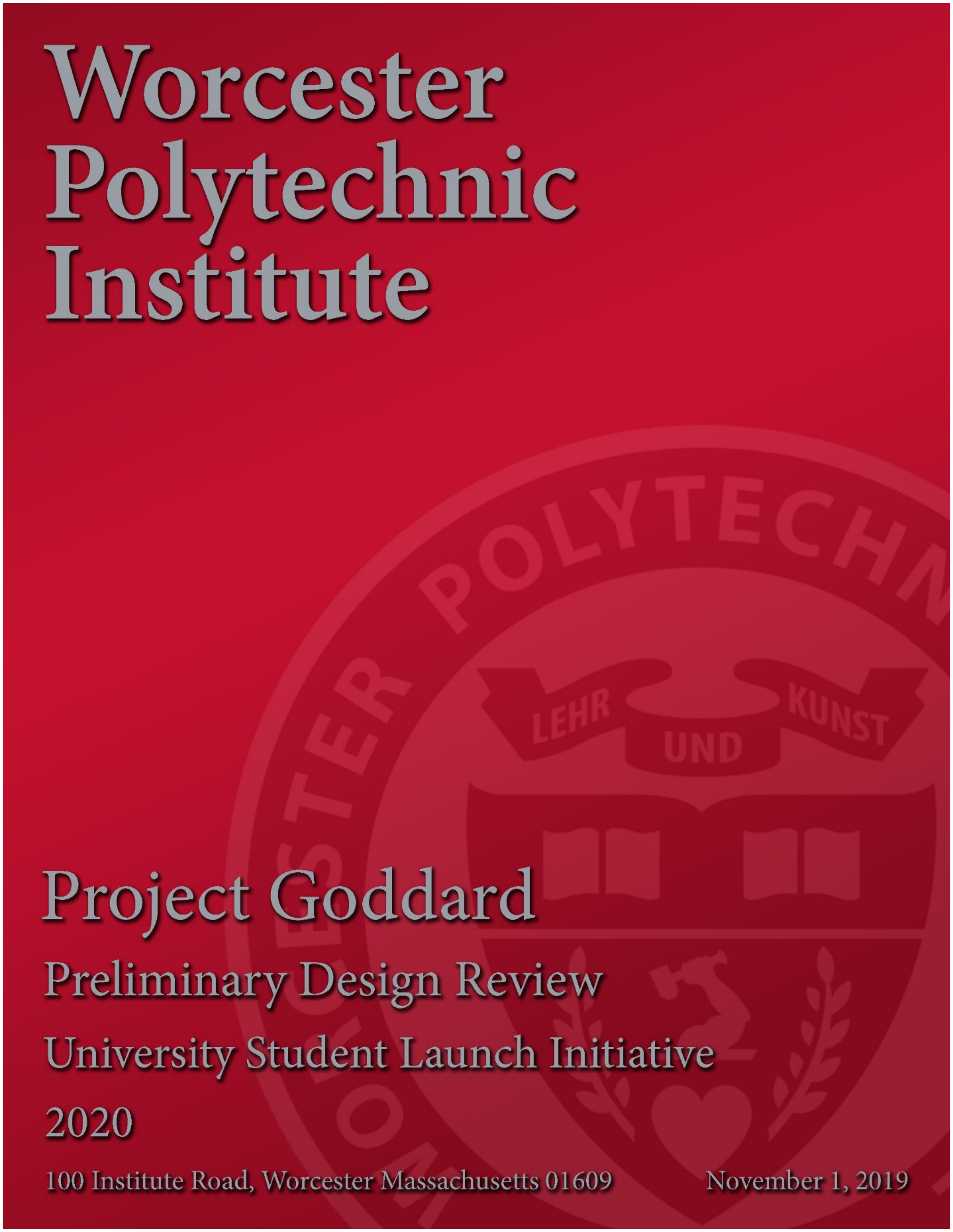

Worcester Polytechnic Institute

Project Goddard

Preliminary Design Review

University Student Launch Initiative

2020

100 Institute Road, Worcester Massachusetts 01609 November 1, 2019

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Acronym Definitions

3D: Three Dimension
AGL: Above Ground Level
AIAA: American Institute of Aeronautics and Astronautics
APCP: Ammonium Perchlorate Composite Propellant
CNC: Computer Numerical Control
CTI: Cesaroni Technology Incorporated
ESC: Electronic Speed Controllers
E-Bay: Electronics Bay
FMEA: Failure Modes and Effects Analyses
GPS: Global Positioning System
LiPo: Lithium Polymer
LoRa: Long Range
MSDS: Material Safety Data Sheet
NAR: National Association of Rocketry
NASA: National Aeronautics and Space Administration
PETG: Glycol Modified Polyethylene Terephthalate
PLA: Polylactic Acid
PPE: Personal protective equipment
RSO: Range Safety Officer
SLI: Student Launch Initiative
STEM: Science, Technology, Engineering, and Math
TRA: Tripoli Rocketry Association
UAV: Unmanned Aerial Vehicle
USLI: University Student Launch Initiative
WPI: Worcester Polytechnic Institute

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Executive Summary

This document is the written proposal of Worcester Polytechnic Institute's (WPI) local American Institute of Aeronautics and Astronautics (AIAA) chapter for the National Aeronautics and Space Administration's (NASA) University Student Launch Initiative (USLI) competition. The Academic Affairs Office at NASA Marshall Space Flight Center (MSFC) conducts the Student Launch Initiative (SLI) each year.

The goal of WPI's USLI team is to design a rocket and payload to complete the requirements outlined in the Student Launch Handbook. In summary, these goals are to launch a rocket containing a selected payload, which will (upon landing) deploy and complete a simulated lunar ice recovery mission. In order to achieve these requirements, the team has split into two divisions; a rocket team and a payload team each further splitting into smaller sub-teams working on individual components of the rocket or payload. Each division will collaborate and design compatible parts to launch and deploy in sequence, land and complete the outlined objectives. Upon test launches, minor changes will be made based on experimental data to ensure the success of our goals. All changes made will be reviewed by the team's mentor, NASA SLI representative and Range Safety Officer (RSO) to ensure that they comply with safety protocols outlined by the National Association of Rocketry (NAR) and the Federal Aviation Administration (FAA).

Mission Statement

Through competing in USLI, our team aims to help our members develop an understanding of teamwork, rocketry, robotics, and the engineering design processes and to share the knowledge we gain through this competition with our community to promote interest and excellence in Science, Technology, Engineering, and Math (STEM).

Team Summary

1.1. Adult Educators

Jason Nadeau

Lake Winnipesaukee High Powered Rocketry

Mentor

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Associate Professor, Mechanical Engineering

University Advisor

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1.2. Team Leaders

Christian M. Schrader

Captain

BS Aerospace Engineering

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(781) 290-3098

Christian Maximilian Schrader is a Junior pursuing an Aerospace Engineering major and Computer Science minor. He currently has a level 1 high powered rocketry certification and is pursuing a level 2 certification. As Captain, his responsibilities include being a point of contact for the team, leading the Officer Board, and coordinating the team as a whole. This includes planning to ensure the team meets deadlines and ensuring the team follows competition regulations from NASA (National Aeronautics and Space Administration), WPI (Worcester Polytechnic Institute), and AIAA (American Institute of Aeronautics and Astronautics). His experience includes becoming an Eagle Scout, working as an Intern Group Lead at NASA Ames, and serving as the Safety Officer and Co-Founder on the team last year.

Sophie Balkind

Rocket Lead

BS Aerospace Engineering

sbalkind@wpi.edu

(978) 270-2900

Sophie Balkind is a Junior Aerospace Engineering major with concentrations in both aeronautics and astronautics. She is currently pursuing her level 1 certification in high powered rocketry. As Rocket Lead, Sophie’s responsibilities are to facilitate the design, construction, and documentation of the Launch Vehicle. She will lead the design of the launch vehicle with input from the other officers and general team members. When time for construction Sophie will ensure that the team has adequate knowledge through workshops, organize construction times, and aid in the actual construction. She is also responsible for leading sub teams within the Rocket Division and communicating with the captain and payload lead. Sophie’s background participating in Sailbot provided her with a technical and competitive background. Her participation in Real World Design Challenge in high school also provided her with experience writing extensive technical reports.

Thierry de Crespigny

Payload Lead

Worcester Polytechnic Institute

BS Aerospace Engineering

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(650) 515-0615

Thierry de Crespigny is a Junior Aerospace Engineering major with concentrations in both aeronautics and astronautics along with minoring in Robotics Engineering. He is currently pursuing his level 2 certification in high powered rocketry. As Payload Lead, Thierry’s responsibilities are to facilitate the design, construction, and documentation of the payload. He will lead the design of the payload with input from the other officers and general team. During construction Thierry will ensure that the team has adequate knowledge through workshops, organize build and design times, and aid in the actual construction. He is also responsible for leading sub teams within the Payload Division and communicating with the captain and rocket lead. Thierry’s background participating in Battle of the Rockets provided him with a technical and competitive background in designing and building payloads.

1.3. Safety Officer

Veronika Karshina

Safety Officer

BS Aerospace Engineering

vkarshina@wpi.edu

Veronika Karshina is a Sophomore at WPI pursuing a Bachelor of Science in Aerospace Engineering with a minor in Computer Science. Currently pursuing her class 1 certification in high powered rocketry, Veronika has taken a principle of personal and social safety class in high school where part of the syllabus included safety procedures in case of dangerous chemicals release. Veronika has received a junior lifeguard training and was a counselor in training at a summer camp, where she got more training in first aid. Veronika Karshina was a member of WPI USLI (University Student Launch Initiative) team last year, where she was involved closely in the design, construction and launch of the rocket, learning safety principals along the way. All this training and skills gained from it make Veronika Karshina qualified to be Safety Officer of this team.

1.3.1. Safety Officer Roles

The role of the Safety Officer is to ensure the wellbeing of all people, objects, and facilities affected by the inherently dangerous task of manufacturing and launching a class 2 launch vehicle. Our Safety Officer, Veronika Karshina, will supervise a group of safety personnel drawn from every sub team of the WPI USLI team. The Safety Officer will examine the potential risks of using various hazardous materials or procedures and create a risk mitigation plan for each such instance. WPI USLI defines risks as follows:

- potential for bodily harm
- potential for damage/destruction of personal property
- potential for damage/destruction of equipment
- potential for damage/destruction of facilities
- Any other potential risk that the Safety Officer or Safety Personnel deems critical

In addition to risk definition and management, the Safety Officer must have in depth knowledge of NAR (National Association of Rocketry) High Powered Rocketry Code. It is the role of the Safety Officer to maintain compliance with this code as well as risk recognition and mitigation plans throughout the team. The Safety officer will complete this task by supervising a team of safety personnel that will be instructed in all relevant codes and plans. It will then be the safety personnel's' job to be present at all USLI event where potential risks could arise and ensure all codes/plans are followed during the duration of the event.

Lastly, it is the role of the Safety Officer to ensure that that all team members are versed in NAR High Powered Rocketry Code and with the safety procedures detailed above. This will be done through mandatory safety trainings, maintaining availability of safety personnel, written procedures/codes, and fostering a culture of asking clarifying questions regarding procedures, laws, regulations, or risks.

