University of Notre Dame
2018-2019

Notre Dame Rocket Team
Proposal

NASA Student Launch 2018

UAV and Air Braking Payloads

Submitted September 19, 2018

365 Fitzpatrick Hall of Engineering
Notre Dame, IN 46556

Contents

List of Tables

List of Figures

1 Team Information

1.1 General Information

School Name:	University of Notre Dame
Team Name:	Notre Dame Rocketry Team
Location:	University of Notre Dame 365 Fitzpatrick Hall of Engineering Notre Dame, IN 46556
Faculty Advisor:	Dr. Aleksander Jemcov Research Assistant Professor Department of Aerospace and Mechanical Engineering e: ajemcov@nd.edu p: (574)631-7576
Graduate Student Advisor:	Emma Farnan PhD Candidate Department of Aerospace and Mechanical Engineering e: efarnan@nd.edu p: (631)572-6091
Team Lead:	Patrick Danielson e: pdaniels@nd.edu p: (937)760-4366
Safety Officer:	James Cole e: jcole8@nd.edu p: (347)835-3922
Mentor:	Dave Brunsting (NAR/TAR Level 2) e: dacsmema@gmail.com p: (269)838-4275.
NAR/TAR Section:	TRA #12340, Michiana Rocketry

1.2 Team Organization

The Notre Dame Rocketry Team consists of approximately 70 active members with over 20 members returning from last year. The team has representation from all undergraduate grade levels and almost all majors within the College of Engineering. This was accomplished by recruiting in undergraduate courses with the goal of drawing on the breath of knowledge from across the college to support the technical challenges of the project.

The large size of the team requires the project to be well organized to best meet the team's goal of keeping everyone involved regardless of prior experience. For this reason, the project has been broken up into sub-teams based on technical design as follows:

- **Vehicle Design** - responsible for the design, test, and construction of the launch vehicle to meet all vehicle requirements. Additional responsibilities include ensuring proper simulation and apogee prediction as well as integration of all subsystems and payloads.
- **Recovery Subsystem** - responsible for the design and test of the avionics to ensure compliance with all recovery requirements. Additional responsibilities include ensuring the safe landing of the rocket and reliability of chute deployment.
- **UAV Payload** - responsible for the design, construction, and testing of the Unmanned Aerial Vehicle (UAV) Payload. Additional responsibility includes supervising an Electrical Engineering senior design team to ensure a fully functioning payload at competition.
- **Air Braking System** - responsible for the design, construction, and testing of the Air Braking System (ABS). Additional responsibilities include integration of the ABS into the vehicle and validating the system's effects on vehicle drag.

Each of these sub-teams has a designated lead position operating under the supervision of the team captain, vice-captain, and safety officer. This team structure is further shown in Figure 1. They each possess intimate knowledge of the project through their prior experience on the team and the current leadership of the Notre Dame Rocketry Team is confident in their ability to lead their respective sub-teams. They possess the technical skills necessary to meet the challenges of the project and are dedicated to providing an excellent practical engineering experience for undergraduate students at Notre Dame.

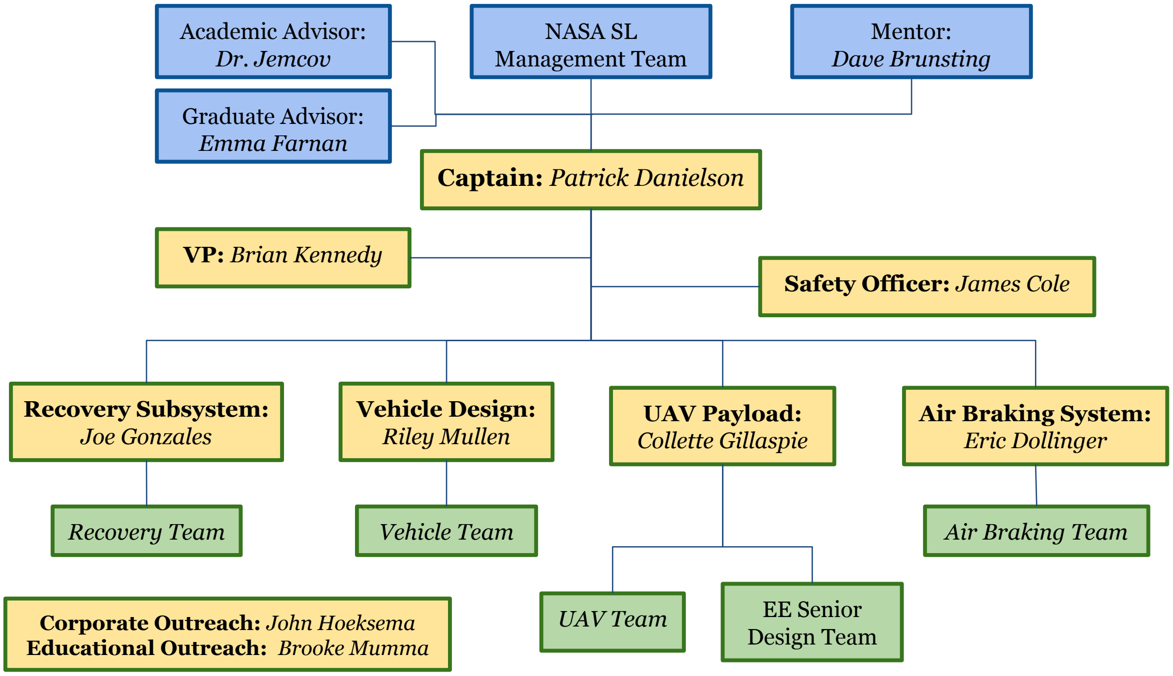


Figure 1: NDRT Organization Flowchart

2 Facilities Overview

2.1 Stinson-Remick Hall of Engineering

Contact: Natalie Gedde — ngedde@nd.edu

Stinson-Remick Hall is the main work location for the Notre Dame Rocketry Team. It will be used by the entire team for weekly meetings and allow for 24 hour access to all Notre Dame engineering students. There are several multi-purpose rooms complete with whiteboards, projectors and computers. The main workspace will be in room 213, which is reserved specifically for the team every Sunday. There is also a large storage closet where the team has the ability to store all major vehicle components and presentation materials.

Stinson-Remick also includes the Electrical Engineering Senior Lab, and the Student Fabrication Lab. Both spaces contain tools and electronics used for prototype and full-scale fabrication. The Unmanned Aerial Vehicle team will use the Electrical Engineering Lab to test general electronics, prototype, solder, and have weekly design meetings. The team officers will have access to the Student Fabrication lab after completing required training for more advanced prototyping purposes. General team members will be restricted from utilizing this lab unless under the direct supervision of the lab TA and NDRT officer.

2.2 AIAA Workshop

Stinson-Remick Hall of Engineering: Room 209, South Bend, IN 46637

Contact: Natalie Gedde — ngedde@nd.edu

The AIAA Workshop, also located in Stinson-Remick Hall, is a standard fully equipped workspace. It will be used by the general team under the supervision of NDRT officers. This shop has various pieces of equipment useful for construction such as a laser cutter, belt sander, several Dremel sets, drill press, and assortment of hand tools. All team members will be trained on these tools prior to using the space and only team officers will have access to the workshop.

2.3 White Field Drone Testing Facility

White Field Research Laboratory — Notre Dame, IN 46556

Contact: Dr. Jane Cleland-Huang — jhuang13@nd.edu

White field is a facility that is part of the Institute for Flow Physics and Control at Notre Dame. It features multiple wind tunnels amongst other facilities used for research, and will be used by the UAV team to fly and test their drone during inclement weather.

2.4 Schlafly Electronic Circuit Lab

Cushing Hall of Engineering: Room 253, Notre Dame, IN 46556

Contact: Clint Manning — cmanning@nd.edu

The Schlafly Electronic Circuit lab contains tools and electronics that students can use to design and create prototypes. The Air Braking System and Recovery teams will be using it to test general electronics, solder, and create basic prototypes. Access is granted by the Department of Electrical Engineering and members will be restricted from using the space unless an officer is present.

2.5 Materials Tensile Properties Lab

Fitzpatrick Hall of Engineering: Room B14, Notre Dame, IN 46556

Contact: John Ott — jott@watt.ame.nd.edu

The Materials Tensile Properties Lab will be used by the Vehicle Design team to evaluate properties of materials under consideration for the launch vehicle. The tests conducted would provide the stress and strain profiles of the materials in consideration. This information is then utilized by the team, so that they may make more informed decisions of what materials to use for each system. The lab is overseen by Dr. Ott and any testing done in the space will be supervised by either himself or a graduate student in his research group.

2.6 Hessert Laboratory Wind Tunnel

Hessert Laboratory for Aerospace Research: South Bend, IN 46637

Contact: Dr. Matlis — ematlis@nd.edu

Hessert Laboratory contains the main aerodynamics labs with a variety of size wind tunnels available for use in testing aerodynamic forces on the launch vehicle. It will be used by the Vehicle Design and Air Braking System teams. The lab houses three open-return wind tunnels, an Environmental Wind tunnel, three tri-sonic wind tunnels and an anechoic open jet wind tunnel. These wind tunnels all have different flow velocity capabilities as well as different test section sizes. The Notre Dame Rocketry Team plans to take full advantage of these capabilities to analyze the flight characteristics of the launch vehicle. They will also serve to test the effect of the air braking system on the vehicle while in flight. Access to this lab is restricted and any testing done will be under the direct supervision of the team's academic or graduate advisors.

3 Safety

3.1 Safety Plan

The Safety Officer position on the Notre Dame Rocketry Team for this year's competition is James Cole The role of safety officer includes the following responsibilities:

- Ensure the team is regularly brought up to date on the most relevant information pertaining to safety and its applications for the project
- Enforce the use of appropriate PPE at all stages of design, construction, and launch
- Certify every member of the team for appropriate workshop usage and make them aware of safety procedures during construction
- Create and distribute a safety manual to all members of the team
- Certify every team member has read the manual and is trained to work in the workshop

- Compile all necessary MSDS sheets and ensure they are updated and readily available in all major workspaces
- Provide tool manual operations to ensure safe tool use and tool control
- Create a risk assessment matrix to rank risks to their level of importance and develop appropriate mitigations
- Restrict launch personnel to only members that have passed a launch test
- Create and follow plan for the obtaining, using, and disposing of all hazardous materials
- Ensure team compliance with all local, state, and federal laws and regulations
- Ensure team compliance with all NAR/TRA rules and regulations
- Ensure team compliance with all NASA Student Launch rules and regulations
- Ensure team compliance with all University of Notre Dame rules and regulations

These responsibilities result directly from the Safety Committee's goal of ensuring the safety of all individuals, both public and team members, at all stages of the project. The responsibilities also ensure the team's full compliance with all local, state, and federal laws and regulations, as well as any safety requirements set forth by NASA Student Launch or the University of Notre Dame. The safety officer will be assisted by a designated Safety Committee to aid in the execution of responsibilities. Each design sub-team will contribute a returning member to the Safety Committee to improve communication of procedures and hazards to all team members.

3.1.1 Hazard Analysis

Hazards are evaluated at a level of risk based on their severity and probability of occurrence. This method shall be applied to every step of the project and team operations. Each hazard identified shall be evaluated by the Safety Committee and documented such that the team will be proactively and promptly become aware of all hazards and mitigations. Thus, safety will be an iterative and interactive document that will remain ahead of any and all risks the team may encounter. In order to assist with this, the Safety Committee will be using a scoring system when evaluating risks.

Probability of occurrence will be score on a scale of 1 through 5, with 5 being that the event in question is almost certain to happen under present conditions, and 1 being that it is improbable the event occur. The criteria for this scoring is outlines in Table 1 below.

Table 1: Probability of hazard occurrence classification

Description	Value	Criteria
Improbable	1	Less than 5% chance that the event will occur
Unlikely	2	Between 5% and 20% chance that the event will occur
Moderate	3	Between 20% and 50% chance that the event will occur
Likely	4	Between 50% and 90% chance that the event will occur
Unavoidable	5	More than 90% chance that the event will occur

As mentioned, this probability is evaluated according to present conditions, meaning two assumptions were made. The first is that if the conditions change, the probability will be re-evaluated and changed accordingly. The second assumption is that all personnel involved in the activity will have undergone proper training and clearly acknowledged understanding of the rules and regulations outlined in safety documentation. This may include, but not limited to, the safety manual, compiled SDS document, FMEA tables, most recent design review, and lab manual if applicable. The evaluation of occurrence probability will also assume that proper PPE was used, all outlined procedures were correctly followed, and all equipment was inspected before use.

Severity of the incident is evaluated on a scale of 1 through 4, where 4 is that the incident will prove catastrophic, and 1 is that the incident will prove negligible. Severity is evaluated according to the incident's impact on personal health and well-being, impact on mission success, and the environment. The score shall be based off of whatever the worst case scenario for the types of impacts being considered. These considerations will be re-evaluated anytime new hazards are identified. The criteria used to evaluate severity of each hazard is outlined in Table 2 below.

Table 2: Severity of hazard classification

Description	Value	Criteria
Negligible	1	Could result in insignificant injuries, partial failure of systems not critical to mission completion, or minor environmental effects.
Marginal	2	Could result in minor injuries, complete failure of systems not critical to mission completion, or moderate environmental .
Critical	3	Could result in severe injuries, partial mission failure, or severe and reversible environmental effects.
Catastrophic	4	Could result in death, total mission failure, or severe and irreversible environmental effects.

By combining the severity and probability values, a risk score will be assigned to each hazard. Risk scores will fall within a range from 2 to 9, where a higher score indicates a higher risk level. Risk levels can be reduced through mitigating actions which will lower either the severity score or the probability score. Actions will be taken starting with the highest risk level hazards, and will continue through the lower levels until all hazards have been reduced as much as possible. All hazards pose a risk and will not be ignored, but the classifications help the Safety officer prioritize resources to those that require the most immediate attention. Mitigations can take the form of design considerations to reduce severity or probability of failure, verification systems created to ensure proper operating conditions, and better handling procedures to follow. Risk scores and the risk levels that correspond with each score are outlined in the risk assessment matrix shown in Table 3 below.

Table 3: Risk assessment matrix

Probability Level	Severity Level			
	Negligible (1)	Marginal (2)	Critical (3)	Catastrophic (4)
Improbable (1)	2	3	4	5
Unlikely (2)	3	4	5	6
Moderate (3)	4	5	6	7
Likely (4)	5	6	7	8
Unavoidable (5)	6	7	8	9

Through the use of the tables shown in this section basic preliminary risk assessments have been conducted for possible hazard that have been identified thus far.

3.1.2 Identified Risks

Using the hazard analysis methods outlined in section 3.1.1, preliminary risks assessments for various areas and stages of the competition have been identified and documented in tables that can be found in Appendix B. As the design process is still in its early stage, the Safety Committee will be looking for additional hazards and continue re-evaluating. If a high risk hazard is identified, the Safety Committee will respond with mitigating actions. Additionally, all scores are relatively conservative as there are still several avenues of uncertainty in the design. The safety officer will work to clarify this, but a certain level of uncertainty will always be present in a real system. Thus, the goal shall be to make the safety of the team as robust as possible.

3.1.2.1 Lab and Machine Shop Risks

Construction of the launch vehicle involves the extensive use of machinery, hand tools, and chemical adhesives in a lab environment. The risks assessed for these types of operations are presented in Table 28 in Appendix B.

3.1.2.2 Launch and Flight Risks

The initial launch and subsequent descent of the rocket poses multiple possible safety hazards. These risks include the potential for structural failures, payload and parachute malfunctions, and issues with the motor. In order to mitigate these risks, team members will be trained in the procedures for hazard avoidance as well as identification and proper corrective actions in the chance a safety issue does arise.

Most issues posed in this stage have small probability of occurrence based on the assumption of thorough testing prior to launch and, therefore, pose a minimal amount of risk to the program. This risk analysis can be found in Table 29 in Appendix B.

3.1.2.3 Recovery Risks

The hazards outlined in Table 30 in Appendix B are risks that could be associated with the recovery phase. including the risks of handling the recovery system and potential issues that could arise during the recovery of the rocket.

3.1.2.4 Vehicle Assembly Risks

The risks involved in the construction and assembly of the launch vehicle, specifically during the pre-launch phase, are outlined in Table 31 in Appendix B.

3.1.2.5 Environmental Hazards to Rocket

Table 32 in Appendix B details the risks associated with potential environmental hazards that could affect the performance of the rocket. A majority of the hazards present moderate risk and cannot be reduced as they are dependent on weather conditions of the day of launch. These hazards are out of the team's control, so the mitigating action taken shall be to delay the launch until the hazard subsides and a low risk level can be attained. The Team Captain and Safety Officer will be responsible for giving the go for launch after the weather risk has passed.

3.1.2.6 Hazards to Environment

In addition to hazards posed by the environment, the launch vehicle itself creates hazards for the environment. Table 33 in Appendix B details these potential hazards.

3.1.3 Construction Procedures

Prior to construction, the Safety Committee and team leadership shall develop procedures for the construction of all vehicles, subsystems, and payloads. The technical design leads will have primary input to ensure procedures will lead to high quality construction techniques. The safety officer will then review all procedures to ensure that they outline a safe and low-risk construction method. If this is not the case, the safety officer will recommend changes to the procedure, and construction will not proceed until changes are agreed upon. At this point the construction procedures will be released to the team and shall be published in the safety manual. Team members will not be allowed to participate in construction until they have read and acknowledged the procedures for that construction phase.

3.1.4 Launch Procedures

Prior to any launch the Safety Committee and team leadership shall develop procedures and checklists for launch days. The technical design leads will have input to ensure that each launch will be conducted in a way that will allow for successful flight and including proper verification of all requirements. If this is not the case, the safety officer will recommend changes to the procedure, and launch will not occur until changes are agreed upon. At this point the launch procedures will be released to the team as a whole, and will be published in the safety manual. Team members will not be allowed to participate in the launch until they have read and acknowledged the procedures for that launch.

3.1.5 Materials Handling Procedures

A Material Safety Data Sheet (MSDS) shall be obtained from the manufacturer for every material used in constructing the rocket, especially all chemical adhesives. Every member of NDRT will be responsible for knowing hazards and risks based on information from each MSDS and where to obtain the documents. Hazards and risks related to materials handling will be communicated to all members of the team as they become relevant.

