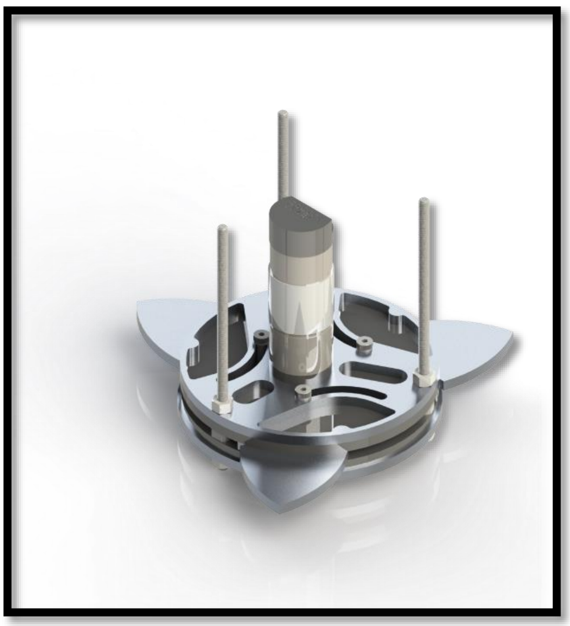


Figure 13: VDS assembly CAD model.

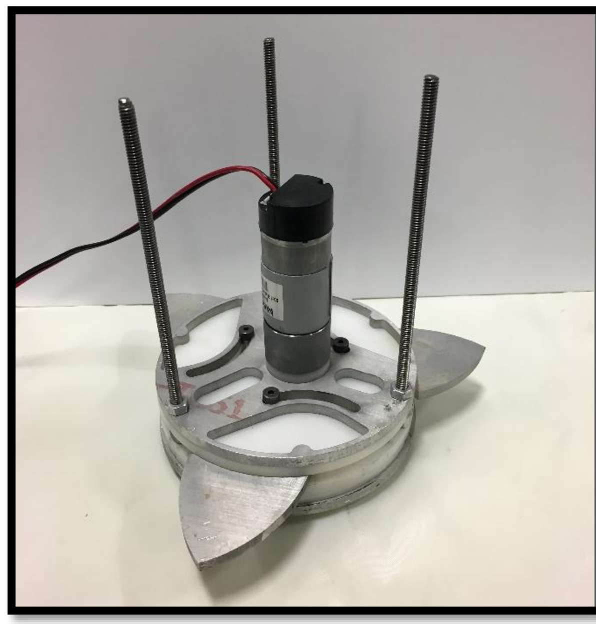


Figure 14: VDS assembly manufactured prototype.

4.3.1 Design Overview

In order to accomplish the main goals of the VDS outlined above, the team decided to design the VDS so that the drag inducing blades actuate perpendicular to the airflow instead of against the airflow. A majority of air braking designs in previous NSL teams have had actuating joints that work against the incident airflow. Through the perpendicular actuation of this design, the overall volume is minimized and the motor does not have to directly counteract the drag force. Minimizing the mass of the VDS allows the overall deceleration of the launch vehicle from the VDS to increase. By making the VDS as compact as possible, the overall launch vehicle length is reduced, thus making the launch vehicle more efficient. 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.

4.3.2 Actuation

In order to optimize the actuation speed of the VDS, the drag blades radially extend perpendicular to the rocket body. The load of the drag force exerted on the drag blades is transferred to the support plates of the VDS, rather than directly on the motor. Actuating the drag blades perpendicular to the drag force reduces the torque the motor will have to output to actuate the drag blades, which in turn allows the drag blades to extend faster. The three drag blades are controlled simultaneously by a central gear, which is attached to the motor via D shaft and set screw. The control of all three drag blades by a central gear reduces the risk of mechanical failure. Each drag blade contains a set of radial gear teeth that mesh with the central motor gear. Involute gear teeth were chosen for the central gear and drag blades due to their reliability and efficiency. The meshing between the central gear and drag blades can be seen below in Figure 15.

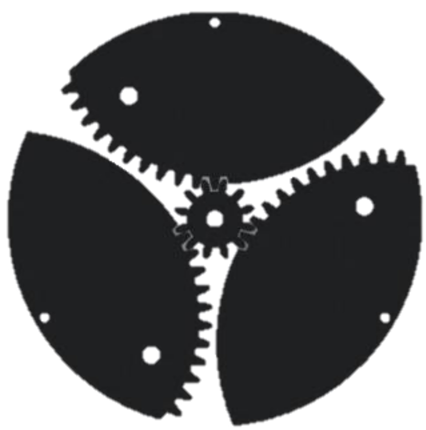


Figure 15: Gear Meshing of Drag Blades.

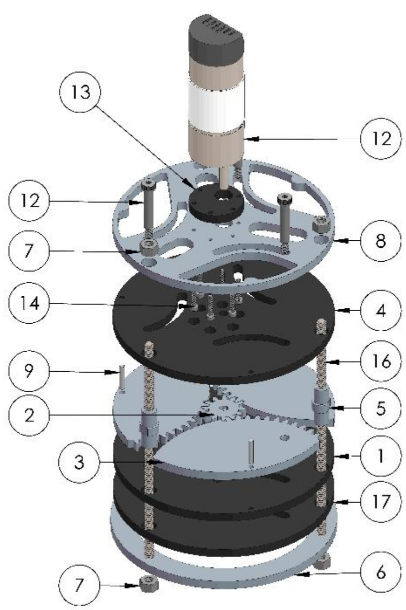
Each drag blade has a through hole for an 18-8 shoulder bolt, which rides in a radial track located in the plates above and below the drag blades. Each drag blade pivots around a $^{1}/_{8}$" Dowel Pin. After full actuation, approximately half of the drag blade is exposed to the exterior of the launch vehicle, and half of the drag blade is located within the VDS assembly. This configuration ensures the maximum amount of area each drag blade extends outside of the airframe of the launch vehicle, while allowing the central motor gear to simultaneously control the actuation of each drag blade. Controlling each drag blade through a central motor gear simplifies the mechanical design and control system of the VDS. Actuation of the blades can be seen in Figure 16 and Figure 17.

Figure 16: VDS top view with no actuation.

Figure 17: VDS top view with full actuation.

4.3.3 Components

A bill of materials of all of the VDS components can be seen below in Figure 18.



ITEM NO.	PART NAME	MATERIAL	QTY.
1	Bottom Delrin Plate	6061 - T6 Aluminum	1
2	DC Motor Gear	6061 - T6 Aluminum	1
3	Drag Blade	6061 - T6 Aluminum	3
4	Top Bearing Plate	Delrin Acetal Resin	1
5	Plate Spacer	6061 - T6 Aluminum	3
6	Bottom Support Plate	6061 - T6 Aluminum	1
7	Hex Nut	Grade 8 Steel	6
8	Top Support Plate	6061 - T6 Aluminum	1
9	Dowel Pin	Type 316 Steel	3
12	Shoulder Bolt	Alloy Steel	3
12	AndyMark NeveRest 60 DC Motor	N/A	1
13	M3-8 Shim	Delrin Acetal Resin	1
14	M3 Socket Head Cap Screw	Class 12.9 Alloy Steel	6
17	Bottom Base Delrin	Delrin Acetal Resin	1
16	All Thread	316 Stainless Steel	3
17	Additional Bottom Delrin Plate	Delrin Acetal Resin	1

PROJECT SECTION :
PART DESCRIPTION:
PART NUMBER/NAME: VDS BOM
QTY: See BOM
Model :
Detail :
MATERIAL:
FINISH:
DO NOT SCALE DRAWING
SHEET SCALE: 1:2
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30
PROPRIETARY NOTE
University of Louisville
River City Rocketry
2016-2017
SHEET 1 OF 1

Figure 18: VDS BOM.

The drag blades are manufactured from $^1/_4$" 6061-T6 aluminum using a Maxiem 450 Water Jet. The drag blades will be 6061-T6 aluminum due to its rigidity because of the drag force they will experience during flight. The drag blades sit between two $^1/_4$" Delrin acetal resin plates, which will be laser cut. Delrin was chosen for the drag blades to slide across due to its low coefficient of friction with aluminum, which is rated at 0.3. Placing the drag blades between a two plates with a material with a low coefficient of friction allows for a precise actuation of the drag blades, while also allowing a slick surface for the drag blades to slide across when compared to aluminum, which is approximately 1.05. An additional Delrin plate was placed below the bottom Delrin plate to hold the dowel pins in place and add support for the drag blades. Three custom machined aluminum spacers, which can be seen in Figure 19, are placed between the Delrin plates to ensure proper alignment of all of the plates of the assembly and prevent overtightening of plates on the drag blades to minimize the friction force of the Delrin plates on the drag blades during actuation.

Figure 19: VDS spacer.

To make the VDS assembly secure and add additional stiffness, 6061-T6 aluminum support plates are placed on top and below the Delrin plates. The DC motor that controls the actuation of the drag blades is mounted to the top support plate of the VDS via six M3 Type 18 - 8 socket head cap screws. The top support plate can be seen below in Figure 20.

Figure 20: Top support plate.

A custom laser cut Delrin shim is placed in between the motor and the top support plate to allow the correct length of each M3 screw to be threaded into the base of the motor. A list of all the VDS components and their respective dimensions can be seen in **Table 7**.

Dimensions	**Components**
Diameter: 5.85 in Thickness: 0.25 in	Top Support Plate Bottom Support Plate Top Bearing Plate Bottom Bearing Plates
Thickness: 0.25 in	Drag Blades
Shoulder Diameter: 0.25in Threads Size: 10-24 UNC Shoulder Length: 1.25 in	Shoulder Bolts
Thread Size: $^1/_4$ in- 20 UNC	All Thread
Thickness: 0.25 in Diameter: 1.46 in	Motor Shim
Diameter: 0.125 in Length: 0.75 in	Dowel Pins
Length: 8 mm	M3 Socket Head Cap Screws

Table 7: VDS components general dimensions.

4.3.4 Motor Selection

In order to calculate the maximum torque required to actuate the drag blades in the VDS, the drag force that each blade experiences was determined using

$$D = \frac{C_d A \rho v^2}{2} \quad (1)$$

where C_d is the coefficient of drag, A is the projected area, v is the velocity, and ρ is the air density. The friction force between each drag blade and the Delrin bearing plates was calculated using

$$f_k = D\mu \quad (2)$$

where f_k is the friction force and μ is the coefficient of friction between aluminum and Delrin. After the friction force is computed, it is then substituted into

$$\tau = f_k r \tag{3}$$

in order to calculate the torque required for the motor to actuate one drag blade where T is torque and r is the distance from the centroid of the friction force to the contact point on the teeth of the servo gear. Using equations (1) through (3), the maximum torque the motor will have to overcome to actuate the drag blades with a factor of safety of 2 and a gear inefficiency of 70% is 357.6 oz-in. Initially, a servo was chosen to actuate the VDS. However, a servo with the required torque and desired speed could not be found. In order to find a motor with acceptable specifications and account for uncertainties in the team's calculations, the team decided to utilize the AndyMark Neverest 60 DC motor for the prototype launch vehicle test flights to ensure functionality of the VDS. The specifications of the AndyMark Neverest 60 DC motor can be seen in Table 8.

Motor Specifications	**Numerical Value**
Gearbox Output Power	14W
Stall Torque	593 oz-in
Required Torque	357.6 oz-in
No-Load Speed	105 rpm
Weight	.776 lb

Table 8: AndyMark Neverest 60 DC Motor Specifications.

4.3.5 Analysis

By analyzing past failure modes of other teams' air braking designs, the team wanted to design a robust system that would be able to withstand all of the worst case scenario drag forces during flight. Due to the uncertainties in our forces the VDS was subjected to several conservative assumptions in order to make design decisions on the structure of the VDS. Several FEA simulations were run to ensure that the VDS would be robust enough to survive the results from the team's conservative calculations. After analyzing the data of the test launches in which the VDS was active, the team was able to increase the accuracy of the team's initial calculations by comparing them to the exact deceleration of the launch vehicle due to the VDS. Preliminary FEA simulations with conservative assumptions were conducted with the results from the test flights and the team found that the minimum factor of safety in the configuration that it was tested in was 58. The factor of safety plot and the stress analysis from the FEA simulation can be seen below in Figure 21 and Figure 22.

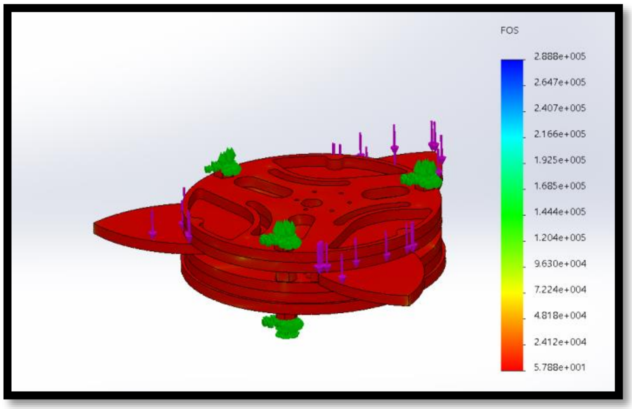


Figure 21: FEA factor of safety simulation.

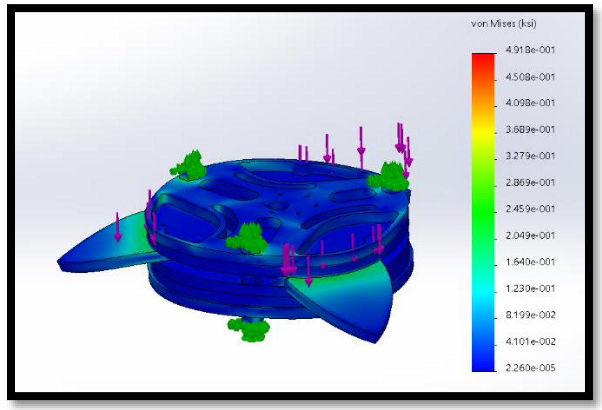


Figure 22: FEA stress simulation.

4.3.6 Improvements

Now that the team has a greater certainty in our calculations, the VDS will be optimized. Some optimizations to be made include adding limit switches prevent the motor from actuating the drag blades past their mechanical limit, reducing the thickness of the Delrin plates and drag blades, optimizing the geometry of the support plates to reduce mass, and choosing a faster and lighter motor. A rendering of the preliminary VDS design for the upcoming season can be seen below in Figure 23.

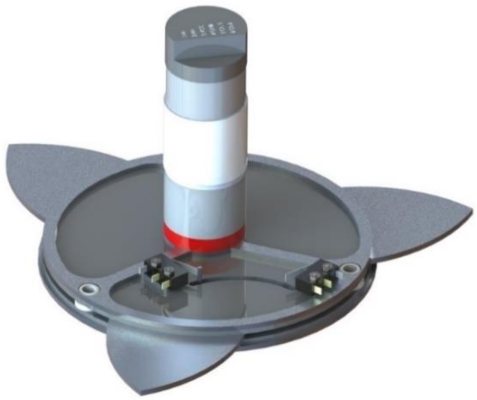


Figure 23: Updated VDS.

During one of the test launches with the VDS, the drag blades were actuated at 50 meters after burnout of the vehicle to verify the load that they would experience during a flight. A graph of the vertical acceleration of the prototype launch vehicle during this launch can be seen below in Figure 24. The difference in vertical acceleration of the launch vehicle at the time at which the VDS actuated the drag blades is 5.39 m/s^2, according to the fitted curve of the raw data.

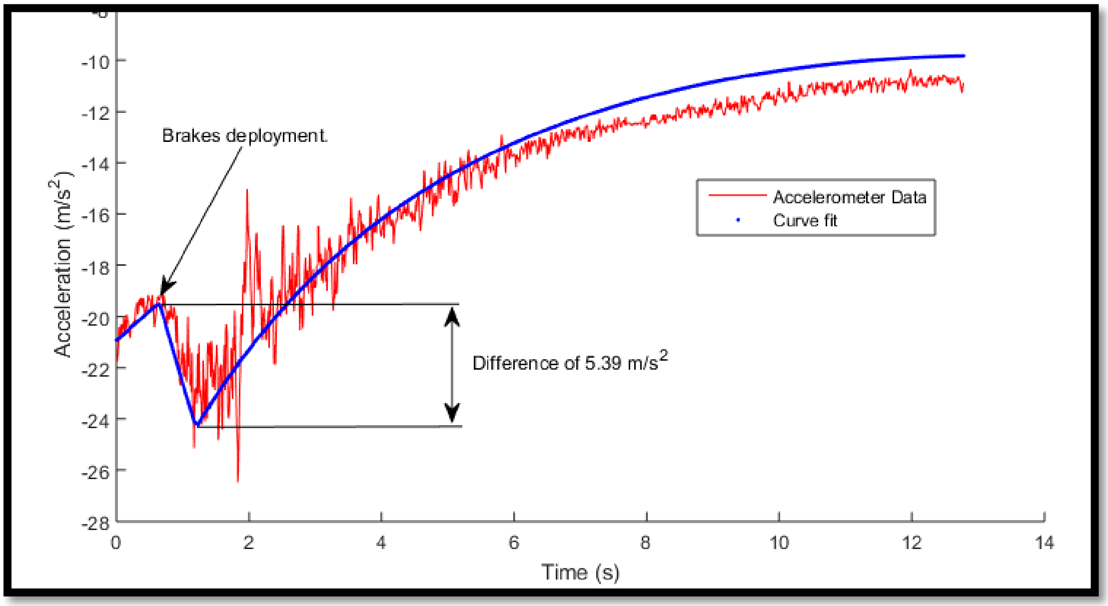


Figure 24: Acceleration vs time of the prototype launch vehicle with VDS.

During this flight, the drag blades of the VDS induced a drag force of 75 N on the launch vehicle, which indicated that the motor had to overcome 125.2 oz-in. This experimental number verified equations (1) to (3) and allows for a greater amount of certainty in choosing a faster motor for the VDS system in the future. To further increase the actuation speed of the VDS, the AndyMark Neverest 40 DC Motor will be selected. The technical specifications can be seen below in Table 9.

Gearbox Output Power	14W
Stall Torque	350 oz-in
No-Load Speed	160 rpm
Weight	.75 lb

Table 9: AndyMark Neverest 40 DC Motor Specifications.

4.4 Experimental Results

Four full-scale test launches have been conducted to provide data on the VDS. This data has been used as a basic proof of concept for the project as well as to provide validation for the model equations. These test launches also provide concrete justification for many proposed upgrades. A summary of these launches is below in Table 10.

Launch Name	Data/Location	Launch Summary	Apogee Altitude	Burnout*
Control Launch	5-28-16 Manchester, TN	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: 4809.88 ft (1466.05 m)	[x,x]
VDS Prototype Active Launch 1	8-6-16 Manchester, TN	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)	h_0 =628.48 ft (191.56 m) v_0 = 593.27 ft/s (180.83 m/s)
VDS Prototype Active Launch 2	8-27-16 Memphis, TN	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: 1309.5 [m]	h_0 =826.44 ft (251.9 m) v_0 =527.66 ft/s (160.83 m/s)
VDS Prototype Full Deploy Launch	9-10-16 Manchester, TN	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)	h_0 =679.13 ft (207 m) v_0 =564.01 ft/s (171.91 m/s)

Table 10: Prototype launch summary.

*Based on the AIM Xtra flight computer

There are several patterns worth noting in the data provided by the above table. The first is simply the apogee altitude of the control launch compared to the others. The launches with brakes deployed result in lower apogee altitudes, demonstrating that the VDS is capable of braking the vehicle. This is particularly evident in comparing the control launch to the 'full deploy' launch where there is a difference in altitude of 193.95 [m] (636 [ft]).

The second pattern worth noting is the large variance in burnout characteristics. Despite flying 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.

4.4.1 Verification of Model Equations

An important aspect of these launches is that they provide verification/validation of the model equations. Given that the VDS prototype simulator and the SPP are based on the coast phase model equations, it is important to validate the model equations with experimental data. Several plots of the VDS Prototype Full Deploy Launch are shown below.

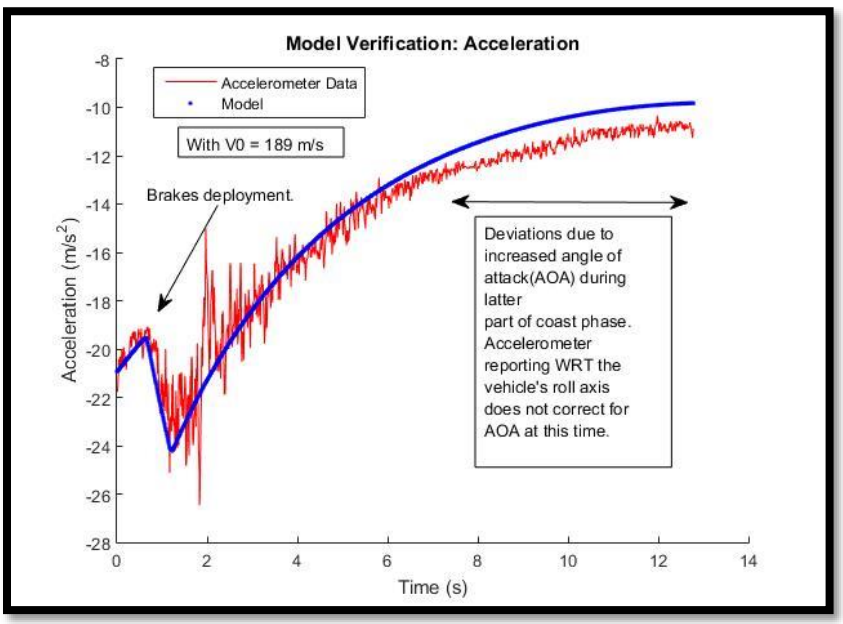


Figure 25: VDS model verification: acceleration.

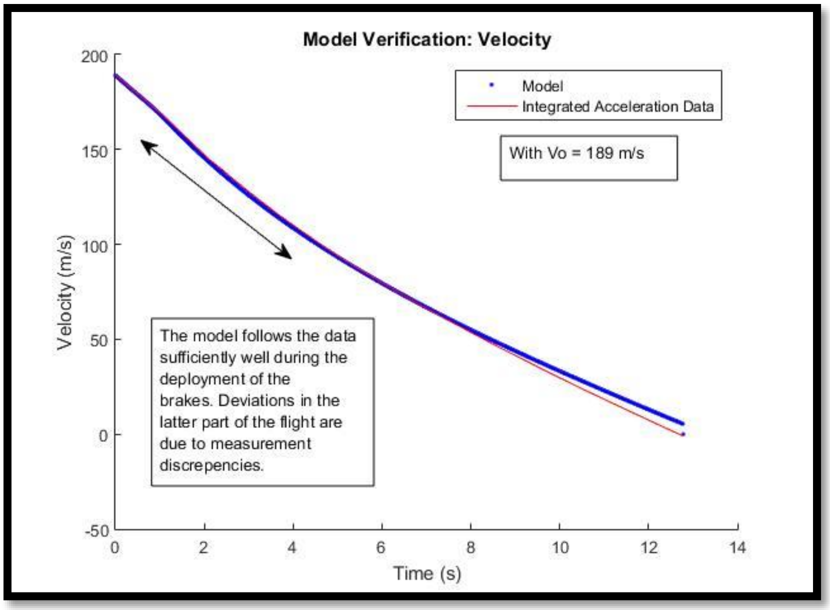


Figure 26: VDS model verification: velocity.

The VDS Full Deploy Launch is particularly useful for the purpose of validating the model equations because it showcases the brakes' performance during the high velocity portion of the coast phase as well as the latter part of the coast phase. This is useful considering the v^2 component of the drag equation and also considering that the model and data digress in the latter portion of the coast phase due to measurement discrepancies with the Aim Xtra flight computer's accelerometer reporting WRT to the roll axis of the vehicle. The upgraded VDS will feature its own accelerometer and, combined with gyroscopic and magnetic sensors, will account for the increased angle of attack that occurs in the latter portions of the coast phase.

Determining the Coefficient of Drag

An important component of the model equations is the coefficient of drag constant on the drag term.

$$a = -g - \frac{C_d \rho A v^2}{2m}$$

This constant is difficult to determine analytically and had to be determined experimentally. In the case of the VDS, it was known that there would exist two different coefficients: one for the vehicle itself, C_r, and another for the vehicle with the brakes deployed, C_{r+b}. These constants, respectively, were determined to be 0.4 and 0.54 for the prototype launch vehicle. These numbers were determined in part by 3-dimensional curve-fitting shown below in Figure 27.

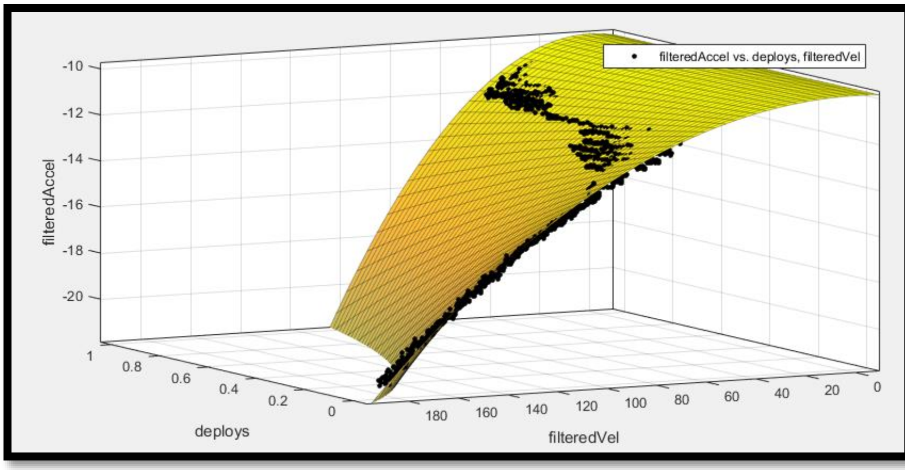


Figure 27: VDS 3D curve-fitting to determine Cd.

By using the observed acceleration data (Z axis), velocity data (X axis), and percent deployment data (Y axis) and the model equations, Matlab's curve fitting tool optimizes the unknown coefficients to find a best fit. In the case of the 'VDS Prototype Active Launch 1' data above, a fitting of r-square equal to 0.9832.

It is also to be noted that this paper is not a study of fluid dynamics. It is likely that these coefficients also account for other, smaller phenomena occurring during the flight and do not purely represent the coefficient of drag. The purpose of these numbers, that in part, represent the coefficient of drag, is purely pragmatic. Their effectiveness in syncing the model equations with the flight data is apparent in the graphs above and will be sufficient in allowing the VDS to achieve its goal.

4.4.2 Sensor Noise

Of all the discoveries made with the four full-scale prototype launches, the most significant in terms of control theory is the low signal-noise ratio. The VDS Electronics prototype, operating on a single barometric pressure sensor, is highly subject to small fluctuations in pressure and results in a noisy input signal. This is particularly true with the VDS Electronics' velocity data, which is obtained by taking the slope of a least-squares fit of the nine most recent altitude points. This serves only to amplify any noise issues, rendering the velocity data useless if the precision of the VDS is to improve. An example of this issue is shown below in Figure 28.

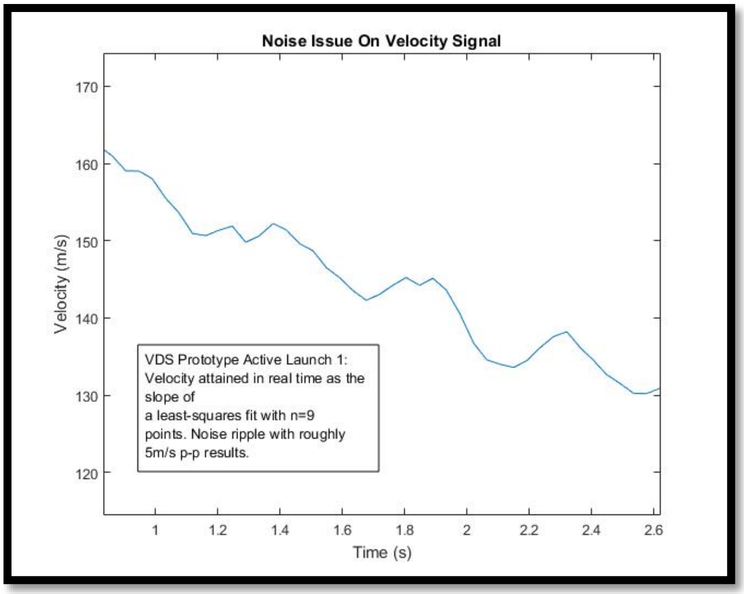


Figure 28: Noise issue on velocity signal

Improving the signal-noise ratio will be achieved with a custom Kalman filter and the implementation of additional sensors on the VDS Electronics. The Kalman filter will fuse the information provided by the array of sensors into coherent data that will have a better signal-noise ratio than what any of the individual sensors could provide individually.