1.4. General Officers

Adrianne Curtis

Philanthropy Officer

BS Aerospace Engineering

aecurtis@wpi.edu

(860)930-4257

The responsibilities of the philanthropy officer include:

- Creating a sponsorship package for potential sponsors
- Making connections with potential sponsors and gather sponsorship funds for the team
- Maintaining a positive relationship with sponsors

Jeremiah Valero

Documentation Officer

BS Aerospace Engineering

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(774) 312-0138

The responsibilities of the documentations officer include:

- Compile all sections of the document
- Finalize all documents to NASA Student Launch Standards
- Ensure that documents are coherent, and the information contained is adequate

Connor Walsh

Outreach Officer

BS Aerospace Engineering

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(978) 846-5438

The responsibilities of the outreach officer include:

- Setting educational engagement goals for the team
- Contacting and working with organizations and programs around WPI focused on STEM (Science Technology Engineering and Math) engagement for children and the community around Worcester
- Creating educational engagement activities for events throughout the year

Chris Renfro

Social Media Officer

Worcester Polytechnic Institute

BS Aerospace Engineering

crenfro@wpi.edu

(508) 365-8470

The responsibilities of the social media officer include:

- Responsible for the team’s social media presence, merchandise, and the website

Kirsten Bowers

Treasurer

BS Aerospace Engineering / Minor in Electrical and Computer Engineering

kmbowers@wpi.edu

(716) 255-3417

The responsibilities of the treasurer include:

- Managing the budget and handling purchasing

Troy Otter

Logistics Officer

BS Aerospace Engineering

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(508) 455-8828

The responsibilities of the logistics officer include:

- Coordinating transportation and lodging for the competition and test launches
- Facilitate spaces to store and build the launch vehicle

1.5. Officer Structure

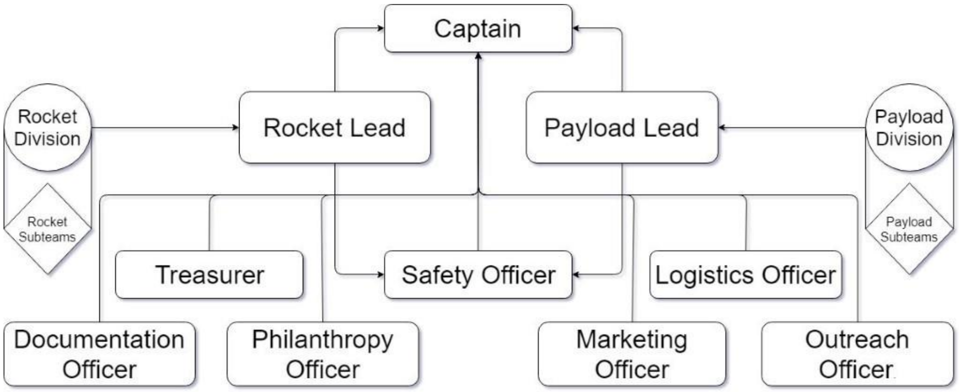


Figure 1.3.1.1 Officer Structure

The above image shows the organization of the officer team, At the head is the captain who oversees all the officers in their duties. The rocket lead, payload lead, and captain form the executive board of the team which makes high level team decisions. Each lead is responsible for their respective division and ensuring that all of their respective aspects of the project are completed. They are also overseen by the safety officer who ensures all member are conducting their work in a safe manor. Below them are the officers for documentation, philanthropy, marketing, outreach, logistics, and treasury who report up to the captain.

1.6. General Members

The rest of the team is made up of general members. Each one is part of a divisions. As of the time of submission, the team has 44 general members. Over the course of the year, this number is expected to fall slightly as a few members lose interest or realize the competition is not for them. This number has significantly increased from last year. In our previous proposal, we reported a team size of 20 general members. Thanks to this significant growth, the team expects to both decrease the workload per student and increase the quality of analysis, testing, and design.

2. Launch Vehicle Summary

The launch vehicle is primarily composed of Always Ready Rocketry Blue Tube 2.0, with foam core carbon fiber fins, and both aluminum and Nylon-X components for the various subassemblies. Designed to reach an apogee of 4750’, the vehicle separates into two sections under drogue connected with shock cord, and then separates into two components with separate main deployments at 550’. Each section will contain its own global positioning system (GPS) tracker. The payload retention system is housed within the upper airframe and nosecone. The lower airframe contains the fin can, motor retention system, and electronics bay, and is connected through the electronics bay to the middle airframe. In addition to this, the middle airframe houses the recovery system. The motor retention system is based on a Aero Pack flanged motor retainer system, with various design improvements to decrease manufacturing complexity. It also incorporates a tail cone to improve vehicle aerodynamics.

The vehicle will be using a Cesaroni Technology Incorporated (CTI) L645 reloadable motor, propelling the vehicle to its 4750’ apogee. The recovery system consists of a single 36” drogue, and a 102” and 84” in main for the lower and upper sections respectively. At apogee, the middle airframe and upper airframe are separated using a black powder charge, deploying the drogue chute and releasing the main chutes. The sections are together under drogue by a Tinder Rocketry Tender Descender until 650’. The main parachutes are held closed by a Jolly Logic Chute Release, which will deploy the chutes at 550’.

The launch vehicle’s flight data will be recorded using StratoLoggerCF that will be housed in the electronics bay. The electronics bay will be bolted between the lower and middle airframe and will also contain the launch vehicle’s batteries.

3. Payload Summary

The goal of the payload is to deploy a UAV which can fly to the sample site and collect a soil sample. The portion of the payload which safely retains and then deploys the UAV is called the Retention System. The retention system will extend the payload from the launch vehicle’s tube via a lead screw. The retention system will then rotate to point the UAV upwards. A scissor platform will then lift the UAV above the retention system body where the UAV will then have its four arms swing out. Two latches will fold away and unsecure the UAV. The props will automatically extend when the motors spool up and the UAV will leave the retention system. The UAV will then fly to the sample area where it will land and use a scoop on the bottom of the craft to scoop up the soil sample. The UAV will then take off and fly away to complete the challenge.

Figure 1.3.1.1 Isometric View of Payload

4. Changes Made since Proposal

4.1. Airframe

Our initial airframe design consisted of the upper, middle, and lower airframe with respective lengths of 24”, 18”, and 34”. The lengths have changed to 26”, 28”, and 33”, respectively, to fit updated components (payload retention system, motor, electronics bay). The measured outer diameter of the airframe has also changed from 6” to 6.079”. This change in value is a result of more accurate measurement of the airframe.

In the proposal document, we had considered both Blue Tube and carbon fiber as potential materials for the launch vehicle. Our hope was to reach an agreement with a potential sponsor to be provided with carbon fiber as a donation to our team, eliminating the cost of the material. Our sponsor did not get back to us with our timeframe, so we decided to use Blue Tube for the launch vehicle so that we could move ahead in the design and build process. Carbon Fiber would have been a stronger material choice but the budget for our club meant that we would be unable to buy it and were reliant on this potential sponsor if we were to use carbon fiber.

Additionally, the launch vehicle will have a gloss coat of spray paint to seal the airframe from water damage, because we launch on a frozen lake and other locations covered in snow. The spray paint will also be used for cosmetic purposes to add design to our launch vehicle. The switch to Blue Tube and spray paint will increase the total weight of the launch vehicle.

4.2. Ballast

The ballast system will be a housing 3D (Three Dimension) printed from Nylon-X to fit into the airframe at the launch vehicles center of gravity. It will be attached using epoxy approximately 7” from the electronics bay, wherever the final measured center of gravity is located. The casing will have 8 equally spaced holes, each holding a machined steel cylinder, with a lid to hold the cylinders in. The ballast system will be able to hold up to 2 lb., including the weight of the system itself. We will be using the constructed weight of the subscale to estimate the constructed mass of the full scale to refine our estimate. The ballast system will be used to lower the apogee of the rocket to our predicted apogee, as well as account for any weight variations in the final rocket from what is currently predicted.

4.3. Fin Can and Motor Retention System

The fin can design was modified since the proposal to be lighter, consist of fewer components, and be easier to machine. The switch from a threaded closure to a bolted flange reduces the overall weight of the component, as well as dramatically decreases machining complexity as it removes all threads from the assembly. This also means that the tail cone was extended to reach the bottom of the retention system, replacing the angled closure.

4.4. Projected Parachute System

The tender descender will separate at 650 feet Above Ground Level (AGL), as opposed to 575’ as previously designed, in order to accommodate the parachute release. The parachutes are still using the Jolly Logic chute release which will hold the main parachutes closed until their deployment at 650'. The chute release will be programmed for 650' in order to ensure that the parachutes will be completely opened by 550' AGL.

4.5. Projected Flight Plan

As a result of various design changes, as well as motor changes, the flight plan has changed since the proposal. With our new primary motor, the CTI L645, our fully ballasted apogee is now 4703'. With our secondary motor, the CTI L851, our fully ballasted apogee is 5232 ft. More information on specific flight plan data can be found in section 3.2.2

4.6. Project Plan

Since the proposal, the team's subscale preparation timeline has changed and become more defined. Aside from the motor, all components have been ordered. The team plans to launch it on the weekend of the 23rd. The vehicle will finish construction a week before the launch allowing for time to prepare for the launch by training members in the vehicles preparation and creating initial versions of launch procedures.

The team's fundraising efforts have continued according to plan since the proposal. The corporate sponsorship package has been officially approved by WPI and has been sent out to multiple companies and organizations. The sponsorship package itself has been slightly modified from the original plan, specifically the amount of money per specific tier, being bronze, silver, gold and platinum. Refer to section 6.2 for the specific monetary values.

4.7. Motor

The original motor options were CTI's L910 for our main, L645 for our back up. As a result of an increased rocket weight from the proposal, we have switched to the more powerful L645 as our main motor, with the L851 as our backup. The L645 allows us to reach an apogee that falls comfortably within the limits set by the competition requirements, in our case 4750 ft. In the case that our rocket is above the expected weight and the apogee provided by the L645 becomes too low, our backup L851 provides a higher apogee.

4.7.1. Motor Selection

From our original proposal, our motor has changed from the CTI L910 motor to the CTI L645-P to accommodate other changes to our launch vehicle.

The L645-P is an L class motor, manufactured by Cesaroni technology, and the chosen primary motor for the launch vehicle. The motor uses an E-match igniter and has a diameter of 2.95". As can be seen in Figure 4.7.1.1 L645-P Specifications and Figure 4.7.1.2 L645-P Thrust Over Time the L645-P has a total impulse of 3419.8 Ns. OpenRocket 15.03 was used to simulate the flight of the vehicle with the L645.

Motor Specifications	L645
Average Thrust	644.8 N

Class	33.6% L
Delays	Plugged Seconds
Designation	L9645-P
Diameter	75.0 mm
Igniter	E-Match
Length	486.0 mm
Letter	L
Manufacturer	CTI
Name	L645
Peak Thrust	776.6 N
Propellant	APCP (Ammonium Perchlorate Composite Propellant)
Propellant Weight	2072 g
Thrust Duration	5.3 s
Total Impulse	3419.8 Ns
Total Weight	3751.8 g
Type	Reloadable