3.1.6 Personal Protection Equipment

Use of personal protective equipment (PPE) will be standardized and required for the safe conductance of certain activities. The Safety Committee shall identify all hazardous activities that will require PPE, and will document all PPE necessary for the safe completion of the given task. If necessary, training on the use of and access to specific PPE will be made available for team consumption. All PPE will be documented in the team safety manual, which will include a standardized visual indicator for when the use of the PPE is necessary as well as written instructions for the proper use of the PPE.

3.2 NAR / TRA Documentation

The team's TRA certified personnel are the primary mentor mentor Dave Brunsting, and secondary mentor Larry Kingman. Currently, the team's designs do not necessitate the use of black powder, but the rocket motor will be a high energy device that brings with it the necessity to handle hazardous materials and perform hazardous operations critical to mission success. As such, the TRA personnel, specifically the team's mentors, will be responsible for the careful handling of all energetic devices, as is outlined in NAR High Power Rocket Safety Code. Section 3.2.1 outline team compliance with the NAR High Power Rocket Safety Code.

3.2.1 NAR Safety Code Compliance

The Notre Dame Rocketry Team will be taking several steps to ensure compliance with the National Association of Rocketry High Power Rocket Safety Code that has been effective as of August 2012. Table 34 in Appendix B outlines each of the items in the safety code, and how the team and its mentors will be compliant with it.

3.3 Team Safety

A safety briefing will be held at the beginning of each weekly team meeting and sent out as an attachment in a weekly email. All detailed information concerning team safety shall be included in the safety manual, which will be released to the team before any work on construction, testing, or launch can start. Any changes to the manual will be included in the weekly update. The safety manual shall have information regarding the following topics:

- Material Safety
- MSDS Sheets
- Lab Workshop Safety
- Pre-launch and Verification Safety
- Launch Safety
- Requirements for Personal Protective Equipment
- Environmental Safety
- Drone/UAV Safety
- Construction Safety Procedures
- Machine Use Safety
- Local, State, and Federal Law Compliance

- Educational Outreach Safety

All members shall be required to sign a contract stating their acceptance of the information included in the safety manual. In the event that a member of the team violates a section of the safety manual, all access to workshops, construction, and launches will be revoked until the member has met with the Safety Officer. The violation will be evaluated based on severity prior to access to team activities being re-established.

All members will be administered a safety quiz prior to being able to contribute to construction or launches. Team members that fail to achieve a 90% or higher on a quiz will not be allowed to participate in these events.

Work involving drone operation, launches, and machine use will not occur unless there is a member of the safety committee and a team officer present. Additionally, no launch will occur until both the safety officer, team captain, and range safety officer sign off on it. If a launch is deemed unsafe, or there is a severe level of risk, the launch will not occur.

3.4 Local, State, Federal Law Compliance

The team has reviewed and acknowledged regulations regarding unmanned, high-powered rocket launches and motor handling. Specifically, the Safety Officer has read in-depth regarding the use of airspace, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, NFPA 1127 "Code for High Power Rocket Motors." These documents will be made available to all team members in the team Safety Manual upon its publishing. Compliance with all regulations outlined will be ensured by the NAR entity and Range Safety Officer in charge of each launch event the team attends. If any team member has concerns about the launch, they will notify either the Captain or Safety Officer directly. The team will then take corrective action to ensure full compliance with the outlined regulations. Additionally the team will ensure compliance with any and all local and state laws that apply at the time of launch.

3.5 Motor Handling

Team mentors, Dave and Larry, have both obtained their Level 3 TRA certifications. They will be responsible for obtaining, handling, and storing the rocket motors at all times. Any team members that have obtained their Level 2 certification will be allowed to assist in this responsibility previously described. Any individual that has attained the Level 2 certification has demonstrated that he or she understands the motor safety guidelines. Any member that has the necessary certifications and assists in handling or storing the team's motors is responsible for following every appropriate procedure. Both the test and competition motors will be transported by car to the launch site.

3.6 Written Safety Compliance Agreement

The following regulations presented by NASA are understood and will be abided by the Notre Dame Rocketry Team. The guidelines listed below are included in the safety contract that all members of the team will be obligated to sign prior to participating in any launches and builds.

1. Range safety inspection will be conducted on 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. The team mentor is ultimately responsible for the safe flight and recovery of the team's rocket. Therefore, a team will not fly a rocket until the mentor has reviewed the design, examined the build and is satisfied the rocket meets the established amateur rocketry design and safety guidelines.
4. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

4 Technical Design: Launch Vehicle

4.1 Mission Requirements

Design, construct, and launch a rocket to a specific altitude between 4,000 and 5,500 ft. above ground level while carrying at least 1 scientific payload. The vehicle will deploy a restricted main parachute as a drogue which will completely open as a main parachute for recovery purposes. The launch vehicle and its payloads must be reusable on the same day as launch without repairs or modifications.

4.1.1 Vehicle Requirements

- **2.1** Vehicle shall deliver a payload to a specified apogee between 4,000 and 5,500 feet above ground level.
- **2.2** Vehicle target apogee shall be determined by team at PDR.
- **2.3** Vehicle shall contain one commercially available, barometric altimeter.
- **2.4** Each altimeter shall have a mechanical arming switch accessible from the rocket's exterior when in launch position
- **2.5** Each altimeter shall have its own power supply.
- **2.6** The arming switch shall be able to be locked in the ON position during launch.
- **2.7** The rocket and its payload shall be capable of launching again on the same day without modifications or repairs.
- **2.8** The vehicle shall have a maximum of four independent sections.
- **2.9** The vehicle shall consist of one single stage.
- **2.10** The vehicle shall be made ready for flight within two hours.
- **2.11** The vehicle shall be capable of remaining in launch ready position on the pad for at least two hours without failure of any critical components.
- **2.12** The vehicle shall be able to be launched by a standard 12-volt direct current firing system.
- **2.13** Other than what is provided by the launch services provider, the vehicle shall not require any external circuitry or special ground support equipment to initiate launch.
- **2.14** The launch vehicle shall utilize a commercially available solid motor propulsion system using APCP.
- **2.15** Any pressure vessels shall have a minimum factor of safety of 4:1 and shall include a pressure relief valve that is able to withstand the maximum pressure and flow rate of the tank.
- **2.16** The launch vehicle's total impulse shall not exceed 5,120 Newton-seconds.
- **2.17** The vehicle shall have a static stability margin of at least 2.0 at rail exit.
- **2.18** The vehicle shall have a velocity of no less than 52 fps at rail exit.

- **2.19** A sub-scale model of the vehicle shall be successfully launched and recovered prior to CDR.
- **2.20.1** The full scale rocket shall be successfully launched in its final flight configuration and recovered prior to FRR.
- **2.20.2** The full scale rocket containing the completed payload shall be successfully launched and recovered prior to Payload Demonstration Flight deadline.
- **2.22** Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.
- **2.23** Team name and contact information shall be located in or on the main air frame and on any sections that separate during flight and are not tethered to the air frame.
- **2.24** The vehicle shall not
  - **2.24.1** Utilize forward canards.
  - **2.24.2** Utilize forward firing motors.
  - **2.24.3** Utilize motors that expel titanium sponge.
  - **2.24.4** Utilize hybrid motors.
  - **2.24.5** Utilize a cluster of motors.
  - **2.24.6** Utilize friction fitting for motors.
  - **2.24.7** Exceed Mach 1.
- **2.24.8** Vehicle ballast shall not exceed 10% of the total unballasted weight of the rocket.
- **2.24.9** Transmissions from on board transmitters shall not exceed 250 mW of power.
- **2.24.10** No excessive/dense metal shall be used in the vehicle's construction.

4.2 Vehicle Design

4.2.1 Vehicle Description

The design intent of the launch vehicle is to give the UAV Payload the maximum amount of space possible while keeping the overall weight of the rocket at a minimum. Therefore, a larger diameter of 7.675 inches was chosen for the UAV Bay (to accommodate off the shelf nose cones), and the remaining length of the rocket will have a 5.54 inch diameter.

4.2.1.1 Vehicle Dimensions

A list of relevant dimensions of the vehicle can be seen in Table 4.

Table 4: Dimensions of the launch vehicle

Characteristic	Dimension
Length of Rocket (in.)	124
Fore Diameter of Rocket (in.)	7.675
Aft Diameter of Rocket (in.)	5.54
Transition Length (in.)	4
Number of Fins	4
Fin Root Chord (in.)	7
Fin Tip Chord (in.)	7
Fin Sweep Angle (°)	31.6
Fin Height (in.)	7.2
CG Position from Nose Cone (with motor) (in.)	74.775
Weight without Motor (oz.)	652
Weight with Motor (oz.)	805
Estimated Stability Margin without Motor	3.39
Estimated Stability Margin with Motor	2.27

4.2.1.2 Vehicle Layout

The overall layout of the vehicle can be seen in Figure 2 and a description of vehicle sections is found in Table 5.

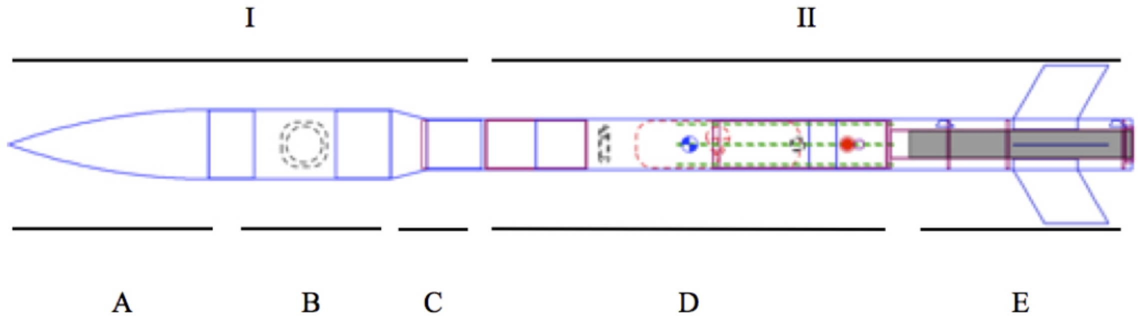


Figure 2: Detailed Layout of Launch Vehicle

Table 5: Description of Vehicle Sections

Section	Sub-Section	Label	Composition	Description
I	Nose Cone	A	Hollow polypropylene nose cone, 22" long and 7.625" in diameter	Foremost component, connected to the UAV payload bay tube (B).
	UAV Payload Bay	B	12" long fiberglass body tube	Contains UAV payload and retention mechanism, connects to transition section
	Transition Section	C	Fiberglass transition	Transition piece measuring 4 inches long altering diameter from 7.675 to 5.54 inches
II	Parachute Bay	D	40" carbon fiber body tube	Holds avionics module, and main parachute
	Fin Can	E	32.5" carbon fiber body tube	Secures four fins, Air Braking System, and motor mounting components to launch vehicle

4.2.1.3 Fin Design

At the base of the rocket, four fins will be attached to maintain stability throughout flight. The aerodynamic fin shape will be a parallelogram because its low Reynolds number helps to increase stability and reduces drag. This fin shape is depicted in Figure 3, with parameters given in Table 6. The four fins will have the same rounded cross section shape and will be distributed 90° around the rocket to ensure all moments are balanced. Epoxy fillets inside the body of the rocket will attach the fins to both the main body tube and the motor mount tube, ensuring that they remain normal to the body during flight.

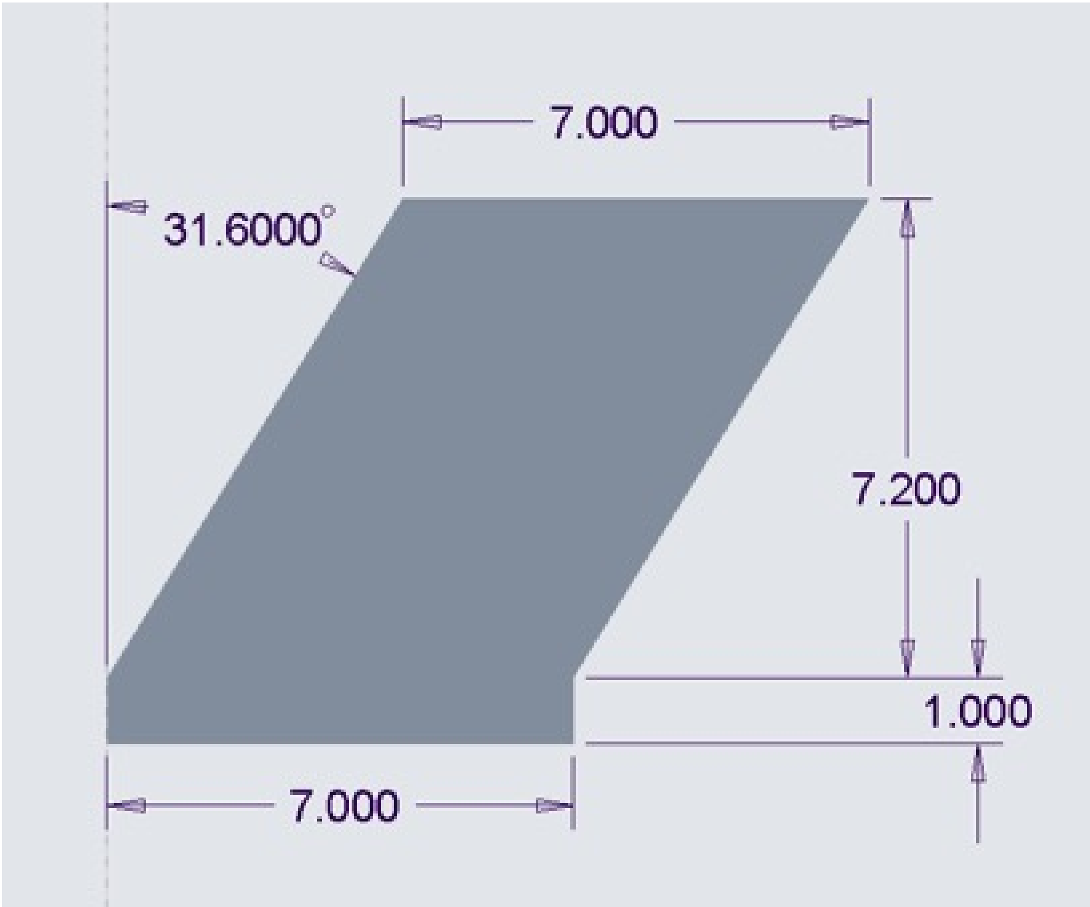


Figure 3: Full-Scale Fin Design (dimensions in inches)

Table 6: Fin Parameters

Parameter	value
Number of fins	4
Fin height	7.2 in.
Fin width	7.0 in.
Sweep angle	31.6°

4.2.2 Applicable Physics

4.2.2.1 Simulations

Simulations will be conducted in OpenRocket and RockSim software to predict apogee as well as other flight parameters. These will be monitored closely throughout the year as the rocket design is finalized in order to track flight configuration and see how design changes will affect flight performance. The two software packages will allow for additional comparison of simulation and recorded flight data. These simulations will also be used for the motor selection of the launch vehicle.

4.2.2.2 Projected Altitude

The proposed target apogee for this year's project is 5,000 ft. This is within the given range of 4,000 and 5,500 ft. as per competition guidelines. In previous years, the team has been close to the maximum impulse of L-class motors in reaching heights above 5,280 ft. Lowering the apogee will allow for a greater selection of motors and a greater vehicle mass budget. This will also give the Air Braking System (ABS) a higher ceiling to bring the apogee down to the predicted value by actuating tabs to increase drag of the vehicle. The three motors currently being evaluated for performance are given in Table 7 and more thoroughly detailed in Section 4.2.4. Additionally, the team will use CFD analysis and wind tunnel tests to calculate drag coefficients which will allow for more accurate apogee calculations. This is being done because OpenRocket and RockSim are not able to model a change in rocket geometry such as ABS actuating tabs. Determination of an accurate drag coefficient is vital to verify ABS effectiveness.

Table 7: Preliminary motor options

Motor	Apogee (ft.)
Cesaroni L1395-BS	5,197
Cesaroni L1115	5,299
Aerotech L1365-M	4,854

4.2.2.3 Stability

The stability of the rocket will be determined using the models created in OpenRocket and RockSim. These programs are able to calculate the locations of center of gravity and center of pressure to return a static stability margine throughout flight. To avoid both instability and over-stability the static stability margin is to be between 2.3 and 2.7 calibers. Prior to every launch, the center of gravity will be physically measured with all components installed to ensure a proper stability margin. Should stability become an issue, ballast will be used to move the center of gravity of the vehicle until this margin is attained.

4.2.2.4 Air Braking System

The Air Braking System will be located at the center of pressure of the launch vehicle, and will actuate tabs radially out from the body of the rocket. These tabs will be perpendicular to incoming flow, increasing drag and therefore decreasing apogee. This will additional drag force, is generally governed by Equation 1 below,

$$F_D = \frac{1}{2} C_D \rho v^2 A \tag{1}$$

where F_D is the resultant drag force, C_D is the drag coefficient measured based on vehicle geometry, ρ is the density of air, v is the speed of the rocket, and A is the combined surface area of the drag tabs normal to the direction of flight. A PID controller will utilize the current rocket velocity and current altitude to predict the change in drag force needed to reach the target apogee. After motor burnout, a servo motor will actuate the tabs until the rocket reaches apogee, at which point the tabs will be retracted back into the body. By placing the air braking system at the center of pressure, no additional moments will be created, and the overall stability of the rocket will not be compromised.

4.2.3 Material Selection

4.2.3.1 Nose Cone

The full scale launch vehicle will have an ogive-shaped polypropylene nose cone purchased from Apogee Rockets. Carbon fiber and fiberglass nose cones were considered, because they are stronger than polypropylene. However, in the past this polypropylene nose cone has provided enough structural strength at a reduced cost to these other materials. These materials are also much more difficult to alter, which they will have to be for payload deployment. It was also considered that the team may create their own nose cone, but this introduces additional room for error. Thus, there is no significant benefit over simply purchasing one made of polypropylene.