DC Motor Feedback Noise

In addition to the sensor noise discussed above, an unusual phenomenon was discovered during VDS Prototype Active Launches one and two that will also be addressed in the new VDS. It was discovered that oscillations in the velocity data corresponded with the $\dot{\theta}$ of the DC motor as shown below in Figure 29.

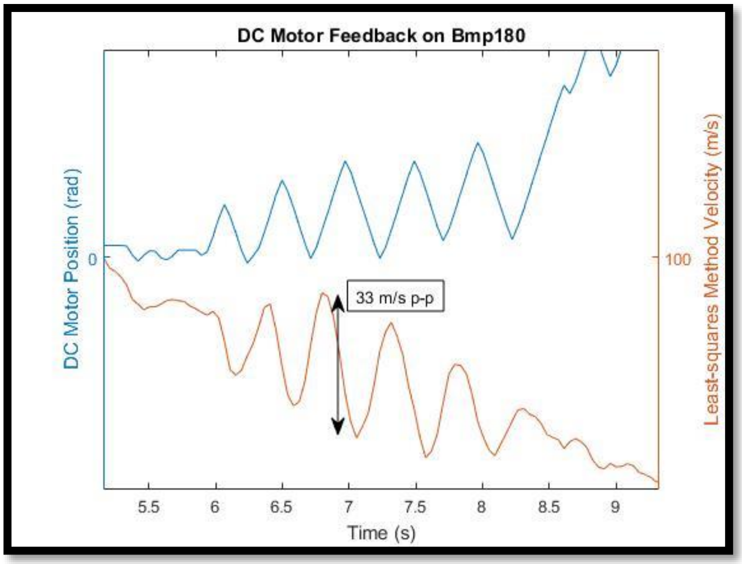


Figure 29: DC motor feedback on Bmp180

Further testing confirmed that the oscillations of the DC motor affect the readings of the Bmp180 sensor. In addition to a root cause analysis, this issue will be further mitigated by the implementation of additional sensors and a Kalman filter. By diversifying the sensor data, the VDS will be less susceptible to anomalies on any one sensor as is the case with the DC motor feedback issue.

4.5 Conclusion

The data gained from a rigorous prototype phase has provided a strong justification for several upgrades to the VDS system. A summary of these proposed upgrades and their justifications are shown below in Table 11.

Upgrade	Justification
Lighter VDS mechanical components.	Test data confirms the maximum force the blades will experience during flight. This allows for more accurate FEA simulations and a reduction in material thicknesses.
Addition of 9DOF sensor and Kalman filter.	Test data indicates a high level of noise and feedback is a result of a dependence on a single barometer. Diversifying the sensors and combining their information with a Kalman filter will greatly increase the fidelity of the VDS data.
Faster DC motor.	Test data confirms the maximum force the blades will experience during flight. This information is used to calculate the amount of torque the DC motor must have to overcome the friction of the blades. This more accurate torque number is used to optimize the trade-off between torque and speed.
Use of Raspberry Pi 3 as main computer.	The addition of the 9DOF sensor and Kalman filter will increase the complexity of the VDS software and a proportional

	upgrade in hardware is necessary to facilitate this. Specifically, the need for high-fidelity floating point arithmetic and program space motivated the upgrade from the Arduino platform to the Raspberry Pi.
New simulator.	The addition of the 9DOF sensor and Kalman filter will change the behavior of the system. This will necessitate a new simulation.
Addition of limit switches.	Because the DC motor angle is reported with relative positioning, limit switches will be necessary to 'zero' the DC motor's and the blades' position.

Table 11: VDS upgrade summary.

5 Technical Design: Launch Vehicle

5.1 Stability and Construction

5.1.1 Applicable Formulations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$q_c = \sqrt{\frac{T - m_c g}{k}} \tag{8}$$

$$x_c = \frac{2kq_c}{m_c} \tag{9}$$

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

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

The coasting distance can then be computed using

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

The peak altitude is then determined using

$$PA = y_1 + y_c \tag{12}$$

The center of gravity location is calculated using

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

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

$$X = \frac{(C_N)_N X_N + (C_N)_F X_F}{(C_N)_N + (C_N)_F} \tag{14}$$

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

$$X_N = \frac{2}{3} L_N \tag{15}$$

where L_N is the nose cone length. C_{NF} in equation 14 is the fin center of pressure coefficient calculated using

$$(C_N)_F = \left[1 + \frac{R}{S + R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_f}{C_R + C_T}\right)^2}}\right] \tag{16}$$

where R is the radius of the body at the aft end, S is the fin semispan, N is the number of fins, L_F is the length of the fin mid-chord line, C_R is the fin root chord length, and C_T is the fin tip chord length. X_F in equation 14 is calculated using

$$X_F = X_B + \frac{X_R(C_R + 2C_T)}{3(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right] \tag{17}$$

where X_B is the distance from the nose tip to the fin root chord leading edge. X_R is the distance between the fin root leading edge and the fin tip leading edge measured parallel to body. Equations 14 through 17 are also known as the Barrowman Equations (The Theoretical Prediction of the Center of Pressure, 1966). Note that Equation 14 is a simplified form because the rocket has no transition in diameter in the body; thus, the transitional terms have been omitted. These equations are used to verify the OpenRocket simulation conducted of the full scale launch vehicle.

5.1.2 Stability

The launch will be constructed primarily from carbon fiber, fiberglass, aluminum, and plywood. In order to maximize the braking power of the VDS and achieve an apogee of 5280 feet, the main goal of the launch vehicle this year will be to minimize mass while optimizing for maximum efficiency. The launch vehicle can be divided into five distinct sections, which is outlined below in Figure 30.

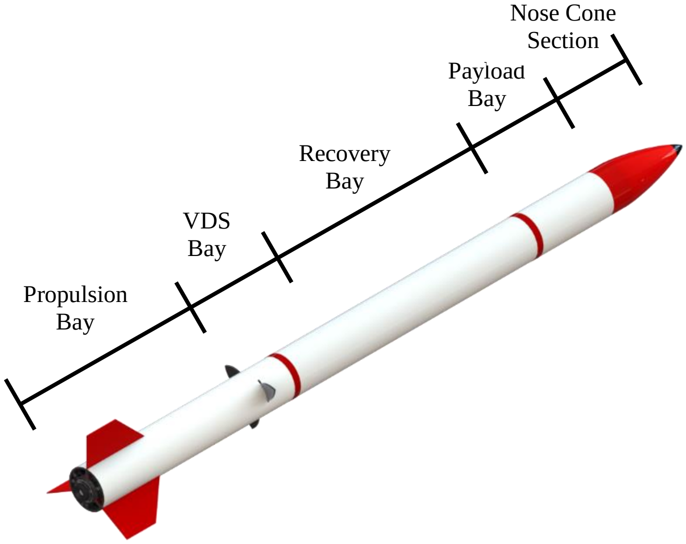


Figure 30: Full scale launch vehicle.

The propulsion bay will consist of the removable fin system, fins, and motor. The VDS will be housed within a 12” by 6” carbon fiber coupler which connects the propulsion bay and recovery bay. There will be one recovery bay, which contains a drogue parachute and a vortex ring, which is further outlined in the Recovery Section. The payload bay will be located forward to the recovery bay and the nose cone will attach to the end of the payload bay. The length and mass of each section of the launch vehicle can be viewed in Table 12.

Section of launch vehicle	Length of section (in)	Weight (lb)
Nose Cone Section	12	2
Payload Bay	12.2	15.6
Recovery Bay	41	6.1
VDS Bay	12	4
Propulsion Bay with Motor	32.25	17.3
Total Length and Weight	**109.45**	**45.0**

Table 12: Launch vehicle overall dimensions.

The launch vehicle was designed so that the drag flaps of the VDS were farthest aft on the vehicle as possible to guarantee that all protuberances are located aft of the burnout of gravity. The VDS drag blades are 24.56in. further aft than the burnout center of gravity. This also reduces the effect that the VDS might have on the location of the center of pressure of the vehicle during flight, in order to maintain a safe stability margin.

The static stability margin of the launch vehicle in its current configuration is 2.39 with a total weight of 45.0 lb. An OpenRocket model was created to verify Equations 1 through 17 which calculate location of the center of gravity, location of the center of pressure, and apogee altitude of the launch vehicle. The specifications of the OpenRocket Simulation of the launch vehicle are shown in Table 13.

Specifications of Full Scale Launch Vehicle	Numerical Value
Center of Gravity (in. from nose)	54.352
Center of Pressure (in. from nose)	68.941
Rail exit velocity (ft/s)	61
Max. acceleration (ft/s2)	243
Predicted apogee altitude (ft)	5460
Thrust to weight ratio	9.08

Table 13: Launch vehicle flight specifications.

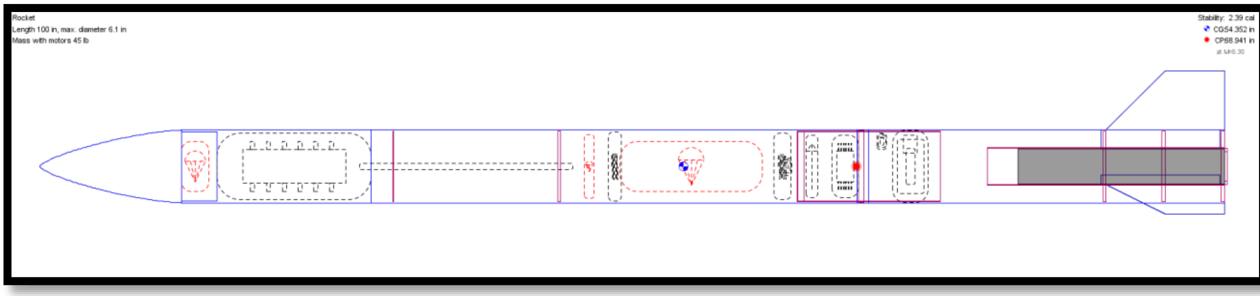


Figure 31: OpenRocket simulation.

As seen above in Figure 31, the launch vehicle will include three clipped delta fins. The clipped delta fin shape was chosen due to its efficiency and durability. Three fins were chosen rather than four to accommodate the VDS system to allow even airflow over all three fins. The drag blades of the VDS are offset by 60 degrees relative to the fins because of the concern of the disruption of airflow around the fins during flight. This minimizes the risk of turbulent air flow over the fins. A CFD simulation was ran at 650 ft/s and validates that the turbulent air flow from the drag blades do not interfere with the air flow over the fins, as shown in Figure 32.

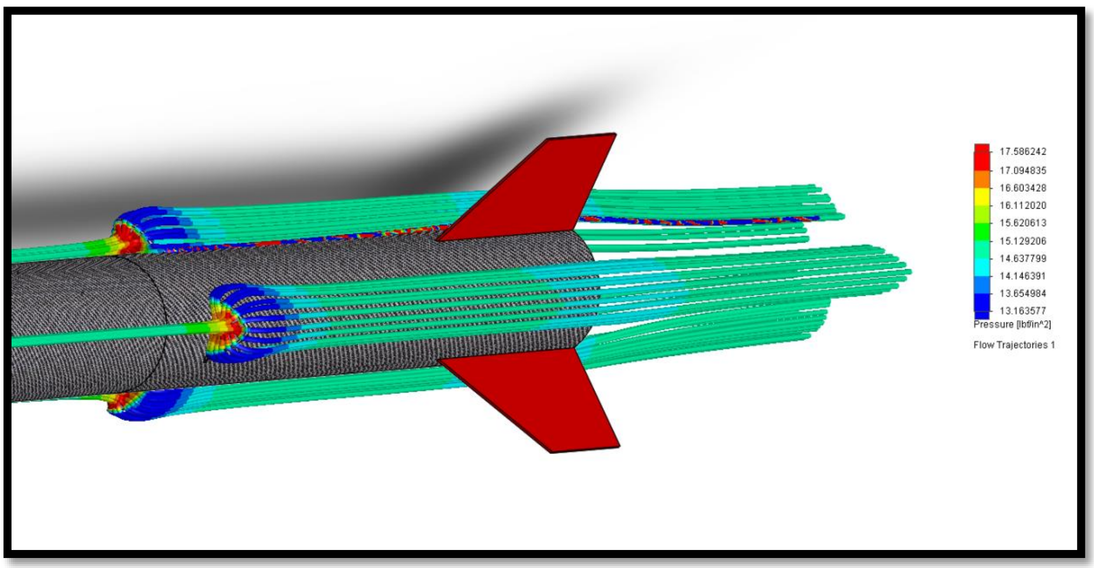


Figure 32: VDS air flow CFD simulation results.

The launch vehicle will be constructed by strictly adhering to proven manufacturing processes. All separating sections of the launch vehicle will be joined to their respective coupler with nylon 4-40 socket head cap screw shear pins. Similarly, each section that will not be separating through the course of the flight will be joined with 6-32 button heed socket cap screws. To better differentiate between the nylon shear pins and the static metal screws, different colored screws will be assigned to the separating and non-separating sections in order to prevent accidental installation of metal screws into separating sections and vice versa. All bulk plates, centering rings, and permanently secured sections of the launch vehicle will be epoxied using Glenmarc's G5000 two component filled epoxy. This epoxy was chosen for its superior strength, as seen in Table 14.

Criteria Analyzed	Result
Tensile strength	7,600 psi
Compression strength	14,800 psi
Shore "D" Hardness	85
Elongation at break %	6.30 %

Table 14: G500 epoxy material properties.

5.1.3 Nose Cone Design

The nose cone will be constructed from 6k carbon fiber filament using the X-Winder. It will be secured to the launch vehicle via three 4-40 SHCS nylon shear pins. The nose cone section will attach to the forward end of the payload, which is further outlined in the 73Technical Design: Payload Section. To ensure that the launch vehicle will be able to reach the required altitude within the L-motor class, the team decided to choose a nose cone profile that provided an ideal coefficient of drag at transonic speeds. The nose cone shape for the launch vehicle will be a 2:1 fineness ratio LD haack series nose cone, which can be seen below in Figure 33. This shape was chosen due to its combination of low mass and relatively low coefficient of drag when compared to other nose cone profiles.

Figure 33: Nose cone rendering.

A CFD simulation was run to calculate the coefficient of drag and maximum pressure of the chosen nose cone shape at burnout velocity, which is approximately 650 ft/s. The results from the CFD simulation can be seen in Figure 34 below. The simulation showed that at 650 ft/s, the coefficient of drag is .218 and the greatest pressure the nose cone will experience is 16.18 lb/in^2.

The pressure results from the CFD simulation can be seen below in Figure 34. Data from this CFD simulation will be used to optimize the mass of the nose cone. Further research will be carried out into the drag characteristics of various other nose cone profiles to ensure that the 2:1 fineness ratio LD hack nose cone is the most efficient nose cone for the launch vehicle.

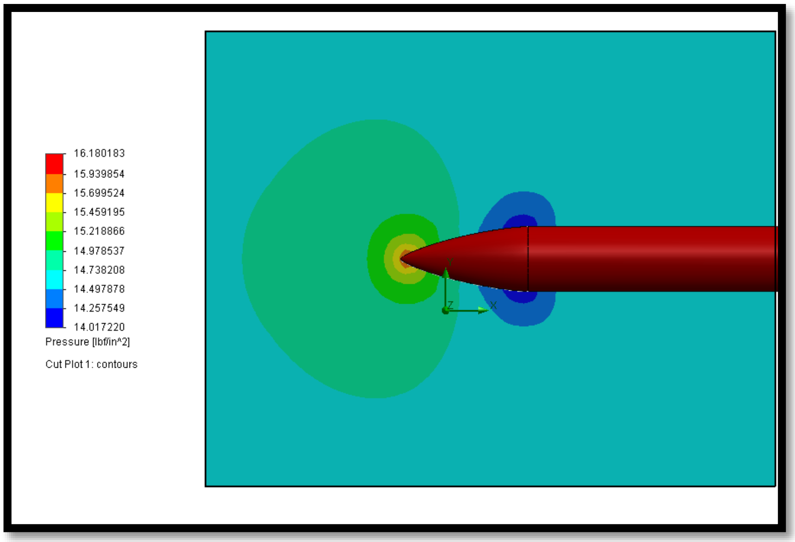


Figure 34: Nose cone CFD simulation results.

5.1.4 Propulsion Bay

The two primary goals achieved with the propulsion bay are to serve as the attachment point for the removable fin system and house the motor and motor casing to propel the launch vehicle.

The propulsion bay airframe will be constructed from 6.0 in. diameter filament wound carbon fiber tubing. In order to ensure that the fin slots are cut at the specified location, a jig has been created to mark where the slots would be placed using a Universal Laser Systems laser cutter. The jig is seen below in Figure 35.

Figure 35: Fin slot alignment jig.

Once drawn, the fin slots will be cut using a rotary Dremel tool with an abrasive cut off tool attachment. The thickness of the stencil, 0.125 inch, used in the jig is identical to that of the fins used in the launch vehicle, ensuring a near perfect fit with the fins.

Motor Tube

The motor mount tube will be constructed from 3.0 in. diameter filament wound carbon fiber tubing. The motor tube will be cut to a length of 20 inches, allowing for motor tube to exceed the motor casing by 4 inches. This allows a majority of the motor casing to be in contact with the motor mount

Removable Fin System

In order to reduce weight, and remove epoxy joints, a precision fin mounting system has been designed for the launch vehicle. This system 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 removable fin system also allows different fin designs to be utilized during test launches to account for mass changes throughout the year.

Figure 36: Propulsion bay assembly.

Figure 36 shows an assembled rendering of the removable fin system as it appears in the propulsion bay. The assembly consists of three centering rings, a rear fin retainer, and a motor casing retainer. The centering rings are the only components epoxied to the motor mount tube and airframe. Proper alignment of the centering rings is critical to the success of the removable fin system. To ensure proper alignment, the fins will be placed in the centering rings during the curing process of the epoxy.

Centering Ring Design

The centering rings will be custom manufactured from a Maxiem 450 Water Jet from 6061 – T6 aluminum. All of the centering rings have specifically sized slots radially separated 120° to insert the three fins into the propulsion bay. The fins are held in place in the propulsion bay by placing the specified fin tab into their proper slots in each centering ring. The fins are inserted into the centering rings and 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. A detailed drawing of the fore centering ring can be seen below in Figure 37.

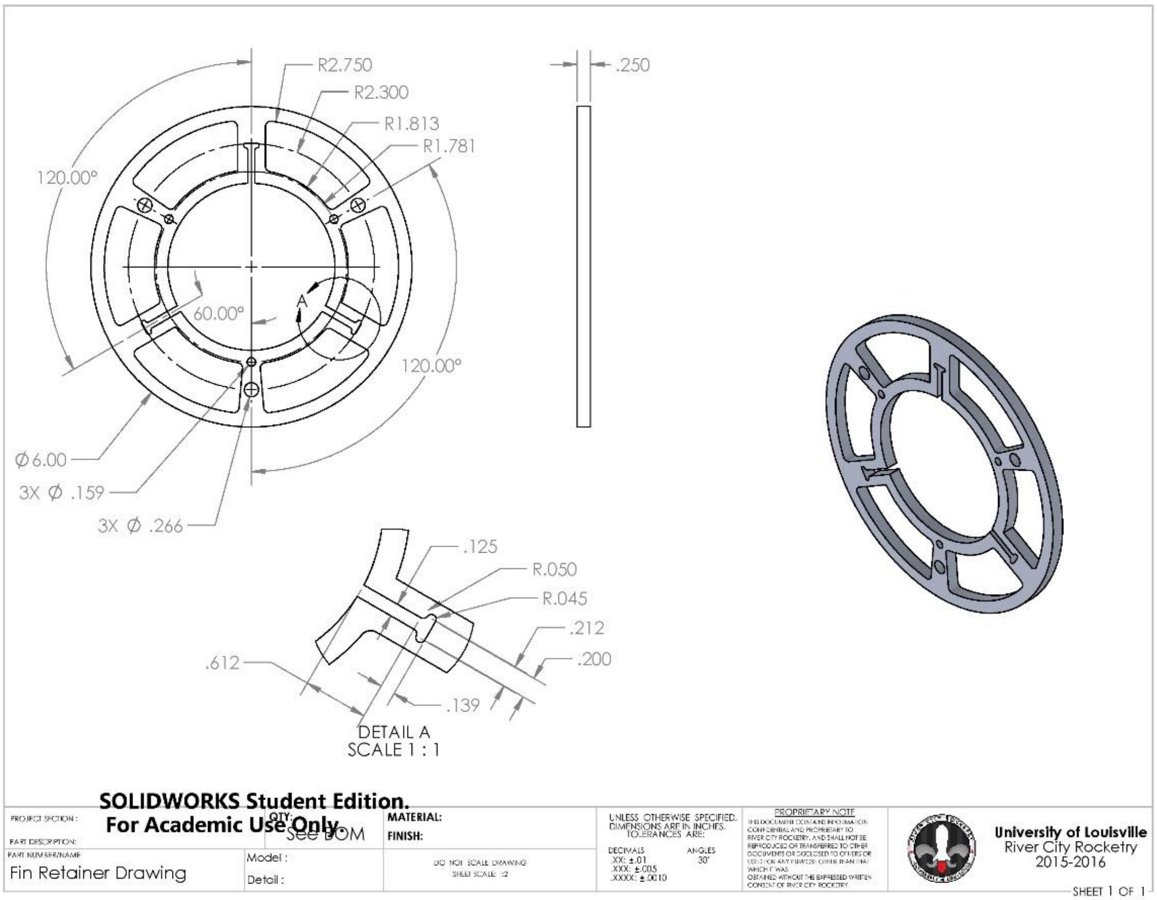


Figure 37: Detailed drawing of fore centering ring

With the motor installed in the casing and motor tube, the motor retainer mounts to the fin retainer via three #10-32 UNF-3A shoulder screws 1 inch in length. All fasteners in the system are made from 18-8 stainless steel. An exploded propulsion bay assembly is shown below in Figure 38.

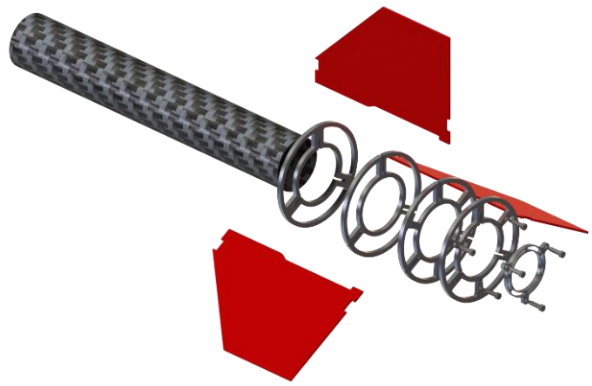


Figure 38: Exploded propulsion bay assembly.

5.1.5 Motor Selection

Several OpenRocket simulations were conducted with different motor configurations in order to choose the motor that produced an appropriate apogee altitude. Due to the mass of the payload and desired apogee altitude of the VDS, the full scale launch vehicle will utilize the Aerotech 1420 Redline motor. This motor was chosen due to its desired total impulse and brand reliability. With this motor, the launch vehicle will reach an estimated apogee altitude of 5460 feet. This apogee altitude was chosen to utilize the VDS, which will deploy the drag blades and decrease the apogee altitude to 5280 feet. The thrust vs time curve and the specifications of the Aerotech L1420 Redline motor can be seen blow in Figure 39 and Table 15, respectively.

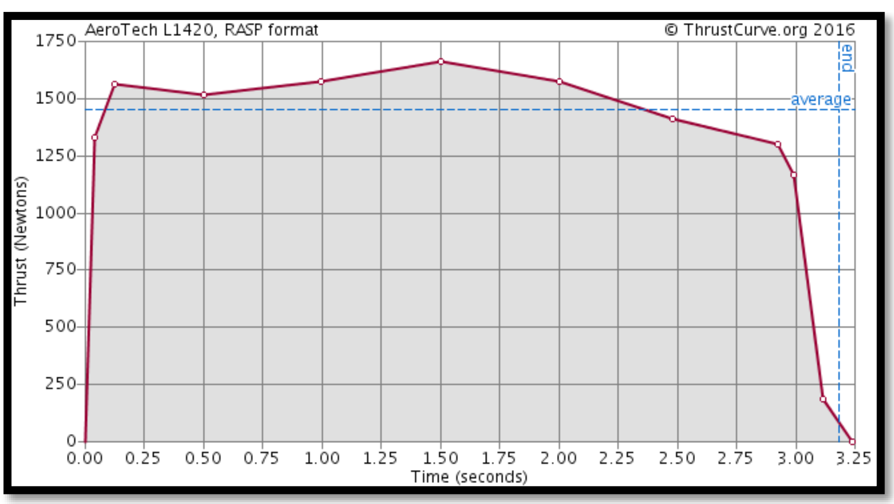


Figure 39; Aerotech L1420R Thrust Curve.

Characteristics	Specs.
Diameter	75.0 mm
Total Weight	160.92 oz
Propellant Weight	90.30 oz
Average Thrust	1420.0 N
Maximum Thrust	1814.0 N
Total Impulse	4603.0 N-sec
Burn Time	3.2 sec

Table 15; Aerotech L1420 Redline Specifications.

5.1.6 Airframe

The motor mount and airframe will be constructed from 3.0in. and 6.0in. diameter filament wound carbon fiber tubing manufactured using a 4 axis X-Winder, as seen in Figure 40.

Figure 40; 4-axis X-Winder

In the past, the team has implemented 5 layers of 6k carbon fiber filament to wind the airframe and motor mount tube. Last year, the winding angle of each layer of the airframe and motor mount, from innermost to outermost respectively, were 45°, 35°, 45°, 35°, and 65°, measured from the center axis of the mandrel. To further improve the efficiency of the launch vehicle, the team will be researching further into the structural properties of specific winding angles and what effect the different combinations of winding angles have on the structural quality of various sized composite tubes.

5.2 Statement of Work Verifications

Challenges	Solutions
The vehicle shall deliver the science or engineering 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 5280 feet.
The vehicle shall 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.
All recovery electronics shall be powered by commercially available batteries.	The primary and redundant altimeters will be powered by 9 volt Duracel batteries.
The launch vehicle shall 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. Though appropriate material selection and manufacturing techniques, the rocket will be able to land at the maximum allowable kinetic energy without incurring any damage. Landing within these constraints will leave our launch vehicle in a reusable state.
The launch vehicle shall have a maximum of four (4) independent sections.	The launch vehicle will be comprised of four independent sections: the nose cone, the payload bay, the recovery bay, and the rest of the launch vehicle, which includes the VDS bay and the propulsion bay.
The launch vehicle shall be limited to a single stage.	Having a limited altitude of 5280 ft eliminates any need for staging of our launch vehicle. Motor selections have been made to accomplish all necessary altitude requirements on a single stage launch vehicle.
The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation	A comprehensive launch procedure checklist will be constructed by the team to allow for accurate and expedited vehicle assembly

Administration flight waiver opens.	while preparing for flight.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	The power supplies for the payload electronics, altimeters, and flight event devices have been chosen to eliminate the chances of power failure for an extended period of time.
The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system.	The launch vehicle will utilize 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
The launch vehicle shall 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.
The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The team will use an Aerotech L1420 Redline motor for its full scale launch vehicle.
Pressure vessels on the vehicle shall be approved by the RSO.	The current design of the launch vehicle does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.
The total impulse provided by a Middle and/or High School launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	The total impulse of the Aerotech 1420 Redline motor is 4603.0 Newton-seconds
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	In the current configuration of the launch vehicle, the static stability margin is 2.21 and the rail exit velocity is 61 fps.
All teams shall successfully launch and recover a subscale model of their rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.	The team will design a 1:2 scaled model of the full scale launch vehicle. The subscale launch vehicle will be used to test stability and integration of various systems seen in the full scale launch vehicle.
All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight con-figuration. The rocket flown at FRR must be the same rocket to be flown on launch day.	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.