Figure 4.7.1.1 L645-P Specifications

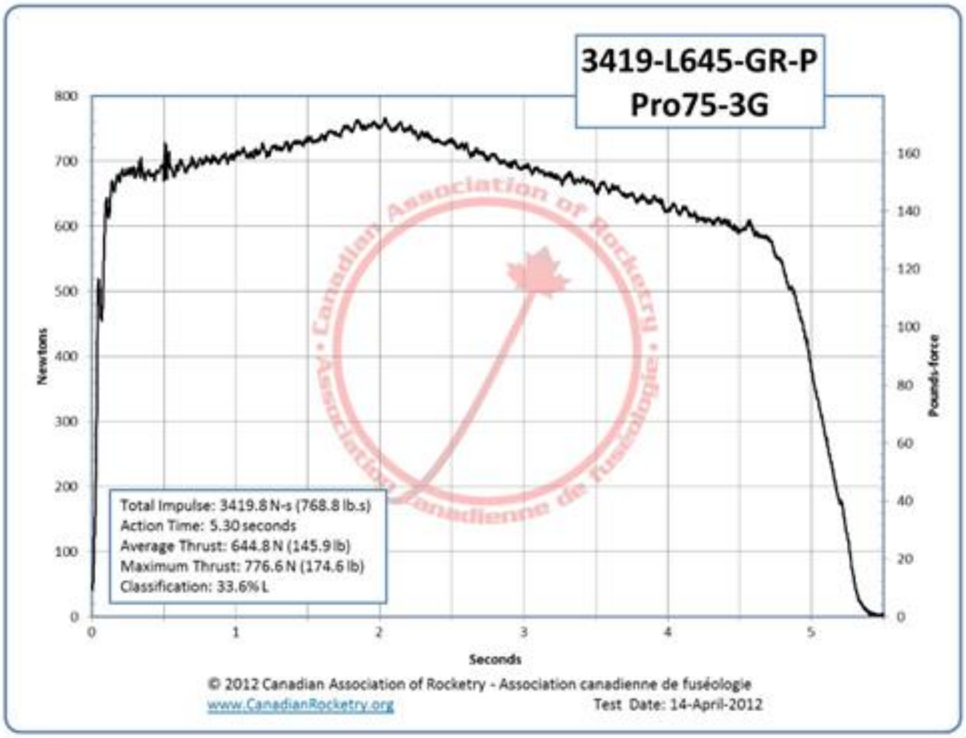


Figure 4.7.1.2 L645-P Thrust Over Time

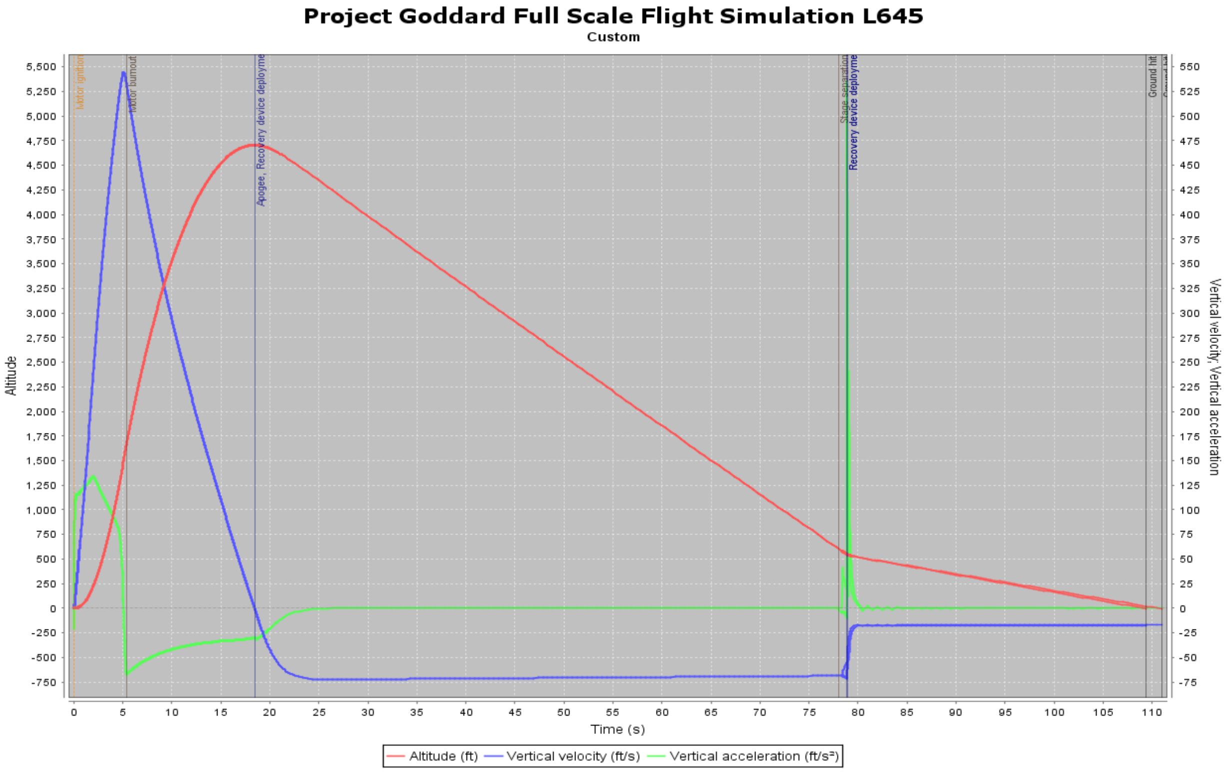


Figure 4.7.1.3 Flight Simulation

The L851-P serves as the backup motor. This motor is 19.13” in length, 2.95” in diameter and has a total impulse of 3683.2 Ns. These values are higher than that of the L645, which allows us to switch to this motor should the rocket weigh more than expected, however the ballast system should allow for more variations in this.

Motor Specifications	L851
Average Thrust	849.1 N
Class	43.9% L
Delays	Plugged Seconds
Designation	L851-P
Diameter	75.0 mm
Igniter	E-Match
Length	486.0 mm
Letter	L
Manufacturer	CTI
Name	L851
Peak Thrust	989.9 N
Propellant	APCP
Propellant Weight	2,110 g
Thrust Duration	4.34 s
Total Impulse	3683.2 Ns
Total Weight	3789 g
Type	Reloadable

Figure 4.7.1.4 Backup Motor Specifications

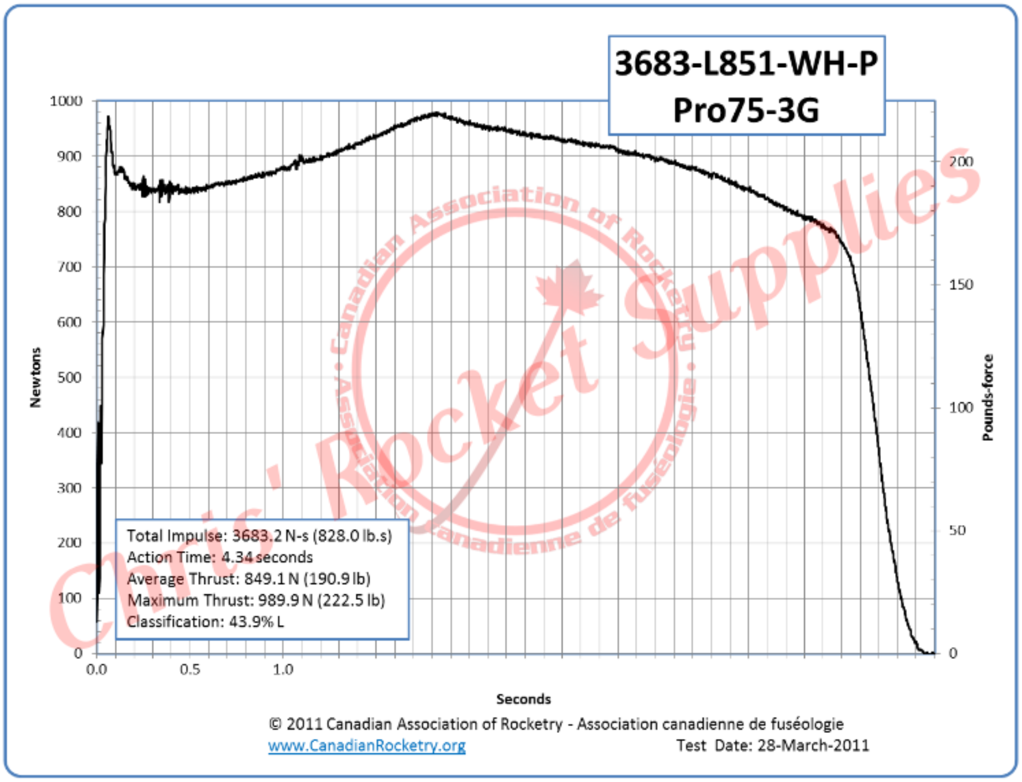


Figure 4.7.1.5 Thrust vs Time (Backup)

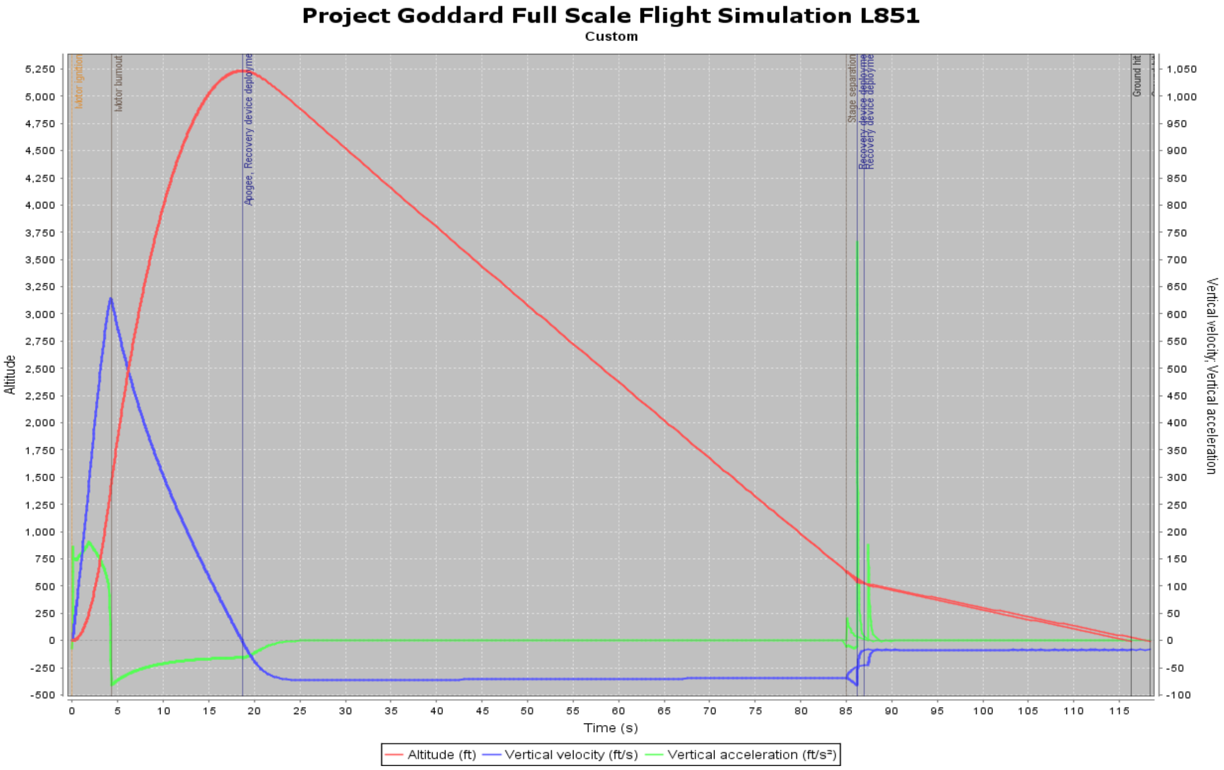


Figure 4.7.1.6 Flight Simulation (Backup)

5. Vehicle Criteria

5.1. Selection, Design and Rationale of Launch Vehicle

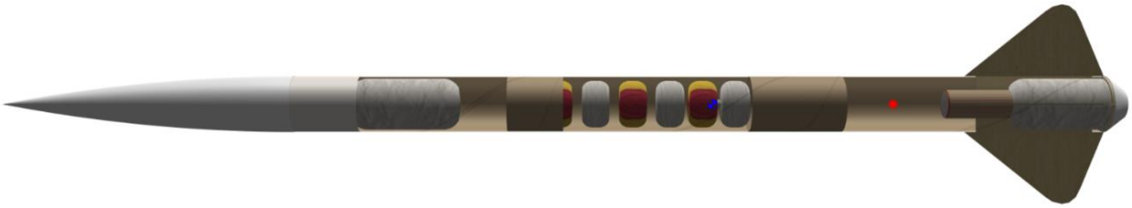


Figure 4.7.1.1 Cut Away view of launch vehicle

Figure 4.7.1.2 Render of Launch Vehicle

5.1.1. Nose Cone

Our chosen nosecone is of a tangent ogive shape, with a length of 31” and a shoulder length of 7.13”. The nosecone is constructed out of fiberglass, due to its high strength and relatively low weight, the weight of the aluminium tip will improve stability by raising the center of mass. The aluminium tip will also improve the structural integrity of the nosecone since it will take the impact forces of a nose-down descent and protect the fiberglass. This method was used last year as well and improved the nosecone’s durability during flight and recovery. The payload retention system will also be integrated within the nosecone and it will actively retain the nosecone with the use of a threaded drive rod as seen in section 4.1.3. No changes have been made to the nosecone design since the proposal.

Figure 5.1.1.1 Nose Cone

Some other alternative shapes for the nosecone are parabolic, elliptical, bi-conic, and spherical blunted. Since the launch vehicle will be travelling at transonic speeds, conical and ogive nose cones will work the best. When choosing between the conical and ogive designs, we decided that a tangent ogive had aero dynamical properties that would work best with our launch vehicle design.