The nose cone selection is satisfactory for the team in that it is lightweight, low cost, and reliable. Reasoning for the use of an ogive-shaped cone is based on historical data and has been proven in flight. Furthermore, ogive nose cones are easily constructed and readily available. Polypropylene is a synthetic resin that is strong enough to resist any forces in flight, and light enough as to not add any unnecessary weight. To match the inner diameter of the body tube section that contains the UAV payload, the outer diameter of the shoulder of the nose cone is 7.675 inches. The dimensions of the nosecone can be seen in Table 8.

Table 8: Dimensions of Nose Cone

Dimension	Value
Length (in.)	22
Shoulder Length (in.)	5
Weight (oz.)	30.66
Outer Diameter (in.)	7.675
Inner Diameter (in.)	7.51

4.2.3.2 Body Tube

The smaller section of the body tube will be composed of carbon fiber. It has been used by the team in the past and has been proven in flight. Another option considered was phenolic, however, carbon fiber is a much stronger material, and will provide a lager factor of safety and reliability. The upper section of the body tube that houses the UAV payload will be made out of fiberglass. Fiberglass will be used because carbon fiber would block radio waves from reaching the UAV. Fiberglass will also be used for the transition section of the body tube. Carbon fiber is another option because of its lower weight, but it is considerably more difficult to shape into the transition section than fiberglass. Table 9 below details the properties for both carbon fiber and fiberglass.

Table 9: Material Properties — Carbon Fiber vs. Fiberglass

Property	Carbon Fiber	Fiberglass
Density (lb/in.^{3})	0.0578	0.055
Tensile Strength (ksi)	300-350	250-300
Tensile Modulus (msi)	15-30	0.8-1.4
Compressive Strength (ksi)	82-120	140-350
Shear Modulus (msi)	0.6-0.725	4.351

4.2.3.3 Fins

Along with the majority of the rocket, the fins will also be constructed from carbon fiber. Carbon fiber was chosen due to its strength, durability, and shock resistance. Plywood was also considered, however, it was decided that the trade off in weight is balanced by the increased strength of the material. The carbon fiber for the fins will be bought from the same supplier as the rest of the vehicle, ensuring the same quality standards and material properties. There will be four fins; all cut, constructed, and shaped on Notre Dame's campus. These fins will be mounted by slits onto the fin can and adhered to the motor mount. A comparison of material properties of carbon fiber and pine plywood can be found below in Table 10.

Table 10: Material Properties — Carbon Fiber vs. Plywood

Property	Carbon Fiber	Plywood (pine)
Density (lb/in^3)	0.0578	0.0181 - 0.0235
Tensile Strength (ksi)	300-350	5.8
Tensile Modulus (msi)	15-30	1.305
Compressive Strength (ksi)	82-120	4.5 - 6.0
Shear Modulus (msi)	0.6 - 0.725	20.0 - 30.0

4.2.3.4 Integration

All bulkheads and centering rings will be made of fiberglass. Fiberglass provides several structural and performance advantages over the materials of the previous year, namely plywood. Through the use of fiberglass, the team will be able to build much stronger bulkheads and centering rings.

The couplers and motor mount will be made of carbon fiber. Previous NDRT uses of carbon fiber in construction proved more reliable than phenolic tubes. The same logic applies to the motor mount; the carbon fiber serves as a more sturdy and reliable material than phenolic. Additionally, the carbon fiber material can adequately stand up to heat from the burnout because of its robust thermal properties.

The team has and will continue to use a variety of adhesives when constructing the launch vehicle. For sub scale construction, where different materials will be used, the team will use Great Planes 30 minute epoxy for the attachment of phenolic components. On the full size rocket, Glenmarc RocketPoxy will be used for all carbon fiber and fiberglass pieces. The team will use RocketPoxy to adhere the fins and centering rings to the body of the rocket, ensuring full stability and structural strength throughout the flight. As for the motor mount, JB weld will be the primary adhesive because of its extremely high heat tolerance. This heat tolerance will create a nore robust adhesion of the motor mount to the centering ring and fins.

As the payload design is still in its development stages, more specific information on attachment hardware will be included in later reports. Additional adhesion methods will take into account the same considerations for ensuring high factors of safety in the design.

4.2.4 Propulsion

The initial motor selection is based on a number of motor configurations simulated on a preliminary model of the launch vehicle created in OpenRocket. This initial motor selection process focused mainly on estimated apogee. For this initial design, above nominal weights were allocated to each subsystem design team in order to meet the maximum mass budget for the vehicle. These masses will be updated as components are finalized, especially those in the experimental payloads. Due to the presence of the air braking system and a target altitude of 5,000 ft., motors were selected that estimated apogee within the range of 4,800 and 5,300 ft. The intention is that the air braking system will then be used to decrease apogee to reach the 5,000 ft. target.

After iterative simulations with a different Cesaroni, Loki Research, and Aerotech motors, the three motors selected for the current configuration are the Cesaroni L1395-BS, Cesaroni L1115-P, and Aerotech L1365M-PS, which have predicted apogees of 5,197, 5,299, and 4,854 ft. respectively. The L1395 has a total impulse of 1,101.46 lbf. with a maximum and average thrust of 400.48 and 314.03 lbf. respectively. The L1115-P, on the other hand, has a total impulse of 1,128.38 lbf with a maximum and average thrust of 385.48 and 251.56 lbf. respectively. The L1365M-PS made by Aerotech, has a total impulse of 1074.59 lbf with a maximum and average thrust of 390.04 and 306.86 lbf. respectively. These and some other important characteristics of these motors are shown below in Table 11. The thrust curves from these three motors are also shown in Figures 4, 5, and 6.

Table 11: Motor Properties

Manufacturer	Cesaroni	Cesaroni	Aerotech
Classification	L1395-BS	L1115-P	L1365M-PS
Predicted Apogee (ft)	5197	5299	4854
Diameter (in)	2.95	2.95	2.95
Length (in)	24.45	24.45	24.45
Propellant Weight (lb)	5.17	5.24	5.84
Loaded Weight (lb)	13.24	9.63	10.82
Average Thrust (lbf)	314.03	251.56	306.86
Maximum Thrust (lbf)	400.48	385.48	390.04
Total Impulse (lbf*s)	1101.46	1128.38	1074.59
Burn Time	3.51	4.48	3.5

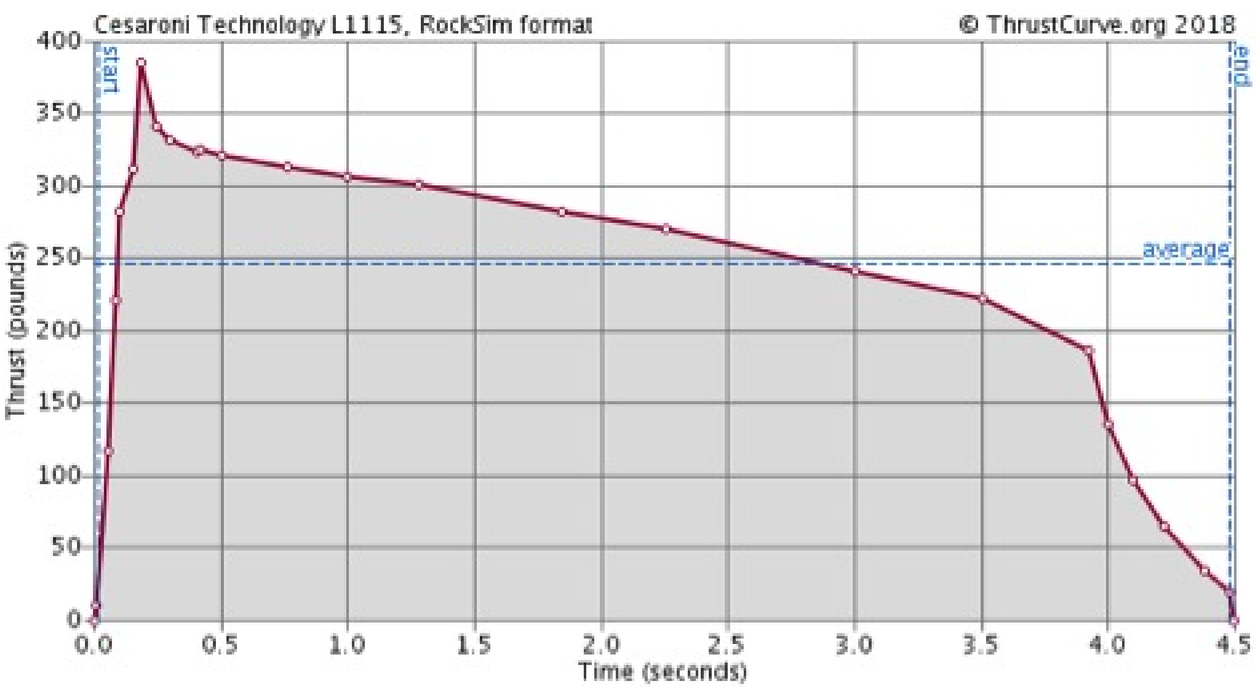


Figure 4: Thrust Curve of Cesaroni L1115 where the thrust is in lbf.

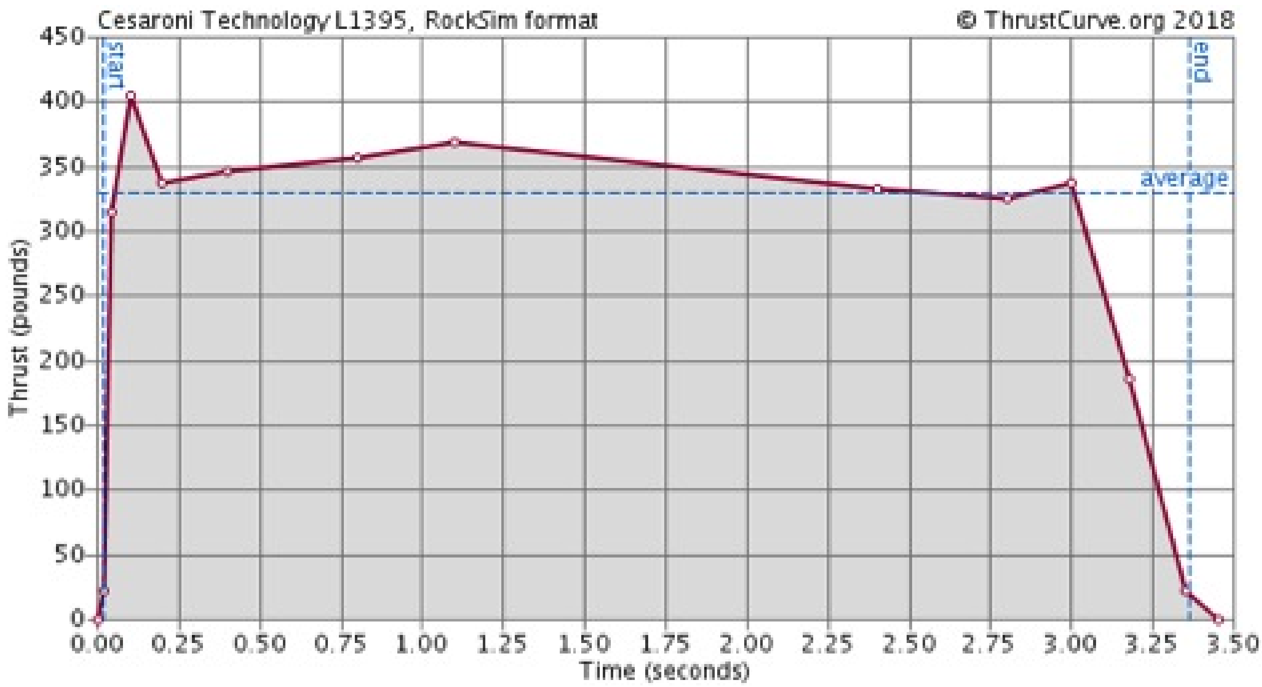


Figure 5: Thrust Curve of Cesaroni L1395-BS where the thrust is in lbf.

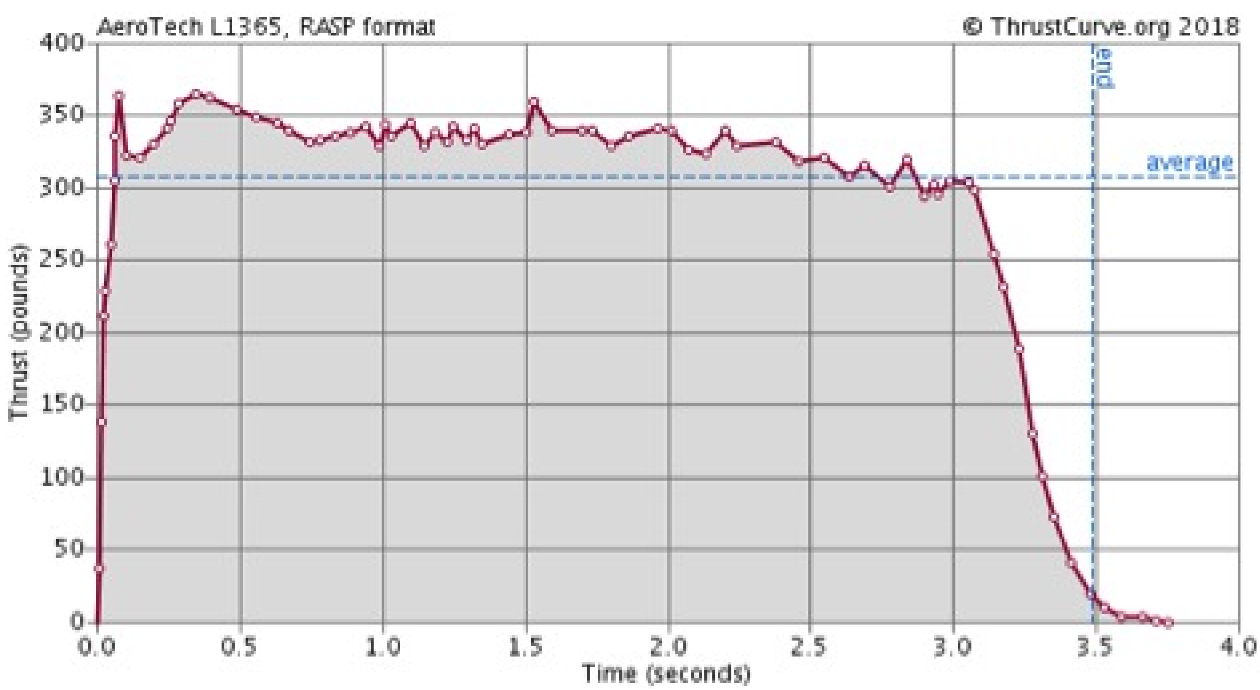


Figure 6: Thrust Curve of Aerotech L1365 where the thrust is in lbf.

4.2.5 Construction Methods

Historically used construction methods have proven to be successful and will be implemented again in the development and construction of the launch vehicle. In an effort to improve and streamline construction techniques, a detailed construction plan will be created with the help of the team's mentor, Dave Brunsting. All basic components of the rocket, such as the body tubes and fins, as well as some payload components will be purchased from an outside vendors to ensure quality.

In order to maintain an attention to detail, smaller segments will be constructed and tested individually before integration into the vehicle. These components will then be assembled with the mindset of ensuring overall structural integrity of the rocket. All load-bearing components will be evaluated for defects prior to assembly. All stationary components of the rocket will be bonded or bolted together. The two sections of the rocket designed to separate at apogee will be mounted with shear pins and dry fitting. These methods ensure both ease of construction and structural integrity during launch.

To ensure quality of materials purchased from a vendor, at least two team members will perform quality control on the components. After assembly, a third team member and the Vehicle Design Lead will verify the component was installed correctly and possesses the intended functionality. Any team member working in the AIAA workshop space will be certified through the Safety Committee and work under the direct supervision of a team officer to ensure safety.

The fin configuration is identified as a flight critical installation that can greatly affect rocket stability. The fins will be constructed to be durable when subjected to all forces experienced during flight. They will be tightly secured and incorporate external RocketPoxy fillets to minimize the shear forces experienced at the joint. Fins will be distributed radially using a fin alignment ring constructed by the team and proven effective in previous years.

In addition, a sub-scale vehicle will be constructed to perform a sub-scale test flight and to analyze the real performance of the vehicle configuration. These tests will be repeated after the construction of the full scale launch vehicle. This data will be collected and compared to simulation data from OpenRocket and RockSim to justify any further changes.

4.2.6 Verification Methods

See Appendix A for the full list of methods.

4.3 Vehicle Test Plan

Table 12: Vehicle Test Plan

Time Range of Test	Test	Purpose of Test
October 2018	FEM Analysis	Analyze load paths and stresses to optimize material usage.
November 2018	Subscale Test	Verify simulations performed in OpenRocket and RockSim and determine correction factors where applicable.
November 2018	Material Stress Test	Verify the strength and stress properties of chosen material.
November 2018	CFD analysis	Calculate a more refined coefficient of drag, finalize ABS tab design
December 2018	Wind Tunnel Analyze	Verify drag estimates during normal flight and during ABP deployment.
February 2019	Full Scale Test	Verify accuracy of simulations and verify all vehicle requirements in Section 4.1.
March 2019	2^{nd} or Back-up Full Scale Test	Verify the requirements in Section 4.1 and test additional features of launch vehicle

5 Technical Design: Recovery System

The recovery system for the proposed launch vehicle will feature dual-stage parachute deployment. A parachute will be deployed at apogee, but be partially constrained using a Jolly Logic Chute Release until approximately 600 ft. above ground level. The parachute will be purchased commercially and be constructed of nylon. Similarly, the shock cords tethering the rocket sections together and to the parachute will be purchased commercially and made of tubular nylon. At the various connection points, steel eyebolts and quick links will secure the separate vehicle sections to the shock cords. The parachute deployment will be controlled by commercially available Raven 3 altimeters.

There are two possible parachute ejection systems under consideration for the recovery system. The first consists of black powder charges ignited by electronic fuses. The resulting pressure increase would break the shear pins holding the rocket sections together and allow for the deployment of the parachute. This recovery system would incorporate triple redundancy to ensure a safe and successful landing of the rocket.