Any structural protuberance on the rocket shall 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 and close to the fins as possible. As a result, all structural protuberances are located aft of the burnout center of gravity.

Table 16: Solutions to the challenges set out by the statement of work.

6 Technical Design: Recovery

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

1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery 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 Range Safety Officer.

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.

3. At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.

4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.

5. The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.

6. Motor ejection is not a permissible form of primary or secondary deployment.

7. Each altimeter shall 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.

8. Each altimeter shall have a dedicated power supply.

9. Each arming switch shall be capable of being locked in the ON position for launch.

10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.

11. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.

12. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).

What follows is an outline of how these criteria are to be met.

6.1 Vehicle Recovery

The recovery system will have to serve multiple purposes, acting as the standard method for recovering the vehicle and acting as a risk mitigation recovery system for the multirotor payload. All sections of the launch vehicle that are independent during any stage of recovery will be equipped with GPS trackers.

6.1.1 Mass Optimization

Given the sophisticated designs of the control system, the payload, and VDS, the launch vehicle is inherently heavy. The weight of the vehicle is directly related to the performance of the VDS and is the primary motivating factor for the design of the recovery system.

A duel deployment system will be sequentially staged from within a single recovery bay, with the drogue acting as a pilot chute for the main parachute until main deployment. A single recovery bay allows the launch vehicle to contain fewer bulkheads, reduce the number of couplers required for deployment, and reduce the total length of airframe needed for the recovery system. The reduction in weight to the launch vehicle will result in a more effective VDS.

6.1.2 Deployment Procedure

In order for the vehicle to be recovered safely and in a reusable state, two deployment events will have to occur, with a potential third auxiliary deployment in the multirotor risk mitigation configuration. The sequence is detailed below in Table 17.

Event	Altitude (ft.)	Phase	Description
1	5,280	Drogue Phase	Launch vehicle separates at the midsection of the vehicle via black powder charge and shear pin configuration (aft end of payload bay) and begins drogue descent.
2	800	Main Deployment	Tender descender disengages drogue shock cord, engaging lanyard attached to vortex ring deployment bag. Vortex ring deploys with drogue now acting as pilot chute, pulling the vortex ring from the recovery bay.
3	100	Multirotor Mitigation	This event is described as optional in case a system failure were to occur, a redundant parachute would deploy.

Table 17: Recovery procedure.

For the single-bay dual deployment of the main vehicle, the recovery system will be stowed with the drogue and main parachute in the same recovery bay. The system will use a tender descender to anchor the shock cord of the drogue to the U bolt attached to the bulk plate underneath the main deployment bag. The tender descender in Figure 41 and Figure 42 is a robust steel master link assembly that serves as a load bearing connection point until a black powder charge forces the master link out of the assembly, freeing the quick links on each end. This will ensure that the drogue does not act as the main pilot chute until the main deployment event.

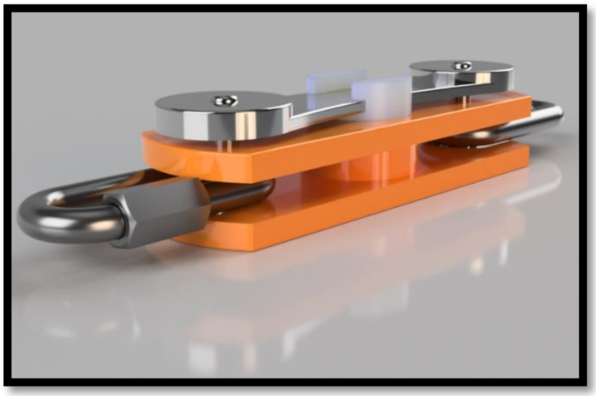


Figure 41: Tender descender engaged.

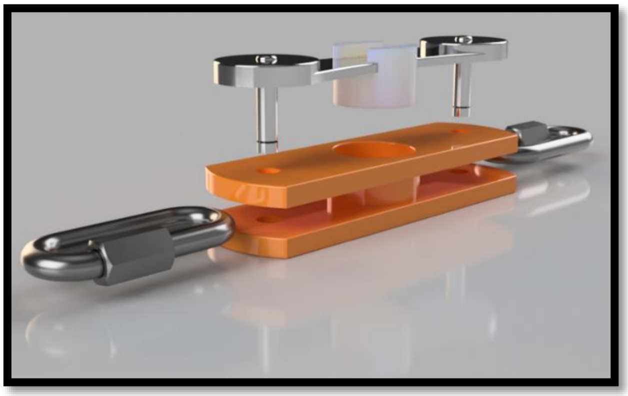


Figure 42: Tender descender disengaged.

As seen below in Figure 43, the tender descender provides a temporary connection point for the drogue parachute to the U bolt connected to the bulkhead of the launch vehicle. This connection maintains slack in the shock cord that runs from the opposite end of the tender descender through the top of the deployment bag, tethering the drogue to the top of the vortex ring.

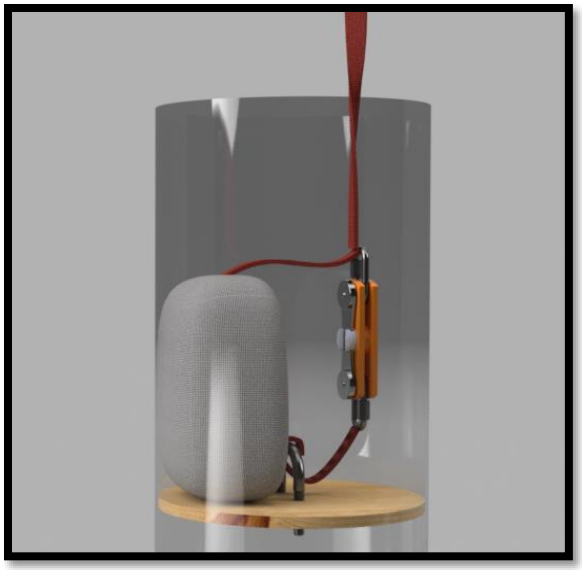


Figure 43: Cutaway view of engaged tender descender inside recovery bay during drogue descent.

During main event, the shock cord is freed from the tender descender, allowing the drogue to now act as a pilot chute for the vortex ring, pulling the deployment bag and main parachute from the recovery bay.

After main deployment, the nosecone will be ejected by black powder charges, putting the launch vehicle into multirotor deployment configuration. The nose cone configuration is shown below in Figure 44 and Figure 45.

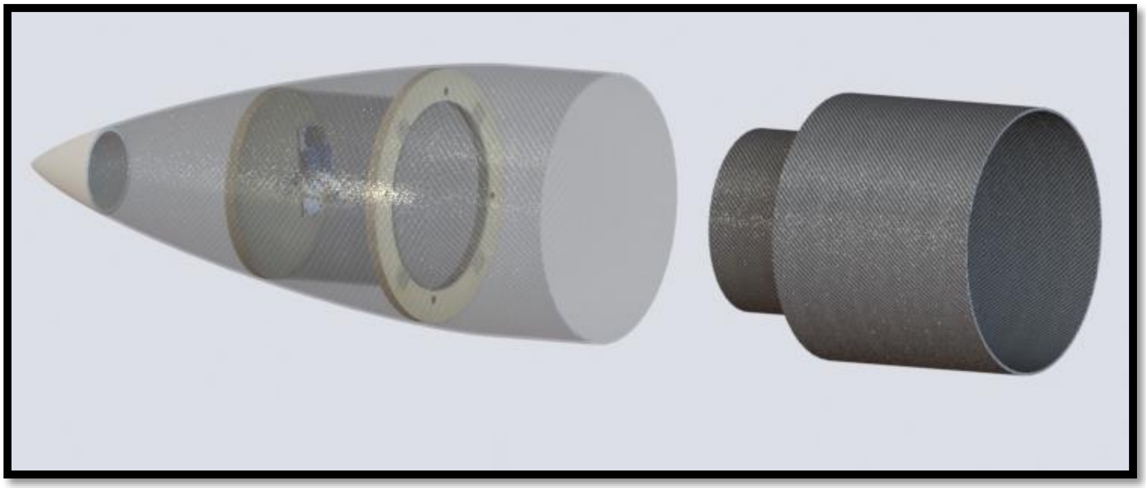


Figure 44: Nose cone configuration.

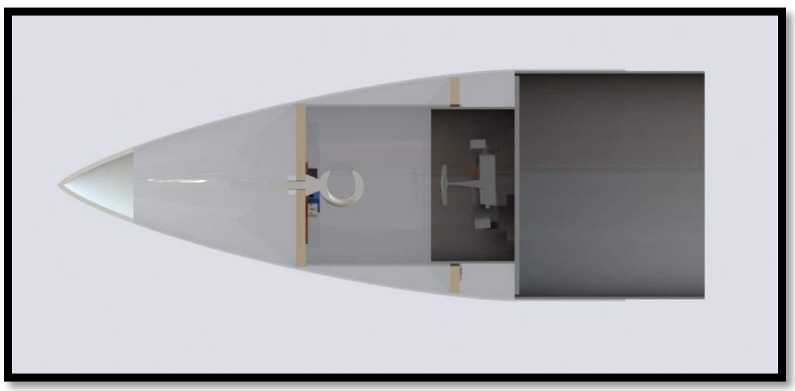


Figure 45: Section view of nose cone configuration.

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

In the interest of streamlining the logistical flow of launch operations, the launch vehicle this year will feature an avionics bay directly adjacent to the recovery bay that houses all electronic control interfaces, including altimeters integrated into the recovery system. All electronics will be accessible through a hinged door for easy access during any stage of launch preparation.

6.1.3 Vortex Ring

For the main parachute, a vortex ring has been chosen for two reasons: mass efficiency and stability. Vortex ring parachutes offer the highest drag coefficient available in modern parachutes

(C_d = 1.5 – 1.8) and produce equivalent drag forces to comparable parachutes with less material. This extremely high C_d is a result of the rotating motion the vortex ring generates, which is enabled by a swivel joint connection to the vehicle. This rotating motion generates a lift vector, increasing the drag coefficient of the parachute. The vortex ring also features an incredibly low angle of oscillation (± 2˚), making it an ideal choice for the stable state required to properly and safely deploy the multirotor payload during main descent.

Figure 46: Preliminary vortex ring rendering.

The initial competing proposed parachute designs and their parameters are listed below [2]

Parachute Type	Constructed Shape			Inflated Shape	Drag Coefficient	Opening force Coefficient	Avg. Angle of Oscillation
	Plane	Profile	$\left(\frac{D_c}{D_o}\right)$	$\frac{D_p}{D_o}$	C_{D_o}	C_x	θ
Annular			1.04	0.94	0.85 – 0.96	≈1.4	<6°
Cruciform			1.15 – 1.19	0.65 – 0.72	0.6 – 0.85	1.1 – 1.2	0° – 3°
Vortex Ring			1.9	N/A	1.5 – 1.8	1.1 – 1.2	0° – 2°

Table 18: Comparing multiple parachutes against multiple parachute characteristics.

Due to the difficult and temperamental deployment and inflation characteristics of vortex rings, the recovery system will utilize a technique described [3] and shown in Figure 47 in which the

[2] T.W, Knacke,*Parachure Recovery Systems Design Manual*, 1st ed. Santa Para, 1992.
[3] T. W. Knacke, *Parachute Recovery Systems Design Manual*, 1st ed. Santa: Para, 1992.

vortex ring is deployed with a pilot chute that is attached via a set of bridles to the 4 interpanel lines. The upward action of the pilot chute on the interpanel lines encourages parachute deployment and inflation, and has shown success with trials.[4]

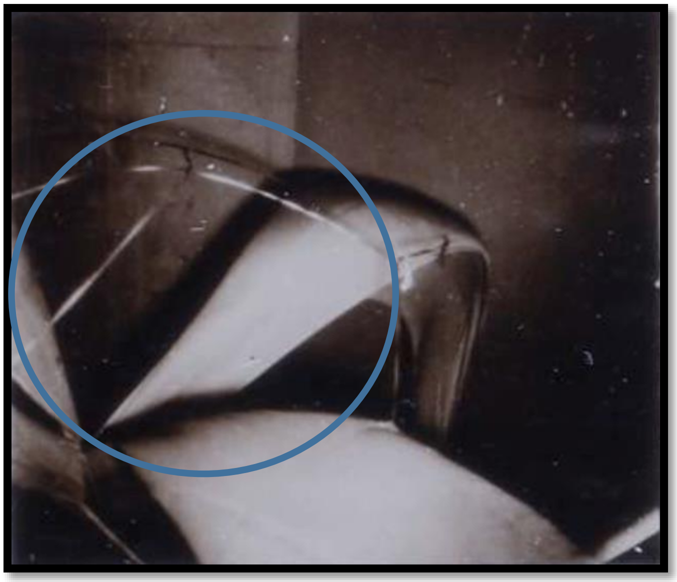


Figure 47: Interpanel bridle lines from reference.

[4] D. Barish, Technical report on vortex ring parachute wind tunnel tests at United Aircraft Corporation (Parachute History Collection). Manchester, Conn.: Pioneer Parachute Co., Inc., 1959.

6.1.4 Multirotor Risk Mitigation System

The multirotor payload must also be considered to be a part of the launch vehicle, and must satisfy the requirements outlined in the statement of work for a safe recovery. To accomplish this, the multirotor will feature a small bay that holds a reserve parachute that will be deployed by a Perfectflight stratologgerCF at 100 feet if the abort condition is met. In the event of an uncontrollable flight anomaly, the multirotor will power itself down to prevent damage from the rotors to the recovery system, and begin a freefall to the deployment altitude.

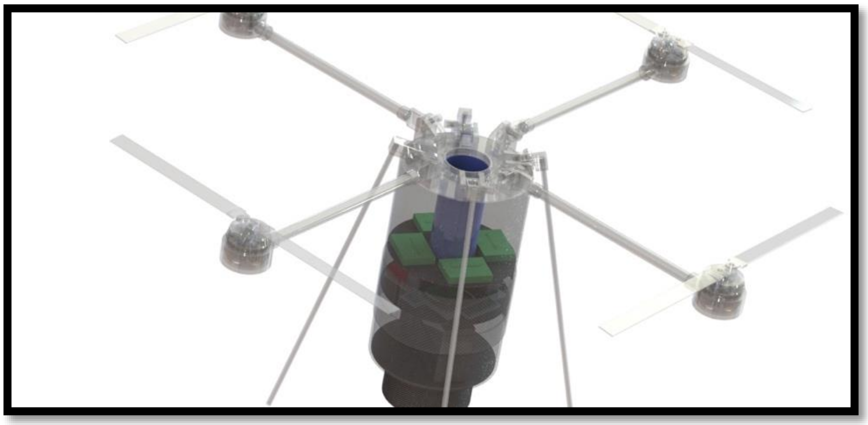


Figure 48: Multirotor reserve parachute bay highlighted in blue.

6.2 Design Validation

6.2.1 System Testing

The advanced nature of the vortex ring design, while paying massive dividends in mass optimization and functionality, is a very parametrically sensitive system and slight changes can often make the difference between nominal operation and system failure. As such, a robust scale testing program will be needed for this system.

While full scale tests are valuable, they are of limited utility since failure modes cannot be analyzed up close and in real time. In order to provide a sufficient degree of repeatability and meaningful analysis, preliminary wind tunnel tests before full scale flight will be conducted to ensure the system’s success. This will greatly reduce the guesswork in calculating the drag coefficient of the vortex ring and allow a more accurate calculation of impact kinetic energy.

6.2.2 Test Feasibility: Wind Tunnel

For subscale wind tunnel testing, some initial analysis has been conducted to determine whether construction of a small scale vertical wind tunnel is a more viable option than usage of an existing wind tunnels.

In regards to scalability, subscale tests are largely a linearly scaling criteria to a certain point. No known calculations or knowledge exists on small size limiting factors of subscale tests, so the wind tunnel assumes a test chamber with a 1.5'x1.5' cross sectional area. This should allow for a subscale parachute that is large enough that material properties do not overwhelm the performance properties of the system and obscure test data while still leaving a margin to provide a large enough tunnel mouth to create a choke flow condition.

For submach airflow (M < 1) incompressible flow can be assumed within the tunnel. As such, we can begin with a basic conservation of mass equation to derive an equation relating our airflow velocity to the cross sectional area of our wind tunnel. The conservation equation is given by

$$\dot{m} = \rho v A = constant \tag{7}$$

where ρ equals density, v equals velocity, and A equals' area. We may now relate these quantities as follows, noting that ρ lacks a subscript since density remains constant in incompressible flow:

$$\rho v_1 A_1 = \rho v_2 A_2 \tag{8}$$

We can now solve for v_2 to find the airflow velocity inside the test chamber, and the density term drops out:

$$v_2 = \frac{v_1 A_1}{A_2} \tag{9}$$

This can be used in conjunction with specifications of commercially available fans. The volume flow of commercially available fans is given in CFM ($\frac{ft^3}{min}$). We can use drogue descent speed from last year's competition flight (≈ 70ft/s = 4200ft/min) to for a baseline velocity at main opening to replicate within the chamber. Using this to solve for our needed CFM assuming a standard 2' box fan:

$$\boldsymbol{v_2 = \frac{CFM}{A_2} \xrightarrow{yields} CFM = v_2 A_2} \tag{10}$$

However, in order to determine equation (4) the following was given:

$$4200\frac{ft}{min} \times 2.25ft^2 = 9{,}450CFM \tag{11}$$

The largest volume flow available in commercial fans is around 9,000 – 12,500 CFM. These fans are prohibitively expensive which eliminates construction of a wind tunnel as a viable option. The team will need to arrange for wind tunnel tests at an established facility.

7 Technical Design: Payload

7.1 Payload Requirements

Target Detection and Upright Landing has been selected. The payload will be designed to meet the following criteria:

1. The payload must be capable of identifying between three adjacent 40'X40' targets that will be randomly placed within 300ft of the launch pad.
2. The Payload will utilize an onboard camera system to identify and differentiate between the three targets.
3. After recognizing the targets, the payload must land upright and provide evidence of a successful landing.

Different solutions to this challenge have been considered such as visual recognition system, which acts upon ascent of the launch vehicle, a glider system capable of guiding the payload towards the targets, and a drone based multirotor system.

Of these solutions, the drone based multirotor system will be utilized to accomplish the requirements. A drone based system was chosen due to drone’s abilities to navigate airspace effectively and for their stability during landings. The final general solution is still being reviewed and is subject to change by PDR.

During ascent and descent of the vehicle there are many uncertainties which could affect the camera system placed within the launch vehicle from being capable of identifying and differentiating between the three targets. Such factors include uncertainties in drift during recovery, stability of the launch vehicle, and the viewing window due to the descent rate of the vehicle during recovery. Considering these factors, a drone based system capable of deploying from the rocket and being recovered independently would be the optimum solution. A section of the launch vehicle’s upper airframe will act as the experimental payload. Figure 49 displays the deployed payload in its flight configuration.

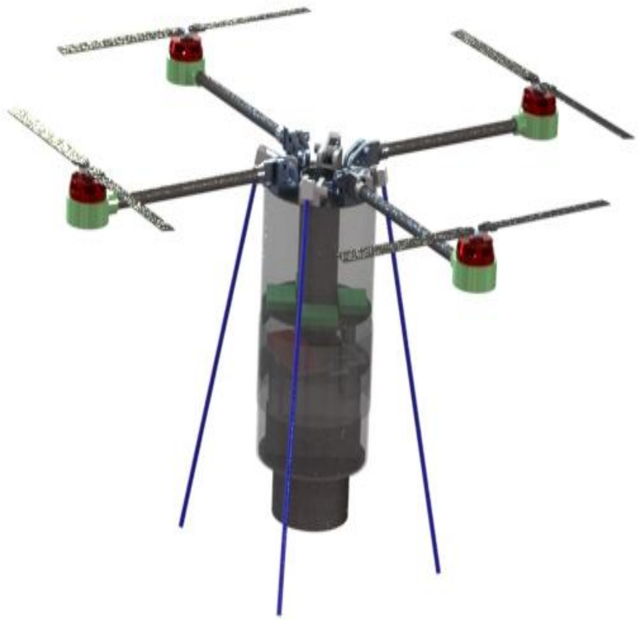


Figure 49: Rendering of the experimental payload assembly.

The payload will be organized into multiple subsystems in order to organize the design tasks. Table 19 depicts the payload subsystems and their purposes. The preliminary payload dimensions are shown in Table 20.

Payload Subsystem	Description
GNC	Logic which will execute the payload's flight commands.
Camera System	System responsible for visually detecting and differentiating between the provided targets.
Flight System	System responsible for navigating the payload to a position where the camera system will have the opportunity to differentiate between the provided targets.
Isolated Emergency Override System	Redundant embedded system capable of monitoring the state of the payload and deploying secondary parachute.
Payload Structures	System responsible for carrying flight and landing loads induced by the payload and for carrying the aerodynamic loads from the launch vehicle.

Table 19: Payload subsystems and their descriptions.

Weight (lb)	Width (in)	Length (in)	Height (in)
10.5	35	35	14.03

Table 20: Overall Payload dimensions.

The overall design goals of the payload will be to develop a robust system capable navigating the payload above the three targets while minimizing the overall dimensions and reducing weight.

7.2 Guidance, Navigation, and Control

The GNC of the payload will be broken up into several different processes which are listed out in Table 21. A visual schematic of the operating scheme is seen below in Figure 50.

Step number	Process
1	Initialization of GPS way points
2	Payload deployment
3	Navigation over targets
4	Landing

Table 21: GNC operating scheme.

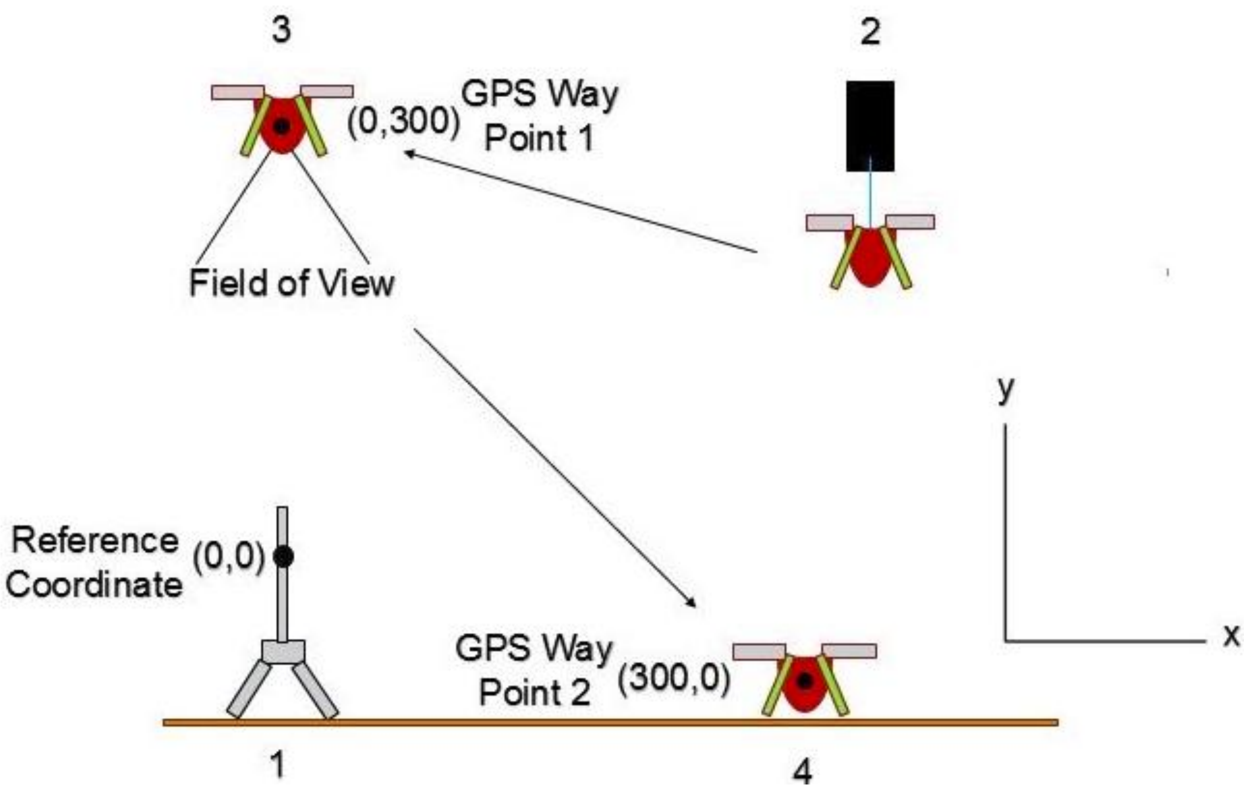


Figure 50: GNC flight schematic.

Step 1 in Figure 50 depicts the launch vehicle on the pad prior to launch. During this step, the payload will initialize its current location as a reference coordinate for the duration of the flight. Using this reference coordinate, the payload will initialize GPS Way Point 1 which will be located +300ft in the vertical direction above the launch rail. The payload will also initialize GPS Way Point 2 which will be located +300ft down range of the launch rail during step 1.

Step 2 in the schematic depicts the drone deployment during recovery. During this step, the drone will detach from the launch vehicle. Once detached, in order to not interfere with the launch vehicle the drone will quickly navigate away from the launch vehicle and elevate to a height above the location of where the deployment process was initialized. This maneuver will guarantee that the drone and launch vehicle will not interfere with one another during recovery. Once the drone deploys and stabilizes, the drone will navigate to GPS Way Point 1 shown in step 3. From this vantage point, the camera will be able to view the full area in which the targets could be located. The payload will then identify and differentiate between the targets.

Once the targets have been identified and differentiated, the payload will navigate to GPS Way Point 2 shown in step 4 of the schematic. The drone will keep its current altitude and navigate laterally to the landing coordinates. Once the payload navigates directly above the Way Point 2, it will perform the landing procedure.

7.3 Camera System

The camera system will be designed with the following criteria in mind:

- Select a camera with optimal optical parameters which will allow for the vision detection software to easily recognize and differentiate between the three targets.
- Develop a program capable of quickly distinguishing between three 40'X40' targets.
- Design a mount capable of stabilizing the camera so that movement and vibration from the flight of the payload doesn't adversely affect the vision of the camera.

7.3.1 Target Detection Electronics and Software

Optical and computer vision systems shall rely on a combination Raspberry Pi/Pi Camera setup. OpenCV will be utilized to generate target vectors using multiple points of interest which will be communicated to the flight controller. The video feed from the Pi Camera will be analyzed extensively to ensure that the appropriate target is selected. Before a target is identified, it must first pass a set of tests, each checking different constraints to maximize the chance of proper target identification. Alongside shape and color recognition, relative size will also be taken into account in order to confirm the intended target is the correct one. Below in Equation 1 is the equation required to perform this check, commonly referred to as the pinhole projection formula.

$$d = \frac{f h_r h_i}{h_o h_s} \quad (1)$$

Where d is the distance to the object in mm, f is the focal length in mm, h_r is the real height in mm, $h_i$is the image height in pixels, h_o is the object height in pixels, and h_s is the sensor height in mm.

Physical restrictions will require testing to find limitations such as maximum operational speed though several stabilization solutions have been developed to combat these variables (to be detailed in a later section). The rate at which the Pi Camera captures video is the limiting factor of vector generation. While the camera is capable of recording video in a multitude of different resolutions and framerates, a strong balance of the two must be met to generate reliable information as soon as possible. These factors shall ultimately determine maximum operational altitude and speed the payload can travel while searching.