5.1.2. Airframe

The launch vehicle was designed using Open Rocket version 15.03. The launch vehicle airframe is divided into three sections: upper airframe 26”, middle airframe 28”, and lower airframe 33”, each with an outer diameter of 6.079”. The diameter of the airframe provides the spatial capacity for components like the electrical bay and payload retention. The airframe holds the recovery system; parachutes, chute release, and tender descender; without restriction to ensure it will deploy smoothly. When the parachute it tightly packed into the airframe cavity it restricts the deployment and puts more stress onto the recovery system. According to the NAR, the airframe of a rocket must be able to withstand forces 40-60 times the rocket’s total weight of 33.93 lb., this was considered when making our material choice.

The airframe will be made of Blue Tube due to its durability and resistance to abrasion. Furthermore, Blue Tube is less costly and considerably lighter than fiberglass. These characteristics make this material useful for the purpose of the launch. To seal our airframe from water damage, we will use either epoxy or spray paint to waterproof the rocket.

We chose to separate the airframe sections at the specified lengths in order to incorporate the necessary systems for our launch vehicle. The upper airframe of the launch vehicle will house the selected payload and will also act as a retention system. The middle airframe of the launch vehicle will house the three parachutes associated with the recovery system. The coupler connecting the middle and lower airframe components will be used to house the electronics bay and is made of Blue Tube inner tube. The lower airframe of the launch vehicle will house a 25” long inner tube of 2.15” outer diameter and 2.11” inner diameter to house the selected motor. The inner tube will also be constructed out of Blue Tube. The lower airframe will also hold the attachments for the fin can.

The entirety of the launch vehicle’s construction will be carried out on the campus of Worcester Polytechnic Institute within the Foisie Innovation Studio, Washburn Shops, Higgins Laboratories, and the Robotics Pits. Proper safety measures will always be taken to ensure the safety of the members during the launch vehicle’s construction.

5.1.3. Ballast System

The ballast system will be made up of a 3D printed body housing various steel ballast cylinder. The body and lid will be printed from Nylon-X filament to ensure the housing’s ability to retain the ballast. It will be attached using epoxy to the middle airframe, approximately 6” above the electronics bay at the center of mass. By attaching the ballast at the center of mass, there is no effect on the stability of the rocket and adding or removing weight will only affect the rocket’s apogee.

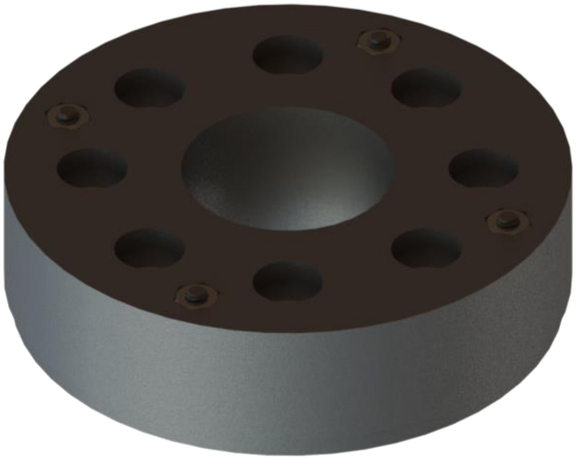


Figure 5.1.3.1 Showing Ballast System

The housing will have eight equally spaced holes, each holding a machined steel cylinder, with a diameter of 1”, and a height of 1.125”, with a lid to hold the cylinders in. With each steel cylinder weighing 0.25 lb., we will be able to ballast the rocket in increments of 0.25 lb. while preserving stability. As the ballast will be located above the electronics bay, the design includes a large hole through the center to allow the shock cord to pass through to the U-Joint at the top of the electronics bay.

The maximum ballast capability of the system will be 2 pounds. Our apogee estimate will be based on a maximally weighted ballast, however, an increase in the weight of the rocket will be expected, as OpenRocket 15.03 cannot account for variables in weight such as epoxy use. As we expect the rocket to be heavier than what is indicated in the software, having an adjustable ballast allows us to remain close to our calculated apogee taking this weight change into account.

One of the alternatives for the ballast system is to use a software that can estimate the rockets weight more accurately than OpenRocket 15.03. Doing so, we would not need a ballast system at all, as our apogee could already be based on the final weight of the launch vehicle. However, finding such a software is not trivial, and the number of variables that go into the final weight make it nearly impossible to get a precise estimation.

Another alternative would be to use an air brake system to actively adjust our apogee in flight. Using an active airbrake would not only account for any weight variations, but also for any variations in the thrust profile of the motor, likely bringing us closest to our planned apogee if tuned. Our team determined that designing an airbrake system would be unfeasible for this competition, as doing so would be a significant engineering and programming challenge and would require multiple test flights to correctly adjust the control system. The team is already incorporating a completely new fin can and motor retention system, as well as exploring a new recovery system, and did not feel we could dedicate the necessary resources to such a development.

A final alternative is to forego any type of active apogee control and estimate the apogee to the best of our ability based on the OpenRocket 15.03 calculations and previous experience of added weight. However, with the relative simplicity of a ballast system, and the affect our apogee can have on the success of our rocket, it was determined that a ballast system was the best option.

5.1.4. **Fins**

The fins will provide stability throughout our launch vehicles flight by determining the locations of the center of pressure for the launch vehicle. A stable launch vehicle requires the center of pressure be behind the center of gravity, along the ram axis. Fines increase the surface area of the launch vehicle to affect the center of pressure in a desired manner. The distance between the rockets center of gravity and center of pressure defines the launch vehicles stability. If a rocket is too stable, it can become susceptible to weather cocking and turn into the wind. Therefore, adequate stability factors are required to maintain a successful vertical flight.

Our rocket design consists of four fins attached in a fin can at the rear of the rocket. The fins will be bolted into the can via 4.25-20 x 1.75” bolts. The fin tabs that are inserted into the fin can will be 12.5” x 1.49”. Each of these fins will be a total length of 15 inches.

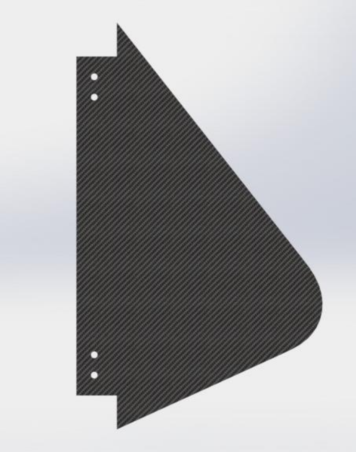


Figure 5.1.4.1 Carbon Fibre Foam Composite Fin

The shape of the fin is considered a modified delta as seen in Figure 5.1.4.1 Carbon Fibre Foam Composite Fin. The modifications we have chosen for the fin include a rounded trailing corner as well as sweeping the trailing edge to the rear of the rocket. We have also decided to chamfer the leading, outer edge of the rocket fin. These modifications were made to reduce the amount of drag and to achieve the desired stability.

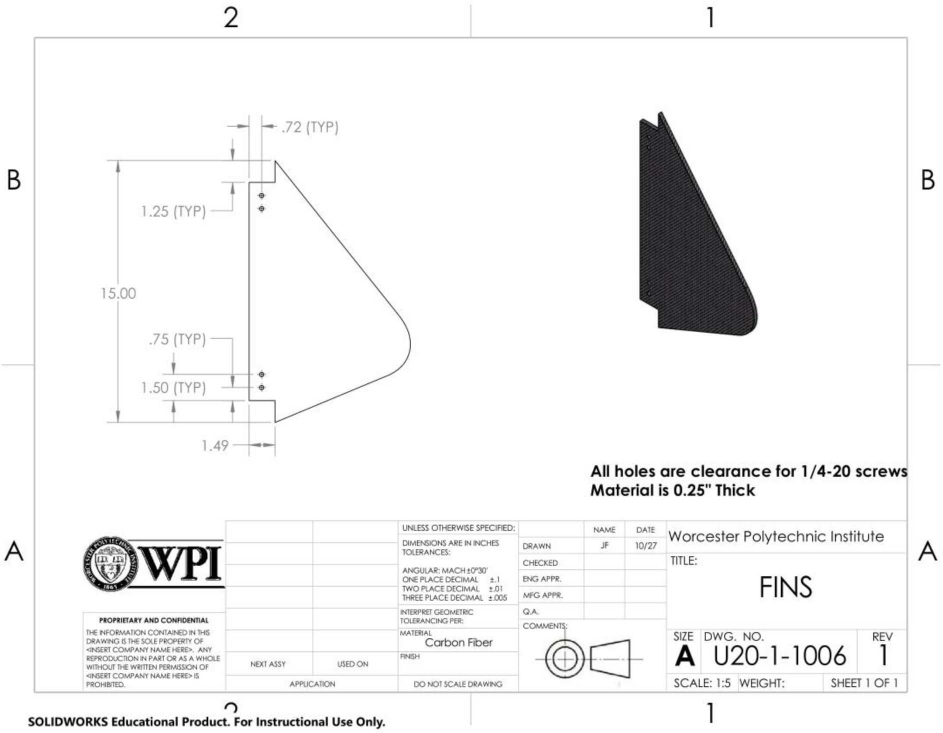


Figure 5.1.4.2 Fin Technical Drawing

This shape will be easily manufactured, as proven by a trial fin that we made. The fin is constructed with a carbon fiber (2x2 twill weave pattern) exterior molded around a foam interior with the leading edge being constructed out of 3D printed Glycol Modified Polyethylene Terephthalate (PETG). The carbon fiber exterior will provide the rigid structure and strength needed to absorb a hard landing of the launch vehicle. The interior being made of 3D printed material (PETG) and foam (1/8-inch polyurethane) helps bring the total weight of the fins down while also providing structure for the carbon fiber. The constructed fin will be approximately 0.25" thick. We have successfully made a trial fin of carbon fiber exterior around a foam core. This has given us the confidence that the design will be able to be made using the materials and processes described below.

The fin will be constructed by cutting the foam piece with a knife using a template of the final shape of the fin while leaving space for a 3D printed chamfer to be added later. The 3D printed leading edge will then be printed and placed adjacent to the foam cut out to create a full fin interior. This interior will be coated generously with epoxy and we will then lay the carbon fiber fabric on top and add more epoxy to ensure the proper finish. Once this is done the same process will be completed for the opposite side of the fin. To ensure a proper seal between both sides of the fin we will use a brush to dab epoxy over the edges of the fin to allow all fabric to get enough epoxy. The fin will then be laid between two glass surfaces to ensure a smooth finish on both sides of the fin. This glass set up will be placed and sealed in a vacuum bag and placed in a temperature chamber to ensure a proper cure. When the fin has cured, the edges will be trimmed and sanded to the appropriate dimensions.

Alternatives

In the early stages of design, the launch vehicle needed the larger fin area as shown below. We had chosen a rounded trapezoidal fin shape which has a higher area with a greater distance to the CG, which we no longer needed.

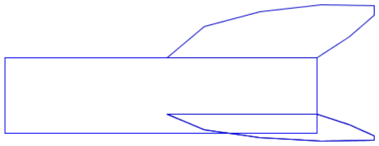


Figure 5.1.4.3 Version 1 Fin Shape 1

As components of the launch vehicle and payload came together, it became evident that the rocket would become over stable. We adjusted the fin shape to a modified delta fin shape to correct for this.

5.1.5. **Fin Can**

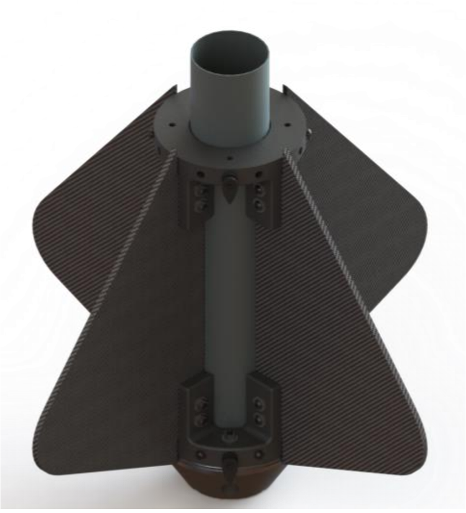


Figure 5.1.5.1 Showing Fin Can assembly

The fin can is a system designed to both hold the fins in place, as well as provide a mounting point for the motor retention system at the bottom of the rocket. The fins will be held in by two 3D-printed fin brackets printed out of Nylon-X, a strong and lightweight carbon fiber reinforced nylon filament.