Redundancy is established with three altimeters connected to three independent power sources dedicated to igniting independent black powder charges at each parachute stage. The system will be designed such that any one charge will be capable of deploying the parachute, but the added redundancy will take effect in case of any primary circuit failures. This system was verified to work previously in four separate launches.

The second potential ejection system relies on a compressed spring held down by four separate nylon shock cords which will be released by a servo motor and latch mechanism. After being released, the spring would push a moveable bulkhead to separate the rocket sections and cut the shear pins, allowing for parachute deployment. Two independent servos would provide the system redundancy in this case. Due to the fact that this system would be completely reusable and not require the use of explosives, it could be tested numerous times to ensure functionality. Figure 7 is a schematic of the preliminary design.

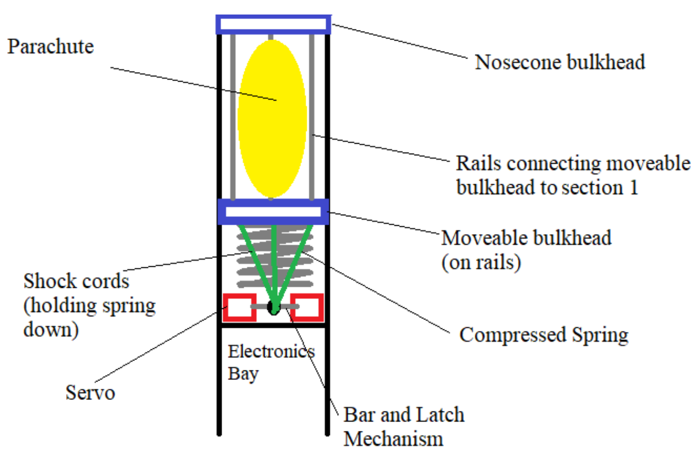


Figure 7: Schematic of proposed recovery mechanism

The avionics will be housed within a component called the Compact Removable Avionics Module (CRAM), which has provided extensive reliability in the past. This component will be addressed in more detail in subsequent sections.

5.1 Recovery System Requirements

Recovery subsystem requirements taken from the SLI Handbook are as follows:

- **3.1** The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude.
- **3.1.1** The main parachute shall be deployed no lower than 500 feet.
- **3.1.2** The apogee event may contain a delay of no more than 2 seconds.
- **3.2** 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.
- **3.3** At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.
- **3.4** The recovery system electrical circuits will be completely independent of any payload electrical circuits.
- **3.5** All recovery electronics will be powered by commercially available batteries.
- **3.6** The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.
- **3.7** Motor ejection is not a permissible form of primary or secondary deployment.
- **3.8** Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.
- **3.9** Recovery area will be limited to a 2,500 ft. radius from the launch pads.
- **3.10** Descent time will be limited to 90 seconds (apogee to touch down).
- **3.11** An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.
- **3.11.1** Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.
- **3.11.2** The electronic tracking device(s) will be fully functional during the official flight on launch day.
- **3.12** The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).

- **3.12.1** The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
- **3.12.2** The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.
- **3.12.3** The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.
- **3.12.4** The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

5.2 Altimeters

The Featherweight brand Raven 3 altimeter is intended to be used as the primary and redundant controller for the parachute ejection electronics. The Raven 3 allows up to 4 fully programmable launch events, though only the apogee deployment channels will be used for our flights. The Raven 3 takes barometric pressure readings at 20 Hz to determine altitude and velocity, as well as axial accelerometer readings at 400 Hz, and lateral accelerometer readings at 200 Hz. The Ravens used in the rocket will be powered by a dedicated 9V battery and armed by a locking switch that is accessible from the outside of the rocket body through designated holes. Specifications for the Raven are shown below in Table 13.

Table 13: Recovery altimeter specifications

Feature	Specification
Power source	9V Battery
Maximum operational altitude	100,000 ft
Altitude resolution	0.00004 atm
Sample rate	20 Hz
Dimensions	0.8” x 1.8” x 0.5”
Weight	6.6 grams
Drogue deployment detection	Zero vertical velocity (Apogee)
Primary Parachute Ejection	Apogee
Secondary Parachute Ejection	Apogee +1 sec

To prevent the rocket from drifting outside the designated launch area, a Jolly Logic Chute Release will be used to tether the main parachute until the desired opening altitude. The Chute Release is a barometric altimeter connected to a mechanical release latch and an elastic band. The band will be wrapped around the folded main parachute to prevent the parachute from opening up during primary ejection. The tethered parachute will act as a drogue parachute or streamer, slowing down and stabilizing the descent of the launch vehicle sections, until 600 ft. above sea level. At this point, the latch holding the elastic around the parachute will be released and the parachute will be allowed to open to its full diameter, slowing the rocket down to a safe landing speed.

5.3 Electrical Component Considerations

Within the recovery system, three altimeters will operate from distinct power sources, namely three 9V batteries housed in dedicated battery boxes with breakout wires running directly to the altimeters and a common ground. The primary electrical consideration is the possibility of stray electromagnetic waves activating the altimeters prematurely. To prevent this, the avionics will be encapsulated within a coating of copper tape, effectively creating a protective Faraday cage. Another concern is vehicle vibration causing wires to loosen or become unattached. This will be a major point of emphasis in this year’s design and will be addressed by the inclusion of new electrical contacts rather than wires. A final consideration is the stress caused by the stored potential energy in a mechanical system. The system will be put through thorough ground testing to verify the electronics are durable enough to withstand the forces created by the system.

5.4 CRAM Details

The Compact Removable Avionics Module (CRAM) is a Notre Dame Rocket Team original concept now on its fifth iteration. The CRAM is an alternative to the traditional avionics coupler situated between body tube sections. Instead, the CRAM is typically housed within a dedicated body tube along with parachutes and shock cords.

The advantages of the CRAM are multifaceted. Among the benefits are reduced space consumption, improved avionics protection, simplified vehicles integration, and increased reliability. The CRAM is formed from a central 3D printed structure known as the Core, to which the altimeters and batteries are secured. The Core is housed within the CRAM Body which protects the avionics and integrates the system into the launch vehicle. Depending on the use of a fully mechanical system, the CRAM Body design may be significantly modified. However, in the current black powder separation design, the Body remains protected from black powder residue by acrylic bulkheads above and below the CRAM body. The Body is fastened within the recovery body tube by integrating a twist-to-lock mounting method to allow for quick and robust placement of the CRAM. Figure 8 below shows the configuration differences between a traditional avionics bay and the CRAM.

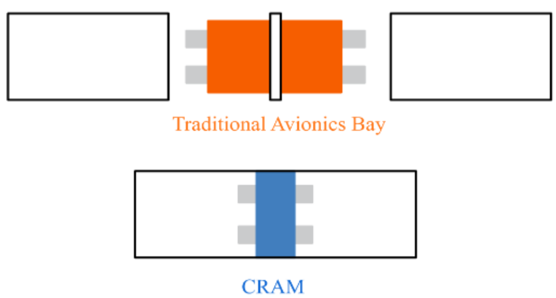
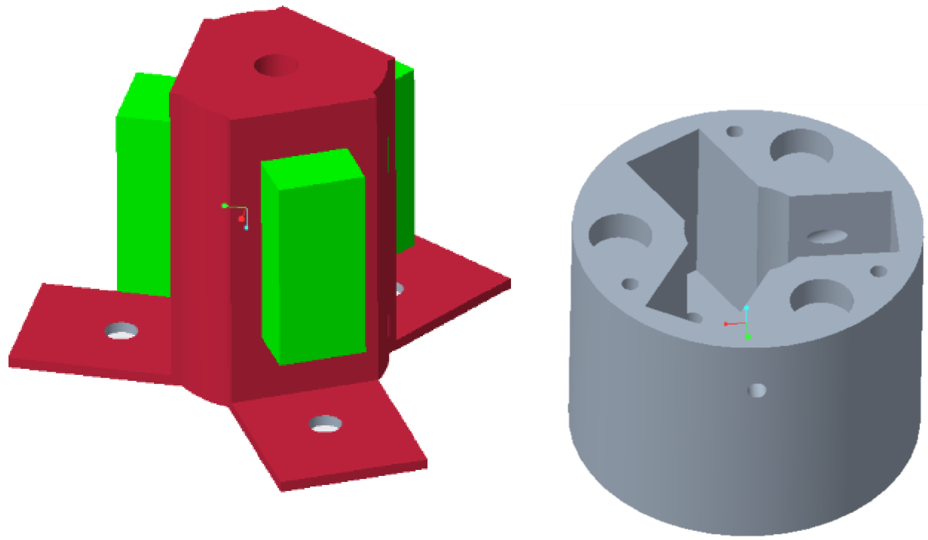


Figure 8: Traditional avionics bay vs. CRAM.

The mounting method of the recovery system will use a twist-to-lock mechanism further secured by external screws, which has been successful during previous launches. This design may change if a mechanical system is implemented, but preliminary CAD renderings and stress analysis still serve to demonstrate the basic system functionality. Figure 9 below shows the Core, the location of the altimeters, and the CRAM Body. Figure 10 below shows the CRAM v5 in full assembly, with the acrylic bulkheads and PVC pipes for black powder not shown.



(a) Core (b) CRAM Body

Figure 9: The Core and CRAM body with altimeters highlighted in green

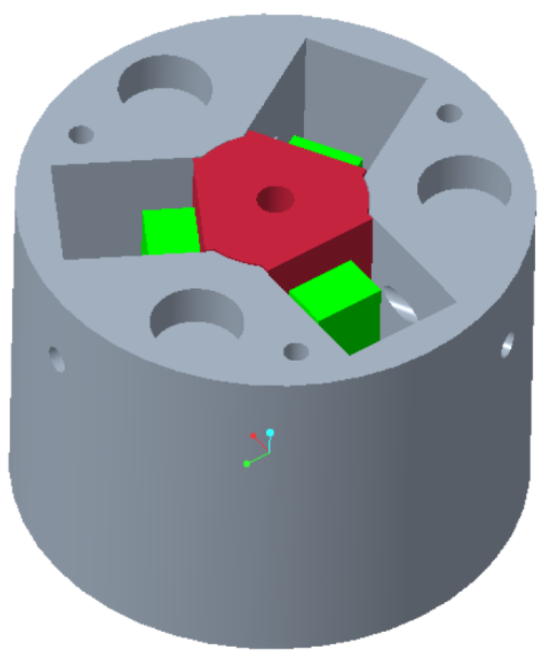


Figure 10: CRAM assembly

5.5 Testing Protocol

The chosen deployment system will undergo thorough ground testing prior to any launches. The primary design choice is to develop the mechanical deployment system. For this mechanism, the spring will be compressed as it would be in flight with all four shock cords keeping it in compression. Servo motors will be used to provide enough power to release the shock cords and deploy the parachute. This will demonstrate full system functionality and allow for verification of the design.

Calculations will be performed to determine how much the spring needs to be compressed in order to duplicate the pressures provided by a black powder ejection system. These tests will be performed multiple times to ensure consistency in the effectiveness of the spring and fidelity of the electronic components.

In addition, tests of the black powder's effectiveness will take place prior to any sub-scale or full-scale launches. Representative body tube sections will be connected by shear pins, and charges will be wired in their flight configuration. The charges will then be ignited to ensure that enough force is generated to separate the rocket.

Calculations will be performed to determine the necessary amount of black powder for each ejection charge once the exact recovery system dimensions and components are determined. Based on the data from previous years, 3-5 grams can be expected for each charge with increasing amounts designated for the secondary and tertiary charges to further ensure successful deployment.

The Raven altimeters have the capability to run full flight simulations, which will test the on-board components and the ejection charge triggers. These simulations will be run with LED indicators instead of energetics to verify the altimeters activate at the expected times.

5.6 Kinetic Energy at Landing

The Student Launch Handbook limits the kinetic energy at landing of each independent section to 75 ft-lbs. The size of the main parachute will be selected as a function of the terminal descent velocity of the vehicle and the vehicle's mass. Therefore the use of the appropriate parachute will ensure the kinetic energy at landing of each section is less than 75 ft-lbs.

Three different methods will be used to calculate the descent velocity. The OpenRocket software package will be used to estimate the descent velocity based on the parachute and launch vehicle configuration. The second method will take a more direct approach by using the coefficient of drag of the parachute (provided by the manufacturer) to determine the terminal velocity. Such calculations will be carried out by utilizing a custom MATLAB program along with relevant physics equations. Third, software on the parachute manufacturer website will be employed to further verify the accuracy of the previous two methods.

5.7 Systems Integration

The recovery payload will be located in section 1 of the rocket, which will be connected to section 2 via couplers. Shear pins will hold the sections together until the ignition of ejection charges, or deployment of the spring system, triggered by the avionics module to cause body tube separation. The recovery section will house the parachute in addition to the Compact Removable Avionics Module (CRAM). The CRAM will be located at the aft end of the section and aft of the main parachute. The parachute will be attached via shock cord to a 1,500 lb-rated steel eye bolt on the CRAM. The quick links connecting the shock cords to the parachute are rated for 2,000 lbs. These specifications have been used successfully in past years. The CRAM itself will be screwed into a 3D printed coupling inside of the recovery section of the rocket. Additionally, the CRAM will be held in place via a screw perpendicular to the rocket body to further prevent spinning and/or detachment of the CRAM from the airframe.

5.8 Statement of Work Verification

Table 14: Technical challenges that may arise during construction.

Item	Requirement	Action Plan
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude.	A single parachute will act as a drogue until the launch vehicle reaches a lower altitude where a Jolly Logic chute release will allow it to fully deploy
3.2	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.	Each section of the recovery system will be individually tested, and the recovery system will be ground tested before launche.s

3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	The parachute will be sized in order to meet the kinetic energy requirement.
3.4	At The recovery system electrical circuits will be completely independent of any payload electrical circuit.	There will be no communication between the recovery system and any other electrical systems.
3.5	At All recovery electronics will be powered by commercially available batteries.	Altimeters will be powered using standard 9V batteries.
3.6	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The recovery system will use at least two independent Raven altimeters.
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	The motor will be retained over the course of the flight of the launch vehicle.
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Shear pins will be used to hold sections together before parachute deployment.
3.9	Recovery area will be limited to a 2,500 ft. radius from the launch pads.	Parachute size and main deployment will be modified to limit drift under reasonable wind conditions.

3.10	Descent time will be limited to 90 seconds (apogee to touch down).	Parachute size will be modified in order limit descent time.
3.11	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Location will be transmitted to a ground station.
3.12	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	A Faraday Cage will be used to shield recovery electronics during flight.

6 Technical Design: Unmanned Aerial Vehicle

6.1 Mission Requirements

Requirements for the deployable UAV taking from the SLI handbook are as follows:

- **4.4.1.** Teams will design a custom UAV that will deploy from the internal structure of the launch vehicle.
- **4.4.2.** The UAV will be powered off until the rocket has safely landed on the ground and is capable of being powered on remotely after landing.
- **4.4.3.** The UAV will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the UAV if atypical flight forces are experienced.
- **4.4.4.** At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the UAV from the rocket.
- **4.4.5.** After deployment and from a position on the ground, the UAV will take off and fly to a NASA specified location, called the Future Excursion Area (FEA). Both

autonomous and piloted flight are permissible but all reorientation or unpacking maneuvers must be autonomous.

- **4.4.6.** The FEA will be approximately 10 ft. x 10 ft. and constructed of a color which stands out against the ground.
- **4.4.7.** One or more FEA's will be located in the recovery area of the launch field. FEA samples will be provided to teams upon acceptance and prior to PDR.
- **4.4.8.** Once the UAV has reached the FEA, it will place or drop a simulated navigational beacon on the target area.
- **4.4.9.** The simulated navigational beacon will be designed and built by each team and will be a minimum of 1 in W x 1 in H x 1 in D. The school name must be located on the external surface of the beacon.
- **4.4.10.** Teams will ensure the UAV's batteries are sufficiently protected from impact with the ground.
- **4.4.11.** The batteries powering the UAV will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other UAV parts.
- **4.4.12.** The team will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).
- **4.4.13.** Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.

6.2 System Components

Table 15: UAV System components and requirements.

System	Description
UAV Body	Robust design to remain intact during launch and protect the simulated navigational beacon. The body will deploy from its housing inside the rocket. A detailed description of the mechanical design can be found in Section 6.3, and a detailed description of the electrical design can be found in Section 6.4.

Deployment System	Allows for the proper takeoff of the UAV. A mechanical system will push the UAV out of the nose cone and allow for its deployment for flight configuration. A description of the launch vehicle housing may be found in Section 6.5, and an analysis of the current deployment options may be found in Section 6.7.
Orientation Correction System	Ensures the proper positioning of the UAV upon landing of the rocket. Allows the drone to exit the launch vehicle in a controlled manner to enable take-off. A detailed description can be found in Section 6.6.
Flight Control System	Controls the flight of the UAV as it moves from the deployment area to the FEA. The UAV's rotors will be in an X-configuration, allowing the system to control roll, pitch, and yaw by adjusting the throttle of individual motors. A description of the specifics of quadcopter flight may be found in Section 6.8.
Target Detection System	Visually recognizes the FEA to start the Beacon Delivery Process. The process is detailed in Section 6.9.
Beacon Deployment System	Facilitates deployment of the navigational beacon via activation upon detecting the Future Excursion Area. Two systems of deployment are under development, as can be seen detailed in Section 6.10.
Beacon Body Design	Navigational beacon which is delivered to the Future Excursion Area. Two body designs are under review, as is detailed in Section 6.10.