#	Resolution	Aspect Ratio	Framerates (fps)	Video?	Image?	FoV	Binning
1	1920x1080	16:9	1-30	X		Parti al	None
2	2592x1944	4:3	1-15	X	X	Full	None
3	2592x1944	4:3	0.1666-1	X	X	Full	None
4	1296x972	4:3	1-42	X		Full	2x2
5	1296x730	16:9	1-49	X		Full	2x2
6	640x480	4:3	42.1-60	X		Full	4x4
7	640x480	4:3	60.1-90	X		Full	4x4

Table 22: Input Options for the PiCamera, firmware revision #656, PiCamera User Documentation.

7.4 Flight System

The payload flight system (PFS) encompasses the electronic components of the payload that will be handling target acquisition and safe, autonomous flight of the payload to the ground. Specifically, it will handle payload control loops, localization, telemetry, and software safety redundancies. It will also interface with what is known as the isolated emergency override system (IEOS) to expand the capabilities of failure mode detection and handling.

In order to be considered a success, the PFS must achieve the following goals in its operation:

- Onboard flight controller will independently handle feedback controls for Payload flight.
- Onboard computer will handle computer vision and target acquisition.
- Reliable and quick communication between the onboard computer and flight controller.
- Constant GPS communication for accurate localization.

- Multiple software redundancies to ensure safe operation of the Payload.
- Optional telemetry system to communicate real-time flight information to a ground station.
- The IEOS will constantly monitor all flight systems and deploy the backup parachute in the event of an failure during flight.

Figure 51 outlines the preliminary flight and auxiliary safety electronics system.

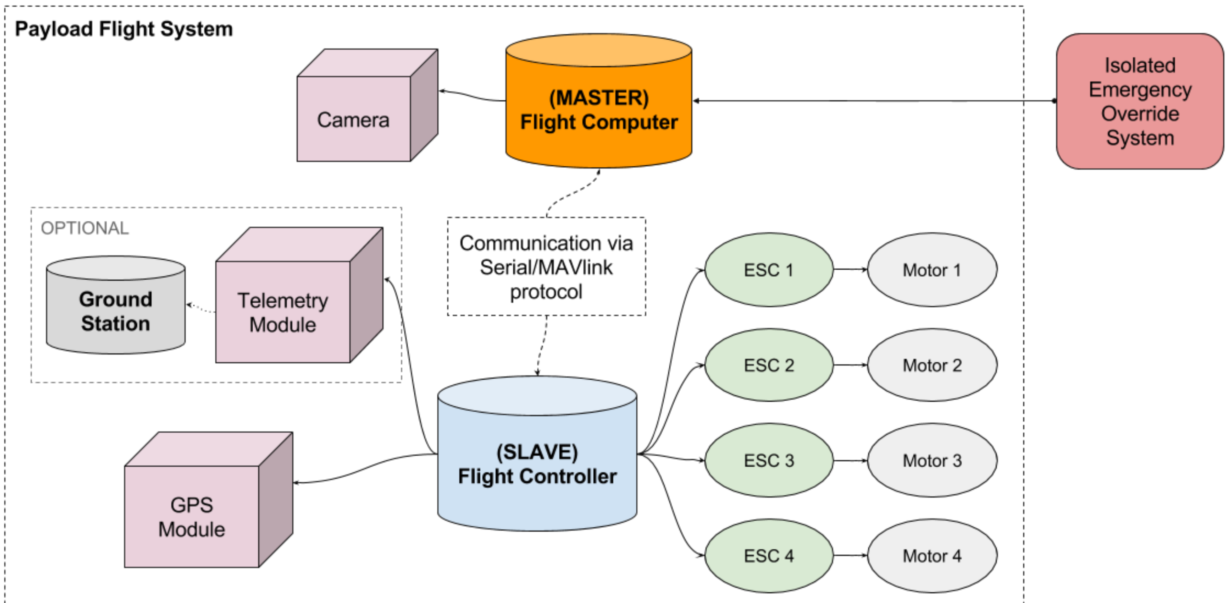


Figure 51: Block diagram of the payload flight system.

7.4.1 Flight System Hardware

Flight Computer

The onboard flight computer of choice will be the Raspberry Pi 3 Model B. The goal of this system is to handle all autonomous decision making for the PFS. Its specific duties are outlined below:

- Interface with onboard camera and utilize OpenCV to handle target acquisition
- Perform constant sensor polling to verify safe operation of the Payload
- Act as a master to the flight controller to command high-level operation of the Payload

Flight Controller

The selected flight controller will be the Holybro Pixhawk PX4 2.4.5. The core job of the flight controller is to act as a low-level, black box for UAV flight by performing all relevant sensor interactions and control loop calculations. It will also act as an interface to the onboard sensors for the flight computer. Below are the general duties of the flight controller:

- Directly communicate with ESC's (electronic speed controller) to control motors
- Utilize GPS for accurate localization
- Utilize internal IMU and barometer inputs for relevant control loops

- Perform all calculations for proper feedback control of the UAV
- Handle certain failure modes (see Isolated Emergency Override System)
- Provide high-speed data logging

Additionally, the flight controller will act as a slave device to the flight computer for simplified access to all onboard sensors. This will be achieved through the use of a UART interface which implements the MAVLink protocol. MAVLink stands for "Micro Air Vehicle Link" and was created by Lorenz Meier in 2009. It is under an open license (LGPG) and is the protocol of choice by the developers of the ArduPilot flight controller firmware.

GPS Communication
The chosen Ublox NEO-M8N GPS module is a solitary system that handles all interaction with GPS satellites and communicates that information to the flight computer via a UART interface.

Motors/ESCs/Propellers
The all-in-one DJI E1200 Pro Tuned Propulsion System consists of a 4216 brushless DC motor, 40A electronic speed controller, and a 17-inch collapsible propeller. The system is designed for multi-rotor aircraft with a 7-15 kg mass limit, therefore it will be very capable of handling the estimated mass of our payload.

Camera
The Pi Camera will provide a constant view of the ground in order for the flight computer to perform target acquisition and differentiation.

7.5 Isolated Emergency Override System

The isolated emergency override system (IEOS) is a fully separate embedded system that acts as a redundancy to safety protocols already onboard the PFS. The IEOS will react to failure conditions during the flight of the payload in case the flight computer cannot. This will result in a parachute being deployed if a failure condition is met. The safety electronics will be monitoring flight conditions through an altimeter and a gyroscope. The L3DG20H gyroscope and the BMP180 Barometric Pressure sensor will be used as the monitoring sensors. The justification for these sensors are stated below:

L3DG20H gyroscope
The L3DG20H gyroscope shown below in Figure 52 is well documented with tutorials and supported arduino libraries. This gyroscope also provides a wide range of angular acceleration sensitivities of ±250, ±500, or ±2000 degree-per-second.

Figure 52: L3DG20H gyroscope.

BMP180 barometric pressure sensor

The BMP180 Barometric Pressure Sensor displayed in Figure 53 is a sensor that the team is very familiar with. Similarly, to the L3DG20H gyroscope, this sensor is very well documented and there are many supported libraries, tutorials, and documents.

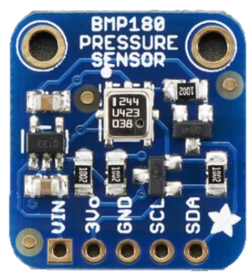


Figure 53: BMP180 barometric pressure sensor.

The flight computer and the flight controller will monitor flight conditions for emergency recovery. A dedicated micro controller will also be used to control the safety electronics. An Arduino Pro Mini will be used as our designated microcontroller. The Arduino Pro Mini was chosen due to its lightweight and simplistic operation for the safety system. An isolated system will minimize the external interference to the safety electronics. Table 23 and Figure 54 display safety concerns for the deployment and flight of the payload.

Safety Concern	**Solution**	**Designated Controller**
Potential damage to drone on descent due to deploying in unstable circumstances	Do not deploy the payload due to the onboard altimeter changing too fast	Flight Computer/Flight Controller & IEOS
E-match wire getting entangled in separation mechanism	Quick disconnect wire through joining bulk plate to black powder charge collar (long end of the wire hangs from the joining bulk plate)	Flight Computer
Arms and legs are not fully extended out of the airframe	Attach limit switch to each propulsion arm and landing leg to validate that all of the components have fully extended	Flight Computer
Payload not disconnected from	Attach limit switch to the torque flange which will	Flight Computer

airframe	sense whether the payload has fully detached from the airframe	
Payload falling uncontrollably	Disconnect the command ESC's via altimeter reading or gyro reading. Deploy backup recovery	Flight Computer/Flight Controller & IEOS
No way to differentiate between targets	If within rocket, don't deploy payload. If out of the rocket, deploy backup recovery	Flight Computer
Payload does not end up over initial GPS coordinate.	After flying around a 600ft radius of sight (flying up, subject to change), assume payload didn't fly over original GPS point, deploy recovery	Flight Computer
Won't be able to eject backup parachute	Redundant altimeter	IEOS

Table 23: Payload safety matrix.

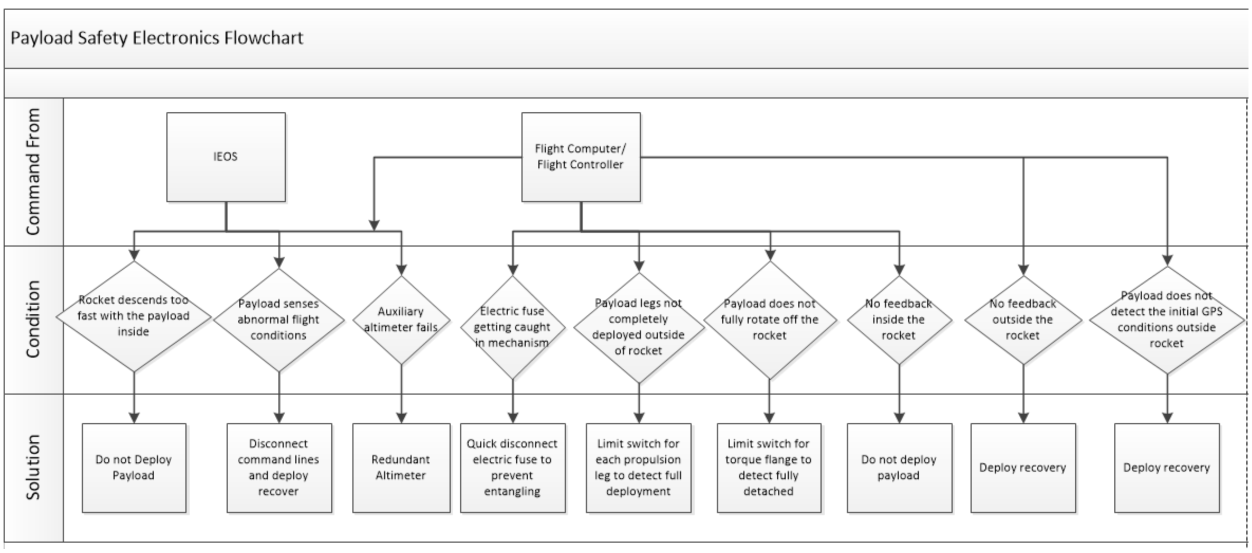


Figure 54: Payload safety electronics flowchart.

7.6 Structural Design

In order to satisfy the requirement 2 of the payload criteria, a section of the launch vehicle must perform an upright landing. The coupler section between the nose cone and the payload deployment bay was selected to be the section of the rocket which will house the onboard camera system and perform a controlled upright landing.

7.6.1 Airframe

The payload's airframe refers to the carbon fiber section which doubles as the payload's main housing. Utilizing a coupler allows the payload to minimize weight and reduce its length when stored in the launch vehicle. Figure 55 depicts a section view of the payload airframe and its internal components.

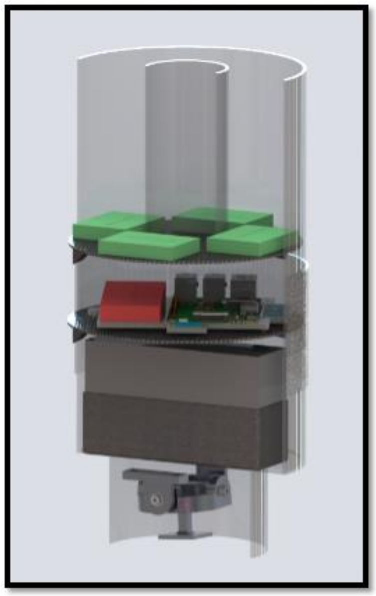


Figure 55: Payload airframe section view.

Payload Airframe Dimensions

Length (in.)	Weight (lbs.)	Diameter (in.)
12.2	4.81	5.85

Figure 56: Overall payload dimensions

The payload is housed in a carbon fiber coupler which joins the deployment bay and nosecone. The payload body is separated into four bays. From bottom to top payload bays include: camera bay, battery bay, electronics bay, and recovery bay. Figure 57 below shows the payload compartment layout.

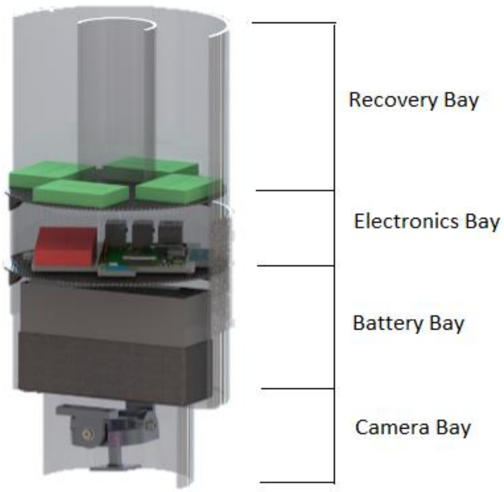


Figure 57: Payload compartment layout.

Removable Bulkplates

Removable bulkplates will be integrated into the payload for ease of assembly and maintenance. Carbon fiber sheets 0.125in. thick were selected for the bulkplate material in order to minimize weight. Future testing and analysis will be accomplished to ensure the bulkplates can withstand loads experienced during flight.

Each bulkplate will be connected to the airframe by three carbon fiber brackets. The bulk plates will be installed into the airframe by screwing three 8-32 SHCS into the carbon fiber brackets. Figure 58 and Figure 59 below illustrate the bulkplate and bracket orientation for installation.

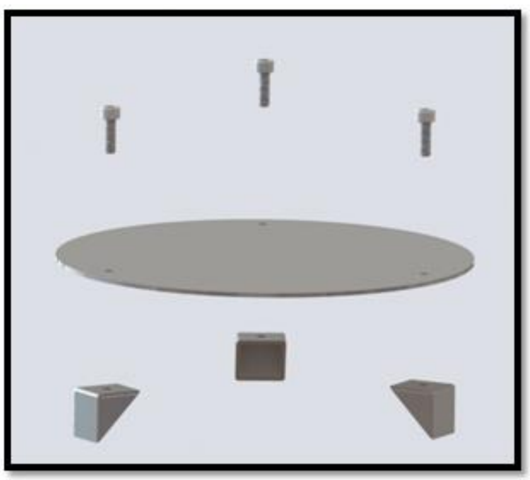


Figure 58: Exploded view of a removable bulkplate assembly.

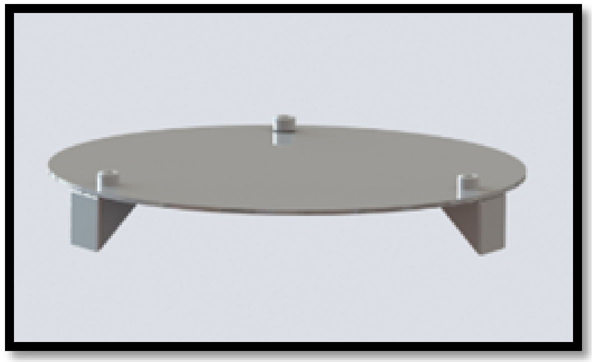


Figure 59: Installed removable bulkplate assembly.

7.6.2 Camera Bay

The camera bay houses the onboard camera and gyroscope assemblies at the bottom payload body. Its location allows the camera to be facing towards the ground after nosecone separation. A 4in. diameter carbon fiber tube epoxied to the bottom bulkplate surrounds the camera and protects the camera and gyroscope assembly from the black powder charge which separate the nose cone. Separation mechanisms are further explained in the recovery section. Exposing the camera bay mitigates the risk of an exterior lens distorting the camera's view.

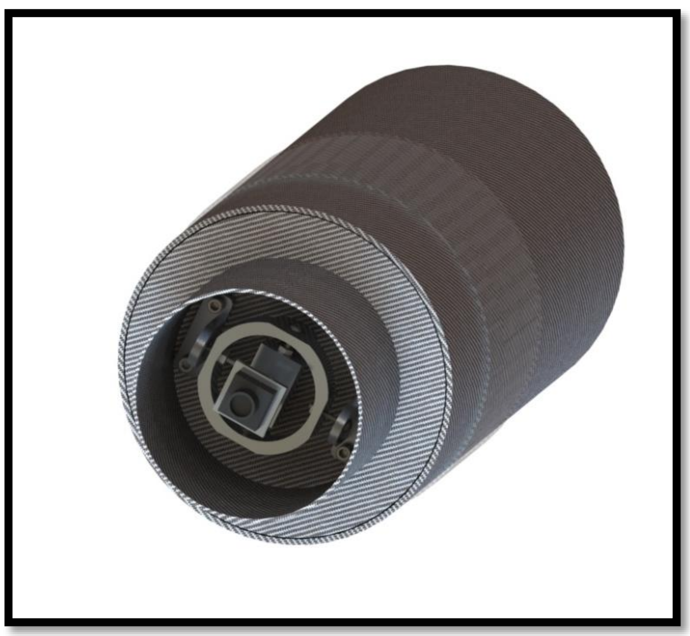


Figure 60: Frontal view camera bay rendering.

Bay	Length (in)	Weight (lbs)	Inner Diameter (in)
Camera Bay	2.2	.18	5.85

Table 24: Camera Bay Dimensions.

7.6.3 Gyroscope Camera Mount

During the flight of the payload, vibration and pitching of the payload section will negatively affect the camera's image quality. In order to negate these flight effects on the camera's image, a passive gyroscope will be used to stabilize the camera. A rendering of the gyroscope is pictured in Figure 61.

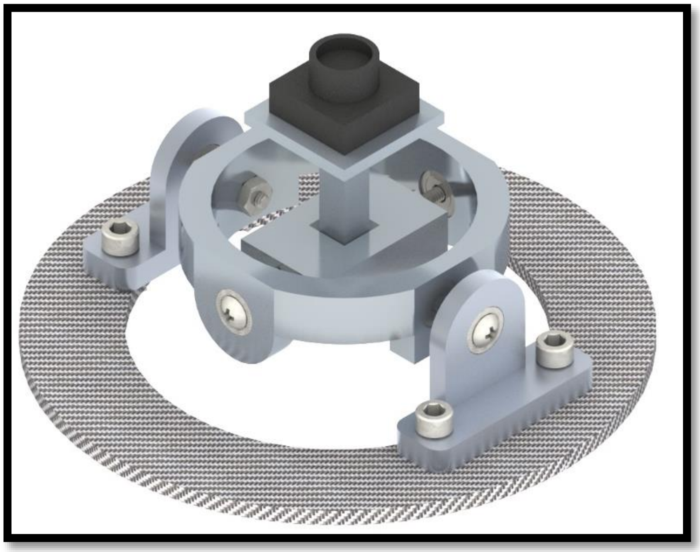


Figure 61: Gyroscope assembly rendering.

The approximate overall dimensions to the Gyroscope are shown in Table 25.

Weight (lb)	Height (in)	Width (in)	Depth (in)
.20	2.5	4.5	4.5

Table 25: Gyroscope dimensions.

An exploded view of the Gyroscope is pictured below in Figure 62.

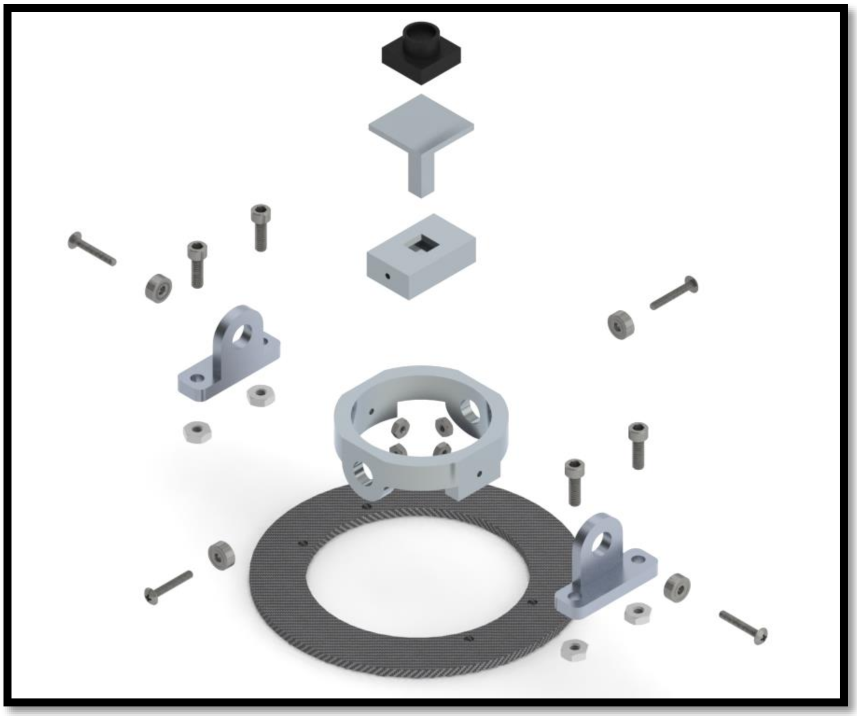


Figure 62: Gyroscope exploded view.

Mechanical Design

The gyroscope will have two degrees of freedom which will allow independent orthogonal rotation about rotation around the x and y axes. These axes are defined as the orthogonal axes on the plane of the carbon fiber mounting plate.

The passive actuation of this gyroscope is governed by the weight of the camera. Due to the rotational degrees of freedom of the gyroscope, the gravity vector will always orient the camera in its direction orthogonal to the ground.

6061-T6 aluminum was chosen for the machined parts due to its light weight, durability, and high machinability. The aluminum parts will be machined using a CNC mill and water jet. The center mount and camera boom will be joined through a TIG welding process.

Low friction joints, precise CG, and the weight of the camera are design factors that are crucial to the successful gyroscope performance. The joints between the ring, clevises, and center mount must have very low friction to give the assembly its two rotational degrees of freedom. Ball bearings with machine screws mounted through the center will be used to achieve a low coefficient of friction. The ball bearings will be press fit into the clevises and ring.

Analysis will be done to determine the precise dimensioning and appropriate tolerance of the ball bearing press fit. Dimensioning of the assembly components must place the CG in the exact geometric center. If the CG is not in the center, the resting position of the center camera boom will not be directly towards the ground. The weight of the camera must be large enough to overcome the friction of the bearing and keep its orientation facing towards the ground. Testing will be done to determine the proper weight of the camera and camera boom needed to overcome the friction.

Future Changes and Testing

A dampening system will be researched and implemented to counteract the vibrations from flight. During ascent, the gyroscope assembly needs to be restrained until the nose cone section is facing towards the ground. An ascent restraining mount will be designed and inserted into the model. Electrical routing of the camera will be accomplished at a later date when the configuration of the payload electronics has been finalized. Prototyping and testing will be accomplished to determine the optimum weight of the camera.

7.6.4 Battery Bay

The payload battery is housed directly above the camera bay. The battery's placement in the payload is to ensure a low center of gravity. This aids the payload in maintaining stability during deployment from the launch vehicle and during flight. The batteries configuration is shown below in Figure 63.

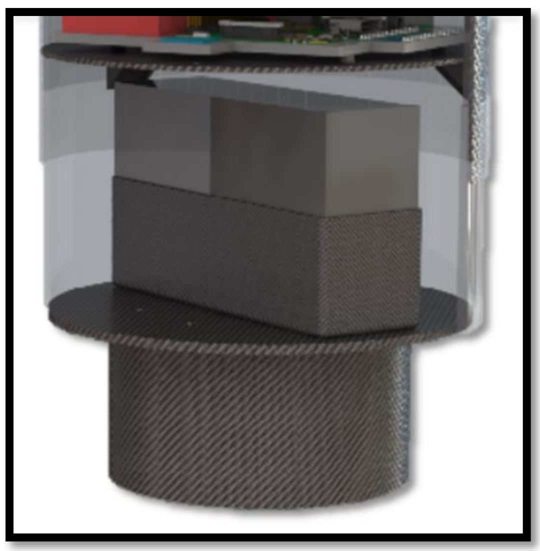


Figure 63: Battery Bay.

Bay	Length (in)	Weight (lb)	Inner Diameter (in)
Battery Bay	3.44	2.3	5.85

Table 26: Battery bay dimensions.

The battery will be housed in a .0625in. molded carbon fiber case which is epoxied to the bottom bulkplate. The battery housing will be tested to validate that it will be restrained during any vibrations or movements during flight.

7.6.5 Electronics Bay

The electronics bay is located above the battery bay. It is responsible for housing a Raspberry Pi, Holybro flight controller, Ublox GPS, L3DG20H gyroscope, BMP180 barometric pressure sensor, and an Arduino Micro. All electrical components inside the electronics bay are mounted to a .125" aluminum electronics sled. Aluminum offers superior quality compared to 3D printed plastics. CNC milling capabilities will be utilized to mill cut-outs into the aluminum which fit each specific electrical member. Electronics will be bolted to the sled and insulated with rubber washers. Figure 64 displays a rendering of the electronics bay along with the components it houses. Table 27 displays the overall dimensions of the electronics bay.

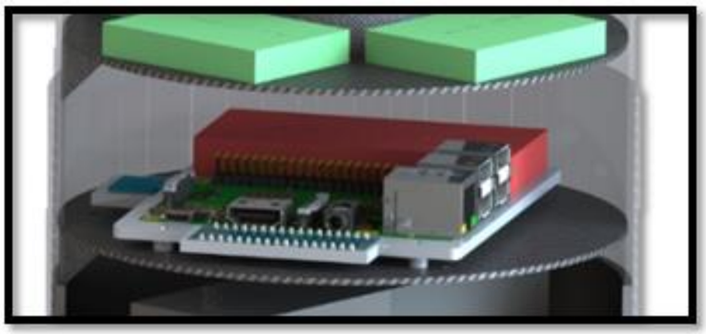


Figure 64: Electronics Bay

Length (in)	Weight (lb)	Inner Diameter (in)
1.94	0.15	5.85

Table 27: Electronics bay dimensions.

Flight Controller

The current configuration of the electronics bay houses the flight controller off the payloads center of rotation. While developing the preliminary design for the electronic sled it was learned that the flight controller must be located along the axis of the payload. Future configurations of the electronics bay will house the flight controller along the payloads center of rotation and close as possible to the payload center of gravity.

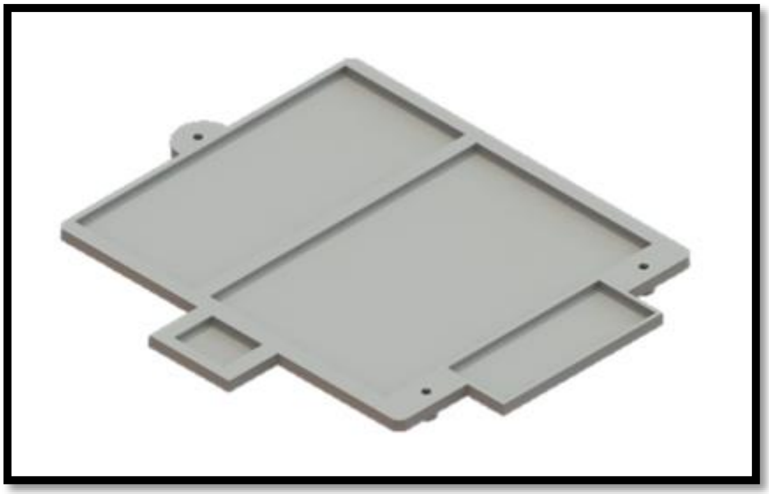


Figure 65: Aluminum electronics sled.