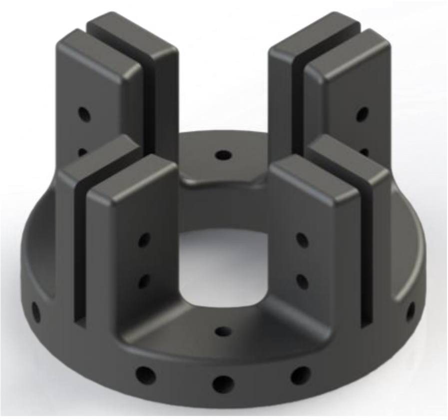


Figure 5.1.5.2 Showing Fin Bracket

Each fin bracket will be held within the lower airframe by four 0.25”-20 bolts placed through the outside of the airframe. The fin brackets will have holes with 0.25”-20 expanding threaded inserts to accept the bolts. At the top fin bracket, four bolts will be spaced around the bracket, and at the bottom, each panel will have two bolts, totaling eight bolts on the lower bracket. Alongside the bolts, the rail buttons will be bolted to the fin brackets using the same expanding inserts. Each bracket accepts two bolts per fin, placed through holes in the fin tabs. The fin brackets have the dual effect of acting as the centering rings for the motor tube.

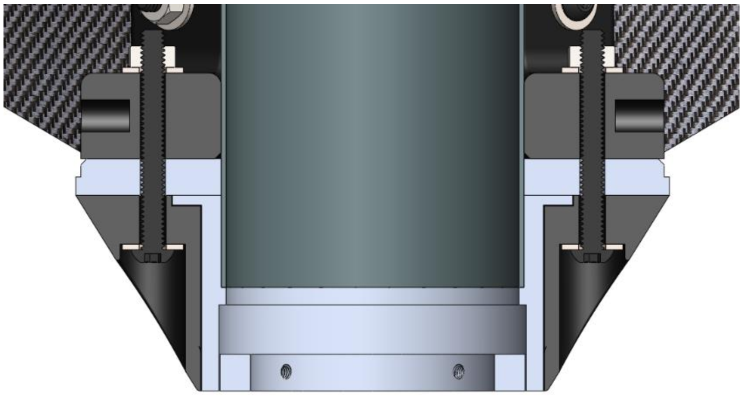


Figure 5.1.5.3 Showing Cross Section of Motor Retention System and Fin Bracket

The motor retention system makes up the lower portion of the rocket’s airframe. Its primary purpose is to secure the rocket motor within the rocket body, withstand the thermal effects of the motor firing, and allow for the removal of components after flight. The outermost portion of the system is a 3D printed tail cone, made from Nylon-X, improving the aerodynamics of the bottom of the rocket.

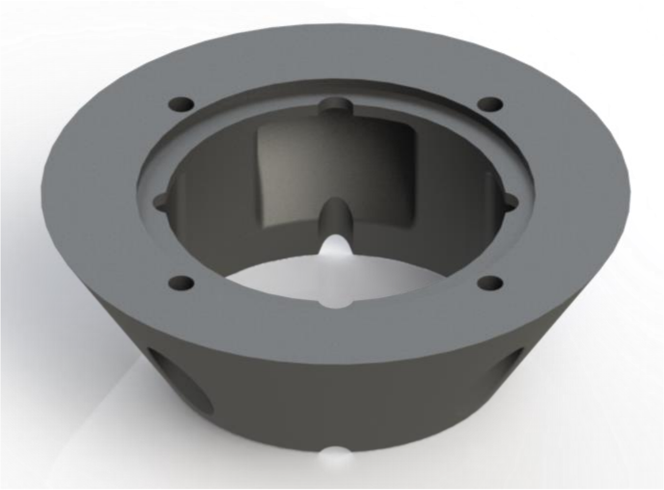


Figure 5.1.5.4 Showing Cross Section of Motor Retention System and Fin Bracket

The tail cone mounts to the launch Vehicles body through four 0.25”-20 bolts that pass through the thrust plate and the lower fin bracket. The tail cone serves to secure the motor retention sleeve against the thrust plate. The motor retention sleeve, CNC (Computer Numerical Control) machined out of 6061-T6 Aluminum, is epoxied to the bottom of the motor tube, and contains a space for the aft closure beneath an internal flange, designed to transfer the force of the motor through the sleeve to the thrust plate. Below this, a series of 4 holes sized to fit #8-32 bolts allow for the attachment of the motor retention flange, a small disk with 4 threaded #8-32 bolt holes, that prevents the motor casing from ejecting from the bottom of the rocket.

The thrust plate is CNC machined out of a piece of 0.375” 6061-T6 aluminum, and seats on the bottom of the lower airframe, with a flanged edge halfway along its thickness to contact the bottom of the airframe. The thrust plate serves to transfer the force of the motor to the airframe, negating the need for epoxied centering rings, while adding modularity and ease of disassembly to the motor retention system.

Figure 5.1.5.5 Showing Thrust Plate

Stress analysis was conducted on both the motor retention sleeve and on the thrust plate to ensure that they would be able to handle the forces of the motor firing. Our primary motor exerts a maximum force of 1047.5N, so the parts must be designed to handle that force.

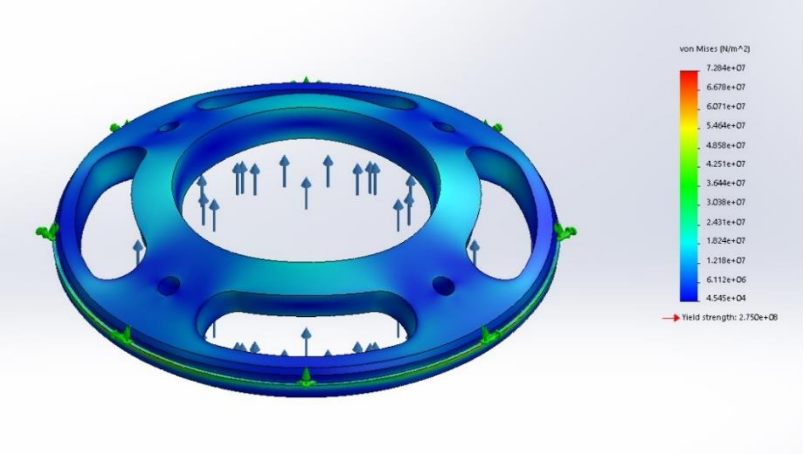


Figure 5.1.5.6 Showing von Mises Stress on Thrust Plate

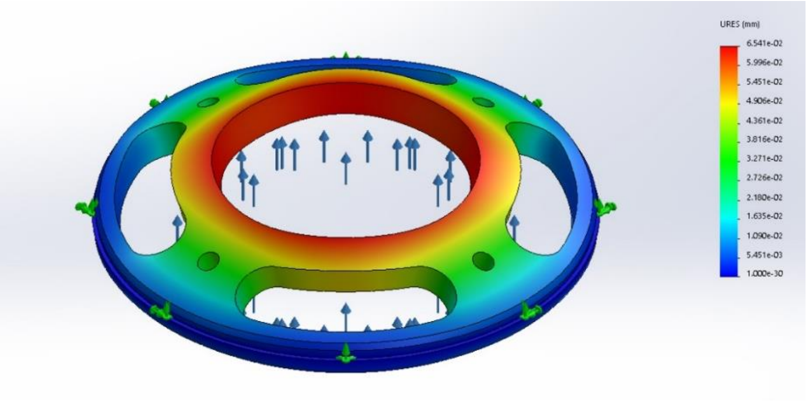


Figure 5.1.5.7 Showing von Mises Stress on Thrust Plate

For the thrust plate, the maximum von Mises Stress was calculated as 7.284e+07 N/m^2. With the yield strength for Aluminum 6061-T6 at 2.75e+08 N/m^2, the resulting safety factor is 54.9, well above our limit of 3. However, to reduce the amount of material in the part in order to lighten it and bring it closer to a reasonable safety factor would make it more difficult to machine. Displacement is also negligible, with a maximum displacement of 6.541e-02 mm.

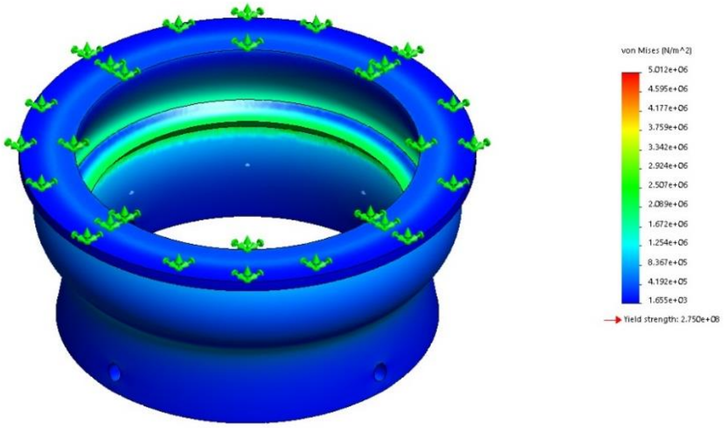


Figure 5.1.5.8 Showing von Mises Stress on Motor Retention Sleeve

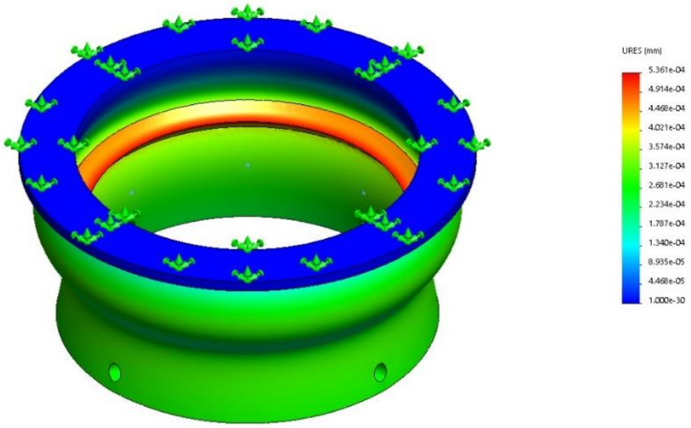


Figure 5.1.5.9 Showing Motor Retention Sleeve Displacement

For the motor retention sleeve, the maximum von Mises Stress was calculated as 5.012e+06 N/m^2. With the yield strength for Aluminum 6061-T6 at 2.75e+08 N/m^2, the resulting safety factor is 3.78, above our limit of 3. Displacement is also negligible, with a maximum displacement of 5.361e-04 mm.

The fin can and motor retention system designs allow for modularity and easy assembly and disassembly of the lower airframe, making shipping considerably cheaper and easier. As only the motor retention sleeve and motor tube are permanently attached, should a part be damaged this design would allow us to replace it easily.

Components of the Motor Retention System

Component Name	Material	Purpose
Thrust Plate	6061-T6-Aluminum	Mounts to the bottom of the fin can, supports the motor retention system, and is subject to the majority of the forces during launch. A piece of 0.375” aluminum, the plate includes four holes allowing for 0.25” bolts to pass through the motor retention system and the fin can, sandwiching it between the two. The plate also features a flanged edge, allowing the upper half to fit inside of the rocket tube, while the bottom half is slightly larger, matching the outer diameter of the launch Vehicle.
Fin Bracket	Nylon-X	Provides secure mounting points for the fins, while preserving modularity and easy disassembly for transport. Serves as the mounting method for the fin can and motor retention system, through bolts attached through the outer airframe. Secures the motor retention system to the bottom of the Launch Vehicle.
Tail Cone	Nylon-X	Secures the motor retention sleeve and all attached components against the thrust plate. Improves aerodynamics at the bottom of the Launch Vehicle.
Motor Retention Sleeve	6061-T6-Aluminim	Located in between the aft closure and the thrust plate, the motor retention sleeve transfers the force of the motor to the thrust plate and attaches the motor tube to the retention system.
Motor Retention Flange	6061-T6-Aluminum	Prevents the motor casing from ejecting from the launch Vehicle while not under thrust

Alternative Designs:

An alternative design for the motor retention system was to use a series of brackets attached to the thrust plate to secure the motor casing in the motor tube. This design, while mechanically simpler, would complicate the integration of a tail cone onto the rocket. The motor needs to be offset downwards from the bottom of the rocket, to avoid excessive heating of the tail cone, which would be difficult to accomplish with the brackets. Our use of a thrust plate also requires a flanged sleeve to transfer the thrust of the motor to the thrust plate, which is not feasible with the bracket system while including the necessary motor offset.