6.3 Mechanical Design

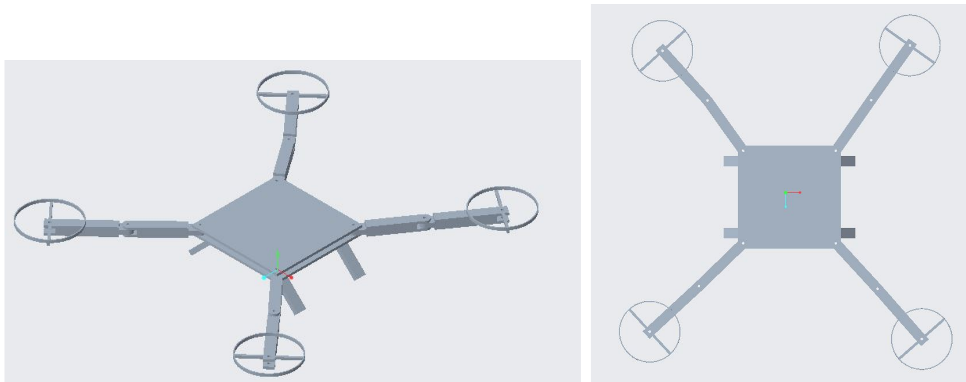
For the mechanical design of the UAV, the team has pinpointed three design constraint areas of focus: weight, size, and functionality. For weight restrictions, the team has determined that the maximum weight of the UAV will be 60 ounces. This value allows the team to use an ample amount of material while also ensuring that the lift generated from the rotors will overcome weight. For size restrictions, the UAV will reside in a cylindrical chamber at the fore section of the rocket. The chamber will roughly have a diameter of 7 inches and a length of 20 inches, so the UAV must fit those dimensions when it is not in flight-mode. There will not be any size restrictions after the UAV is launched, but the length of the rotor arms must be reasonable in order to fit the storage constraints once the arms are folded. To do so, the arms will each be about 5 inches long.

For the functionality restrictions, the UAV will have a set of fixed landing gear so that the payload carrying device has enough room at the bottom of the UAV to be housed safely during storage. Additionally, the size of the four rotors will be 2-3 inches in diameter. This size will generate the proper amount of lift without adding too much weight. Finally, the body of the UAV will be thick enough to ensure strength and ensure the Electrical Design Team has space to integrate all electronic components.

The UAV will be constructed from polylactic acid (PLA) or carbon fiber. Other materials may be considered in the future; however, the material chosen must be lightweight without sacrificing strength.

The design process of the UAV body will consist of using the Creo 4.0 CAD software create 3D models of any parts to be printed using one of the MakerBots in Stinson-Remick Hall. Any PLA components can be printed with the MakerBots, however, carbon fiber will be printed by an external manufacturer. Therefore, part modification is easier using PLA as opposed to carbon fiber due to its high cost and manufacturing lead time. The material chosen will ultimately depend on a stress-strain analysis that will be conducted before the PDR milestone.

The UAV will consist of a central platform with four identical prop arms extending out from the corners. A six-prop configuration was considered but determined to be the less optimum design. This decision was made to create a simpler, more symmetric design that will be easier to deploy after landing. Each prop will have two blades, though more may be added if additional lift is required after later design iterations. Additionally, each prop will have a circular shielding around its tip to protect both the blades and any environmental obstacles that it might come in contact with during flight. A proposed design of the UAV is seen in Figure 11.



(a) Standard view (b) Top view

Figure 11: CAD drawings of proposed UAV design.

The prop arms will be attached to the main body by joints at the corners and will be collapsed in during flight. During the deployment phase, they will swing out from the main body and lock into their extended position for flight. Motors were considered to power this transition, but after further analysis, springs were determined to be a better alternative, as they will have a smaller mass and take up less space. Furthermore, the arms will only need to be deployed once, so there is no need to include motors at these joints. The arms will consist of either one solid piece or two smaller pieces which would extend and lock together during the deployment phase. Further modeling and consideration of available space is required before the optimal decision choice can be identified.

6.4 Electrical Design

The UAV will be a quadcopter powered by four brushless motors. The arms of the quadcopter will be spring-loaded and folded during flight. Once the launch vehicle has landed and as the UAV is being deployed from the payload housing, the spring loaded arms will unfold. A rotating camera will be mounted on the bottom of the UAV for the video and image processing necessary to detect the target location. The quadcopter will also be equipped with a Raspberry Pi, seen in Figure 12, and separate telemetry whose primary function will be to stream the video feed to a ground station for data processing.

Figure 12: Raspberry Pi to reside on UAV board.

A Pixhawk mini controller, seen in Figure 13, will be used to control the flight of the quadcopter. The Pixhawk mini will connect to multiple sensors, including but not limited to GPS, altimeter, gyroscope, and accelerometer.

Figure 13: Pixhawk mini controller to reside on UAV board.

The Pixhawk will be programmed using MAVProxy or DroneKt-Python. A PIC32 microcontroller, seen in Figure 14, will control all other UAV functionality and programmed separately.

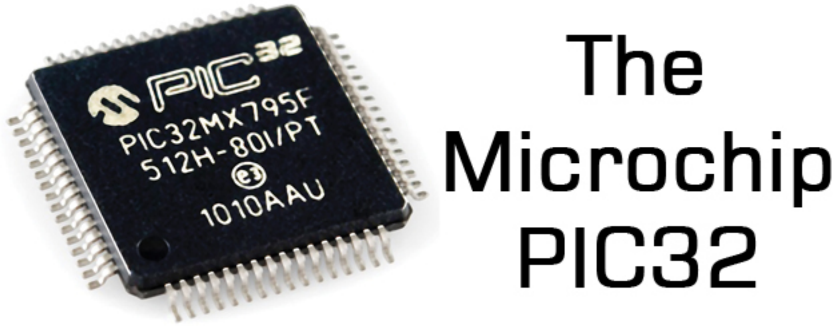


Figure 14: PIC32 microcontroller to reside on UAV board.

The UAV functionality will include the deployment from the payload housing, changing the orientation of the on board camera, and dropping the beacon once the target site is detected. Each motor will be driven by an Electronic Speed Controller (ESC), seen in Figure 15.

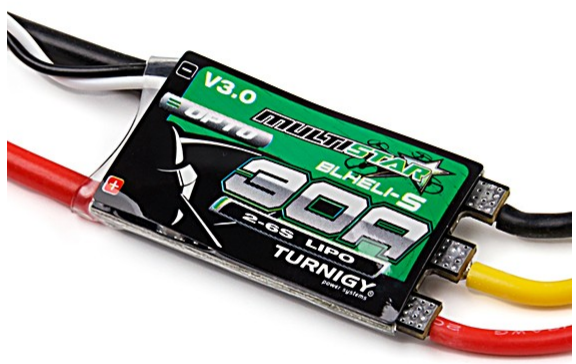


Figure 15: Electronic Speed Controller to reside on on UAV board.

For safety concerns, the amperage rating for each ESC will be well above the expected peak current draw of the motors, but not so large that the system bears unnecessary weight. There will be a unique power source, powered by Lithium-Polymer batteries. Additionally, there will be a separate power module to provide consistent 5V supply to the autopilot, a power distribution board to power the motors, and likely multiple voltage regulators. A transmitter and receiver with the DSMX communication protocol will be used to manually control the quadcopter. The transmitter may be seen in Figure 16.

Figure 16: Transmitter to manually control the UAV.

The quadcopter will also have two sets of telemetry operating on different frequencies. One set will provide communication between the Pixhawk mini and a laptop for autopilot. The second set of telemetry will live stream video back to the ground station for field-of-view and video processing needs. The transmitter will have a safety switch to allow for manual takeover during autonomous flight.

6.5 Launch Vehicle Housing

The UAV payload will be located in the fore section of the rocket, between the nose cone and transition section. The nature of the housing will be closely linked to the method of deploying the UAV from the rocket and the orientation correction system. The weight of the UAV will most likely be supported by a sheet of fiberglass, which will be mounted to the inside of the orientation correction bearing. Fiberglass would provide ample strength to support the UAV for takeoff, however additional materials such as plywood can be considered to reduce cost. The UAV can be secured using R-clips, seen in Figure 17, which would also prevent movement during flight but can still be disengaged when the payload moves out of the launch vehicle in preparation for flight.

Figure 17: R-clip to secure the UAV.

Pipe flanges can be mounted to the fiberglass base for the UAV. The cylindrical struts or landing gear of the UAV could then be inserted into the flanges. R-clips would be inserted through the flanges and the legs of the UAV. As a motor pushes the UAV and its base out of the rocket, strings attached to the R-clips would tighten, thus removing the clips from the four flanges and four struts of the UAV. The opposite end of the string could then be fixed to a bulkhead in the transition section. R-clips through the flanges and struts would help prohibit all degrees of freedom during flight. Upon the correct application of force, most likely via the strings, the pins would be removed, and the payload would be able oriented for take-off. Once out of the rocket, the UAV would be ready for a vertical takeoff. Utilizing the motors already needed in the payload section, this idea could help save both weight and cost. Furthermore, it is a relatively simple system; the mechanical locking mechanism of an R-clip requires no technology, such as a motor or an electronic lock. Additionally, the method of unlocking the clips via tightening strings also requires no electronics or motors. Figure 18 shows a view of the design.

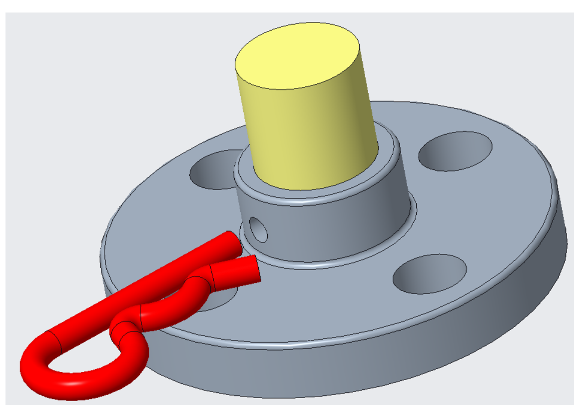


Figure 18: Pipe flange mechanism with R-clips for strut stabilization.

Due to the limited amount of space inside the rocket, adjustments need to be made to accommodate the booms and props. If a gear motor-lead screw mechanism is used for UAV deployment from the rocket, its booms could be spring-loaded. A part could run along the length of the lead screw to keep the spring-loaded booms in place while inside the rocket. The rotational motion of the lead screw turning would then translate into linear motion. A spring or bumper system could also be used with this mechanism behind the UAV and toward the aft end of the rocket. This system would provide a visual means of ensuring the UAV is pressed tight toward the aft end of the rocket during flight. Compressed springs would be a good indicator that the gear motor is tight.

6.6 Orientation Correction

Quite possibly the most important part of launching a UAV from the launch vehicle is ensuring correct orientation upon departure. Because the UAV will only have one set of rotors, it is of paramount importance to maintain proper orientation so that resulting lift vectors ensure a stable, controlled take-off. There are two potential orientation correction systems that could be employed to meet this goal.

First, it would be possible to use a counterweight driven ball-bearing system. This system would be locked during flight as to avoid any changes to the rocket's center of gravity and flight path. When the rocket lands, the system would be unlocked and the counterweight would cause the bearing to rotate and reorient the UAV along the axis of the rocket. One possible challenge to this method is the chance that the counterweight gets stuck in the opposite position as desired. This, however, is extremely unlikely, as it would be the case of an unstable equilibrium point, which is easy to mitigate.

The second system is similar to the first in that it involves a bearing system; however, instead of being driven by a counterweight, it would be motorized. As in the first system, this would also be locked during flight to avoid the same problems. When the rocket touches down, accelerometers would be used to determine the current orientation of the bearing system, and small motors would then be used to rotate the bearing to the correct position. One possible challenge with this method is the chance of the mechanical or electrical aspects being damaged or losing calibration during flight. Either of the presented methods of orientation correction are deemed viable and effective and will both be considered extensively going into PDR.

6.7 Launch Vehicle Deployment

One potential method for deploying the UAV utilizes one to two stepper motors positioned around the UAV. The UAV itself would be attached to the top of a platform that would rotate via a bearing system after touchdown to ensure the correct take off orientation. The stepper motors, attached to the platform, would be housed in the payload bay during the launch. After landing, the platform would extend forward to both push off the nose cone and move the mounting platform for the UAV out of the payload bay. The principal limitations on this concept are whether the stepper motors would actually generate sufficient force to remove the nose cone, and whether they can be long enough to extend the UAV fully out of the payload bay. Thus this system is highly dependent on the sizing of UAV and payload bay.

Another potential deployment method in consideration is to use a rack and pinion system to deploy the UAV. After the UAV is positioned in its correct orientation, a servo motor will rotate a pinion, which allows the interior rack to move axially forward on the guide rack. The forward linear motion will force the R-clips to release from the strut mounts, allowing the UAV to be free for take-off. The front of the mount will force the nose cone open, given enough torque from the motor. Compressed air or black powder charges may be considered as an alternative or redundancy to remove the nose cone as well. Table 17 gives examples of the pros and cons of this mechanism.

Table 16: Pros and cons of deployment methods.

	Pros	**Cons**
Stepper Motor	Simplicity: same system used to remove nose cone and move UAV	Torque limitations of stepper motors
	No black Powder for nose cone removal	Length limitations of lead screw inside payload bay
Rack and Pinion	Simplicity: same system used to remove nose cone and move UAV	Torque limitations of servo motor
	Saves space by allowing an interior rack to extend from an exterior guide	Weight of having two racks, one housed inside of the other

6.8 Flight Plan

The UAV must have control over the roll, pitch, yaw, and throttle in order to properly lift off after the rocket lands. It then must move to a Future Excursion Area (FEA) to drop off a beacon. A quadcopter design will be used for the UAV, so the control of the aircraft will be the product of motor spin direction and speed. Being able to vary these parameters allows the aircraft to be controlled remotely. For steady flight, the four rotors will all be spinning at the same rate, with two spinning clockwise diagonally from each other and the other two spinning counterclockwise. Figure 19 shows a diagram of this orientation system.

Figure 19: "X-configuration" for quadcopter design.

By orienting the rotors in this way, the quadcopter is stabilized, with no tendency to rotate due to moment imbalances. To maximize control, the UAV will be flown in the "X-configuration", as shown below. This configuration dictates how the roll, pitch, and yaw rates are controlled.

To rotate along the vertical axis (rolling axis), the throttles of either the right or left side of motors increase while the throttles of the other side are decreased. This will result in a roll in the direction of the decreased rotors. To rotate about the horizontal axis (pitching axis), the throttles of either the front or the back motors increase while the throttles of the other side decrease, resulting in a pitching moment. To rotate clockwise about the yaw axis, the throttles of the clockwise-rotating motors are increased, with the same holding true for counterclockwise motors and rotation. Since the UAV will be able to support its own weight in trimmed flight at around 75% power, increasing the power for specific motors to control the direction of flight should not be an issue.

In order to carry out its mission, the quadcopter will have a flight plan that consists of the following phases: (1) climb and acceleration to cruise, (2) cruise out to destination, (3) loiter and beacon delivery, (4) FEA evacuation and landing. For its first phase of flight, the quadcopter will accelerate to a flight ceiling at which it will cruise to destination. For this to occur, the thrust produced by the rotors must be greater than the total weight of the vehicle, which includes the payload weight, structure weight, and battery weight. For the second phase, the vehicle will cruise out to the Future Excursion Area (FEA). During this phase, the thrust needs to be vectored. Vectoring the thrust will allow the vehicle to maintain steady-level flight and move towards the FEA. To maintain steady-level flight, the vertical component of the vectored thrust must be equal to the total weight of the vehicle.

To ensure the vehicle travels at a constant velocity, the horizontal component of the thrust must be equal to the drag. Once the vehicle has reached the FEA, it will enter its third loiter phase. During this phase, the vehicle will descend and hover above the FEA, so that the navigational beacon can be dropped on the target area. To descend, the thrust of the rotors will need to be less than the total weight of the vehicle. To hover, the thrust, which at this point is not vectored, will again be equal to the total weight of the vehicle. For the final phase of its flight plan, the vehicle will move away from the target area and safely land. Moving away from the FEA will require the vehicle to vector its thrust again. Once away from the FEA, the thrust can be decreased so that it is slightly less than the total weight of the vehicle. The thrust should be decreased so that a controlled landing may be accomplished.

6.9 Target Detection

The target detection system consists of a camera mounted on the bottom of the UAV. The camera will be on a gimbal that is connected to a Raspberry Pi. The Pi will have telemetry, so that the video from the camera can be transmitted to the ground station. A Python script using the OpenCV library will be used to autonomously detect the colors of the FEA and calculate which FEA is closest to its current location and identify that FEA as the target. The UAV will then direct its flight towards the target utilizing a DroneKit-Python program to control the movement of the UAV.

In the event that the target detection system does not accurately identify the FEA, a remote control handled by a team officer will act as a fail-safe to identify and direct the UAV to the nearest FEA based on the video stream. Figure 20 shows a flowchart for the target detection process.

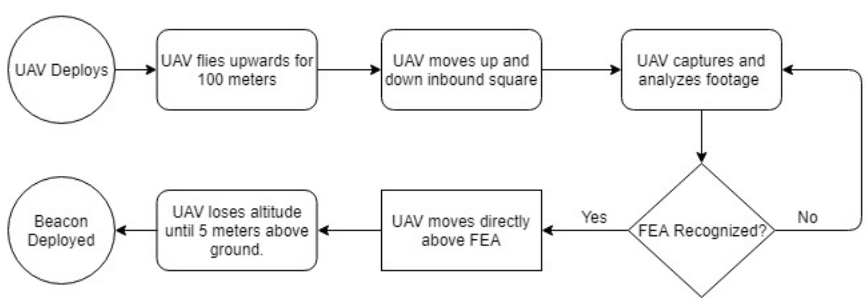


Figure 20: The target detection process.

An example of the Python code that the team will adapt for the color detection of the Future Excursion Area may be found in Appendix A.2.

6.10 Beacon Deployment and Design

The team has created two preliminary designs for the navigational beacon which is to be deployed by the UAV, both of which attempt to maximize the ability of the UAV to deploy the beacon onto the Future Excursion Area. The first of these, as seen in Figure 21, is reminiscent of a singular road spike, in the shape of a tetrahedron. It would be constructed by bending two metal rods and welding them at their centers, with the NDRT acronym painted on the sides. This design would minimize the chances of rolling post-touchdown of the beacon with the target, but would be of significant weight due to its metallic properties, potentially hindering the UAV.