Electronics Sled

The electronics mount is fastened to a removable bulkplate with three 8-32 bolts. Risers on the bottom of the sled ensure space is left between the sled and bulkplate. This reduces the risk of overheating electronics during flight.

7.6.6 Recovery Bay

The recovery bay is located in the top of the payload. It comprises of the safety parachute, parachute guide tube, and 4 DJI speed controllers. The recovery bay's main function is to deploy a parachute in the case of bad payload deployment, electrical failure or instability. The parachute is housed inside the parachute guide tube. The parachute guide tube is a 2" carbon fiber tube epoxied to the bottom of the recovery bulkplate. The guide tube allows the parachute to deploy through a 2" hole in the top bulkplate.

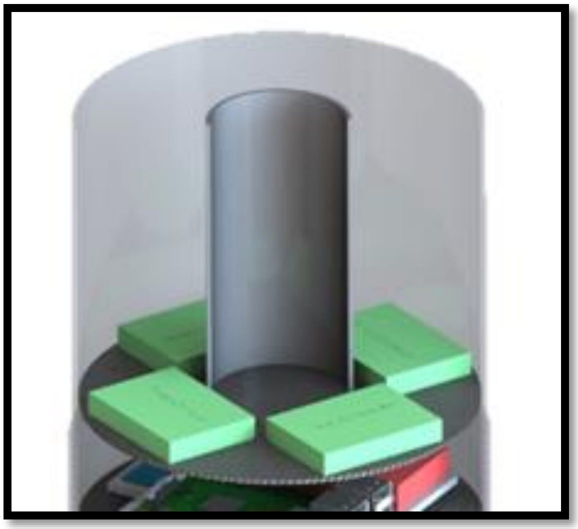


Figure 66: Recovery Bay.

Length (in)	Weight (lb)	Inner Diameter (in)
4.38	.35	5.85

Table 28: Electronics Bay Dimensions.

Speed Controllers

Limited size in the electronics bay forces the four speed controllers to be housed in the recovery bay. They are mounted along the inner airframe wall in the recovery bay.

Future Testing

The following table outlines future testing to be conducted on payload structural components.

Parameter	Description
Bulkplates	Carbon fiber bulkplates will be secured in their flight configuration and tested with weights to prove they are capable of handling loads experienced during launch.
Battery	The battery will be ran at maximum power while housed inside the payload body. Its temperature will be monitored throughout flight and recorded. High battery temperatures pose a risk to flight electronics functionality.
Battery Housing	Battery housing will be tested to guarantee battery cannot come detached from housing during flight.
Payload	Test flights will be completed to validate that electrical and mechanical joints

Structure	remain functional after vibrations

Table 29: Future testing for the payload section.

7.7 Propulsion and Landing Structure

The propulsion system of the payload is based off of a quadcopter layout. Four arms and four landing legs extend out from the airframe during deployment and lock into place on the top bulkplate of the payload. Figure 67 shown below depicts the stowed and deployed configurations of the propulsion and landing leg structure.

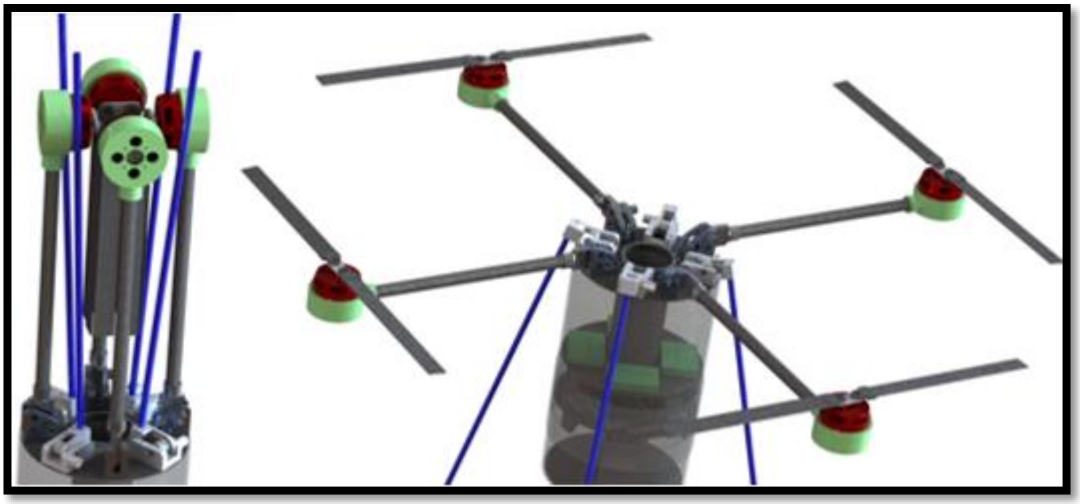


Figure 67: Rending of the stowed and deployed configurations of the propulsion and landing leg structure.

Motor and propellers

The payload will utilize the DJI E1200 series propulsion system seen below in Figure 68. Table 30 displays specifications of the E1200 series propulsion system.

Figure 68: E1200 standard propulsion motor and foldable propeller assembly

Max Thrust (lb/motor)	Propeller Diameter (in)	KV (rpm/V)	Max Allowable Voltage (V)	Max Allowable Current (A)
8.6	17	310	26	40

Table 30: Specifications of the E1200 standard propulsion system.

This propulsion system was selected because of DJI's reliability and the level of efficiency provided by the E1200 propulsion system. The E1200 propulsion system is also desirable for this application due to the built in propeller stowing capabilities. The E1200 series propellers are designed to move independently of each other on a common motor connection component for simplicity of stowing and decreasing the moment of inertia of the propeller assembly. This makes selecting this system ideal for the application in which it will be utilized.

Propulsion Arm Lock Joint Mechanism

Lock joint mechanisms will be utilized to rigidly fix the propulsion arms into place once deployed. The lock joint mechanism assembly will consist of the arm cam housing, the propulsion arm cam, the locking shear pin and compression spring, and a torsion spring guaranteeing the deployment of the rotating assembly. The lock joint clevis and arm cam will be machined out of 6061-T6 aluminum. The locking pin will be machined out of 416 stainless steel. Figure 69 displays the propulsion arm lock joint mechanism in the stowed and deployed configuration. Figure 70 shown below displays the locking pin which will lock the arm cam in place during deployment of the assembly.

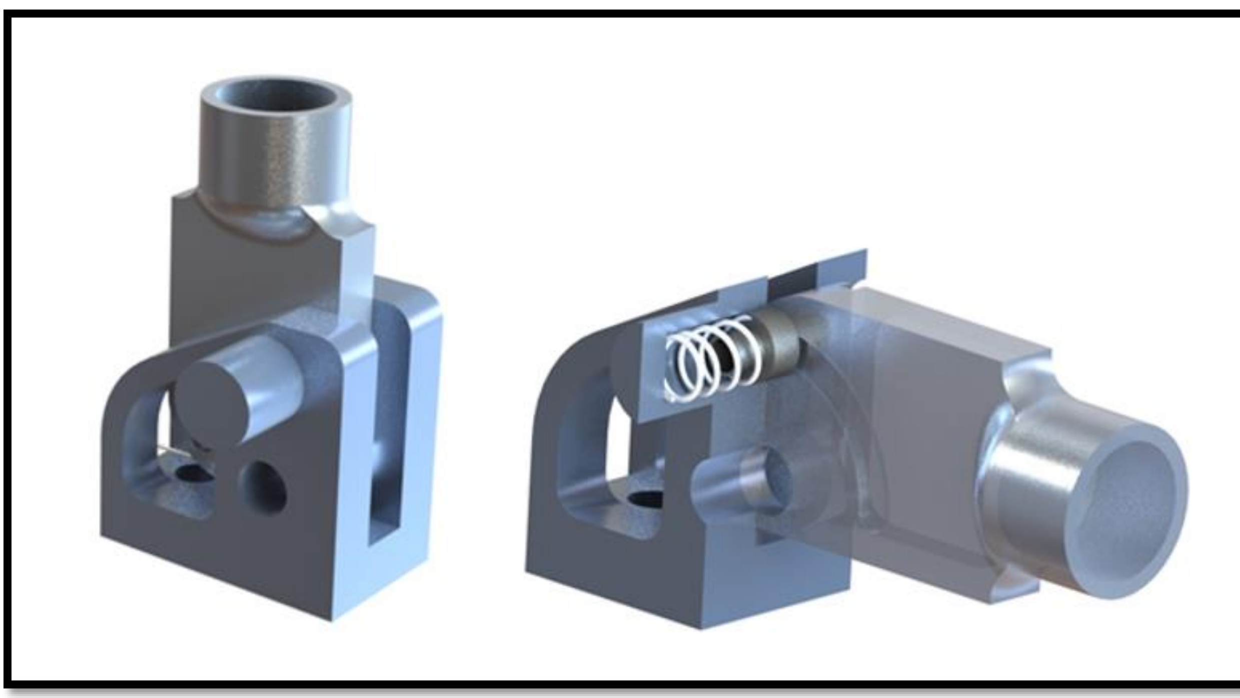


Figure 69: Renderings of the propulsion arm lock joint assembly in the stowed configuration (left) and the deployed configuration w/ transparent arm cam and section view of locking pin (right).

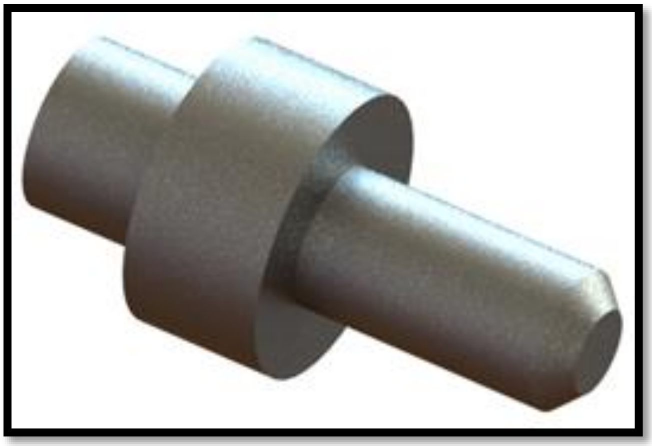


Figure 70: Locking pin rendering.

Upon deployment from the vehicle the torsion spring will induce a torque on the arm cam to rotate the propulsion system out into the deployed position. Once the arm has rotated 90 degrees into the proper deployment position the pin will lock into place. Future analysis will be provided to verify that impact of the arm cam into the clevis housing will be sufficiently low and the locking pin will fully engage with the arm cam.

0.5in. diameter 9.25in. long carbon fiber filament wound rods will be utilized to offset the motor and propeller assemblies from the body of the payload. Future analysis and testing will be completed in order to verify bending stiffness and deflections are of acceptable levels. Figure 71 displays a rendering of the carbon fiber propulsion rods.

Figure 71: Rendering of a carbon fiber arm.

Landing Legs and Lock Joint Mechanism

Similarly, to the propulsion arm lock joint mechanism, the landing leg lock joint mechanism will be utilized to allow for easy stowage and deployment of the landing legs. In order to satisfy requirement 3.2.2, the landing leg lock joint assembly will essentially mirror the propulsion lock joint mechanism in component makeup. The payload will consist of four individual landing legs which will snap into place once the payload has been deployed from the launch vehicle's airframe. The lock joint clevis and leg cam will be machined out of 6061-T6 aluminum. Figure 72 displays the deployed landing leg assemblies.

Figure 72: Rending of the landing leg lock joint assembly in the deployed configuration.

Upon deployment from the vehicle the torsion spring will induce a torque on the leg cam to rotate the landing leg out into the deployed position. Once the leg cam has rotated 180 degrees into the proper deployment position the pin will lock into place. Future analysis will be provided to verify that impact of the arm cam into the gel dampener will be sufficiently low and the locking pin will engage with the cam as well.

The payload will be equipped with 15in. long carbon fiber filament wound rods as landing legs. om the body of the payload. Future analysis and testing will be completed in order to verify the rigidity and resistance to buckling of the landing leg. Figure 73 displays a rendering of the carbon fiber propulsion rods.

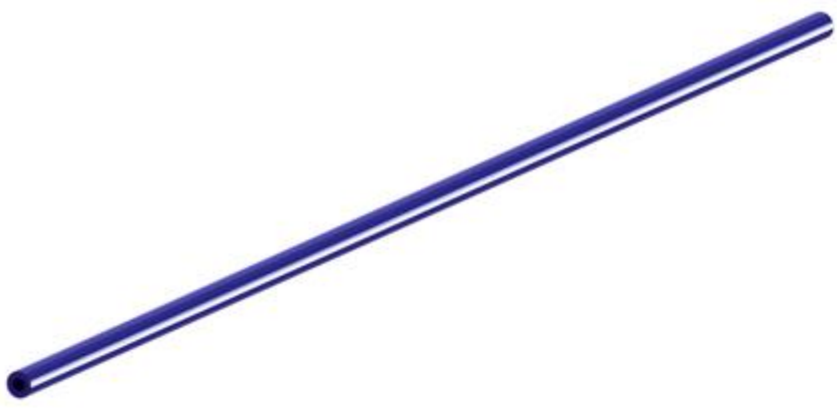


Figure 73: Carbon fiber landing leg rendering.

Future Analysis and Testing of Locking Mechanism

Analysis and testing will be conducted to implement a robust lock joint mechanism. Future analysis will seek to determine the optimal parameters shown in Table 31.

Parameter	Description
Lock pin spring sizing	The lock pin spring will determine the magnitude of the counter torque induced on the rotation cam's in both the landing leg and propulsion arm assemblies. The stiffness of the spring will also determine how the lock pin will mate into the cam restrain hole which makes the locking assemblies rigid when deployed
Torsion spring sizing	The torsion spring will determine the initial rotational effort of the propulsion arm and landing leg assemblies.
Angular velocity of rotational cam	During the deployment of the propulsion and landing leg assembles, a maximum rotational deployment speed will be established through the dynamic modeling of the two parameters listed above to ensure the proper seating of the locking pin into the rotating cams.

Table 31: Lock joint parameters.

7.8 Deployment Mechanisms

In order for the payload to detach from the launch vehicle safely, a robust deployment system will be implemented. The design objectives of the deployment system are as follows:

- Design a stable mechanism capable of allowing the payload's propulsion arms and landing legs to deploy safely and reliably.
- The deployment system must not negatively impact the overall structural integrity of the launch vehicle's airframe.
- The system must be capable of deploying the payload from the launch vehicle under worst case weather and flight conditions.

The deployment mechanism will consist of a section of the launch vehicle known as the deployment bay. This bay will consist of a telescoping deployment arm assembly and a joint bulkplate assembly. Figure 74 displays the payload stored within the deployment bay. Figure 75 displays the deployed payload and deployment bay. Figure 76 displays the deployment bay assembly. Table 32 displays the overall dimensions of the deployment bay.

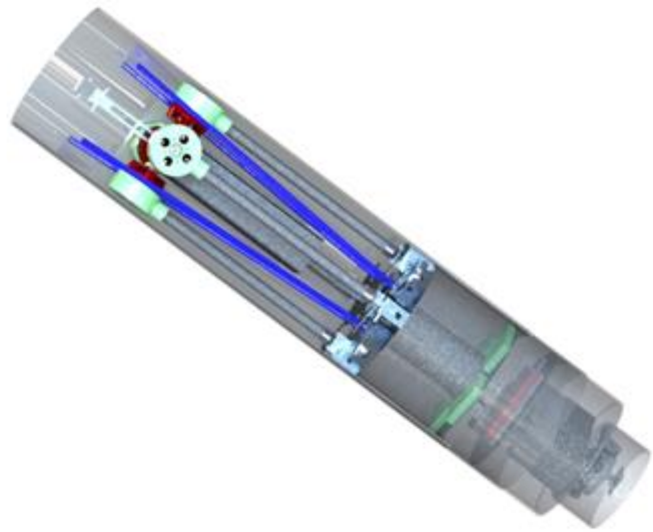


Figure 74: Rendering of the payload and deployment bay.

Figure 75: Rendering of deployed payload and deployment bay assembly.

Figure 76: Rendering of the deployment bay and telescoping deployment arm joint bulkplate assembly.

Weight (lb)	Overall length while stowed (in)	Overall length while deployed (in)
1.25	21.5	30.86

Table 32: Dimensions of the deployment bay.

Listed as steps 1-3, Figure 77 depicts the sequential order of events in which the deployment system will perform. The payload deployment sequence begins once the main parachute of the launch vehicle has been deployed and the nose cone section has successfully separated from the bottom of the payload. Event 1 occurs once the initial descent conditions (see Isolated Emergency Override System) have been met. A black powder charge will be utilized to separate the payload from the deployment bay of the launch vehicle. Event 2 depicts the separated payload hanging by the telescoping deployment arm assembly. This configuration allows the propulsion arms and landing legs to deploy while the payload is still falling under main parachute with the rest of the launch vehicle. Event 3 depicts the propulsion system activating and spinning up. The payload will induce a rolling moment about its own axis and spin out of the thread coupler on the telescoping deployment arm assembly.

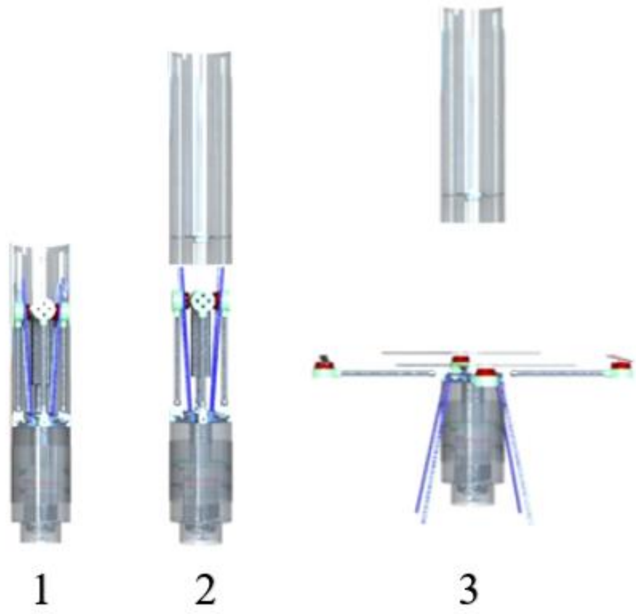


Figure 77: Payload deployment process events 1-3 (from left to right).

Torque Flange

The torque flange is the component which will be used to separate the payload from telescoping the deployment arm assembly. The torque flange will have external threads on the outer edge that will allow for the mating between its outer surface and inner surface of the thread coupler. This design will allow for the payload to spin off of the thread coupler during the deployment sequence. The torque flange bolts into the top bulkplate of the payload and is seated concentrically onto it. The torque flange will be machined out of 6061-T6 aluminum. The torque flange also serves as the opening for the redundant recovery parachute. Figure 78 below displays the torque flange. Figure 79 displays how the torque flange mates with the thread coupler. Table 33 displays the overall dimensions of the torque flange.

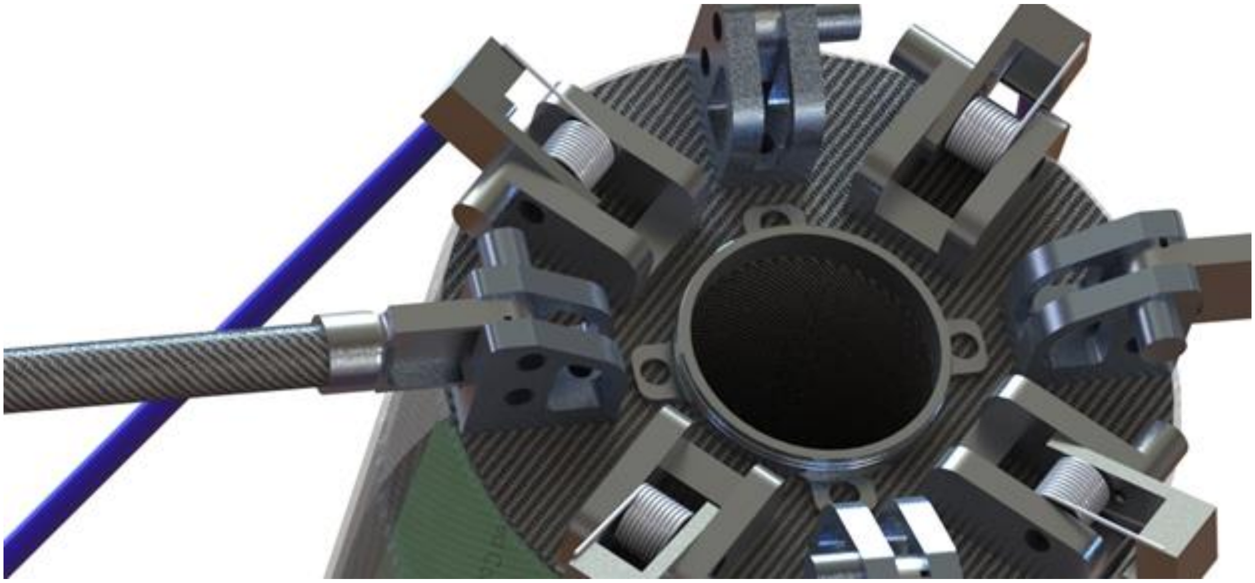


Figure 78: rendering of torque flange installed on the top bulk plate of the payload

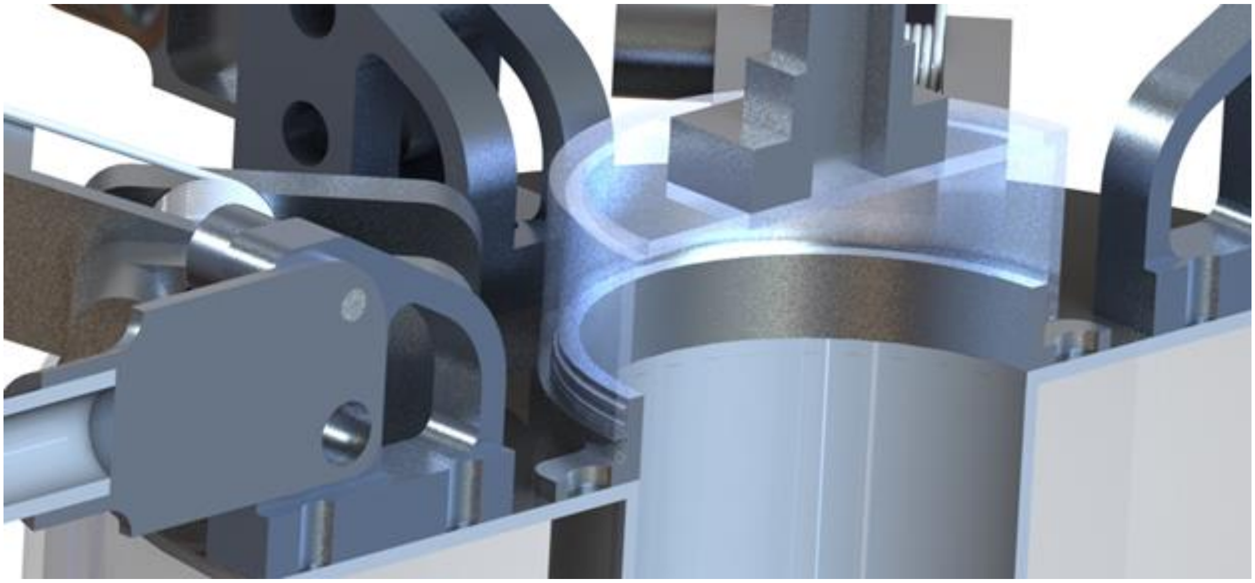


Figure 79: Section view of the thread coupler mated from above onto the torque flange

Weight (lb)	Outer Diameter (in)	Inner Diameter (in)	Height (in)
.02	2.16	2.0	.33

Table 33: Dimensions of the torque flange.

Telescoping Deployment Arm and Joint Bulkplate Assemblies

The telescoping deployment arm mechanism used to deploy the payload from the launch vehicle is pictured below in Figure 80. Table 34 displays the dimensions of the telescoping deployment arm.

Figure 80: Rendering of the deployment arm assembly and thread coupler.

Weight (lb)	Overall Length (in)	Overall Width (in)
.16	18.75	2.29

Table 34: Deployment arm dimensions.

The Joint bulkplate assembly consists of a profiled carbon fiber bulkplate and the black powder collar which is epoxied 3.5” above the leading edge of the deployment bay. Figure 81 below depicts the assembly. Future development will be accomplished to ensure smooth actuation of the telescoping deployment arm through the bearing surfaces located within the joint bulkplate assembly.

Figure 81: Joint bulkplate and black powder collar.

The initial actuation of the deployment mechanism begins with a black powder charge that is detonated within the black powder collar and the thread coupler. The detonation drives the telescoping arm into the torque flange which as a result separates the payload from the deployment bay. Figure 82 displays a section view of the black powder pocket formed by the thread coupler and the black powder collar. The volume of the pocket allows for up to 2.47 cubic centimeters of black powder.

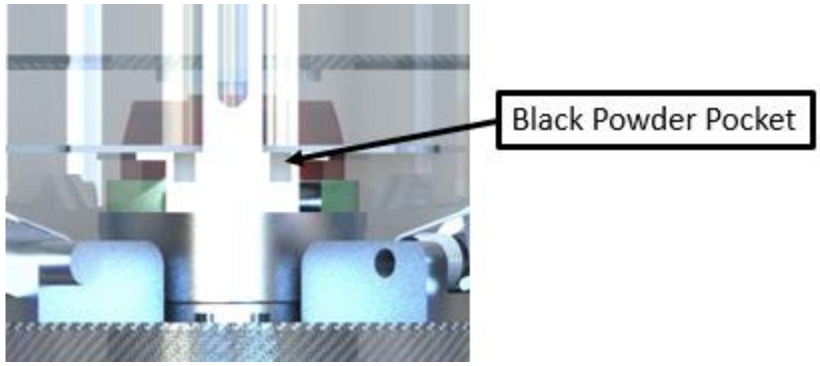


Figure 82: Section view of black powder pocket between the telescoping arm and the black powder collar.

7.9 Statement of work verification

Challenges	Solutions
Teams shall design an onboard camera system capable of identifying and differentiating between three randomly placed targets.	The payload will consist of a Raspberry Pi/Pi Camera and will also be outfitted with multi-rotors capable maneuvering the camera's field of view over the targets.
After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.	The drone will perform the landing maneuver. Utilizing camera footage, the team will provide feedback of a successful landing.
Data from the camera system shall be analyzed in real time by a custom designed-on board software package that shall identify and differentiate between the three targets.	A Raspberry Pi/Pi Camera will be integrated with a custom software suite utilizing OpenCV that will analyze the ground and targets in real time in order to differentiate between them.

Table 35: Challenges and solutions associated with SOW.

8 Educational Engagement

Throughout the course of the past four years, the University of Louisville River City Rocketry Team has managed to reach out to over 5,000 students and adults in the local community. The team's outreach gives back to the to the state of Kentucky by teaching the youth about engineering, math, technology, logical thinking, and of course rockery. The team strives to maintain relationships built with organizations in the community while continuing to reach people in new ways. The focus is never on how many people can be reached, but the quality of education that can be brought to each and every individual.

Figure 83: Denny and Ben building paper rockets at Boyce College.

8.1 Classroom Curriculum

The University of Louisville River City Rocketry Team has developed a variety of programs that are to be incorporated in this year's outreach program. Included is a list of the different activities in which the team has participated in the past and will continue to do this year.

8.1.1 6 Day Programs

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

6 Day Aerospace Program Curriculum

Figure 84: A young engineer building a paper rocket at E-Expo.

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

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

Day Two: Apollo Program History:

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

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

Figure 85: Emily helping students prepare their rocket for launch.

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

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

- Understand the use of composites vs. metals in aerospace applications.
- Design a payload that would fit inside the space shuttle cargo bay.