The final motor retention system itself went through a series of design improvements during the design phase. The retention system is based on an Aeropack flanged retainer, which uses a motor retention sleeve which contains the motor tube and motor casing, and a thread on retainer cap to secure the motor casing into the rocket. This design allows for the incorporation of a motor offset to the bottom of the tail cone, and also allows for a flange at the thrust plate contact point. However, this specific design was not well suited for our needs, as the machining of each part would be needlessly complex. Through various design revisions, we settled on our current design, using the same sleeve with a separate internal flange that Is bolted to the sleeve, simplifying the machining, as well as reducing the weight and cost of the overall system.

5.1.6. Electronics Bay

The electronics bay will house primary and backup StratoLogger altimeters which will be wired to an external switch on the main body of the launch vehicle. When powered on, the altimeters will perform a specific set of beeps to ensure the continuity of the charges and indicate their recognition of the launch vehicle on the pad standing by for flight. The StratoLogger is a robust and accurate altimeter with a simple cost-effective design sufficient for our purposes, as it has been reliably used by many individuals in model rocketry for years. It is designed for the use of a dual-deploy system and provides real time altitude data to be used for telemetry systems while logging this data to be viewed after recovery of the vehicle. Though it does not have an accelerometer, the trackers will include an accelerometer and gyroscope for both transmitting and logging this data for analysis post-flight. The full electronics bay assembly will be contained in an inner tube frame with four small static pressure sampling holes on the sides of electronics bay necessary for a non-airtight yet sufficient seal to read the changes in pressure due to altitude variations during flight.

A two cell LiPo (Lithium Polymer) battery was chosen this year as opposed to the previously used 9-volt batteries. LiPo batteries have the highest energy density per weight and are very compact. They are better at handling the forces of launch so they can be reliably reused while 9-volt batteries get less reliable after every launch due to the forces and power draw from pyro ignitions. LiPos are additionally much more resistant to the cold, as our test launches will be done in the northern winter months, making them the more reliable selection. Wherever present, the LiPos will be physically shielded by their own 3D printed protective casing due to probable high temperatures, forces and pressure during flight.

The tracking system for the launch vehicle for flight analysis and recovery is a small custom assembled and programmed circuit board. Shown in Figure 5.1.6.1 Rocket tracker and telemetry prototype board below, this perf board assembly was made for rapid testing and debugging of the various components necessary for gathering both required and desirable flight data. Its modular design enables quick replacement of different components should one or more be suspected of failure or damage in flight and will be secured in the electronics bay using a 3D printed casing. Similar to the design used by the team last year, the peripherals include an Arduino Nano as the main processor and breakout boards for the NEO-6MV2 GPS and RFM95W LoRa (Long Range) radio transceiver. Unlike last year, these boards will include the MPU-6050 gyroscope and accelerometer as well as a data logging system for transferring data of interest in to an SD card to be analyzed post-flight. All of these components have the benefit of being readily available and having a large amount of resource information due to their widespread use, as this was a key factor in their selection for this assembly. Additionally, important data will be transmitted using the LoRa radios to the ground station in real time throughout the flight to act as a means of rapid analysis of the mission performance and a fail-safe should the launch vehicle be destroyed or in any way unrecoverable during the launch.

Figure 5.1.6.1 Rocket tracker and telemetry prototype board

The altimeters, batteries, and trackers along with additional necessary components will be secured to a plywood sled held within the electronics bay by brackets 3D printed from Nylon-X. The sled will be drilled to mount components and/or their 3D printed housings comfortably along the length of the electronics bay. These brackets, as well as two smaller brackets will serve as the mounting system for the electronics bay, being bolted with #8-32 hardware to the bulkheads and through the outer airframe. Such an attachment method eliminates loading on the sled due to ejection and transfers all the force into the airframe and coupler, allowing us to reduce the strength, and therefore weight of the sled.

Figure 5.1.6.2 Electronics bay cutaway view

The main and secondary LiPos will fit tightly in 3D printed casings which will slide and screw into the sled. For ease of access and efficient use of space, the components will be placed on both sides of the sled, with the batteries, altimeters, and pyros on one side, and tracker with the radio and GPS antennas on the reverse side. Both Stratologger altimeters will be shielded from electromagnetic interference from the antennas with a metal plate mounted on the sled. This modular design will improve ease of access to both essential flight components and the sled itself.

Alternatives

For our electronics bay, we used Stratologgers for our altimeter. Alternatives to this altimeter exists the notable Raven, which this team has used in past years. However, the Raven altimeter has failed due to technical errors in the past, so this team chose Stratologgers because it is a more reliable altimeter. Further, we chose Stratologgers over other altimeters due to its popularity among other USLI teams and in the amateur rocketry industry in general.

5.2. Recovery Subsystems

5.2.1. Projected Parachute System

The recovery system will consist of three parachutes to slow down the launch vehicle. All parachutes will be stored in the middle airframe. They will be stored with the drogue parachute will deploy at apogee and be stored in between the main parachutes in the middle airframe in accordance. The two mains for the upper and lower airframes will be held closed by a Jolly Logic Chute Release but will deploy from the airframe at apogee with the drogue parachute. At 650’, a Tinder Rocketry Tender Descender L3 will deploy and detach the upper airframe and its main from the middle and lower airframe. At 550’, the main parachute for the upper airframe and the main parachute for the lower airframe will deploy. The purpose of the drogue parachute is to slow the descent of the launch vehicle until the main parachutes are deployed resulting in the main parachutes not experiencing a high impulse upon deployment.

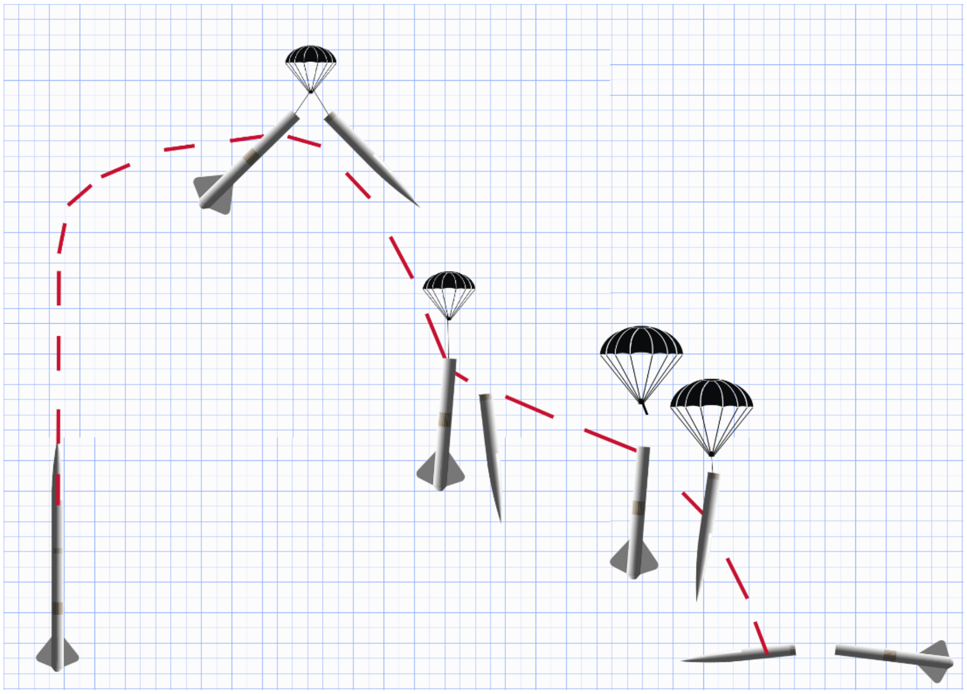


Figure 5.2.1.1 Recovery System - Full General Deployment

Once the drogue parachute is deployed, a drag force upwards will begin to slow the launch vehicle down until it reaches a terminal velocity, which is slower than the terminal velocity if there was not a drogue parachute. Once the system reaches terminal velocity, the weight of the system will be equal to the drag of the system. At this point the vehicle is no longer accelerating. The weight is equal to the mass of the launch vehicle and the parachute multiplied by acceleration due to gravity. In order to determine the radius of the parachute needed, we can use the equation to calculate drag and rearrange it to solve for the radius.

Though there are many resources online to calculate the radius necessary for a parachute, it is important to understand the process. The University of Idaho walks through the process of calculating this in their “Sizing a Parachute” article online. When the launch vehicle starts from rest at apogee, it will accelerate to a terminal velocity at which point it will have no acceleration and therefore a net force of zero. At that point, the weight (W) will be equal to the drag force (D).

$$W = D \tag{1}$$

The equation for weight, in general form, is mass (m) multiplied by acceleration (a). In this case, we know the acceleration is just the force of gravity on the system.

$$W = ma = mg \tag{2}$$

The drag force is calculated using the coefficient of drag (C_d) of the parachute, the area of the parachute (A_p), density of the fluid (ρ), in this case air, and relative velocity of the fluid (v).

$$D = \frac{1}{2} C_d A_p \rho V^2 \tag{3}$$

Knowing the equation for area of a circle, we can equate the equations for weight (2) and drag (3) and solve for the radius of the parachute.

$$r = \sqrt{\frac{2mg}{\pi C_d A_p v^2}} \tag{4}$$

Through this process, and confirmed through online resources, we have decided on tentative radii for the three parachutes we will be using. The drogue parachute will have a canopy diameter of 36 in, an upper main of 84 in, and a lower main of 102 in. All the parachutes will have a canopy made of rip stop nylon (67g/m^2). The parachutes will be attached to the airframe sections using 1 in width tubular nylon shock cord with a total length of 250 in.

Using the MATLAB code shown in Mission Performance Predictions with the above calculations, we determined the calculated descent time for the lower section to be 90 seconds, and 87.5 seconds for the upper section. The ground velocity upon landing for the lower section is projected to be 17.5 ft/sec, resulting in a kinetic energy upon landing of 74.7 ft*lbf. The upper section is projected to impact the ground at 19.1 ft/sec, resulting in a kinetic energy upon landing of 70.7 ft*lbf.

5.2.2. **Projected Flight Plan**

The projected flight plan has been updated to reflect a fully ballasted launch vehicle. The projected flight plan of our launch vehicle was simulated using OpenRocket 15.03.

On our primary L645 motor, the launch vehicle will reach an apogee of 4703’ in 18.4 seconds, a maximum acceleration of 134 ft/s^2 at approximately 2.5 seconds, a max velocity of 546 ft/s at approximately 5 seconds. The main parachutes are deployed at 550’ at approximately 78 seconds while moving at a downward velocity of 73 ft/s.