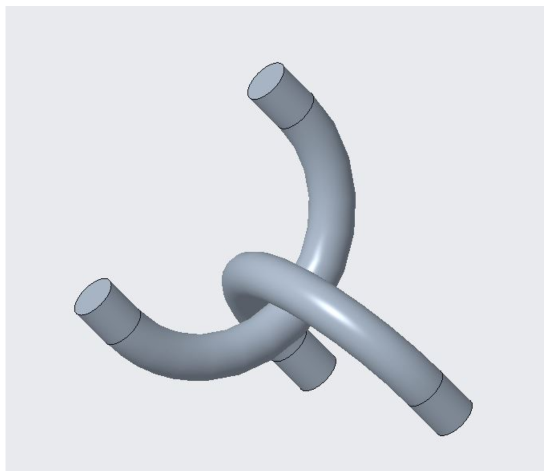


Figure 21: Road spike beacon design.

The second design, as seen in Figure 22, is a cube with the NDRT acronym on each side, and would be 3D printed. This design would be lightweight and easy to fabricate. Additionally, it would easily to secure to the UAV by using a hole placed in the middle of the cube. However, this design holds a risk of rolling post-touchdown with the target, due to its weight and shape. Both of these beacon designs would be confined to a 1 in^3. size to minimize the weight. The team will run extensive tests with each beacon design to determine which of the two is appropriate for the drone, specifically testing the behavior of the beacon post-impact and the affect weight of the beacon has on the flight time, as well as the ease-of-deployment from the UAV.

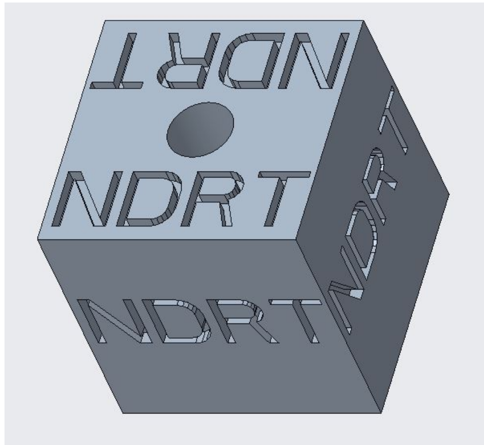


Figure 22: Cube beacon design.

The team has designed two preliminary beacon deployment methods for the UAV. The first design can be seen in Figure 23 and Figure 24. This design works specifically with the second design for the beacon (Figure 22). The beacon is stationed on the rod, as depicted above, which lays on the top of the lower platform. Upon deployment, a servo motor, yellow in the model, will activate and rotate the platform ninety degrees, thus giving the beacon zero support. The beacon will then slide down the rod and onto the target due to gravity. Benefits to using this deployment system are the need for only one servo motor and the ability of the system to simply hold the beacon in place before deployment. With this system, however, only the second beacon design could be utilized effectively.

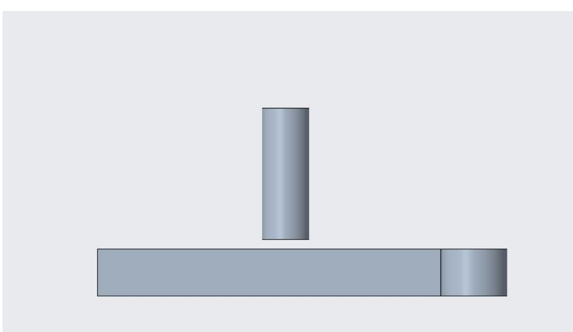


Figure 23: Side view of servo-platform deployment design.

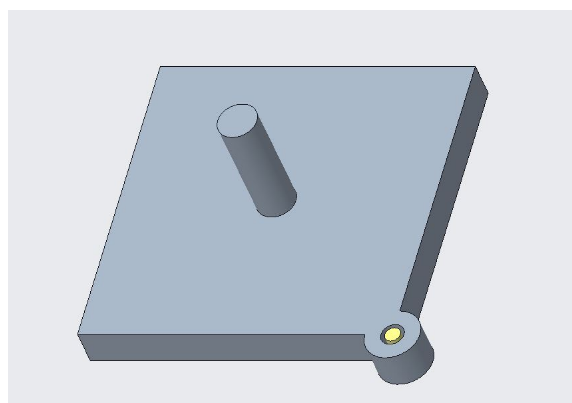


Figure 24: Standard view of servo-platform deployment design.

The second beacon deployment design can be seen in Figure 25. This system can work for both navigational beacon designs. The beacon sits on the bay doors, which are closed during the flight of the drone. Upon receiving the deployment signal, two servo motors, colored yellow in the figure, activate and rotate the bay doors open. The navigational beacon then falls out of the UAV and onto the FEA due to gravity. Benefits to using this system are, as stated previously, that both beacon designs can be utilized. This system, however, requires the use of two servo motors, which could drain battery power from the UAV and add weight. Additionally, this system does not account for holding the beacon firmly in place during flight, which could compromise the stability of the UAV. Both of these systems will be tested by the team to determine which provides the highest chances of successful.

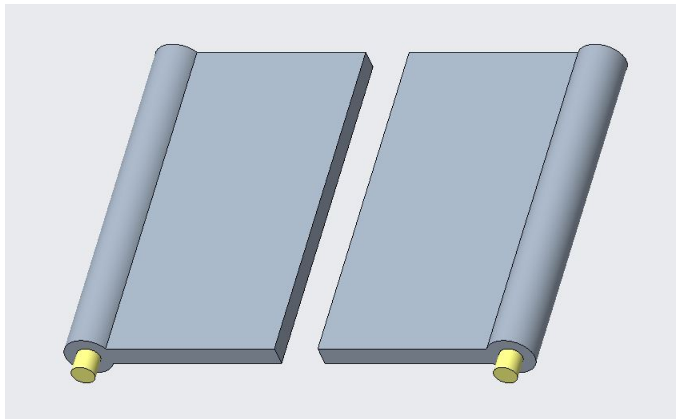


Figure 25: Bay door deployment design.

The height from which the navigational beacon is to be deployed will also be tested. The considerations for beacon deployment are as follows: (1) the beacon will be dropped from a certain height or (2) the beacon will be placed upon the target by the UAV. Benefits to placing the beacon directly on the target are the minimization of drift that could occur during free fall, as well as offer more control of the beacon's placement in the FEA. Benefits to deploying the beacon in free fall include not requiring a programmed landing to facilitate placing the beacon. NDRT has also considered the attachment of a parachute on the navigational beacon, but this could cause significant difficulties with increased drift and drag on the beacon.

6.11 UAV Payload Cost Estimate

Table 17: Cost estimate

Materials	Cost	Qty.	Vendor	Total
PixyCam	$70	1	Amazon	$70
Pixhawk Mini Controller	$134.95	1	Amazon	$134.95
Raspberry Pi	$35	1	Adafruit	$35
PIC32 Microcontroller	$13	2	Mouser Electronics	$26

Electronic Speed Controller	$11.41	8	Amazon	$91.28
Power Distribution Board	$11	1	Amazon	$11
Power Module	$13	1	Amazon	$11
DX Transmitter	$200	1	Spektrum	$200
DSMX Remote Receiver	$34.99	1	Spektrum	$34.99
Metal Bar	$6	2	Home Depot	$12
3D Printing Material	$0	N/A	ND Fab. Lab	$0
Stainless Steel Cotter Pin	$15	8	McMaster-Carr	$120
Raspberry Pi Camera Module V2-8 Megapixel, 1080p	$25.28	2	Amazon	$51.26
Unthreaded PVC Pipe Flange	$8.19	4	McMaster-Carr	$32.76
Miscellaneous Items (wires, screws, etc.)	$50	N/A	McMaster-Carr	$50
Brushless Motor	$69.90	6	RobotShop	$419.40
CNC Stepper Motor	$38.00	2	Amazon	$76.00
Lithium Polymer Battery	$35.99	3	Amazon	$107.97
Adapter Rings	$2.49	1	APC Prop	$2.49
Carbon Fiber Prop (2 pc)	$51.99	2	Vertigo Drones	$103.98
CSCA070 Thin Section Open Bearing 7"x7 1/2"x1/4" inch	$319.95	1	VBX Bearings	$319.95
			Total:	**$1,912.00**
			Allocated:	**$2,200.00**
			Margin:	$288.00

6.12 Plan of Action

The following Table offers a preliminary plan of action to meet all NASA Student Launch milestones as well as design deadlines determined by the team.

Table 18: Schedule for the UAV Team.

Date	Task
October 21, 2018	Final UAV design decided for all system components, including total payload weight and payload dimensions.
November 2, 2018	Preliminary Design Review submitted to NASA with final UAV design.
December 2, 2018	All UAV parts ordered by this date.
January 4, 2019	Critical Design Review submitted to NASA with final UAV design, notes on specific materials ordered prior to the University of Notre Dame's winter break (December 15 - January 13), and the total cost of the payload experiment.
January 14, 2019	First meeting after winter break. UAV team starts building with materials delivered over break.
January 15-17, 2019	Continue building the UAV with delivered materials and test system functionality.
January 26, 2019	First UAV test launch with faculty advisor, Dr. Jane Cleland-Huang.
February 2, 2019	Backup UAV test launch with faculty advisor, Dr. Jane Cleland-Huang in the event schedule skips.
February 9, 2019	First full-scale test launch housing the active payload with rocketry advisors from the Michiana Rocketry Club.
February 16, 2019	Additional testing after the full-scale launch to fix any issues that might have arisen.
February 23, 2019	Backup additional UAV testing date.

March 4, 2019	Flight Readiness Review submitted to NASA with data from the Payload Demonstration Flight. The Flight Readiness Review will include all payload information because the UAV will have flown during the full-scale vehicle demonstration flight.
March 25, 2019	Flight Readiness Review Addendum submitted to NASA with data from the Payload Demonstration Flight. This is a backup date in the case that unforeseen complications arise in the second semester of building, and the team was unable to launch the active payload before March 4, 2019.
April 3-7, 2019	NASA Student Launch Competition in Huntsville, Alabama.
April 26, 2019	Post-Launch Assessment Review submitted to NASA.

6.13 Technical Challenges

The following Table outlines the major forseen technical challenges facing the development of the UAV as well as corrective action the team will take to address these challenges.

Table 19: Technical challenges that may arise during construction.

Technical Challenge	Solution
Size and weight constraints	Maintain open and frequent communication with the Vehicle Design Team.
Deployment	House the UAV in a tube with a system to help the UAV orient itself; the servo motor will be controlled by PIC32.
Control	Use Pixhawk PX4 flight controller (GPS, antennae, accelerometer, altimeter, remote control).
Delivering the beacon	Have a motorized spike with flanges go into the beacon. Once the UAV is over the target area, the flanges will release and the beacon will drop.

Target detection	Use live video (PIC32 microcontroller) and OpenCV (Python library) to detect target.
Not enough lift or flight time	Run calculations using typical motor performance and ensure they fall well within parameters.
Breaking inside rocket	Allow the UAV no room to shift during flight.
Breaking upon landing	Equipt the UAV with landing gear.
Other hardware failure	Testing/referencing material to determine the amount of stress each component can handle.
Budgetary concerns	Price ideal design, cut spending or increase budget as needed.

6.14 Statement of Work Verification

The following Table outlines the method by which the chosen design will be verified to comply with the most complex NASA requirements for the payload. Additional requirements and verification methods will be derived prior to PDR.

Table 20: Most challenging requirements for experimental payload.

Item	Requirement	Action Plan
4.4.1.	Teams will design a custom UAV that will deploy from the internal structure of the launch vehicle.	A wireless signal will remove the UAV from the rocket, power it on, and launch it.
4.4.5	After deployment and from a position on the ground, the UAV will take off and fly to a NASA specified location, called the Future Excursion Area (FEA). Both autonomous and piloted flight are permissible but all reorientation or unpacking maneuvers must be autonomous.	Open CV will be utilized to detect the nearest FEA, and the UAV will autonomously navigate towards it.

4.4.8	Once the UAV has reached the FEA, it will place or drop a simulated navigational beacon on the target area.	Servo motors will be used to open the compartment holding the beacon, which will then be released over the target area. Lastly, the UAV will move a safe distance away from the FEA, and land.

7 Technical Design: Air Braking System

The apogee of the launch vehicle will be controlled using an Air Braking System (ABS) to adjust the drag force experienced by the rocket during flight. The vehicle shall be designed to overshoot the target apogee by 200 - 300 ft. and the ABS will induce additional drag forces by actuating drag control surfaces from the vehicle body. This will be done after burnout to control the ascent speed of the rocket. These control surfaces will in the form of flat plates, hereby called drag tabs. The drag tabs are controlled by a mechanical system driven by a servo motor and through on board avionics. These electronics will implement a closed loop control system using feedback from on board sensors to predict the flight path of the vehicle and calculate the necessary drag force to bring the vehicle to the designed apogee. It will then actuate the drag tabs accordingly. Figure 26 shows a schematic of a preliminary ABS design.

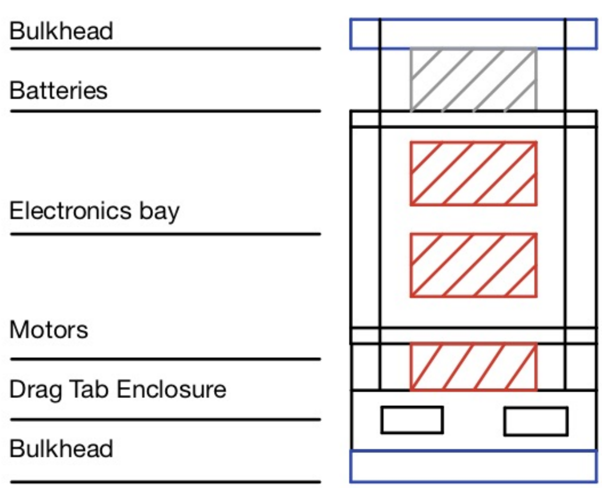


Figure 26: Schematic of proposed ABS design.

7.1 Design Requirements

- The team shall build a system designed to decelerate the rocket by inducing additional drag forces through retractable tabs extended into the flow, with the purpose of reaching the target apogee.
- The system shall use additional control surfaces to induce drag.
- The system shall keep all tabs retracted until the end of motor burnout.
- The system shall be autonomously controlled by on board avionics.
- The drag tabs shall fully retract in the event of jam detection.
- The system shall actuate all tabs simultaneously to prevent moment imbalances during flight.
- The system shall not generate any additional thrust.
- The control surfaces shall be aft of the post-motor burnout center of gravity.

7.2 Applicable Physics and Aerodynamics

The purpose of the system is to get the rocket as close as possible to the designated target apogee. This will be achieved through a control system that will extend and retract drag tabs accordingly through sensor feedback. The Drag force is given by:

$$F_D = C_d * \rho * v^2/2 * A \tag{2}$$

where C_d is the coefficient of Drag, ρ is the fluid (air) density, v is the velocity, and A is the projected area. The Drag coefficient of typical rocket may range from 0.05-0.295, given that the tabs may be approximated as flat plates with a C_d of up to 1.28, the tabs can easily become the primary source of drag induced by the rocket geometry even with a modest area. The fixed width of the tabs also allows the Drag force to be linearly related to tab displacement.

The tabs for the Air Braking System will be located at the center of pressure of the launch vehicle where the moments of the rocket are located, so as to not impact the static stability of the rocket. The symmetry of the tabs around the axis is guaranteed by a single crank that will drive all the tabs simultaneously, which will ensure the cancellation of any additional moments and not affect stability.

7.3 Mechanical Design

The objective of the mechanical design of the ABS is too provide a simple system for controlling the drag tabs through a shaft driven by one servo motor. The shaft will be bolted to a centrally located rotating hub connected direclty to each control surface. As the hub rotates, the connected drag tabs will be extended perpendicularly a controlled distance from the side of the rocket. By eliminating possible irregularities in torque between multiple rotating surfaces with a totally symmetric design, the system is expected to achieve increased reliability and higher precision. The current design is that the components will be fabricated from either Ultra-High-Molecular Weight (UHMW) or aluminum material. The advantage of UHMW is reduced weight, lower material cost, low friction, and simpler fabrication due to using in house capabilities. The advantage of aluminum would be a stronger material and better precision fabrication.

7.4 Control Code Structure

The code structure for air braking system shall receive data from on-board sensors, including at least one barometer and one accelerometer. The system will first activate on the launchpad, giving visual confirmation that it is receiving this sensor data via an LED status light. A Kalman filter will be utilized to dynamically correct sensor noise and error. After launch the system will then use filtered sensor data to detect motor burnout, and it will subsequently begin to compare pre-calculated velocity versus altitude curves against the output of the Kalman filter. Proportional, differential, and integral components of the error are then calculated.

The system will act as a closed-loop controller, constantly recalculating a new drag tab extension based on this error and communicating this extension to the servo motor to actuate the tabs. This process ends when sensor data indicates that the rocket has reached apogee, at which point the tabs will fully retract for the remainder of flight. Additionally, a potentiometer will be used to detect if the mechanism has jammed, in which case the tabs will be fully retracted to prevent damage to the mechanical system or asymmetric deployment of the tabs.

7.5 Electrical Design

The electronic control subsystem will consist of a student-designed printed circuit board and connection scheme integrated with off-the-shelf parts such as batteries, sensors, and a micro-controller. One major function of the PCB will be power division to allow all components to run off the same batteries despite different voltage and current requirements for these respective parts. This is desirable for size and weight considerations because it will eliminate the need for a second battery that would have otherwise been required to run the motors and micro-controller at different power levels.

To avoid possible connectivity issues between electronic components, an increased emphasis will be placed on the type of connectors used, the quality of the installation process, and the overall layout of the components. Implementing this goal will require more direct pin-to-board connections in place of soldered pin-to-wire connections that are more likely to break or short. Components that require direct connections will also be placed in close physical proximity to one another to limit the amount of excess wire running throughout the payload.

7.6 Integration Strategy

The air braking system will utilize tabs be placed aft of the post-burnout center of gravity and spaced radially around the body of the rocket at the center of pressure. They will be attached to the servo motor using steel connecting rods and bevel gears. The system will be housed in a 12 in. coupler and positioned at the fore end of the fin can. A bulkhead will be placed at the top of the coupler to secure the entire system in the tube. Four steel rods will then run axially through the fin can and payload bay. Locking nuts on the steel rods will hold the bulkhead in place. The team is considering designing a slider system parallel to the axis of the rocket to facilitate easier insertion of the Air Braking System into the fin can.