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

Day Four: OpenRocket Simulation:

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

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

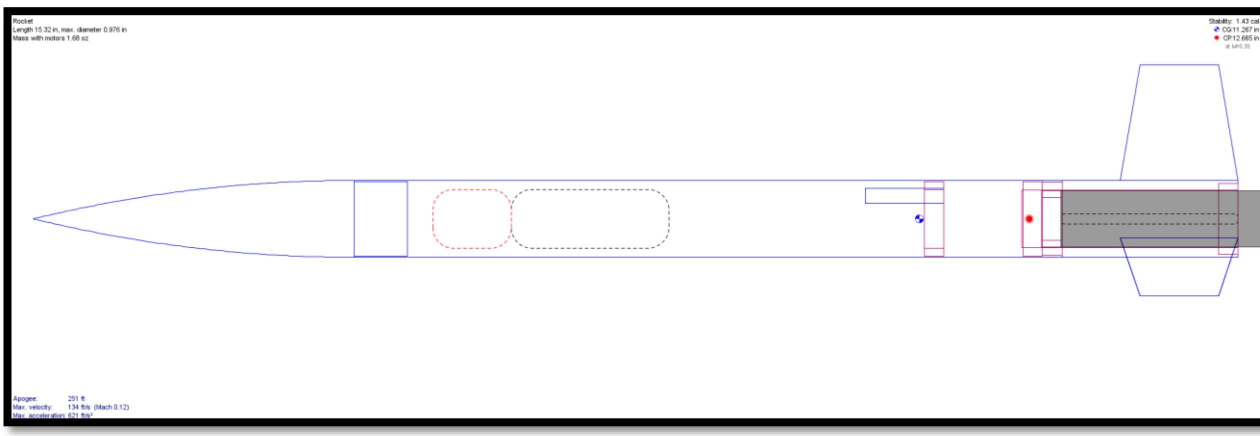


Figure 86: OpenRocket simulation created by students.

Day Five: Rocket Construction:

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

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

Day Six: Final Construction/Rocket Launch:

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

Figure 87: Kevin and Emily preparing Estes rockets.

Six Week Exploring Rocketry and Engineering Program

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

Day One: Programming

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

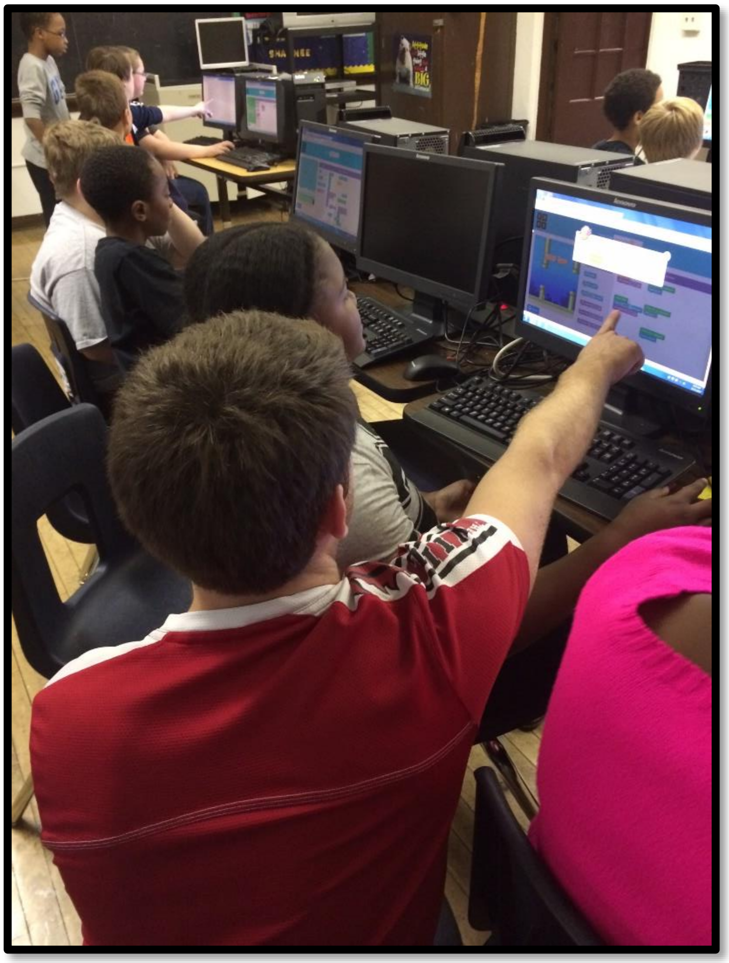


Figure 88: David teaches students how to program a game on code.org.

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

Day Two: Satellites

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

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

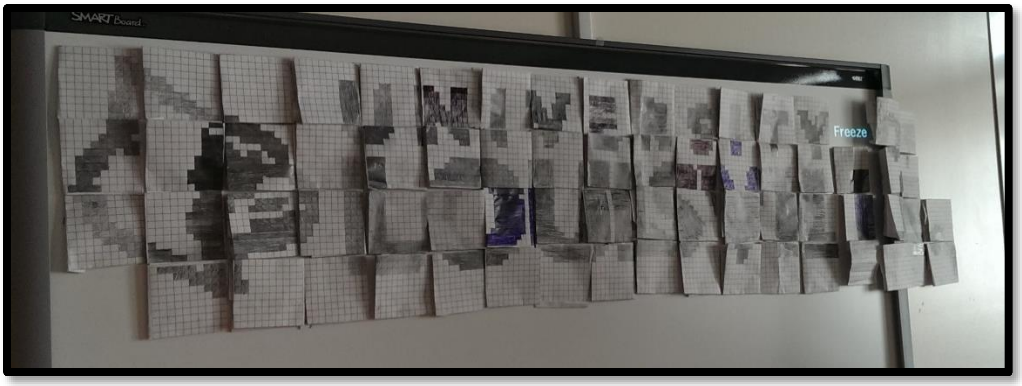


Figure 89: The satellite message that students decoded.

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

Day 3: Circuits

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

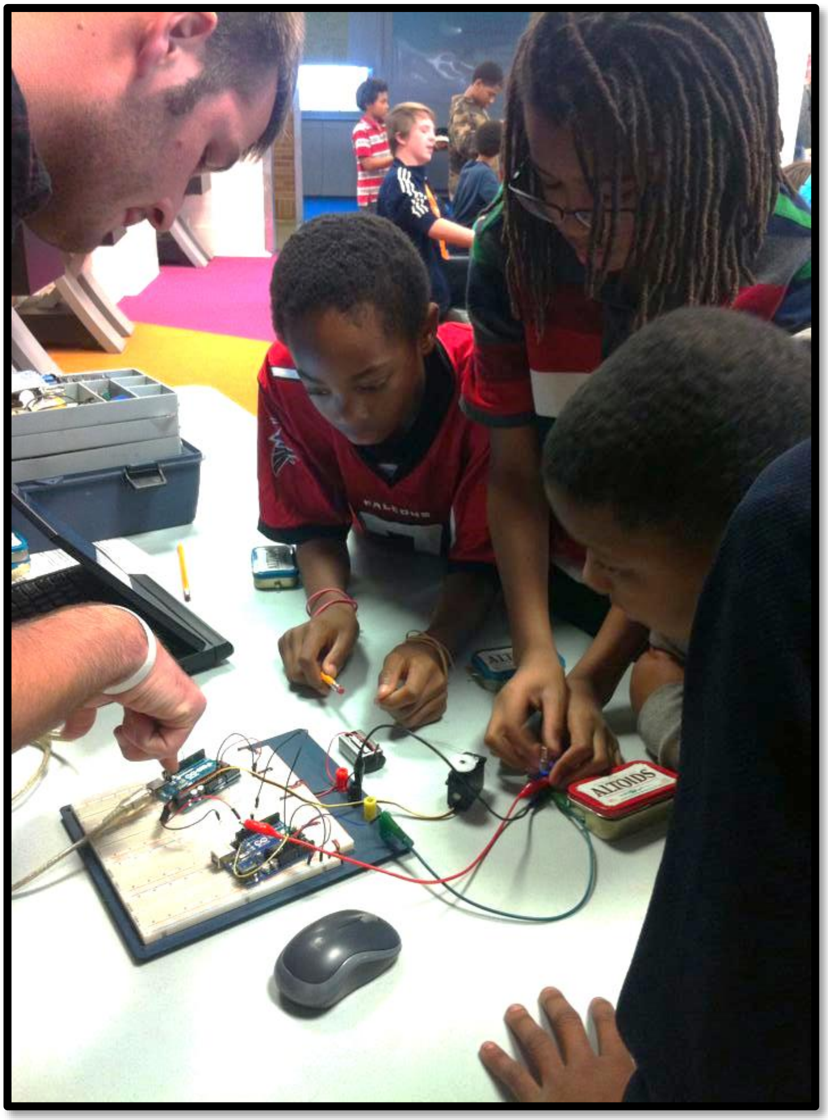


Figure 90: Sherman shows students a circuit that he built and how it works.

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

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

Day 4: OpenRocket Simulations
The team gives a presentation to the students on what it takes to build a high powered rocket. We stress the importance of simulation and how it can affect your design. We walk students through the basics of individual components of a rocket. Each primary component is talked about in great detail to give the students a firm understanding of the complete system. The team brings in last year's subscale launch vehicle to act as a "dissectible patient" so the students could look at both the internal and external components of what goes into a high powered launch vehicle.

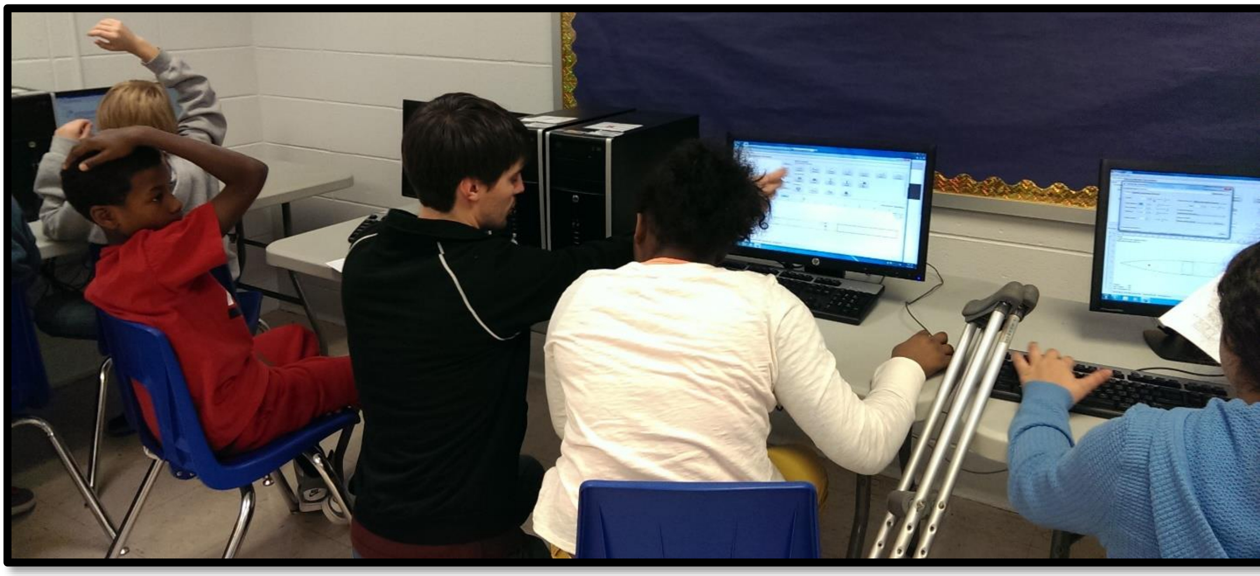


Figure 91: Gregg helps student with her OpenRocket simulation.

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

Day 5: Rocket Construction
Day 6: Rocket Launch
See previous program for details on rocket construction and launch.

8.1.2 Lego Mindstorm Programming

Every year, local students work in teams on building and programming Lego Mindstorm robots to complete specific tasks as defined by the FIRST Lego League competition. The team continually plays a role in educating students on these teams in the fundamentals of robot design and programming. The team regularly meets with the students to mentor them throughout the process. The students write programs, perform testing, and continue to tweak the programs until the robot performs the desired task.

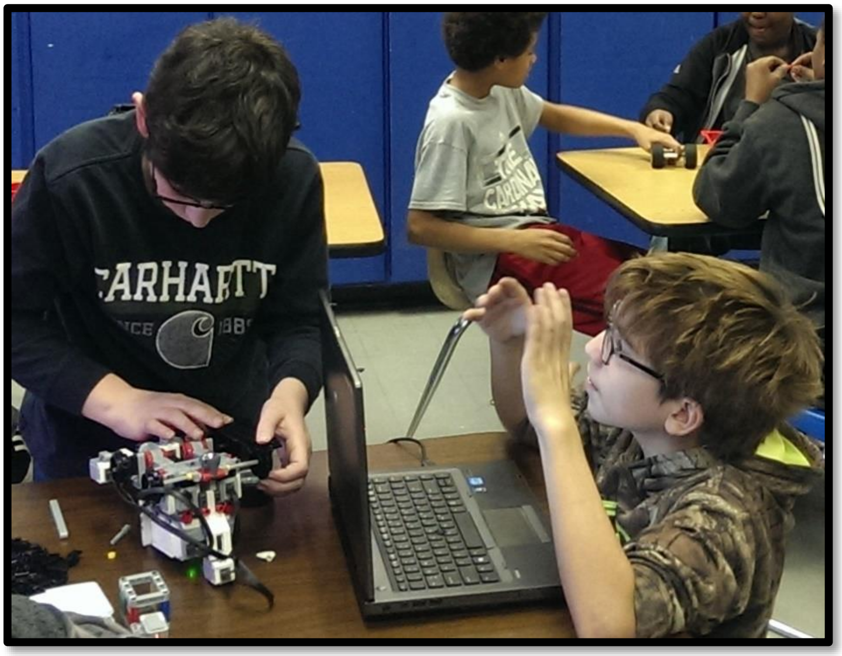


Figure 92: Students discuss designs and modifications to their program.

8.2 Outreach Opportunities

8.2.1 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 Engineering Exposition. The event is geared towards celebrating strides in engineering as well as getting the local youth interested in the field. During the event, the professional engineering societies on UofL's campus set up educational activities and scientific demonstrations for the elementary and middle school students to participate in.

The University of Louisville River City Rocketry Team will host its 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 throughout the day and will conclude the day with the competition. Teams will compete for awards in highest altitude, best constructed rocket, and landing closest to the launch pad. This event has been a huge success in the past and many schools have voice interest in continuing their involvement so we are looking for our best turn out yet this year.

Figure 93: 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 are looking to continue to build up that reputation.

8.2.2 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.

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. We plan to continue to build our relationships with these troops this year.

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

Figure 94: Zak assisting in the construction of a paper rocket at The Big Carnival.

"Kevin and UL Rocket Team,

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

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

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

8.2.5 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 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.

8.2.6 FIRST Lego League Competition

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

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

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

Figure 95: Emily and Kevin presenting at FIRST Lego League Regional Competition.

8.2.7 Louisville Astronomical Society

The team has been invited to be the guest speaker at a Louisville Astronomical Society (LAS) meeting. This event is for both those that are members of LAS as well as the public. This is an opportunity for the team so share what was accomplished during the 2015-2016 season as well as what the team is looking to do during the 2016-2017 season. The setting will allow for technical conversations about the project.

8.2.8 Executive Board of Advisors

The team was invited by the Dean of the University of Louisville J.B. Speed School of Engineering to present to his board of advisors. The advisors included CEO's and management from various companies from the region. This presentation consisted of a technical review of the previous year's design, what the team is about, the tasks that the team are required to complete, and the successes of the season. This provided the team excellent exposure to a variety of companies in the region.

9 Project Plan

9.1 Timeline

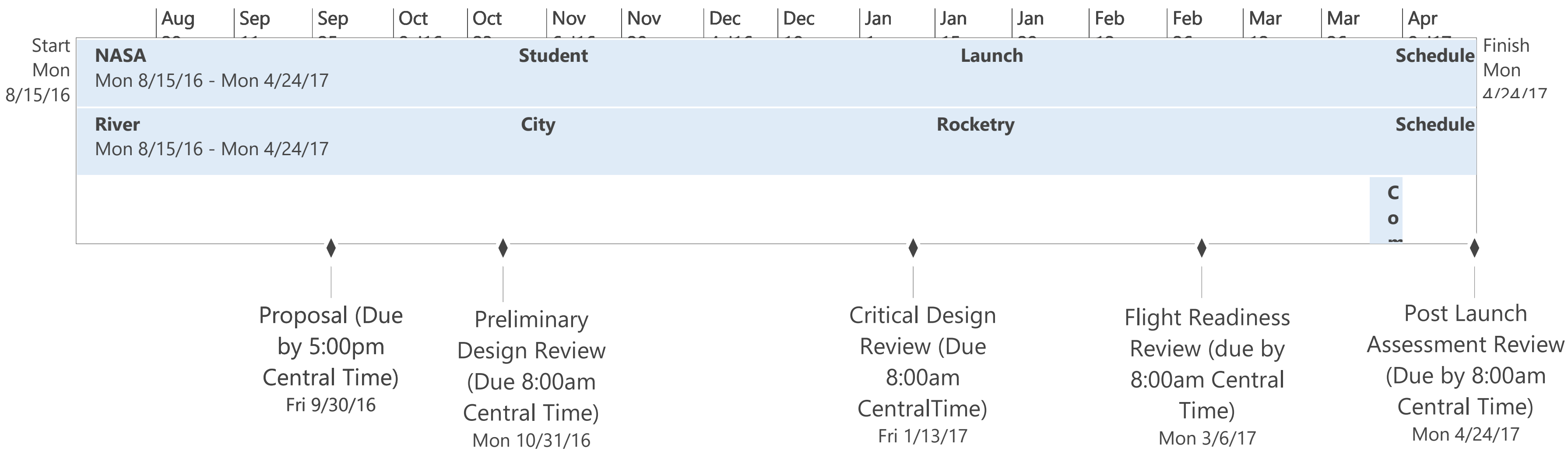


Figure 96: Project timeline page 1 (overview).

RCR_2016-2017_Schedule	**181 days**	**Mon 8/15/**	**Mon 4/24/**	
NASA Student Launch Schedule	**181 days**	**Mon 8/15/16**	**Mon 4/24/17**	
Proposal Time span	35 days	Mon 8/15/16	Fri 9/30/16	
Proposal (Due by 5:00pm Central Time)	0 days	Fri 9/30/16	Fri 9/30/16	
Awarded Proposals Announced	1 day	Wed 10/12/16	Wed 10/12/16	3
Kickoff and PDR Q&A	1 day	Fri 10/14/16	Fri 10/14/16	4
Preliminary Design Review (Due 8:00am Central Time)	0 days	Mon 10/31/16	Mon 10/31/16	5
PDR Video Teleconferences	13 days	Wed 11/2/16	Fri 11/18/16	6
CDR Q&A	1 day	Wed 11/30/16	Wed 11/30/16	
Critical Design Review (Due 8:00am Central Time)	0 days	Fri 1/13/17	Fri 1/13/17	8
CDR video teleconferences	11 days	Fri 1/13/17	Fri 1/27/17	9
FRR Q&A	1 day	Mon 1/30/17	Mon 1/30/17	
Flight Readiness Review (due by 8:00am Central Time)	0 days	Mon 3/6/17	Mon 3/6/17	11
FRR video teleconference	15 days	Mon 3/6/17	Fri 3/24/17	12
Competition Week	4 days	Wed 4/5/17	Sun 4/9/17	13
Post Launch Assessment Review (Due by 8:00am Central Time)	0 days	Mon 4/24/17	Mon 4/24/17	14

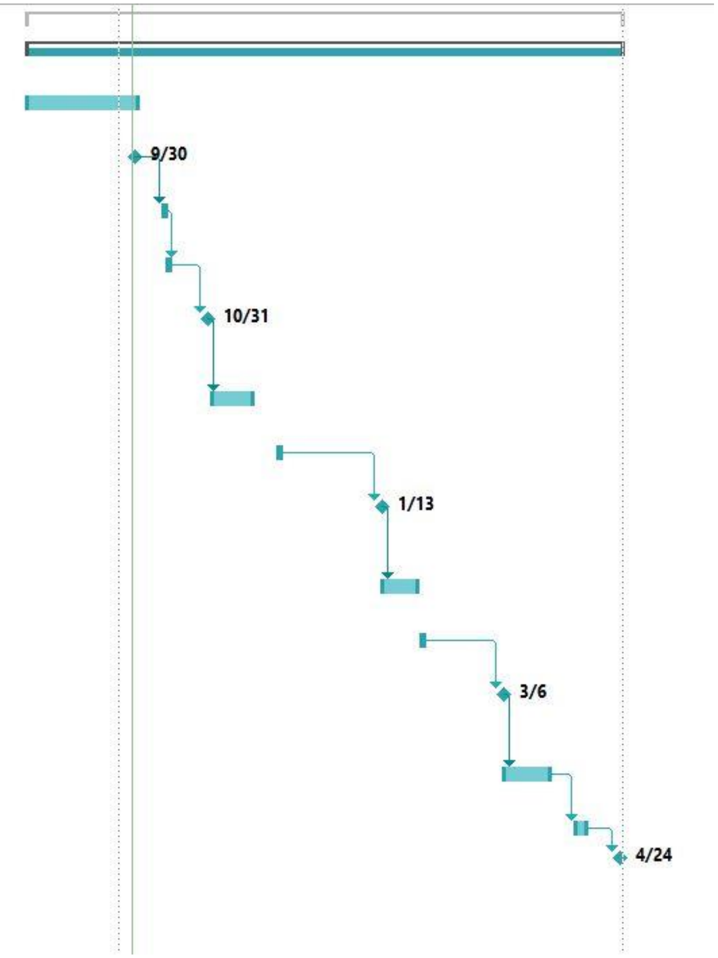


Figure 97: Project timeline page 1 (detailed overview).

River City Rocketry Schedule	**181 days**	**Mon 8/15/16**	**Mon 4/24/17**
Team Meetings	**4 days**	**Tue 8/16/16**	**Fri 8/19/16**
Reading of the rules/brainstorming meeting #1	1 day	Tue 8/16/16	Tue 8/16/16
Branstorming meeting #2	1 day	Wed 8/17/16	Wed 8/17/16
Team Lead Meeting #1	1 day	Thu 8/18/16	Thu 8/18/16
Team Lead Meeting #2	1 day	Fri 8/19/16	Fri 8/19/16
Team Recruitment/Team Development	**34 days**	**Tue 8/16/16**	**Fri 9/30/16**
Brainstorming of recruitment methods (Team Lead Meeting	1 day	Thu 8/25/16	Thu 8/25/16
Speed School Society Picnic	1 day	Tue 9/6/16	Tue 9/6/16
Team Lead Recruitment Meeting	1 day	Fri 9/16/16	Fri 9/16/16
General Team Interest Meeting	1 day	Thu 9/22/16	Thu 9/22/16
Society Summit	1 day	Sat 9/24/16	Sat 9/24/16
Speed School Student Council Meetings	**66 days**	**Thu 9/1/16**	**Thu 12/1/16**
Individual Proposal Sections Due	1 day	Wed 9/28/16	Wed 9/28/16
Individual PDR Sections Due	1 day	Thu 10/27/16	Thu 10/27/16
Individual CDR Sections Due	1 day	Sun 1/8/17	Sun 1/8/17
Individual FRR Sections Due	1 day	Sun 2/5/17	Sun 2/5/17
Sub-Scale Flight Test #1	1 day	Sat 12/3/16	Sat 12/3/16
Sub-Scale Flight Test #2	1 day	Sat 12/17/16	Sat 12/17/16
Full-Scale Recovery Flight Test	1 day	Sat 2/11/17	Sat 2/11/17
Full-Scale Flight Test with payload #1	1 day	Sat 2/18/17	Sat 2/18/17
Full-Scale Flight Test with payload #2	1 day	Sat 2/25/17	Sat 2/25/17

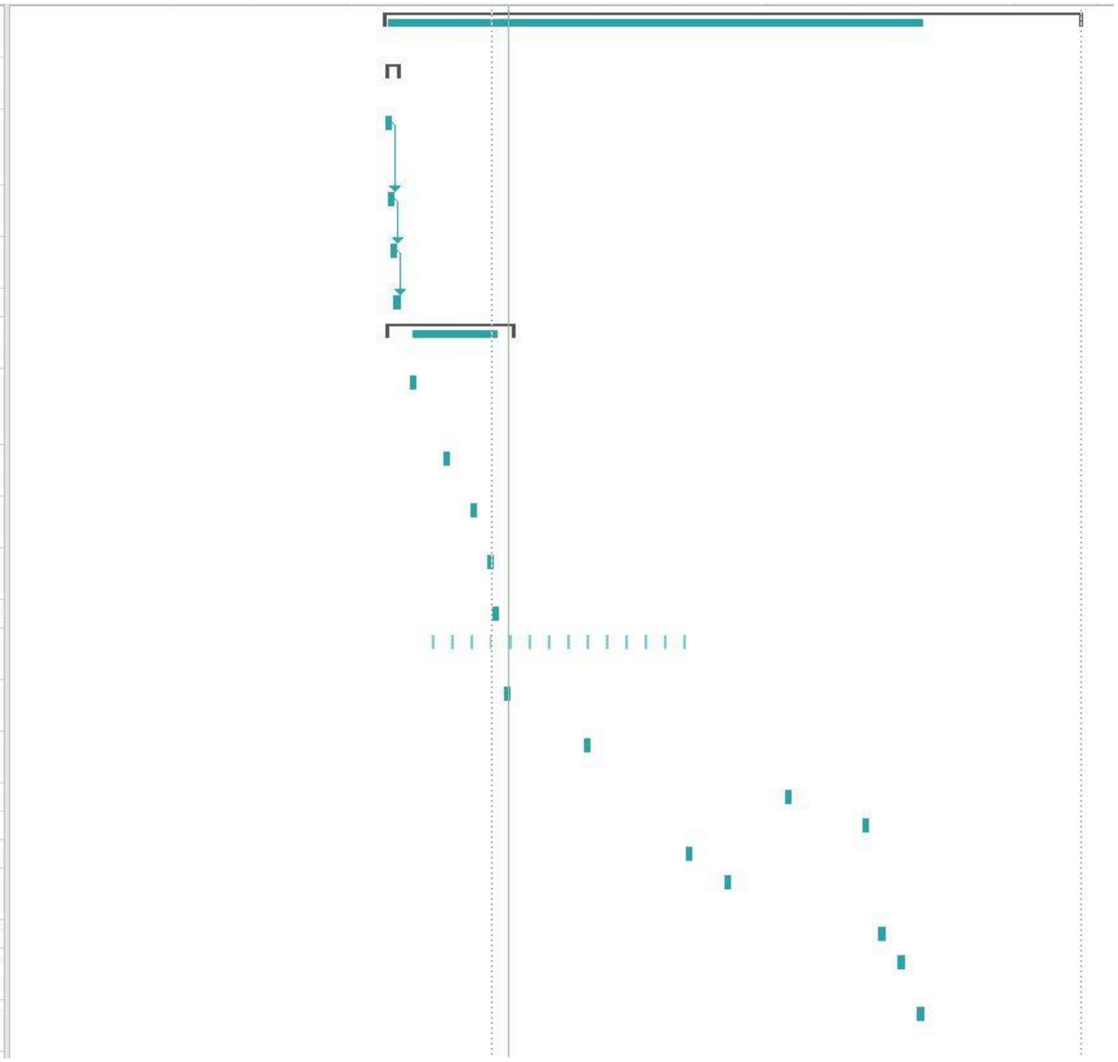


Figure 98: Project timeline page 2.