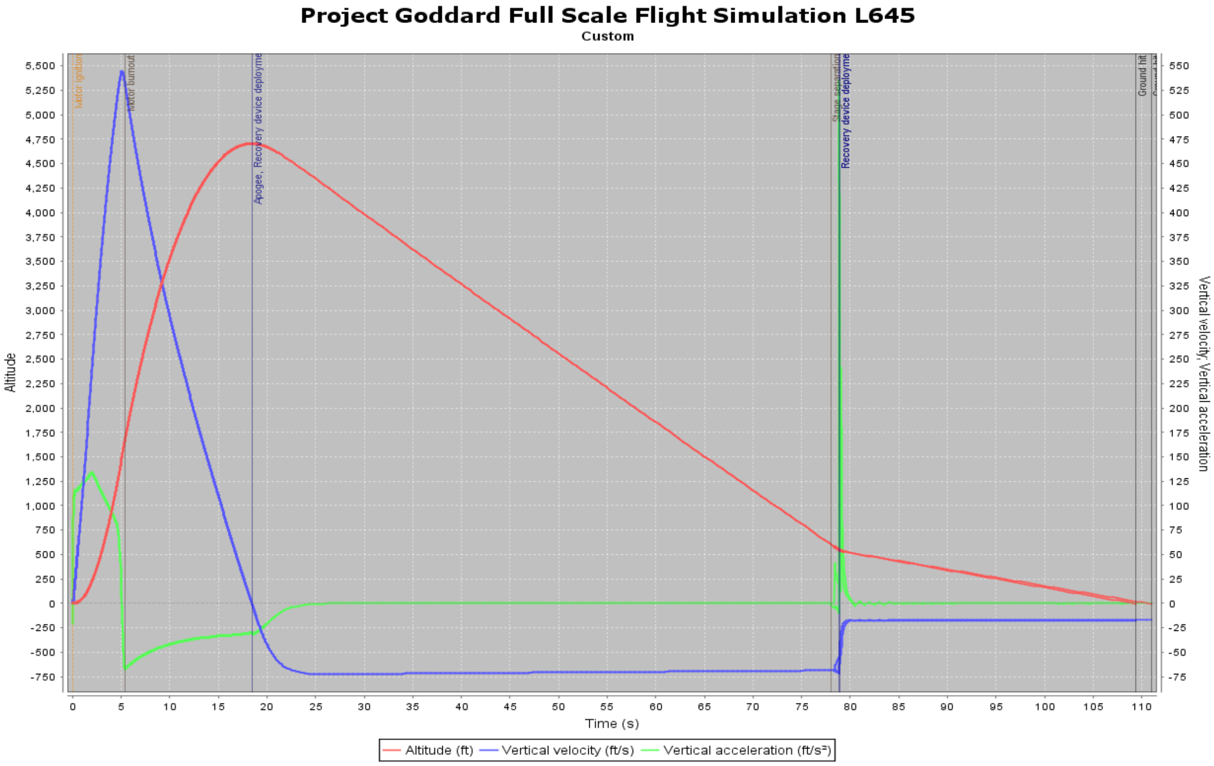


Figure 5.2.2.1 Altitude, Velocity, and Acceleration over time (L645).

The graph below shows the stability of the launch vehicle over time. The stability of the launch vehicle on rail exit is 2.38 cal and the maximum stability of approximately 4.15 cal at approximately 5 seconds.

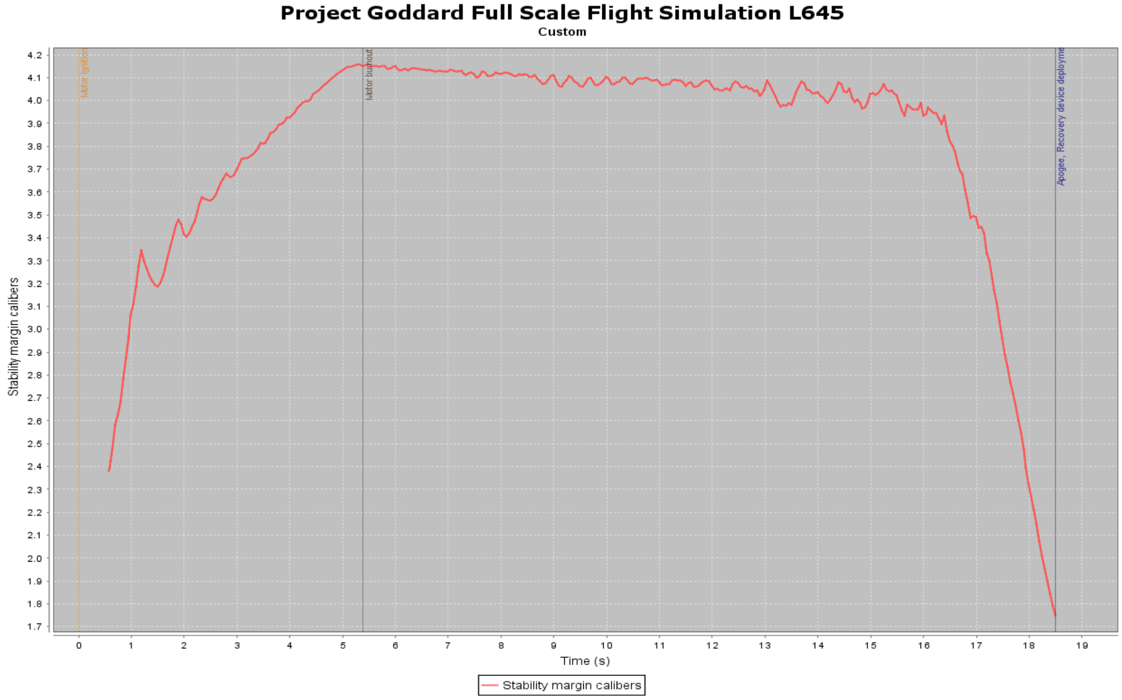


Figure 5.2.2.2 Stability vs Time for the Ballasted Rocket (L645)

On our secondary motor, the launch vehicle will reach an apogee of 5232’ in 18.7 seconds, a maximum acceleration of 181 ft/s^2 at approximately 2.5 seconds, a max velocity of 629 ft/s at approximately 5 seconds. The main parachutes are deployed at 550’ at approximately 86 seconds while moving at a downward velocity of 86 ft/s.

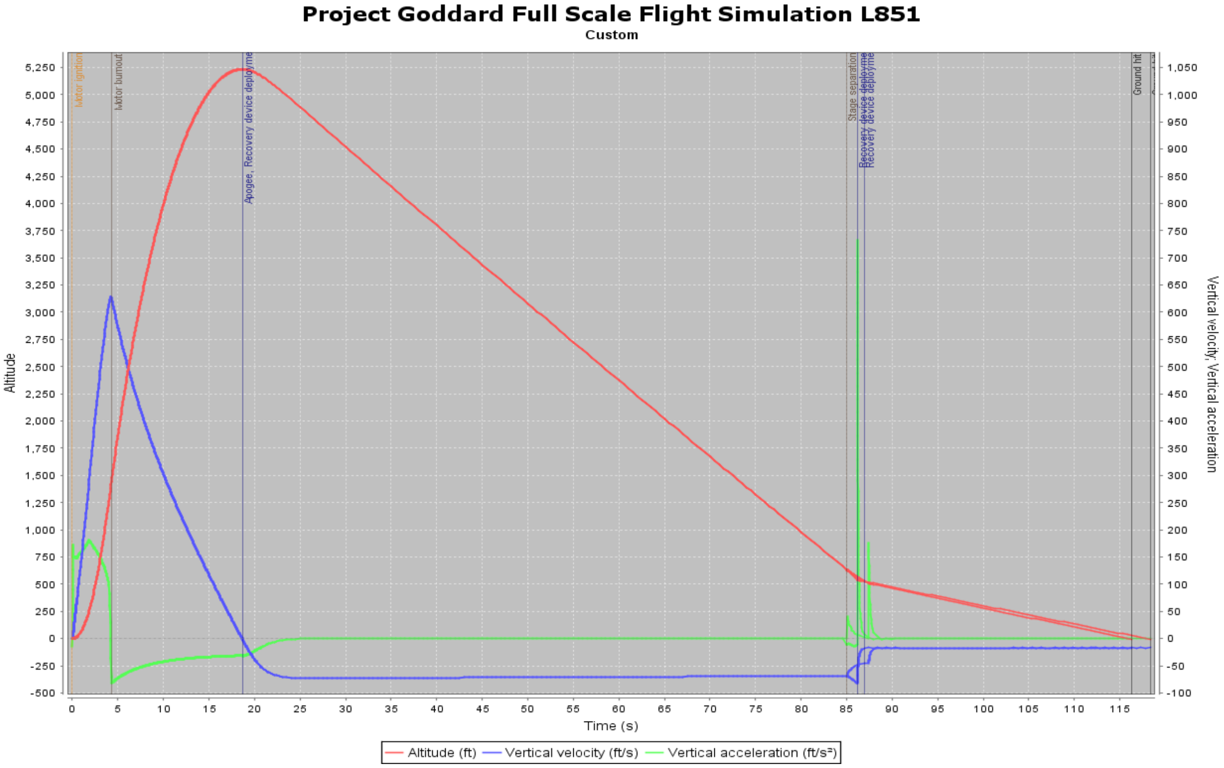


Figure 5.2.2.3 Altitude, Velocity, and Acceleration over time (L851).

The graph below shows the stability of the launch vehicle over time. The stability of the launch vehicle on rail exit is 2.55 cal and the maximum stability of approximately 4.2 cal at approximately 4.5 seconds.

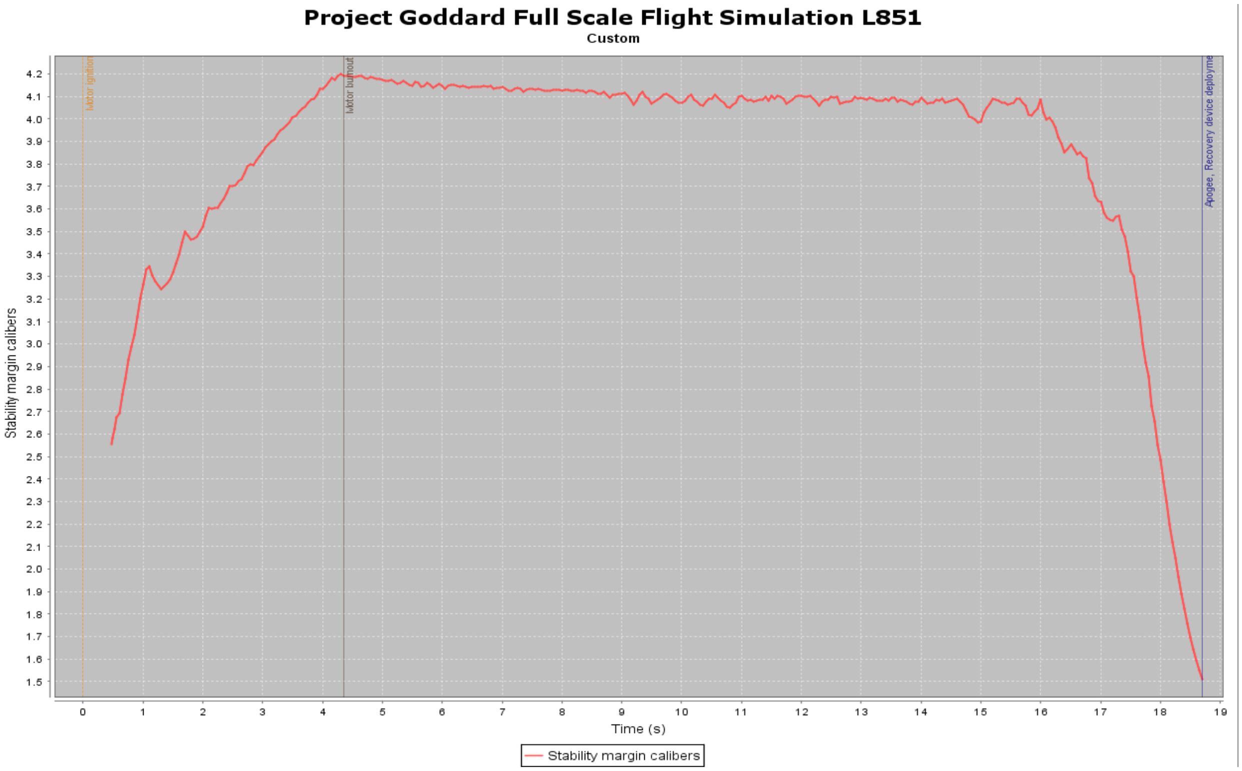


Figure 5.2.2.4 Stability vs time (L851)

5.3. Mission Performance Predictions

All calculations were performed using MATLAB and OpenRocket 15.03. This section shows the calculations for the kinetic energy of each independent section of the rocket, as well as the calculations and data plots for downrange drift. Section 1 consists of the nose cone and payload. Section 2 consists of the rocket airframe and electronics bay. Each of the following section details our MATLAB code, calculations, and results.