The system itself will be divided into multiple compartment bays that encase different components, such as the mechanical system and avionics. The team is considering a redesign of the ABS used last year to utilize a vertical mounting deck as opposed to multiple horizontal circular decks. This design would provide easier access and maintenance of all electrical components. To create a smaller and lighter system than last year, hardware and physical layout will be condensed to reduce the length of the ABS bay through improvements such as a redesigned printed circuit board and use of a single battery.

7.7 Test Plan

The following Table outlines the proposed test plan for the Air Braking System in order to quantify its capabilities and verify functionality.

Table 21: Proposed Test Plan for ABS.

Test Method	Purpose

Sub-scale Flight	Confirm the drag tabs are appropriately sized for the vehicle body and maintain stability. Verify that sub-scale flight apogee is reduced by the predictable amount for full tab extension.
Finite Element Method Simulation	Analysis to confirm acceptable factory of safety for material strength and gather stress data for the proposed design.
Mechanical Ground Test	Verify function of servo motor and drag tab actuation.
Electronics Ground Test	Verify electronic connections and safe power and current draw across ABS system.
Wind Tunnel Test	Gather data on the aerodynamics of the drag tabs and calculate their effect on the drag coefficient.
Simulated Flight Ground Test	Upload simulated flight data and visually verify the system operates as expected. Test with noisy data to verify functionality of control code data filtering.
Full Scale Flight Tests	Verify apogee decrease and stable flight in a full scale launch. Plan to verify functionality by launching a control flight followed by an active Air Braking System flight. Will also verify functionality through recorded altimeter and servo motor encoder data.

8 Educational Engagement

This year the team plans to continue its involvement in the local Notre Dame and South Bend communities in order to promote excitement and education in various STEM topics. The outreach efforts will be geared towards hands-on, direct events in order to truly encourage learning and interest in STEM. The team is building on its connections with organizations such as the Society of Women's Engineers, Boys and Girls Club, the Robinson Community Learning Center, Harrison Primary, and College Mentors for Kids. The team also wants to extend its outreach to more local schools and engage a variety of grade levels. The Notre Dame Rocketry Team (NDRT) also plans on participating in larger scale events such as the Science Alive fair, which proved to be a huge success last year. The team also enjoyed success from structured 5 week programs with partner organizations. This year the team plans on implementing another 5 week program with the Robinson Community Learning Center and the Boys and Girls Club. These educational outreach events continue to be a great way for NDRT to be involved in the community and the team looks forward to inspiring local students to pursue STEM education and connecting with them on a more personal level.

8.1 Lesson Plans

For a few smaller events and the 5 week programs, the team has developed several activities and lessons in order to directly engage the students and allow them to apply their knowledge to project-based activities. These programs can be adjusted for various age groups and project durations. These programs have proven successful in the past and will be adapted in the future in order to better cater to the these students based on their level of experience.

8.1.1 Activity: Touchdown

This lesson focuses on basic concepts of physics in order to demonstrate landing systems and forces. The students are able to apply their knowledge from the lesson by designing and building their own shock absorbing system to protect marshmallow "astronauts". The landing systems will then be tested by dropping them from a designated height. Students will then get to discuss their designs and evaluate the performance of their systems.

8.1.2 Activity: Rocketry 101

This is a 5 week program designed to introduce students to basic concepts of rocketry and the applicable engineering concepts. The first lesson is an introduction to rockets and the history of spaceflight. The students then can take what they learned create their own rocket designs with guidance from NDRT members. The second lesson discusses propulsion and chemical reactions. Students will get to make alka-seltzer rockets and then discuss the principles of propulsion. The third lesson is about recovery systems and the importance of a controlled descent. They will do a similar activity to the Touchdown lesson plan and construct a shock absorbing system that can withstand being dropped from a designated height. The fourth day is the construction of Estes rockets under the supervision of NDRT members. The students will have a lesson on safety and the importance of stability in a rocket. They will then be assisted by NDRT members in building their own rockets. The final lesson will consist of the launch. The students will again be briefed on safety procedures during a launch. Then NDRT will launch the rockets so the students can see the results of what they built. The day will conclude in an assessment of the launch so students can discuss the successes and faults in their systems.

8.1.3 Activity: Flight Basics 101

This is another 5 week program designed to introduce students to aircrafts and aerodynamics. This program was inspired by the team's choice of payload, the UAV. The first lesson will consist of an introduction to components and physics involved with aircraft. It will also cover the history of human flight. The lesson will conclude in construction of paper airplanes to test various aspect ratios and designs. The second lesson will include a more detailed discussion of concepts such as lift, drag, thrust, and weight. The lesson will incorporate experiments demonstrating these concepts. The third lesson will consist of the construction of a pre-designed "control" airplane. The students will put together a standard balsa plane and test them to collect data on air-time, distance, and other factors. Then the students will get to make design changes to the plane to adjust its performance. The NDRT members will then laser cut their designed balsa parts to be assembled in the next lesson. The fourth lesson consists of the construction of the new planes and decorating them. The students will be able to customize their aircraft and prepare them for flight. The final day is the test flight day where students will record data on their planes performance in the same categories as the "control" plane. Afterwards, students will be able to discuss the effects of the design changes and explain the change in performance of the plane.

8.1.4 Activity: Paper Rockets

This lesson plan is an easy one to do for indoor applications and a one time event that will still promote engagement and learning. Students will learn about the physics of rocketry and the components involved in designing a rocket. Students will then get to construct a rocket out of paper and launch them by blowing into a drinking straw. Students can compare their results to other students' designs in order to evaluate performance.

9 Project Plan

9.1 Development Schedule

In order to meet the deadlines set by the NASA Student Launch Management Team, the Notre Dame Rocketry Team has committed to the following timeline shown in Table 22 and project overview shown in Figure 27.

Table 22: Notre Dame Rocketry Team project overview.

Date	Task
September 2018	
22	Proposal Submitted Electronically
October 2018	
04	Awarded Proposals Announced
26	All Social Media Established
November 2018	
02	Preliminary Design Review (PDR) submitted
05-19	PDR video teleconference presentation
08	Wind-Tunnel Testing Complete
15	Sub-Scale Test Launch
January 2019	
04	Critical Design Review(CDR) submitted
07-22	CDR video teleconference presentation
February 2019	
15	Full-Scale Construction Complete
20	Full-Scale Test Flight #1
28	Full-Scale Flight #2 (as needed)
March 2019	
04	Vehicle Demonstration Flight deadline
04	Flight Readiness Review (FRR) submitted
08-21	FRR video teleconference presentation
25	Payload Demonstration Flight deadline
April 2019	
03-05	Huntsville, AL Launch Week Activities

03	Launch Readiness Review
06	Launch Day
06	Awards Ceremony
07	Backup launch day
26	Post-Launch Assessment Review (PLAR) submitted

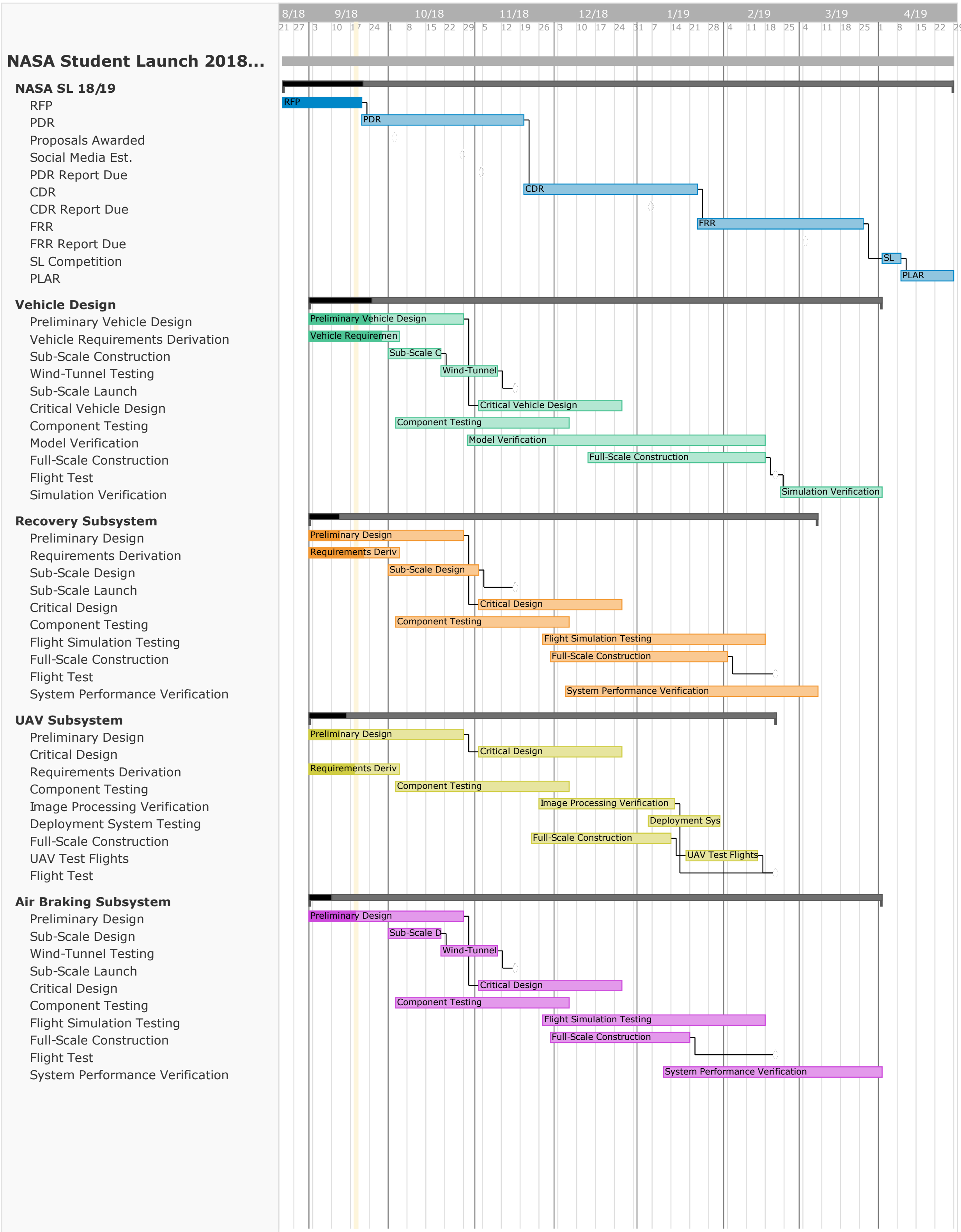


Figure 27: Project Gantt chart

9.2 Budget and Funding Plan

The Notre Dame Rocketry Team funds the project through two primary income streams. The first is in the form of funding from the University of Notre Dame to support student design projects. This fund is replenished annually and is intended to cover the costs of traveling to competition. The money is awarded based on the University's recognition that travel is a necessity for the team and they have pledged to support student travel for competition. The second stream is through corporate relations and charitable donations by sponsor the team. A breakdown of the funds secured for the project this year are given in Table 23.

Table 23: Notre Dame Rocketry Team sponsorship for the year.

Sponsor	**Amount**
Remaining Balance (2017/18)	$ 2,516.54
The University of Notre Dame	$ 2,500.00
ND Day Fundraising	$ 876.46
The Boeing Company	$ 10,000.00
TimkenSteel	$ 1,000.00
TOTAL	$ **16,893.00**

The budget for the project and different sub-teams allows for construct of the launch vehicle and travel to competition. This budget breakdown is shown in Table 24. The budget allocations for each of the sub-teams was based on historical costs and predicted cost of materials for this year. In addition, the team is currently pursuing additional donations by building on connections with industry.

Table 24: Notre Dame Rocketry Team funding allocation.

Allocation	**Amount**
Vehicle Design	$ 5,000
Recovery Subsystem	$ 1,500
UAV Payload	$ 2,200
Air Braking System	$ 1,200

Rocket Subtotal	$ **9,900**
Educational Engagement	$ 300
Competition Travel	$ 5,500
Miscellaneous	$ 500
TOTAL	$ **16,200**

9.3 Community Support

The Notre Dame Rocketry Team (NDRT) is committed to maintaining strong connections with the local TRA club, Michiana Rocketry, and with organizations that have supported the team over the past several years. Michiana Rocketry has been invaluable to the team and has always been enthusiastic to support Notre Dame students who share their passion for rocketry. They have provided mentorship through several years of Student Launch competitions and NDRT is fully committed to maintaining this relationship beyond this year's competition.

In addition, the team is continuing to push educational engagement with youth organizations in the greater South Bend community. Sustaining partnerships with local chapters of the Boys and Girls Club, College Mentors for Kids, and Girl Scouts, as well as the Robinson Community Learning Center allows the team to reach a broad range of youth in promoting STEM education. This is something the team recognizes as a way of giving back to the community and is in line with Notre Dame's vision of a catholic education carried out through principles of Catholic Social Teaching. Through maintaining these relationships for educational engagement, the team hopes to continue its efforts of inspiring young students to pursue a career in STEM, showing them just what is possible through hard work and dedication.

9.4 Project Sustainability

In order to ensure the Notre Dame Rocketry Team is able to continue growing and competing in NASA Student Launch, several measures have been put in place. These measures are intended to provide a dependable revenue stream for the project as well as a means of passing knowledge on to new team members.

The revenue for the project has historically relied on charitable donations from companies the team has established professional relationships with. For the past few years, The Boeing Company has made a sizeable donation to the engineering design teams at Notre Dame, including NDRT. The Boeing Company has expressed their intention to continue this partnership as well as build on their current relationship with Notre Dame. In addition, the team has secured additional annual funding from the university to cover the cost of traveling to competition.

Looking ahead, the Notre Dame Rocketry Team seeks to build additional relationships with industry interested in supporting a student design team. The Corporate Sponsorship Committee has begun working with the College of Engineering development office to build a framework for establishing more of these corporate connections. The goal is to eventually build the team's budget so that there is more money left over at the end of the year to fund research for the project and provide better stability in funding future endeavors.

Additionally, this is the second year that the team has seen a steep growth in the number of active members. This is largely attributed to the method of recruitment used in undergraduate classes across the college. The team targets courses in each grade level offered in the fall being taken by students in a department. This allows the team to circulate information about Student Launch and this year's project throughout the College of Engineering. As a result of the team's past performance and emphasis of involving everyone on the team regardless of experience, the number of active members remains high.

Looking forward, the team is focused on retaining members and ensuring knowledge is passed down. This is being accomplished by giving all new members, especially freshman, access to reports from previous years and tangible responsibilities throughout the year. The returning members and leadership team is constantly being pushed to educate the next generation of the Notre Dame Rocketry Team through delegating tasks and mentoring new members. Through this framework, the team can ensure the future success and innovation for the project.

10 Conclusion

The Notre Dame Rocketry Team is returning to compete in NASA Student Launch and is as motivated as ever to improve on its performance from previous years. Through meeting the following goals, the team hopes to exceed the technical challenges of the competition and provide an unparalleled practical engineering experience for undergraduate students.

- To ensure the sustained growth of knowledge on the team and empower all team members to gain industry critical skills that will supplement their undergraduate education.

- To develop a high standard of documentation and mindset focused around team safety that will drive the team for years to come.
- To provide educational engagement opportunities in STEM education to 1,500+ students in the community, inspiring them and showing what is possible through education.
- To design a fully functioning deployable UAV that integrates into the launch vehicle and will meet all mission requirements.
- To fully implement a high fidelity Air Braking System that will better ensure accurate apogee prediction and flight performance.