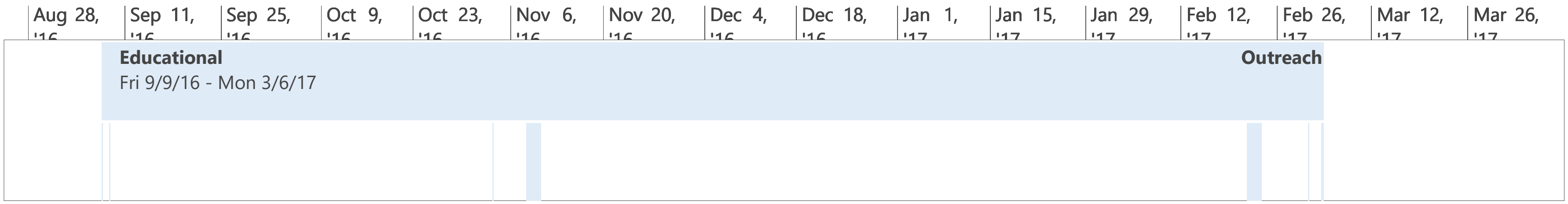


Figure 99: Project timeline page 3 (educational outreach).

Educational Outreach	**127 days**	**Fri 9/9/16**	**Mon 3/6/17**
Fall Festival at Boyce College	1 day	Fri 9/9/16	Fri 9/9/16
Mini-Maker Fair	1 day	Sat 9/10/16	Sat 9/10/16
Youth Science Summit	1 day	Sat 11/5/16	Sat 11/5/16
Advanced Manufacturing	3 days	Thu 11/10/16	Sat 11/12/16
Engineers Week at Kentucky Science Center	3 days	Thu 2/23/17	Sat 2/25/17
Engineering Expo	1 day	Sat 3/4/17	Sat 3/4/17
Goal: Reach 2,000 Students	1 day	Mon 3/6/17	Mon 3/6/17

Figure 100: Project timeline page 3 (detailed educational outreach).

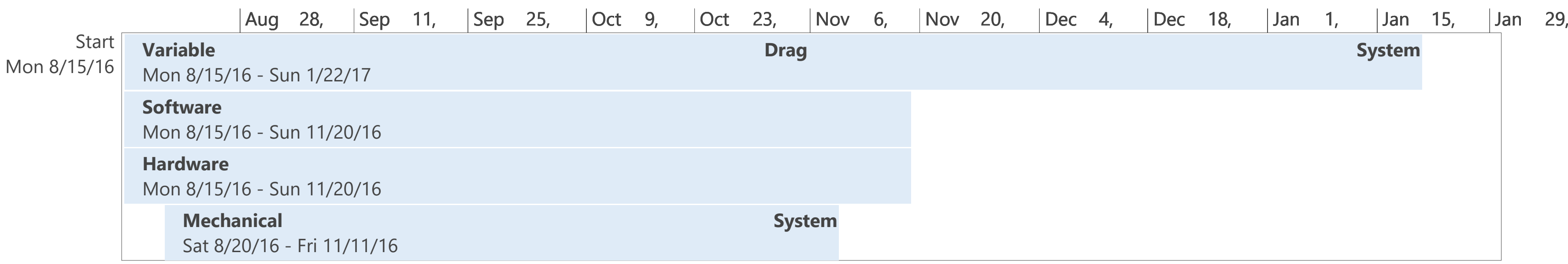


Figure 101: Project timeline page 4 (variable drag system).

Task Name	Duration	Start	Finish
Variable Drag System	**116 days**	**Mon 8/15/16**	**Sun 1/22/17**
Mechanical System	**60 days**	**Sat 8/20/16**	**Fri 11/11/16**
Anaylsis of VDS flight data/components (CFD)	42 days	Sat 8/20/16	Sat 10/15/16
Optimization, re-designing of airbrake components	16 days	Mon 10/10/16	Mon 10/31/16
Construction of new components	7 days	Sat 10/1/16	Sat 10/8/16
Testing of new VDS	1 day	Fri 11/11/16	Fri 11/11/16
Software	**70 days**	**Mon 8/15/16**	**Sun 11/20/16**
Convert to Python	46 days	Mon 8/15/16	Sat 10/15/16
Testing and proof of verification	12 days	Fri 9/30/16	Sat 10/15/16
After validation, propose new software	23 days	Sat 10/15/16	Tue 11/15/16
Integrated into Mechanical system	5 days	Tue 11/15/16	Sun 11/20/16
Hardware	**70 days**	**Mon 8/15/16**	**Sun 11/20/16**
Selecting power components	27 days	Mon 8/15/16	Tue 9/20/16
Selecting controller components/Design PCB board	46 days	Mon 8/15/16	Sat 10/15/16
Manufacturing of PCB	23 days	Sat 10/15/16	Tue 11/15/16
Integrated into Mechanical system	5 days	Tue 11/15/16	Sun 11/20/16

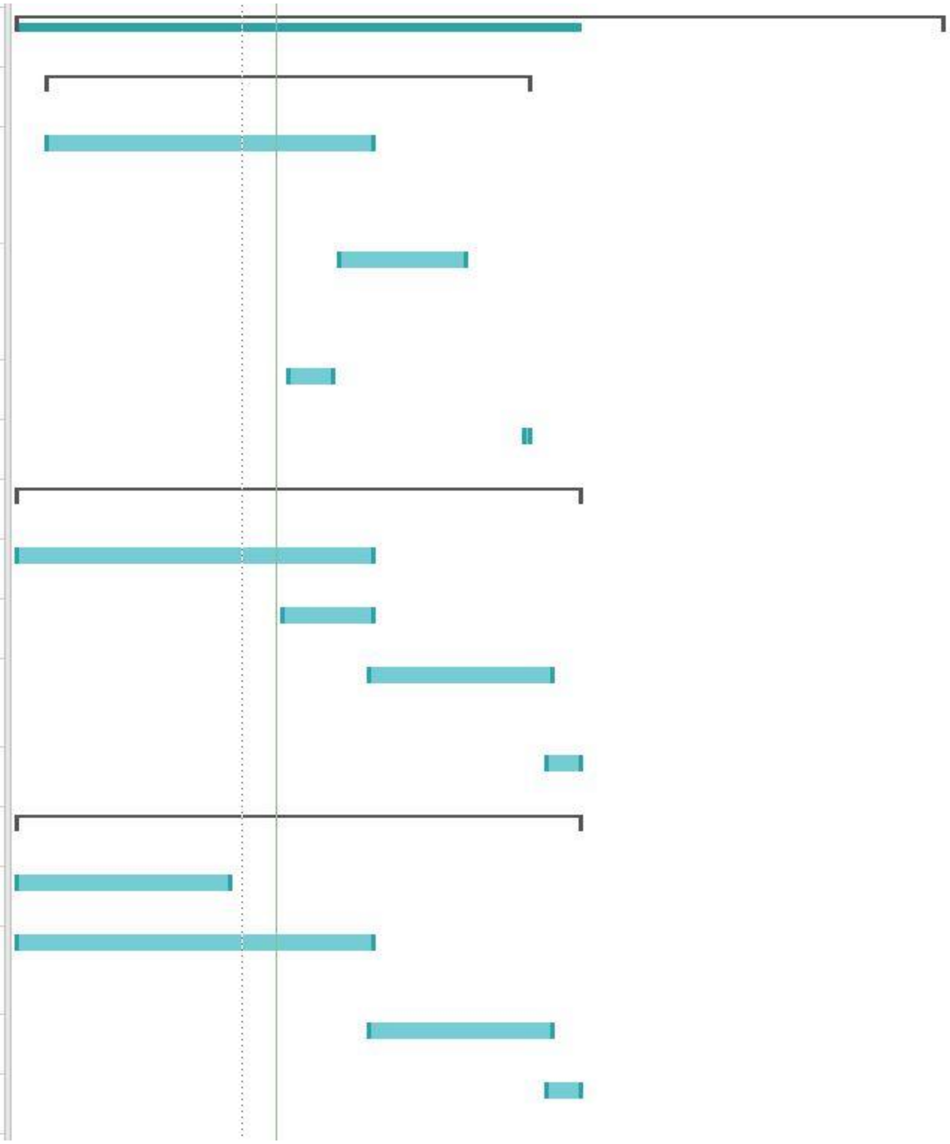


Figure 102: Project timeline page 4 (detailed variable drag system).

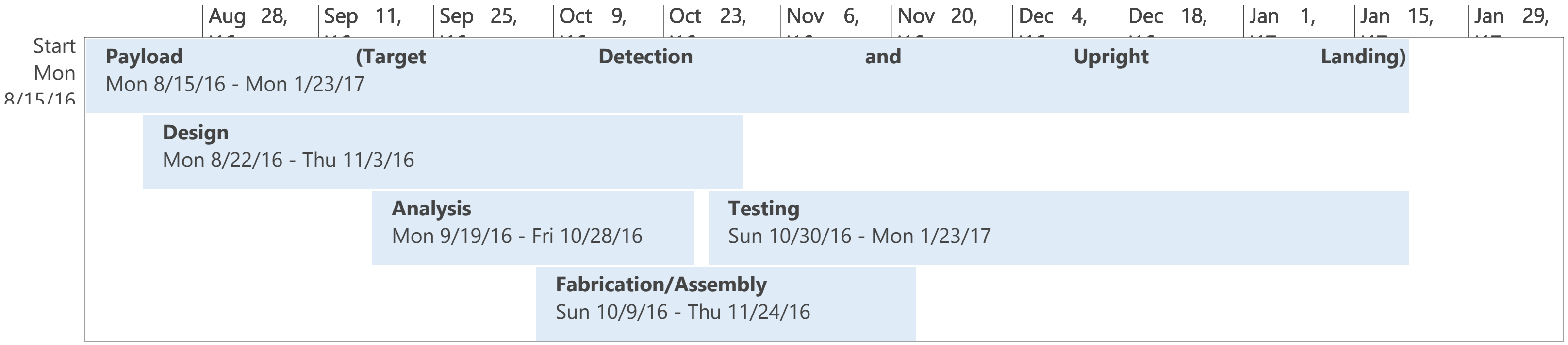


Figure 103: Project timeline page 5 (payload).

Payload (Target Detection and Upright Landing)	**116 days**	**Mon 8/15/16**	**Mon 1/23/17**
Design	**54 days**	**Mon 8/22/1**	**Thu 11/3/16**
Define System/Connection Requirments	17 days	Sun 9/25/16	Sun 10/16/16
Define Components/Circuit Protection	17 days	Sun 9/25/16	Sun 10/16/16
Define Components for Power Design	12 days	Sun 9/25/16	Sun 10/9/16
Breadboard Testing for Power Design of safety electronics	12 days	Sun 9/25/16	Sun 10/9/16
Preliminary Design/Dimensions of Payload Section	14 days	Sat 9/10/16	Wed 9/28/16
Preliminary Design and layout payload systems	25 days	Mon 8/22/16	Fri 9/23/16
Camera recognition software development	18 days	Mon 10/3/16	Wed 10/26/16
Camera stabilization system	18 days	Mon 10/3/16	Wed 10/26/16
Development of GNC and flight logic	18 days	Mon 10/3/16	Wed 10/26/16
Flight and safety electronic design	18 days	Mon 10/3/16	Wed 10/26/16
Detailed design of payload structures	18 days	Mon 10/3/16	Wed 10/26/16
Design of vehicle side deployment mechanisms	18 days	Mon 10/3/16	Wed 10/26/16
Finalize Payload Design	7 days	Wed 10/26/16	Thu 11/3/16
Analysis	**30 days**	**Mon 9/19/16**	**Fri 10/28/16**

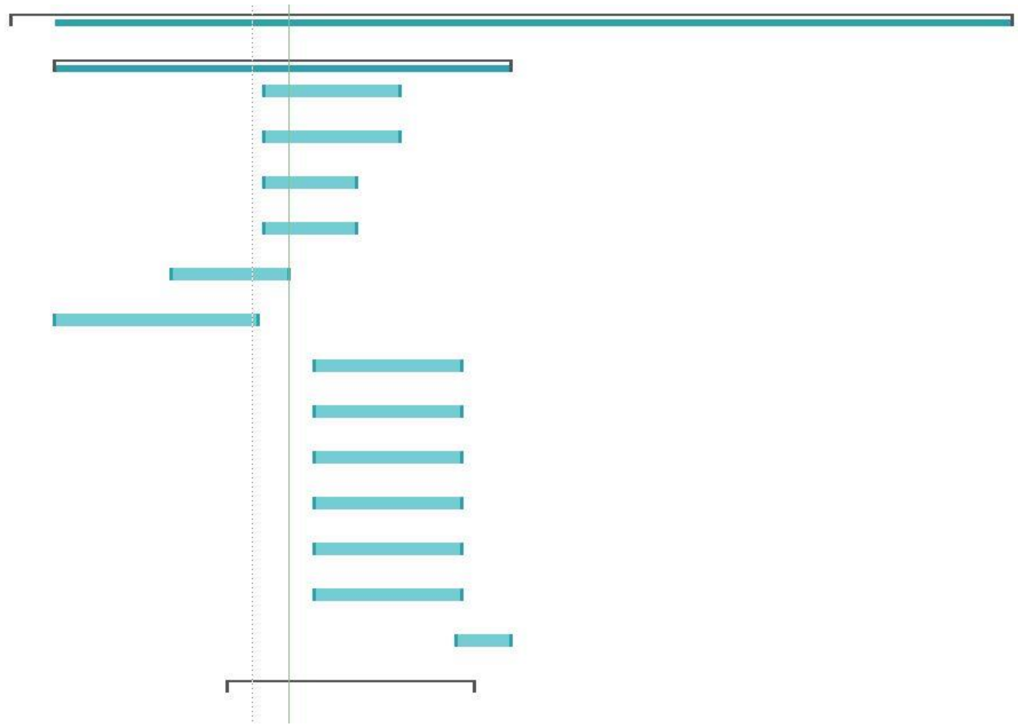


Figure 104: Project timeline page 5a (detailed payload).

Analysis	**30 days**	**Mon 9/19/16**	**Fri 10/28/16**
Vision and target recongnition analysis	30 days	Mon 9/19/16	Fri 10/28/16
Flight and control analysis	30 days	Mon 9/19/16	Fri 10/28/16
Deployment mechanism analysis	30 days	Mon 9/19/16	Fri 10/28/16
Fail safe system analysis	30 days	Mon 9/19/16	Fri 10/28/16
Vibrational and deflection analysis of propulsion structure	30 days	Mon 9/19/16	Fri 10/28/16
Structural analysis of propuslion and landing legs	30 days	Mon 9/19/16	Fri 10/28/16
Fabrication/Assembly	**34 days**	**Sun 10/9/16**	**Thu 11/24/16**
Develop necessary componenets (PCB's for Control Panel)	17 days	Sun 10/16/16	Sun 11/6/16
PCB Conversion of Power Design	17 days	Sun 10/9/16	Sun 10/30/16
Machine propulsion, landing leg, and camera stabilization mechanisms	18 days	Tue 11/1/16	Thu 11/24/16
Wind carbon fiber airframe body	18 days	Tue 11/1/16	Thu 11/24/16
Fabricate electronic sleds	18 days	Tue 11/1/16	Thu 11/24/16
Integrate electronics and propulsion assemblies	18 days	Tue 11/1/16	Thu 11/24/16
Finalize wire routing	18 days	Tue 11/1/16	Thu 11/24/16
Testing	**61 days**	**Sun 10/30/16**	**Mon 1/23/17**

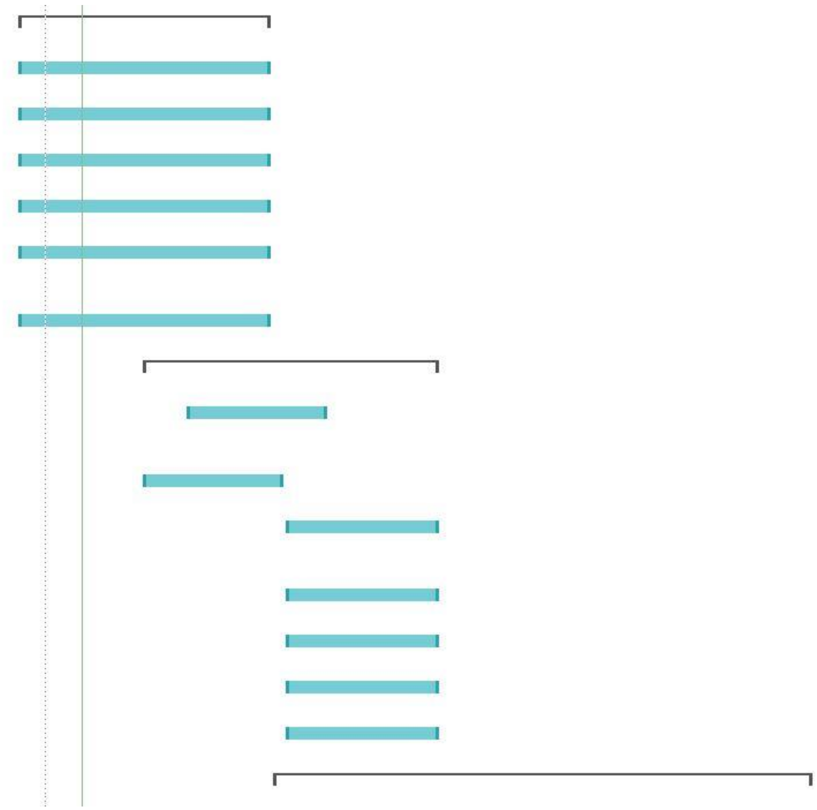


Figure 105: Project timeline page 5b (detailed payload).

Task	Duration	Start	Finish
Testing	**61 days**	**Sun 10/30/16**	**Mon 1/23/17**
Test PCB's for Control Panel	12 days	Sun 10/30/16	Sun 11/13/16
Test PCB's for Power Design	12 days	Sun 10/30/16	Sun 11/13/16
Ground test camera recognition	60 days	Tue 11/1/16	Mon 1/23/17
Ground test deployment mechanisms	60 days	Tue 11/1/16	Mon 1/23/17
Ground test flight electronics and verify failure logic	60 days	Tue 11/1/16	Mon 1/23/17
Low altitude flight test	60 days	Tue 11/1/16	Mon 1/23/17
Drop flight tests	60 days	Tue 11/1/16	Mon 1/23/17
Full scale flight tests	60 days	Tue 11/1/16	Mon 1/23/17

Figure 106: Project timeline page 5c (detailed payload).

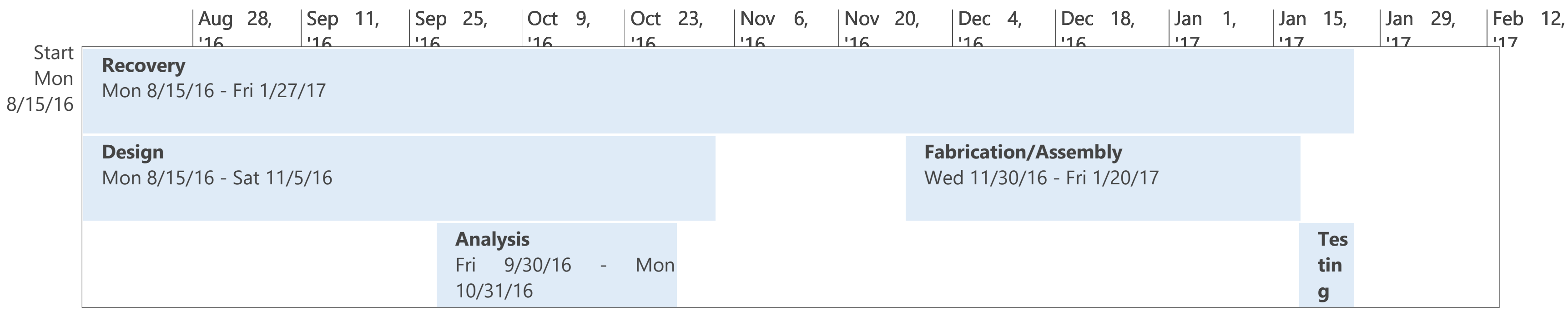


Figure 107: Project timeline page 6 (recovery).

Recovery	**120 days**	**Mon 8/15/1**	**Fri 1/27/17**
Design	**60 days**	**Mon 8/15/1**	**Sat 11/5/16**
Preliminary Design/dimensions/ characteristics	56 days	Mon 8/15/16	Mon 10/31/16
Sizing of Parachute	56 days	Mon 8/15/1	Mon 10/31/
Sizing of Suspension Lines	56 days	Mon 8/15/16	Mon 10/31/16
Sizing of Harnesses	56 days	Mon 8/15/1	Mon 10/31/
Finalize Design	1 day	Sat 11/5/16	Sat 11/5/16
Analysis	**22 days**	**Fri 9/30/16**	**Mon 10/31/**
Drift Calculations	22 days	Fri 9/30/16	Mon 10/31/
Kinetic Energy Calculations	22 days	Fri 9/30/16	Mon 10/31/16
Shock Force Calculations	22 days	Fri 9/30/16	Mon 10/31/16
Fabrication/Assembly	**38 days**	**Wed 11/30/**	**Fri 1/20/17**
Cut templates	38 days	Wed 11/30/	Fri 1/20/17
cut all shroud lines and shock cord	38 days	Wed 11/30/16	Fri 1/20/17
Hem all gores	38 days	Wed 11/30/	Fri 1/20/17
Construct vortex-ring/annular parachute	38 days	Wed 11/30/16	Fri 1/20/17
Construct Deployment Bags	38 days	Wed 11/30/16	Fri 1/20/17
Pack and and verify assembly of parachutes	38 days	Wed 11/30/16	Fri 1/20/17
Testing	**6 days**	**Fri 1/20/17**	**Fri 1/27/17**
Black Powder Deployment test (on ground)	6 days	Fri 1/20/17	Fri 1/27/17
Ground deployment test of parachutes from bags/airframe	6 days	Fri 1/20/17	Fri 1/27/17
Flight Tests	6 days	Fri 1/20/17	Fri 1/27/17

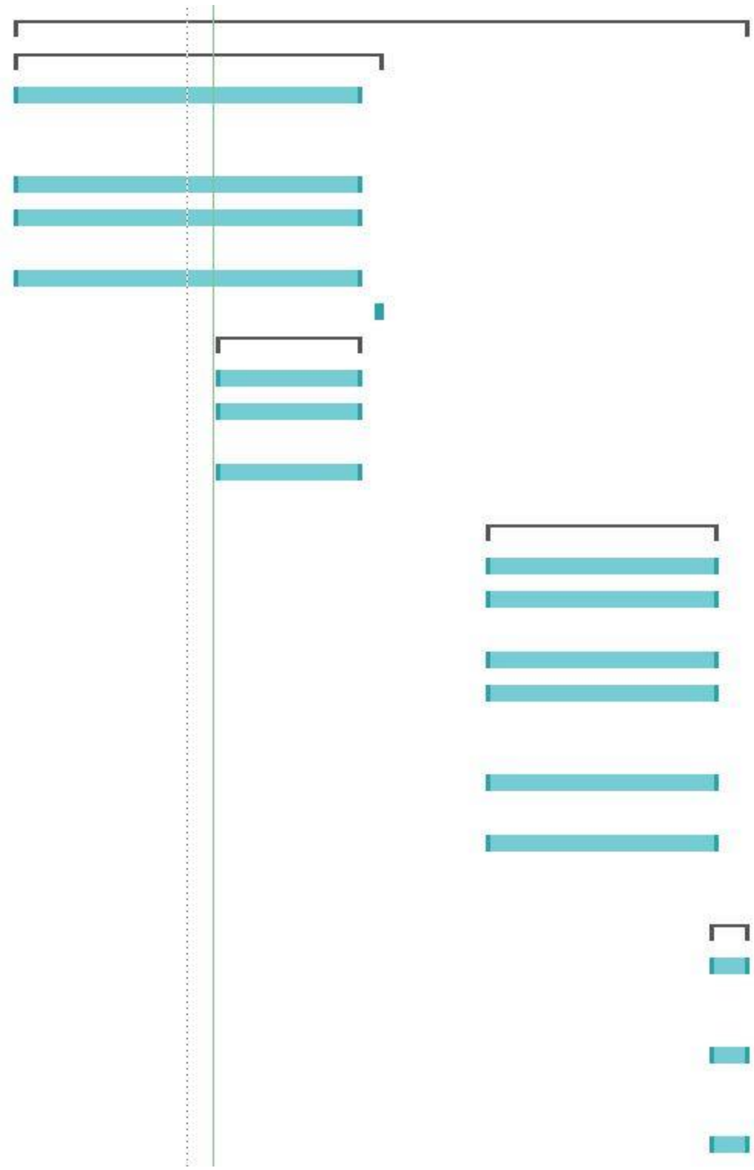


Figure 108: Project timeline page 6 (detailed recovery)

9.2 Comprehensive Budget

Full Scale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
6K Carbon Ribbon Toe, 4.65lbs	2	$279.00	$558.00
Raspberry pi	2	$35.00	$70.00
Fiberglass Tow, 15lbs	1	$245.00	$245.00
1/8" Thick 24" x 36" Fiberglass	4	$35.78	$143.12
6" Plywood Bulkplate - 1/2" Thick (Coupler)	5	$5.90	$29.50
6" Plywood Bulkplate - 1/2" Thick (Airframe)	5	$5.90	$29.50
6" 6061 T-6 Aluminum Centering Rings -1/4" Thick	4	$5.17	$20.68
Aerotech L1420R-P	6	$249.99	$1,499.94
75mm 5120 motor casing	1	$550.00	$550.00
1/4"-20 x 4' Threaded Rod (Aluminum)	3	$4.46	$13.38
1/4"-20 Hex Nuts (Aluminum) (pkg of 100)	1	$6.74	$6.74
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
3/8"-16 for 2.5" OD Black-Oxide (18-8 SS) (pkg of 25)	5	$1.55	$7.75
1/4" Flat Washer (Alumium) (pkg of 100)	1	$6.64	$6.64
3/8" Flat Washer Black-Oxide (18-8 SS) (pkg of 100)	1	$8.49	$8.49
1/4" Thick 6061 T-6 Aluminum Drag Flaps	3	$7.23	$21.69
1/4" Thick 12" x 48" Delrin	1	$85.22	$85.22
1/8" Dowel Pins 3/4" Length (pkg of 25)	2	$10.63	$21.26
6" x 12" Carbon Fiber Coupler	2	$110.00	$220.00
M3-16 mm Socket Head Cap Screws (pkg of 50)	1	$10.20	$10.20
AndyMark DC Motor	3	$28.00	$84.00
Servo	1	$40.00	$40.00
Featherweight Screw Switches	4	$5.00	$20.00
Omron SS-5GL Limit Switch	2	$1.80	$3.60
Momentary Contact Switch	3	$0.98	$2.94
Professional Paint Job for Competition	1	$250.00	$250.00
		Overall Cost	**$3,953.07**

Subscale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Fiberglass Tow, 15lbs	1	$245.00	$245.00
54mm Motor Mount Tube	1	$15.50	$15.50
1/8" Thick 24" x 36" Fiberglass	3	$35.78	$107.34
3" Plywood Bulkplate - 3/16" Thick (Coupler)	5	$1.64	$8.20
3" Plywood Bulkplate - 3/16" Thick (Airframe)	5	$1.66	$8.30
2" Plywood Centering Rings - 3/16" Thick	4	$1.62	$6.48
1/4"-20 x 4' Threaded Rod (Aluminum)	2	$4.46	$8.92
1/4"-20 Hex Nuts Black-Oxide (pkg of 50)	2	$4.53	$9.06
1/4"-20 for 1.5" ID Black -Oxide U-Bolt (Steel)	5	$1.14	$5.70
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
1/4"-20 Flat Washer (Aluminum) (pkg of 100)	1	$6.64	$6.64
PerfectFlight Stratologger	4	$54.95	$219.80
Electric Matches	15	$1.25	$18.75
4FA Powder (1lb)	1	$29.94	$29.94
9V Duracell Batteries (x4)	3	$12.73	$38.19
		Overall Cost	**$733.24**