Appendices

A Technical Design

A.1 Vehicle Verification

Table 25: Vehicle Verification

Requirements	Plan of Verification	Method of Verification
The vehicle will deliver the payload to a specified apogee altitude between 4,000 and 5,500 feet above ground level.	-Calculations including physical properties shall be used to estimate apogee using a coded program. -Software simulations shall be used to verify apogee calculations. -Full Scale Test will confirm that that the full vehicle shall reach the target altitude.	OpenRocket, RockSim, In-house program utilizing physics equations, Full Scale Test
The vehicle shall carry one commercially available, barometric altimeter.	-Inspection: The Recovery Sub-Team Lead shall confirm that the altimeter is on the vehicle.	Inspection
The altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the	-Inspection: The Recovery Sub-Team Lead shall confirm that the altimeter is armed in the correct fashion.	Inspection

The altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	-Inspection: The Recovery Sub-Team Lead shall confirm that the altimeter is armed in the correct fashion.	Inspection
The altimeter shall have a dedicated power supply.	-Inspection: The Recovery Sub-Team Lead shall confirm that the altimeter has a power supply.	Inspection
The arming switch shall be capable of being locked in the ON position for launch.	-Inspection: The team shall verify that the arming switch is capable of being locked in the ON position.	Inspection
The launch vehicle shall be recoverable and reusable.	-The team shall recover the rocket from the Full Scale Test and verify that it is reusable.	Full Scale Test
The launch vehicle shall have a maximum of four (4) independent sections.	-Inspection: The team shall verify that the vehicle has two (2) sections.	Inspection, Full Scale Test
Coupler/airframe shoulders which are located at in-flight separation points shall be at least 1 body diameter in length.	-Inspection: The team shall verify that the coupler/airframe shoulders are at least 1 body diameter in length.	Inspection
Nosecone shoulders which are located at in-flight separation points will be at least 1[U+2044]2 body diameter in length.	-Inspection: The team shall verify that the nose cone shoulders are at least $\frac{1}{2}$ body diameter in length.	Inspection
The launch vehicle shall be limited to a single stage.	Inspection: The team shall verify that the vehicle has one (1) stage.	Inspection, Full Scale Test

The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The team shall prepare the vehicle within 2 hours for the Full Scale Test.	Full Scale Test
The launch vehicle shall be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.	The team shall verify that the vehicle can remain in configuration without losing functionality during the Full Scale Test.	Full Scale Test
The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system.	The team shall use a 12-volt direct firing system during the Full Scale Test.	Full Scale Test
The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The team shall launch without external circuitry or special ground equipment for the Full Scale Test.	Full Scale Test

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 shall use either Aerotech, Cesaroni, or Loki for a motor. This shall be demonstrated on the CDR.	Inspection of TRA and NAR approved motors Full Scale Test
Pressure vessels on the vehicle shall be approved by the RSO and the minimum factor of safety for pressure vessels (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1.	-Inspection: The team shall verify that the pressure vessels are approved by the RSO and comply with the factor of safety.	Inspection of RSO approved pressure vessels
Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	-The team shall verify that the pressure vessel includes a relief valve.	Inspection
Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	-The team shall investigate and describe the pressure vessel, including providing historical data.	Quality

The total impulse provided by the launch vehicle shall not exceed 5,120 Newton-sec-	-The team shall verify that the vehicle does not provide a greater impulse than 5,120 Newton-seconds (L-class).	Inspection
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	-The team shall verify that the static stability margin is above 2.0 via simulations. - The team shall measure the center of gravity before each launch to ensure stability.	OpenRocket, RockSim, Full Scale Test
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The team shall confirm that the minimum velocity off the rail shall not be below 52 fps through OpenRocket and RockSim simulations and the Full Scale Test.	OpenRocket, RockSim, Full Scale Test
The team shall successfully launch and recover a subscale model of the rocket prior to CDR.	The team shall launch and recover a subscale model through the subscale test.	Subscale Test
The team shall successfully launch and recover the full-scale rocket prior to FRR in its final flight configuration.	The team shall launch and recover the rocket.	Full Scale Test
The team shall successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline.	The team shall launch and recover the rocket with the completed payload.	Full Scale Test

A.2 Unmanned Aerial Vehicle Python Code to Adapt for Color-Detection

```
# Citation: Czajka, Adam (2018) colorTracking1 program [Computer program].

# Begin code

import cv2
import numpy as np

cam = cv2.VideoCapture(0)
while (True):
    retval, img = cam.read()
    res_scale = 0.5             # rescale the input image if it's too large
    img = cv2.resize(img, (0,0), fx = res_scale, fy = res_scale)

    # detect selected color
    hsv = cv2.cvtColor(img, cv2.COLOR_BGR2HSV)
    lower = np.array([20, 110, 110])
    upper = np.array([40, 150, 160])
    objmask = cv2.inRange(hsv, lower, upper)

    # you may use this for debugging
    cv2.imshow("Binary image", objmask)

    # Resulting binary image may have large number of small objects.
    kernel = np.ones((5,5), np.uint8)
    objmask = cv2.morphologyEx(objmask, cv2.MORPH_CLOSE, kernel=kernel)
    objmask = cv2.morphologyEx(objmask, cv2.MORPH_DILATE, kernel=kernel)
    cv2.imshow("Image after morphological operations", objmask)

    # find connected components
    cc = cv2.connectedComponents(objmask)
    ccimg = cc[1].astype(np.uint8)

    # find contours of these objects
    imc, contours, hierarchy = cv2.findContours(ccimg,
                                            cv2.RETR_TREE,
                                            cv2.CHAIN_APPROX_SIMPLE)
```

```
# ignore bounding boxes smaller than "minObjectSize"
minObjectSize = 10;

if contours:
    # use just the first contour to draw a rectangle
    x, y, w, h = cv2.boundingRect(contours[0])

    # do not show very small objects
    if w > minObjectSize or h > minObjectSize:
        cv2.rectangle(img, (x, y), (x+w, y+h), (0,255,0), 3)
        cv2.putText(img,                        # image
                "Here's my candy!",         # text
                (x, y-10),                  # start position
                cv2.FONT_HERSHEY_SIMPLEX,   # font
                0.7,                        # size
                (0, 255, 0),                # BGR color
                1,                          # thickness
                cv2.LINE_AA)                # type of line

cv2.imshow("Live WebCam", img)

action = cv2.waitKey(1)
if action==27:
    break
```

B Safety

Figure 28: Lab and Machine Shop Risk Assessment table

Lab and Machine Shop Risk Assessment						
Hazard	**Cause/Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Using power tools and hand tools such as blades, saws, drills, etc.	Improper training and use on tools and other lab equipment.	1. Mild to severe cuts or burns to personnel.	3	2	Moderate	1. Individuals must be trained and get certified by one of the experienced person in order before using these tools.
		2. Damage to rocket or components of the rocket.				2. Safety glasses and gloves must be worn whenever using power tools.
		3. Damage to the equipment				3. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE.	1. Mild to severe rash.	2	3	Moderate	1. Long sleeves should be worn whenever sanding or grinding materials.
	2. Improper training or use of Dremel tools.	2. Irritated eyes, nose or throat with the potential to aggravate asthma.				2. Proper PPE must be utilized such as safety glasses and dust masks with the appropriate filtration required.
		3. Mild to severe cuts or burns from a Dremel tool and sanding wheel.				3. Individuals must be trained and get certified by one of the experienced person in order before using these tools.
		4. Damage to materials being sanded or grinded.				
Machining equipment including CNC, lathe, and saws.	Improper training on tools and other lab equipment.	1. Damage to the equipment.	4	1	Moderate	The machine equipment available to the team requires safety training and certification for each team member. Each piece of equipment has a Job Safety and Sequence Instruction card that details task steps, safety instructions, and ergonomic reminders.
		2. Damage to materials being machined.				
		3. Potentially severe cuts or burns to personnel.				
Working with chemical components.	1. Chemical splash	1. Mild to severe burns on skin or eyes.	3	2	Moderate	SDS documents will be readily available at all times and will be thoroughly with any chemical. Each member must acknowledge the hazards that accompany working with these chemicals. All chemical containers will be marked to identify appropriate precautions that need to be taken. Nitrile gloves should be used when handling hazardous materials.
	2. Chemical fumes	2. Lung damage or asthma aggravation due to inhalation of fumes, or chemical spills.				
		3. Corrosion to equipments or components of the rocket.				
Damage to equipment while soldering.	1. Soldering iron is too hot	1. The equipment could become unusable.	2	3	Moderate	1. The temperature on the soldering iron will be controlled and set to a level that will not damage components.
	2. Prolonged contact with heated iron.	2. Parts of the circuit get damaged and become inoperable.				2. For temperature sensitive components sockets will be used to solder ICs to.
						3. Make sure the soldering iron is completely cooled down after use.
Dangerous fumes while soldering.	1. Use of loaded solder can produce toxic fumes.	1. Inhalation of toxic fumes could make team members sick.	2	3	Moderate	1. Team members must receive training before soldering.
	2. leaving soldering iron too long on plastic could cause plastic to melt producing. toxic fumes	2. Lung irritation may occur.				2. Make sure the soldering iron is completely cooled down after use.
		3. Damage to equipment in the lab.				

Figure 29: Launch and Flight Risk Assessment

Lauch and Flight Risk Assessment Table						
Hazard	Cause/Mechanism	Outcome	Severity Value	Probability Value	Risk Level	Mitigation
Air Braking System deploys early	Error in control code, bad sensor data readings	Flight trajectory altered	3	2	Moderate	Pre-flight tests will ensure robust control code and valid filtered sensor data for ABS. System can be disabled before flight if reliability is questioned based on pre-flight procedures.
Motor failure	Problem with ignition system, bad chemical composition of motor, improper motor install	Motor does not ignite at all, or explodes in undesired manner after ignition	4	1	Moderate	Communication with appropriate safety personnel at launch will begin if issue is suspected, fires will be extinguished and debris collected as required, ignition system will be carefully checked during install and rechecked if behavior not as expected.
Mechanical Breakdown	Forces on rocket components exceed specifications of materials used, bad fitment between rocket and launch tower	Altered flight trajectory, damage to rocket that prevents payload functionality	3	2	Moderate	Materials will be chosen to withstand forces encountered by rocket during typical flight, inspection will be performed when rocket is on launch pad to ensure it is properly installed as dictated by procedure.

Figure 30: Recovery Risk Assessment

Recovery Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity Value	Probability Value	Risk Level	Mitigation
Spring does not separate rocket	Spring does not have enough power to break the shear pins and separate the rocket	Rocket does not slow down and falls to ground at terminal velocity	4	1	Moderate	Calculation of forces required to break shear pins, repeated separation testing prior to launch
Altimeter/Servo Failure	1. Power/Battery failure 2. Failure in Wiring	Rocket does not separate or slow down and falls to ground at terminal velocity	4	1	Moderate	Multiple redundant altimeters and servos set up in redundant fashion such that an altimeter failure does not prevent safe separation of the rocket
Premature release of the spring	1. Latch holding spring down breaks 2. Cables restraining the spring break 3. False reading from altimeters	Rocket sections have potential to become projectiles	3	1	Low	Extensive testing at the component and system level will be done before attempted assembly of the rocket. A physical safety restraint keeping spring in place during assembly (to be removed on the launch pad) will be used. All electronics to be kept off until rocket is vertical on the launch pad. Multiple redundant cables will restrain the spring during normal operation.
Parachute does not open properly	1. Improper folding of the parachute 2. Shock cords get tangled in the parachute 3. Parachute gets caught on internal piece of rocket 4. Chute Release fails to release parachute at proper altitude	Rocket does not slow down to safe speed and falls to ground at terminal velocity	4	2	Moderate	Detailed procedures on proper parachute folding and shock cord wrapping technique will be produced. Any internal structures that might interfere with proper deployment of the parachute will be covered. Multiple redundant Chute Releases will be used.
Rocket descends too quickly	Improper sizing of the parachute	Rocket falls with a greater speed than it was designed to, potentially causing damage to the rocket or payload	3	1	Low	The parachute will be carefully selected to slow the rocket to the appropriate speed. Calculations and simulations will be done to verify.
Rocket descends to slowly	1. Improper sizing of the parachute 2. Chute Release releases parachute too early	Rocket drifts farther than intended, potentially damaging environmental objects outside the launch radius.	2	2	Low	The parachute will be carefully selected to slow the rocket to the appropriate speed. The Chute Releases will be tested prior to launch to verify their accuracy.
Parachute has tear or rip	1. Improper handling of the parachute 2. Parachute catches on internal component of the rocket	Rocket descends with greater speed than it was designed to, potentially causing damage to the rocket or payload	3	1	Low	The parachute will be carefully inspected by multiple team members prior to folding. Any internal structure in the rocket that could impede the deployment of the parachute will be covered.
Recovery system separates from rocket	1. Bulkhead breaks or dislodges from the rocket body 2. Shock cord breaks 3. Eyebolt or quicklink fails	Rocket fails to slow down to safe speed	4	1	Moderate	The bulkheads, shock cords, eyebolts, and other securing hardware will selected/ designed to withstand the expected loads with a sufficient factor of safety.

Figure 31: Vehicle Construction and Assembly Risk Assessment

Vehicle Construction and Assembly Risk Assessment						
Hazard	**Mechanism**	**Outcome**	**Severity**	**Probability**	**Risk**	**Mitigation**
Rocket drop without motor	Mishandling of rocket during assembly	Possible structural damage to rocket	3	2	Moderate	Design rocket in a way to be durable to dropping and landing. Enforce correct handling of all sections of rocket body at all times
Rocket drop with motor	Mishandling of rocket during assembly	Possible structural damage to rocket body, possible explosion	4	2	Moderate	Design the rocket in a way to be durable to dropping and landing. Enforce correct handling of all sections of rocket body at all times. Do not insety motor into rocket until right before launch.
Rocket Sections Separate	Shear pins fall out	Time and evergy wasted in replacing shear pins	1	2	Low	Drill shear pin holes small enough so that the pins are held in place by friction
	Recovery spring releases prematurely	Serious structural damage to rocket section or body	4	3	Moderate	Design multiple fair-safe release systems of the recovery spring to ensure correctly-timed release. Test system through combination of dropping and hitting tests to confirm system's resilience.
Rubbing of edges of rocket section	Angled joining of rocket sections	Damage to edges of rocket section, possibly destructive over time	1	3	Low	Choose rocket body material that is resistant to general wear and tear. Enforce flush connection of rocket sections.

Figure 32: Hazards to Environment Risk Assessment

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Mechanism**	**Outcome**	**Severity**	**Probability**	**Risk**	**Mitigation**
Rain	N/A	Damage to electrical systems, potential for battery leakage, inability to launch	4	2	Moderate	Launch on day with low chance of precipitation, plan to protect electrical components with waterproof bags
High Winds	N/A	Adverse effects on launch angle, reduction of altitude, increased drifting, inability to launch	4	2	Moderate	Launch on day with low chance of high winds
Trees	N/A	Damage to rocket systems, potential for battery puncture and leakage, inability to recover rocket	4	2	Moderate	Launch on day with low chance of high winds, prevent excessive drifting, prevent launch if trees are in estimated drift radius
Swampy/Moist Ground	N/A	Inability to recover rocket	4	2	Moderate	Prevent launch if moist ground is within the drift radius
Bodies of Water	N/A	Damage to electrical systems, potential for battery leakage, inability to recover rocket	4	2	Moderate	Prevent launch if moist ground is within the drift radius, salvage electrical components immediately
Low Cloud Cover	N/A	Inability to launch	4	2	Moderate	Launch on day of no cloud cover, high cloud cover
High Humidity	N/A	Excessive moisture can prevent motor ignition, cause battery leakage	4	1	Moderate	Store electronics, motor in waterproof bag until launch time
Extreme Cold	N/A	Can cause battery depletion, prevent electrical components from functioning, induce critical failures, reduce separation of rocket	4	1	Moderate	Check batteries for charge immediately prior to launch
Extreme Heat	N/A	Can cause battery explosion, degrade electrical systems, melt adhesives	4	1	Moderate	Check batteries for charge immediately prior to launch, remove rocket from direct sunlight
UV Exposure	N/A	Can weaken materials, adhesive failure	1	2	Low	Remove rocket from direct sunlight until launch time

Figure 33: Hazards to Environment Risk Assessment

Hazards to Environment Risk Assessment						
Hazard	**Mechanism**	**Outcome**	**Severity**	**Probability**	**Risk**	**Mitigation**
Release of hydrogen chloride	Burning of motors	Hydrogen chloride dissociates to form hydrochloric acid in water	1	5	Moderate	The amount of hydrochloric acid produced over one season is negligible.
Release of reactive chemicals	Burning of motors	Chemicals react and deplete ozone	1	5	Moderate	The amount of reactive chemicals produced over one season is negligible.
Release of toxic fumes	Burning of motors	Biodegradation of ammonium perchlorate	1	5	Moderate	The amount of ammonium perchlorate burned causes negligible degradation.
Carbon dioxide emission	Travel to and from launch site	Addition of greenhouse gas, heat to atmosphere	1	5	Moderate	Carpooling and commercial air travel produce a negligible effect of carbon dioxide emission per capita.
Production of styrene gas	Fiberglass in vehicle	Toxic emissions	1	5	Moderate	The manufacturer of fiberglass produces toxic pollutants, including styrene, which evaporates into the atmosphere. The quantity of fiberglass used has a negligible effect on the environment.
Grass fire	Burning of motors, electrical component short circuit	Ignition, electrical systems, motor all create heat and have potential to spark, causing a fire	4	2	Moderate	Appropriate fire extinguishing materials will be present at launch, wire connections will be verified before launch.
Groundwater contamination	Leakage, improper disposal of batteries	Chemicals react in water, potentially leading to human ingestion and illness	1	3	Low	NDRT will follow procedures outlined in SDS sheets should chemical spills, leaks occur, and will follow SDS guidelines on disposal of used batteries and chemicals
Spray paint	Use of spray paint in construction	Paint dissolves in water, evaporates in air	3	1	Low	Spray painting will be conducted in a laboratory isolated from water systems or outside air.
Soldering materials	Wires soldered to electrical components	Air, ground contamination	1	5	Low	Vapor produced from soldering causes negligible effects.
Battery leakage	Excessive heat, excessive humidity, battery puncture, damaged casing	Chemicals react in water, potentially leading to human ingestion and illness, potential reaction to cause fire	2	2	Low	Proper precautions, including those recommended by the manufacturer, will be used to prevent the leakage of batteries
Plastic waste	Plastic scraps used in soldering	Sharp plastic waste can lead to harm to animals upon ingestion, humans upon entry into groundwater supply	2	1	Low	Plastic will be disposed of according to applicable SDS, local standards
Wire waste	Waste made during production of electrical components	Sharp wire waste can lead to harm to animals upon ingestion, humans upon entry into groundwater supply	2	1	Low	Wire will be disposed of according to applicable SDS, local standards

Figure 34: NAR High-powered rocketry safety code

Topic	NAR Description	Team Compliance
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.	Team mentors are Level 2 certified and the team will only use a maximum of L class motors.
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.	All design squads, especially the vehicle design squad, will refrain from using materials that do not meet the lightweight requirement. If there is uncertainty, the team will check with the NASA competition officials.
Motors	I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	The team will not use any motors, other than those used by certifiable and trusted rocket motor manufacturers. Motor use will be supervised by team mentors, will be only for the purpose of launching the rocket, and will be under controlled and safe condition.
Ignition Systems	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.	The team's mentors will install all ignition systems and will only do so properly, and according to the NAR regulations outlined here.
Misfires	If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	Team mentors, Safety officer, and Captain must all approve any attempts to approach the rocket in the case of misfires. Even then, it will only be done well after a 60 second waiting period, and will be done only by the team mentors and essential personnel after the area has been determined to be safe.
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 follow all launch instructions given by the Range Safety Officer, and will comply with all rules stipulated here. Additionally, the Safety officer will give a 5 second warning to all personnel in the area prior to launch.
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 only use rails provided by NAR, and will fully comply with this rule.
Size	My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	Rocket design and motor selection will comply with this rule.
Flight Safety	I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	Weather and wind conditions will be evaluated in the week prior to a launch day, as well as on launch day, if conditions are determined to be unsafe, the team will not launch. All necessary FAA waivers and notices will be acquired and in place prior to launch. The team will comply with all launch day determinations made by the Range Safety Officer.
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).	Team launches will only take place at NAR/TRA events. The Range Safety Officer has final say on all matters regarding safety issues.
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 the day of launch.
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 Design Squad will be responsible for designing, testing, constructing, and verifying a safe recovery system that will fully comply with this rule. A pre-launch checklist must be checked off by recovery and signed by the Captain and Safety Officer.
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 determinations made by the Range Safety Officer on launch day. If a safe recovery is not possible for the team, proper authorities will be contacted to ensure a complete and safe recovery.