Recovery Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
PerfectFlite Stratologgers	4	$54.95	$219.80
1" x 25' TUNSC Nylon Shock Cord	2	$19.95	$39.90
18" X 18" FCP Nomac	1	$10.95	$10.95
1/4"-20 Eyebolts	2	$9.71	$19.42
1/4"-20 U-Bolt	1	$0.75	$0.75
5/16"-18 U-Bolt	1	$1.04	$1.04
Flame Resistant Fabric 54"	3	$10.99	$32.97
64" x 1yd Ripstop Fabric	40	$9.00	$360.00
Type II Nylon Shroud Line (100 Yards)	2	$31.50	$63.00
1/4" Quick Links	3	$3.10	$9.30
9/32" Quick links	5	$3.10	$15.50
Electric Matches	50	$1.25	$62.50
11/16" Vials (pkg of 36)	1	$14.47	$14.47
4FA Black Powder (1lb)	1	$24.20	$24.20
9V Duracell Batteries (x4)	3	$12.73	$38.19
Garmin Astro GPS Unit	2	$189.99	$379.98
1/4"-20 Hex Nuts (pkg of 50)	1	$11.46	$11.46
1/4"-20 Washers (pkg of 100)	1	$8.25	$8.25
3" Plywood Bulkplate - 1/4" thick (Airframe)	2	$1.99	$3.98
1/8" Thick 24" x 36" Fiberglass	1	$42.49	$42.49
Nylon Thread	1	$20.99	$20.99
		Overall Cost	**$1,379.14**

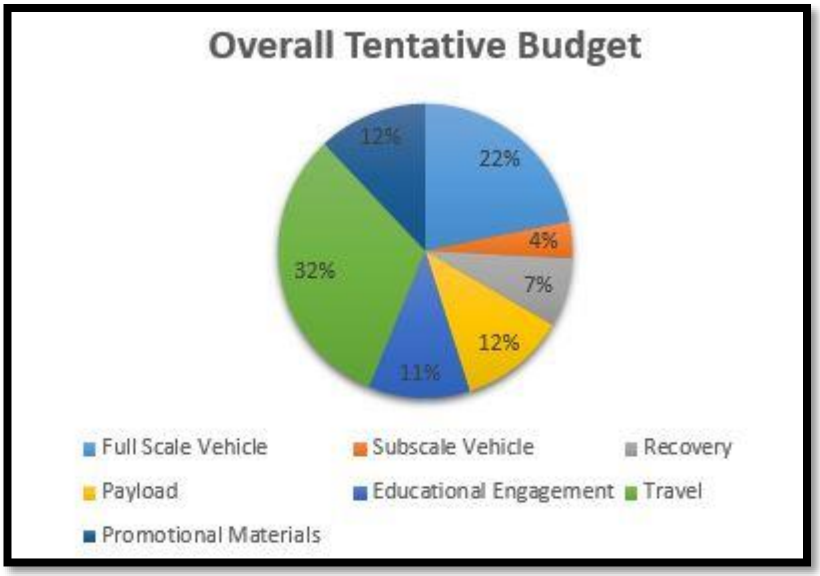
Payload Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
E1200 Propulsion System	1	$420.00	$420.00
ESC's	4	$10.00	$40.00
Lipo Battery	1	$400.00	$400.00
Rasberry pi	2	$35.00	$70.00
Rasberry pi cam	1	$20.00	$20.00
6061-T6 Aluminum 1 -1/2" x 2' x 2'	1	$650.00	$650.00
Carbon Fiber Woven Sheet	1	$58.00	$58.00
Flight computer	1	$300.00	$300.00
GPS sensor module	1	$100.00	$100.00
fastening hardware	1	$50.00	$50.00
Torsion spring	4	$2.00	$8.00
Helical ompression spring	4	$2.00	$8.00
		Overall Cost	**$2,124.00**

Educational Engagement Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Orbit 1" 24V Electronic Valve	3	$12.97	$38.91
7/8" Tire Valve (pkg of 2)	2	$2.09	$4.18
1 NPT Pipe Size Threading Bushing (Brass)	3	$7.70	$23.10
2-1/2" Tube ID x 1/2 Male Pipe Size Barbed Fitting (Brass)	3	$4.66	$13.98
2-1/2" Male x 1 NPT Female Bushing (PVC)	3	$2.80	$8.40
7/32" to 5/8" Hose Clamp (pkg of 10)	1	$5.87	$5.87
1/4" Wide x 14 Yards Teflon Tape	1	$5.19	$5.19
2 Pipe Size x 4' Length (PVC)	1	$36.94	$36.94
2 Pipe Size Cap (PVC)	3	$0.94	$2.82
Plastic Pipe Cement	1	$12.94	$12.94
3/4 Male Adapter to Female Slip (PVC)	6	$0.30	$1.80
3/4 Pipe End male x 1/2 Female Bushing (PVC) 3	3	$0.36	$1.08
3/4 Pipe Size x 5' Length (PVC)	1	$3.25	$3.25
1/2 Pipe Size x 4' Length (PVC)	1	$9.08	$9.08
2 Pipe End Male x 3/4 Female Slip Bushing (PVC)	3	$1.57	$4.71
6mm, SPDT-NO Push Button Switch	3	$6.18	$18.54
15" Length Red Nylon Cable Tie (pkg of 25)	1	$6.12	$6.12
9V Battery (pkg of 12)	1	$14.36	$14.36
9V Battery Snap, I-Style	6	$0.68	$4.08
24 GA 25' Stranded Wire (Black)	1	$3.18	$3.18
24 GA 25' Stranded Wire (Red)	1	$3.18	$3.18
Starhwak Model 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
		Overall Cost	**$2,027.76**

Travel Expenses Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Hotel (Competition in Huntsville, AL)	N/A	N/A	$4,000.00
Hotel (Testing in Manchester, Tennessee, Music City Missiles Club)	N/A	N/A	$500.00
Gas (Competition in Huntsville, AL)	N/A	N/A	$1,000.00
Gas (For all out of town testing)	N/A	N/A	$250.00
		Overall Cost	**$5,750.00**

Promotional Materials Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Shirts	20	$20.00	$400.00
Polos	40	$40.00	$1,600.00
Stickers	750	$0.25	$187.50
		Overall Cost	**$2,187.50**

Overall Tentative Budget	
Budget	**Total Cost**
Full Scale Vehicle	$3,953.07
Subscale Vehicle	$733.24
Recovery	$1,379.14
Payload	$2,124.00
Educational Engagement	$2,027.76
Travel	$5,750.00
Promotional Materials	$2,187.50
Overall Cost	$18,154.71



9.3 Funding

The team utilizes the innovation and success of River City Rocketry to propose funding to multiple commercial companies and grants throughout the year. Each year the team puts effort to reach a remainder balance of $10,000 for next year's team. This allows the team to perform research and development projects over the summer as well as a comfortable budget to assist the kick off of each new season. When a new door opens for funding the team ensures initial contact is made either in email or face to face where a universal sponsorship packet is gifted. This packet consists of a general overview of the NASA Student Launch project, the team's history of results in the competition, summary of accomplishments performed in the past season, and a detailed budget outlining the expenses of the past season. The sponsorship packet can be found on our website (www.rivercityrocketry.org) and is consistently updated from year to year.

The community has supported River City Rocketry in the past and besides grants or commercial sponsors the following individuals have reached out to the team and continue to do so year after year.

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

U of L Today with Mark Hebert: River City Rocketry performed a radio interview with U of L today with Mark Hebert where the discussion of past year's success as well as this year's season tasks took place. The team received an increase in followers not only on our Facebook page but on all sources of social media.

Wave 3 – MathMovesU: The event MathMovesU, which is discussed in further detail in Educational Outreach, brought in Wave 3 News where River City Rocketry got local television coverage over the duration of the event. This promoted the team's educational outreach as well as showed how much community support the team is receiving during this year's season.

WHAS 11 – Mini Maker Faire: River City Rocketry participated in the 2015 and 2016 Louisville Mini Maker Faire. WHAS 11 covered this event, which showcased the team on local television where the team demonstrated last year's Autonomous Ground Support Equipment. 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 2014-2015 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: At the end of last season's competition WDRB interviewed co-captains Greg Blincoe and Emily Robison 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.

Discovery Channel – Daily Planet: On launch day of the 2014-2015 season, River City Rocketry was followed around by Discovery Channel Daily Planet to catch every angle that goes into launch day. The team received international coverage both over the internet as well as broadcasted nationally in Canada.

Louisville Cardinal: The Louisville Cardinal is the independent student newspaper at the University of Louisville. The newspaper is widely read and respected by the students at the university. In years past, River City Rocketry took the opportunity to sit down for interviews with the Louisville Cardinal. This has allowed students from all over the university to see what the team is doing and the progress they have made.

Registered Student Organization: In the Spring of 2012, River City Rocketry became a Registered Student Organization (RSO) at the University of Louisville. Since receiving RSO status, the team has been able to reach out to the Student Senate as well as several of the university's Student Councils to gain support and increase the knowledge of rocketry at UofL. The team has received very positive feedback and was elected "Best New RSO" in its first year as an RSO.

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

9.4 Community Support

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

Due to the mandatory co-op program that the University of Louisville's J.B. Speed School of Engineering has, the team has made many connections with different companies. As a result of team members spending a year of their undergraduate career working in the industry, lasting relationships have been formed between companies and the team. This is a huge contribution to the team's growing network. A compiled list of our community supporters and method of support is shown in Table 36.

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

Table 36: RCR community supports.

9.5 Project Sustainability

Since the start of River City Rocketry, the end goal of every season is to continue on the tradition and success of the team. As we go forth with this season, the team is always looking for more ways to develop community and financial support to ensure the continued presence in this competition.

Local Exposure

River City Rocketry continues its exposure in a multitude of ways. The most primitive are through the following experiences that occur from year to year.

- 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, Discover Channel (Canada), NASA TV, the University of Louisville's webpage and in the University of Louisville magazine.

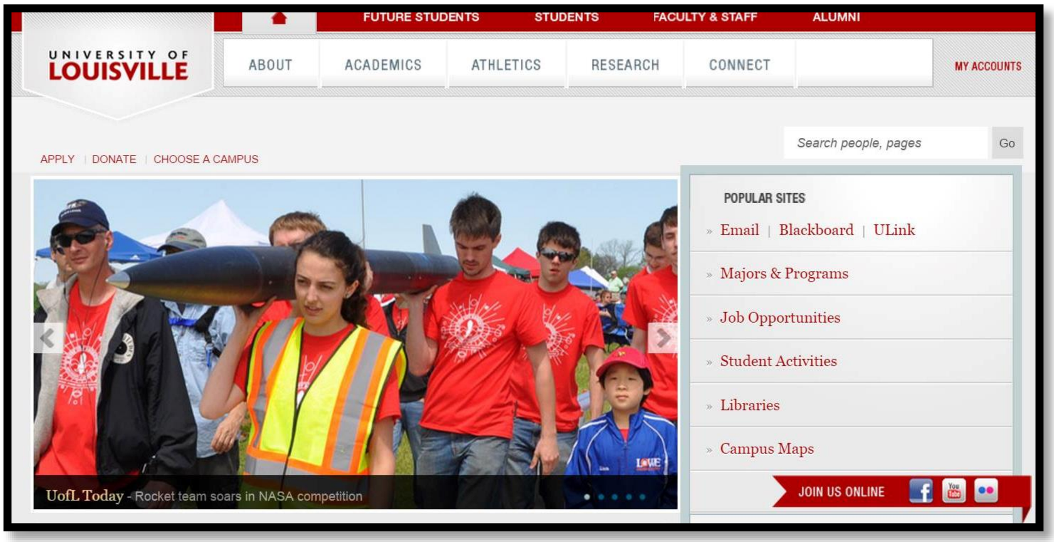


Figure 109: River City Rocketry on the front page of the University of Louisville website.

To further gain additional media exposure locally, the team will develop follow up stories on current team events to continually gain interested media. The team finds that one of the most rewarding methods of increasing exposure is through working with youth. Because of the success of last year, the team plans to cooperate with the Kentucky Science Center in corrdnaing outreach events for this upcoming season that will hopefully gravitate future members to River City Rocketry. Media coverage and publicity regarding previous years' achievements will likely gain the attention of newly interested participants and further the team's success in the NASA Student Launch competition.

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 Variable Drag System (VDS) over the summer. With ongoing projects and periodic launches, member's take great interest in the team and tend to contribute multiple years to the team. To ensure the entire team maintains on the same page bi-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.

Figure 110: Young rocketeers getting their level one certification.

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.

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.

10 Conclusion

River City Rocketry is returning more excited than ever to participate in the NSL competition this season and will strive to accomplish more than it ever has by setting the following goals:

- To continue to set the standard for safety in the NSL competition.
- To engage 2,000+ students in STEM centered outreach events, encouraging enthusiasm for rocketry and the larger STEM fields.
- To design a Variable Drag System (VDS) that will raise the bar for apogee accuracy in NSL flights.
- To design a payload system that reliably detects several targets and lands upright.
- 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.

11 Appendix I – Safety Risk Assessments

Lab and Machine Shop Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Using power tools and hand tools such as blades, saws, drills, etc.	1. Improper training on power tools and other lab equipment. 2. Uniformed on proper tool to use.	1a. Mild to severe cuts or burns to personnel. 1b. Damage to rocket or components of the rocket. 1c. Damage to equipment	2	4	Low	1. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them. 1. Safety glasses must be worn at all times. 1. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE. 2. Improper training on the use of a Dremel tool or other sanding machinery.	1a. Mild to severe rash. 1b. Irritated eyes, nose or throat with the potential to aggravate asthma. 2. Mild to severe cuts or burns from	3	3	Low	1a. Long sleeves should be worn at all times when sanding or grinding materials. 1b. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required.

		a Dremel tool and sanding wheel.				2. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.
Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage due to inhalation of toxic fumes, or chemical spills	1. Chemical splash. 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. All chemical containers will be marked to identify appropriate precautions that need to be taken. 1. Nitrile gloves shall be used when handling hazardous materials. 1. Personnel are familiar with locations of safety features such as an eye wash station, chemical burn station and first aid kit.

						1. Safety goggles are to be worn at all times when handling chemicals. 2. When working with chemicals producing fumes, appropriate precautions should be taken such as working in a well-ventilated area, wearing vapor masks, or working under a fume hood.
Damage to equipment while soldering.	1. Soldering iron is too hot 2. Prolonged contact with heated iron 3. Soldering iron tip varies in temperature along tip	The equipment could become unusable. If parts of the payload circuit get damaged, they could become inoperable.	3	3	Low	1. The temperature on the soldering iron will be controlled and set to a level that will not damage components. 2. For temperature sensitive components sockets will be used to solder ICs to. 3. Proper de-soldering tools and wiping sponges will be available during all soldering tasks.
Dangerous fumes while soldering.	1. Use of leaded solder can produce toxic fumes. 2. Leaving soldering iron too long on plastic could cause plastic to	Team members become sick due to inhalation of toxic fumes. Irritation could also occur.	3	3	Low	1. The team will use well ventilated areas while soldering. Fans will be used during soldering. 2. Team members will be informed of appropriate soldering techniques, avoiding contact of the soldering iron to plastic

	melt producing toxic fumes.					materials for extended periods of time.
Potential burns to team members while soldering.	Team members do not pay attention while soldering	The team member could suffer minor to severe burns.	4	3	Low	Team members will be trained how to solder and will follow all safety protocols related to soldering.
Overcurrent from power source while testing.	Failure to correctly regulate power to circuits during testing	Team members could suffer electrical shocks which could cause burns to heart arrhythmia	2	4	Low	The circuits will be analyzed before they are powered to ensure they don't pull too much power. Power supplies will also be set to the correct levels.
Use of cutting fluid.	Use cutting fluid when machining metals.	Contains carcinogens.	1	5	Low	Face shield shall be worn at all times when machining metals.
Handling Carbon Fiber and Fiberglass Tow	Use in manufacturing airframe and bulkplates	1. Splinters in skin 2. Respiratory irritation	4	3	Low	Team members are required to wear cut resistant gloves, long sleeves, and safety glasses when handling carbon fiber.
Use of white lithium grease.	Use in installing motor	1. Irritation to skin and eyes.	3	4	Low	1. Nitrile gloves and safety glasses are to be worn when applying grease.

		2. Respiratory irritation.				2. When applying grease, it should be done in a well ventilated area to avoid inhaling fumes.
High voltage shock.	Improper use of welding equipment.	Death or severe injury.	1	5	Low	All team members are required to be trained on the equipment prior to use. Any time personnel is welding, there must be at least two people present.
Damage to equipment while winding airframe, X-Winder	1. Improper use of X-Winder equipment. 2. Improper training of program on X-Winder	1a. Running the carriage into the solid stops, damaging the carriage. 1b. Not tightening the chucks that connect to the mandrill; resulting in a damaged mandrill. 2. Writing incorrect program, wasting material, and damage of equipment	2	5	Low	All team members are required to be trained on the equipment prior to use. Any time someone writes or runs the X-Winder must be at least two people present.

Break bit on mill.	Spindle speed too high.	Injury to personnel and damage to equipment and/or part.	2	5	Low	All team members are required to be trained on the mill prior to use. If personnel is uncertain about the proper settings, they are to consult an experienced member prior to operation.
Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	2	5	Low	Team members must wear long sleeves and safety glasses whenever working with metal parts.

Table 37: Lab and machine shop risk assessment.

VDS Actuation Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Structural damage to the airframe during actuation during flight and during pre-flight test.	1. Improper installation, that result in tolerance issues 2. Securing hardware properly 3. Drag blades over rotating/over retracting	1a. Tearing into the airframe resulting in sever zippering. 1b. Prevent drag blades from opening during flight, overshooting the altitude and breaking the waiver. 2. Damage to equipment and possible loss to the	1	4	Moderate	All hardware being checked and proper clearances must be verified by a sub-team lead and a captain.
VDS actuates on rail	1. Electrical and/or programing failure.	1a. Vehicle escapes path of rail and resulting in a unstable	2	5	Low	Consistent testing and validation of the system functions to

		flight. 1b. Potential injury to personal or spectators if the rocket were to go on a rogue flight path.				ensure a premature deployment does not occur.
VDS failing to retract during recovery	1. Drag blades over extending breaking the motor gearbox.	Damage to vehicle sections as they hit each other on descent. Potential to injury to personal or spectators. Shock cord and shroud lines tangling on drag blades causing a free fall of the vehicle.	1	3	Moderate	The team will implement limit switches on both extrema of movement to prevent the overextending or over retracting of the air blades.

Table 38: VDS actuation 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

					Low	throughout the season, having a 100% success rate.
Motor explodes on the launch pad.	Faulty motor	Rocket and interior components significantly damaged.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR in order to ensure that no one is hurt by flying debris. Extinguish any fires that may have been started when it is safe to approach. Collect all debris to eliminate any hazards created due to explosion. The motors the team have selected are from a reliable supplier. The team has had a 100% success rate.
Rocket doesn't reach high enough velocity before leaving the launch pad.	1. Rocket is too heavy. 2. Motor impulse is too low. 3. High friction coefficient between rocket and launch tower.	1,2. Unstable launch.	1	5	Low	Too low of a velocity will result in an unstable launch. Simulations are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in graphite prior to each launch in order to minimize friction. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.
Fins shear during flight.	Insufficient adhesion during installation resulting in a failure in the epoxy.	Unstable rocket, causing the flight path to become unpredictable.	1	5	Low	Confirm all personnel are alert and at a distance allowed by the Minimum Distance Table as established by NAR. Examine external epoxy beads for cracks prior to launch.
Airframe	Airframe	Rocket will	1	5	Low	Through prediction models, appropriate

buckles during flight.	encounters stresses higher than the material can support.	become unstable and unsafe during flight.				material selection, and a secure factor of safety, this failure mode can be nearly eliminated.
Internal bulkheads fail during flight.	Forces encountered are greater than the bulkheads can support.	1. Internal components supported by the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.	1	5	Low	The bulkheads will be designed to withstand the force from the motor firing with an acceptable factor of safety. 1. Electrical components could be damaged and will not operate as intended during flight. 2. A catastrophic failure is likely. A portion of the rocket or the fairing would become ballistic.

Table 39: Stability and propulsion risk assessment.

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

						during flight. If separation does not occur, the rocket will follow a ballistic path, becoming unsafe. All personnel at the launch field will be notified immediately.
Altimeter or e-match failure	Parachutes will not deploy.	Rocket follows ballistic path, becoming unsafe.	1	5	Low	Multiple altimeters and e-matches are included into systems for redundancy to eliminate this failure mode. Should all altimeters or e-matches fail, the recovery system will not deploy and the rocket will become ballistic, becoming unsafe. All personnel at the launch field will be notified immediately.
Parachute does not open	1. Parachute gets stuck in the deployment bag. 2. Parachute lines become tangled.	1,2. Rocket follows ballistic path, becoming unsafe.	1	4	Moderate	Deployment bags will be specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Rocket descends too quickly	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design.

Rocket descends too slowly	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3	3	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Should this be too large, the parachute will have to be resized.
Parachute has a tear or ripped seam	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful inspection prior to packing each parachute, this failure mode should be eliminated.
Parachute or chords become burnt	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful packing and the appropriate use of Nomax material, this failure mode is unlikely.
Recovery system separates from the rocket	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1,2. Parachute completely separates from the component, causing the rocket to become ballistic.	1	5	Low	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Landing of "rest of	1. Vehicle components get	1a. Joining bulk plate is sheared off.	2	4	Low	Proper sizing of parachutes reduce the kinetic energy of the telescoping

vehicle" with deployed telescoping deployment rod	damaged on impact	1b. If drifting over the crowd occurs, injury to personal and spectators.				deployment rod.

Table 40: Recovery risk assessment.

Payload Redundant Recovery Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Premature deployment of payload	1. The main parachute deploys early 2. Shear pins break 3. Telescoping deployment arm failing	1. Significant drift occurs; damaging property or personal. 1a. Environmental hazard if vehicle is lost in drift. 3. Damage to vehicle or components during landing	2	4	Low	1. Ensure safety electronic criteria is valid.
Payload does not detach from telescoping deployment arm via the thread coupler	1. Binding of threads to induce improper detachment.	1. The payload gets tossed of course, runs into airframe, and enters redundant recovery state.	3	4	Low	Through testing, the team can validate the payload detaching the telescoping deployment arm.
Premature deployment of recovery parachute	1. Flight computer/safety electronics misinterpret flight	Ability to visualize targets reduces	5	3	Low	Through testing, the team can validate the functionality of the flight computer and sensors.

	data. 2. Sensor outputs false data					
Avoidance of vehicle after deployment	1. Payload doesn't perform/effectively use avoidance maneuver	1a. Vehicle knocks payload out of the air 1b. Payload can tangle recovery lines/parachute	1	2	High	Through testing, the team can validate the functionality of the escape maneuver to reduce the risk level in the future.
Arms/legs not deploying	1. Torsion spring doesn't provide sufficient torque to rotate the arms/legs down 2. Lock pin does not seat into the arm/leg cam. 3. Dynamic impact of cam fails locking mechanism	Payload arm can jeopardize the flight; Payload leg can prevent landing, but still go through the flight process.	1	2	High	Through testing and prototyping the team can reduce the chance of the locking mechanisms from failing and in return reduce the risk level.

Table 41: Payload redundant recovery risk assessment.

Payload Landing Risk Assessment						
Hazards	**Cause/Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Payload leg breaks on impact	1. Descending too quickly. 2. Motor/propeller failure occurs on descent of payload.	Damage to payload and fragments projecting outward. Injury to personal or spectators from fragmented	2	3	Moderate	Through testing the team can validate the landing procedure and produce a lower risk level.

		pieces.				
Payload lands on launch stand power supplies/other launch vehicles	1. Avoidance controls misinterpret a launch stand from a safe landing area. 2. Power shut off due to an electronic/coding failure	1. Explosion from on board batteries/launch stand batteries. 2. Damage to other launch vehicles and components. 3. Severe injury to personal or spectators.	1	4	Moderate	Through a multitude of ground avoidance tests, the payload will learn recognition faster. Implementation of redundant recovery can also lower the risk level.
Payload tipping over after landing occurs	1. Weather related due to wind. 2. Propellers do not shut off properly and result in potential fragmentation when tipping over occurs.	1. Payload remains on its side failing the upright landing challenge. 2. Fragmentation of propellers occur.	3	3	Low	Continuous testing of the landing procedure to ensure a successful upright landing.

Table 42: Payload landing risk assessment.

Vehicle Assembly Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket drop (INERT)	Mishandling of the rocket during transportation.	Minimal damage and scratches to components of the rocket.	4	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.

Rocket drop (LIVE)	Mishandling of the rocket during transportation.	1. Minimal damage and scratches to components of the rocket if no charges go off. 2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.
Black powder charges go off prematurely	1. Altimeters send a false reading. 2. Open flame sets off charge.	1,2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	All electronics will be kept in their OFF state for as long as possible during preparation. Open flames and other heat sources will be prohibited in the area.
Seized nut or bolt due to galling or cross threading	Repetitive uninstalling and reinstalling of parts made of materials prone to galling.	Component becomes unusable, potentially ruining expensive, custom machined parts. Amount of rework depends on the location and component that seized.	2	4	Low	Through proper choice in materials, appropriate pre-load, and proper installation, the risk of galling can be eliminated.
Pinched shock cord lines or shroud lines	Poor packing of the parachute and its shroud lines. Not following packing procedure check list.	Line over occurs on deployment bag, causing no deployment of main parachute. Shock cord gets tangled causing damage to vehicle and its components.	1	5	Low	Training on packing the parachute along with a detailed check list to follow during launch preparation. Keeping two personal's eyes on the packing of the recovery scheme.

Table 43: Vehicle assembly risk assessment.

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Low cloud cover.	N/A	Unable to test entire system.	1	4	Moderate	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.
Rain	N/A	1. Unable to launch. 2. Damage electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage.
High winds	N/A	1. Have to launch at high angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift

					Moderate	with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the salt flats being extremely soft, as well as local launch sites, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.
Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.
Extremely cold temperatures.	1. Batteries discharge quicker than normal. 2. Shrinking of fiberglass.	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will not separate as easily.	1	5	Low	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.

Humidity	N/A	Motors or black powder charges become moist and don't ignite.	1	5	Low	Motors and black powder should be stored in a location free from moisture to remove
UV exposure	Rocket left exposed to sun for long periods of time.	Possibly weakening materials or adhesives.	4	4	Low	Rocket should not be exposed to sun for long periods of time. If the rocket must be worked on for long periods of time, shelter should be sought.

Table 44: Environmental hazards to rocket risk assessment.

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

						size.
Release of reactive chemicals.	Burning of composite motors.	Reactive chemicals work to deplete ozone layer.	4	1	Moderate	While the probability of releasing reactive chemicals into the environment is high, the quantity released will result in negligible effects. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.
Release of toxic fumes in the air.	Burning of ammonium perchlorate motors.	Biodegradation.	4	1	Moderate	Ammonium perchlorate will be burned in small quantities and infrequently. The amount of toxins released will cause minimal degradation.
Production of styrene gas.	Through the use of fiberglass in the overall design, fiberglass is manufactured by a second party.	Toxic air emissions.	4	1	Moderate	Productions methods for fiberglass produces toxic air pollutants, particularly styrene, which evaporate during the curing process. Due to the quantity of fiberglass utilized on the rocket, the amount of pollutants produced throughout manufacturing process will have a negligible effect on the environment.
Spray painting.	The rocket will be spray painted.	1. Water contamination. 2. Emissions to environment.	2	5	Low	All spray painting operations will be performed in a paint booth. This prevents any overspray from entering into the

						water system or air.
Soldering wires.	All wires will be soldered together to retain strength and proper connection.	1. Air contamination 2. Ground contamination	4	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 according to manufacturer's specifications will be adhered to.
Plastic waste material.	Plastic using in the production of electrical components and wiring.	1. Sharp plastic material produced when shaving down plastic components could harm animals if ingested by an animal. 2. Plastic could find its way down a drain and into the water system.	3	5	Low	1. All plastic material will be disposed of in proper waste receptacles.
Wire waste material.	Wire material used in the production of electrical components.	1. Sharp bits of wire being ingested by an animal if improperly disposed of.	3	5	Low	1. All wire material will be disposed of in proper waste receptacles.
CO_2 emissions.	Travel to launch	Destroying the ozone	4	1	Moderate	While the effects of CO_2

	sites and competition.	layer.				emissions cannot be reversed, the amount produced is negligible.

Table 45: Hazards to environment risk assessment.