5.3.1. Clearing Workspace and Inputting Constants

This section consists of clearing the workspace for our MATLAB code and includes the constants that will be used in the calculations in the next three sections. These constants come in the form of rocket and parachute dimensions, such as mass, diameters and coefficients of drag. Some of these constants for the rocket are split into upper and lower body sections to help with calculations for the second descent phase after the rocket splits. Other constants consist of gravity and the density of air at both sea level and at our expected apogee.

Clear the workspace

```
clear variables; close all; clc;
```

Input Constants

```
rho_sl = 0.002377; % Air density at sea level (slug/ft^3)
rho_apo = 0.002067; % Air density at apogee (slug/ft^3)

g = 32.2; % Acceleration due to gravity(ft/s^2)

w1 = 15.6; % Section 1 (Lower Body) weight (lbs) % Editted 10/31/2019
w2 = 12.5; % Section 2 (Upper Body) weight (lbs) % Editted 10/31/2019

m1 = w1 / g; % Section 1 (Lower Body) mass (slug) % Editted 10/25/2019
m2 = w2 / g; % Section 2 (Upper Body) mass (slug) % Editted 10/25/2019
m_tot = m1 + m2;

diameter_drogue = 3; % Drogue chute diameter (ft) % Editted 10/31/2019
diameter_lower = 8.5; % Lower chute diameter (ft) % Editted 10/31/2019
diammeter_upper = 7; % Upper chute diameter (ft) % Editted 10/31/2019

Cd = 0.75; % Coefficient of drag for parachutes

apogee_alt = 4750; % Apogee altitude (ft) % Editted 10/31/2019
main_deploy_alt = 550; % Main chute altitude (ft) % Editted 10/25/2019

fprintf('Section 1 is the rocket airframe, electronics bay, and payload retainer. Section 2 is the nose cone\n');
```

```
Section 1 is the rocket airframe, electronics bay, and payload retainer. Section 2 is the nose cone
```

Figure 5.3.1.1 Initial Variables

5.3.2. Calculating Descent Times and Velocities

This section consists of MATLAB code used to calculate the respective descent times and impact velocities for the two sections of the launch vehicle.

Descent Times:

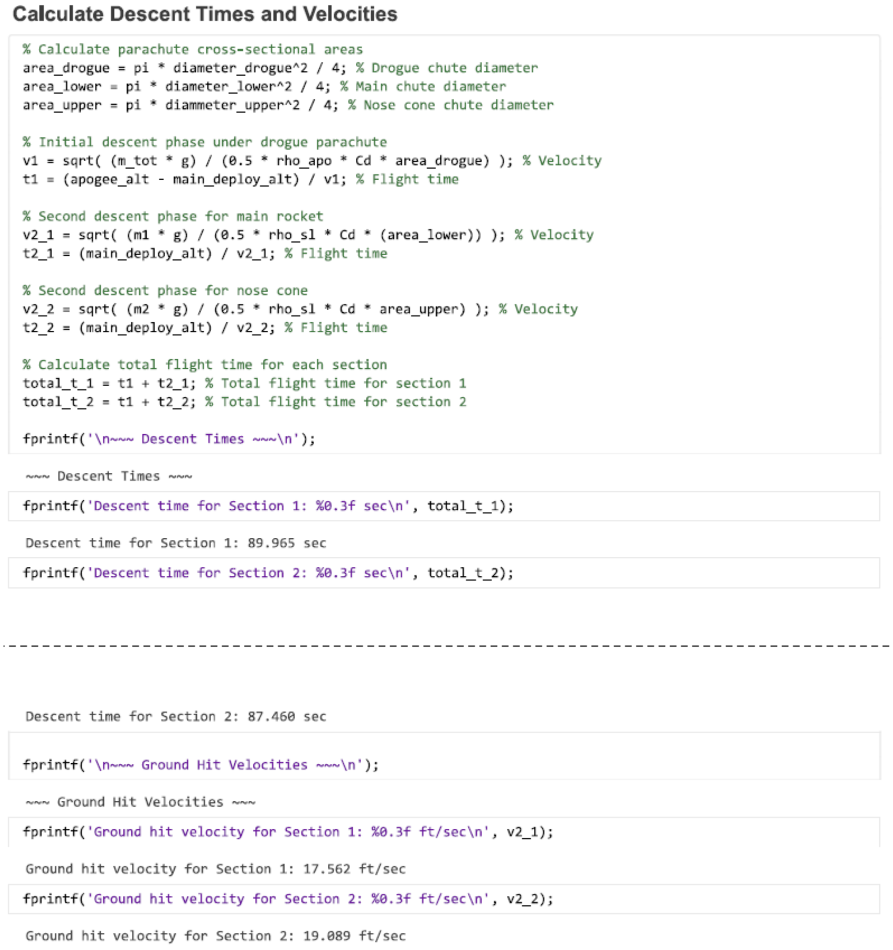
Section 1: 90 sec

Section 2: 87.5 sec

Impact Velocities:

Section 1: 17.5 ft/sec

Section 2: 19.1 ft/sec



Calculate Descent Times and Velocities

```
% Calculate parachute cross-sectional areas
area_drogue = pi * diameter_drogue^2 / 4; % Drogue chute diameter
area_lower = pi * diameter_lower^2 / 4; % Main chute diameter
area_upper = pi * diammeter_upper^2 / 4; % Nose cone chute diameter

% Initial descent phase under drogue parachute
v1 = sqrt( (m_tot * g) / (0.5 * rho_apo * Cd * area_drogue) ); % Velocity
t1 = (apogee_alt - main_deploy_alt) / v1; % Flight time

% Second descent phase for main rocket
v2_1 = sqrt( (m1 * g) / (0.5 * rho_sl * Cd * (area_lower)) ); % Velocity
t2_1 = (main_deploy_alt) / v2_1; % Flight time

% Second descent phase for nose cone
v2_2 = sqrt( (m2 * g) / (0.5 * rho_sl * Cd * area_upper) ); % Velocity
t2_2 = (main_deploy_alt) / v2_2; % Flight time

% Calculate total flight time for each section
total_t_1 = t1 + t2_1; % Total flight time for section 1
total_t_2 = t1 + t2_2; % Total flight time for section 2

fprintf('\n~~~ Descent Times ~~~\n');
```

```
~~~ Descent Times ~~~
```

```
fprintf('Descent time for Section 1: %0.3f sec\n', total_t_1);
```

```
Descent time for Section 1: 89.965 sec
```

```
fprintf('Descent time for Section 2: %0.3f sec\n', total_t_2);
```

```
Descent time for Section 2: 87.460 sec
```

```
fprintf('\n~~~ Ground Hit Velocities ~~~\n');
```

```
~~~ Ground Hit Velocities ~~~
```

```
fprintf('Ground hit velocity for Section 1: %0.3f ft/sec\n', v2_1);
```

```
Ground hit velocity for Section 1: 17.562 ft/sec
```

```
fprintf('Ground hit velocity for Section 2: %0.3f ft/sec\n', v2_2);
```

```
Ground hit velocity for Section 2: 19.089 ft/sec
```

Figure 5.3.2.1 Descent Time and Velocity Calculations

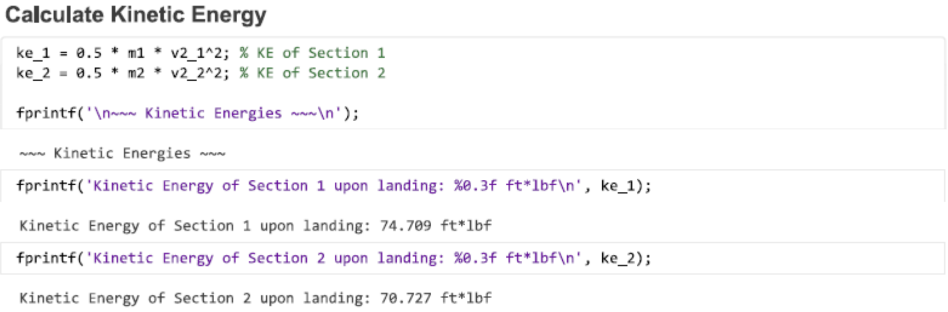
5.3.3. Calculating Kinetic Energy

With the calculated velocities in the previous section, we use the formula for kinetic energy to calculate the kinetic energy of the upper and lower sections of the rocket upon landing.

Kinetic Energy Upon Landing:

Section 1: 74.7 ft*lbf

Section 2: 70.7 ft*lbf



Calculate Kinetic Energy

```
ke_1 = 0.5 * m1 * v2_1^2; % KE of Section 1
ke_2 = 0.5 * m2 * v2_2^2; % KE of Section 2

fprintf('\n~~~ Kinetic Energies ~~~\n');
```

```
~~~ Kinetic Energies ~~~
```

```
fprintf('Kinetic Energy of Section 1 upon landing: %0.3f ft*lbf\n', ke_1);
```

```
Kinetic Energy of Section 1 upon landing: 74.709 ft*lbf
```

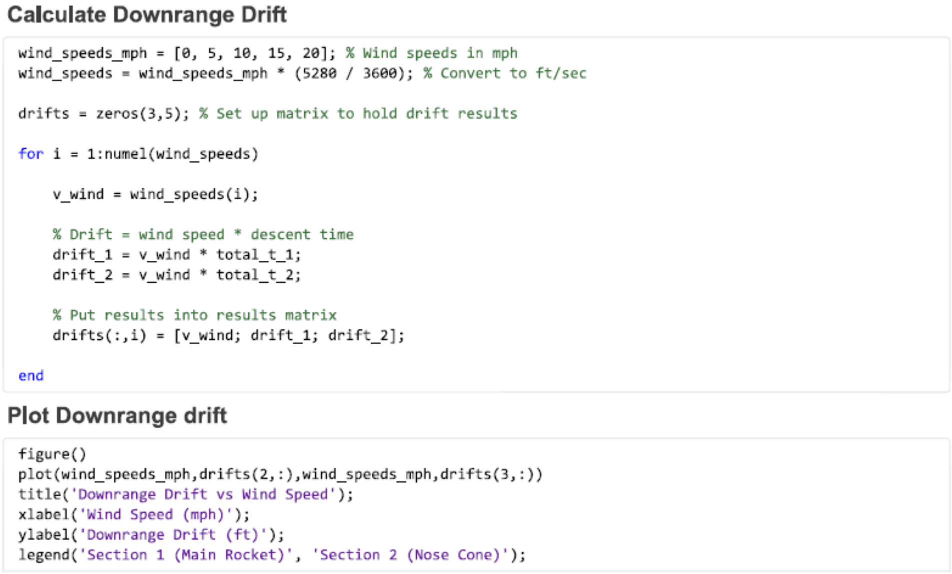
```
fprintf('Kinetic Energy of Section 2 upon landing: %0.3f ft*lbf\n', ke_2);
```

```
Kinetic Energy of Section 2 upon landing: 70.727 ft*lbf
```

Figure 5.3.3.1 Kinetic Energy Calculations

5.3.4. Calculating and Plotting Downrange Drift

This section details calculations and data plots for the downrange drift, both of which were performed using MATLAB. The plot and calculations are as follows:



Calculate Downrange Drift

```
wind_speeds_mph = [0, 5, 10, 15, 20]; % Wind speeds in mph
wind_speeds = wind_speeds_mph * (5280 / 3600); % Convert to ft/sec

drifts = zeros(3,5); % Set up matrix to hold drift results

for i = 1:numel(wind_speeds)

    v_wind = wind_speeds(i);

    % Drift = wind speed * descent time
    drift_1 = v_wind * total_t_1;
    drift_2 = v_wind * total_t_2;

    % Put results into results matrix
    drifts(:,i) = [v_wind; drift_1; drift_2];

end
```

Plot Downrange drift

```
figure()
plot(wind_speeds_mph,drifts(2,:),wind_speeds_mph,drifts(3,:))
title('Downrange Drift vs Wind Speed');
xlabel('Wind Speed (mph)');
ylabel('Downrange Drift (ft)');
legend('Section 1 (Main Rocket)', 'Section 2 (Nose Cone)');
```

Figure 5.3.4.1 Downrange Drift Calculations

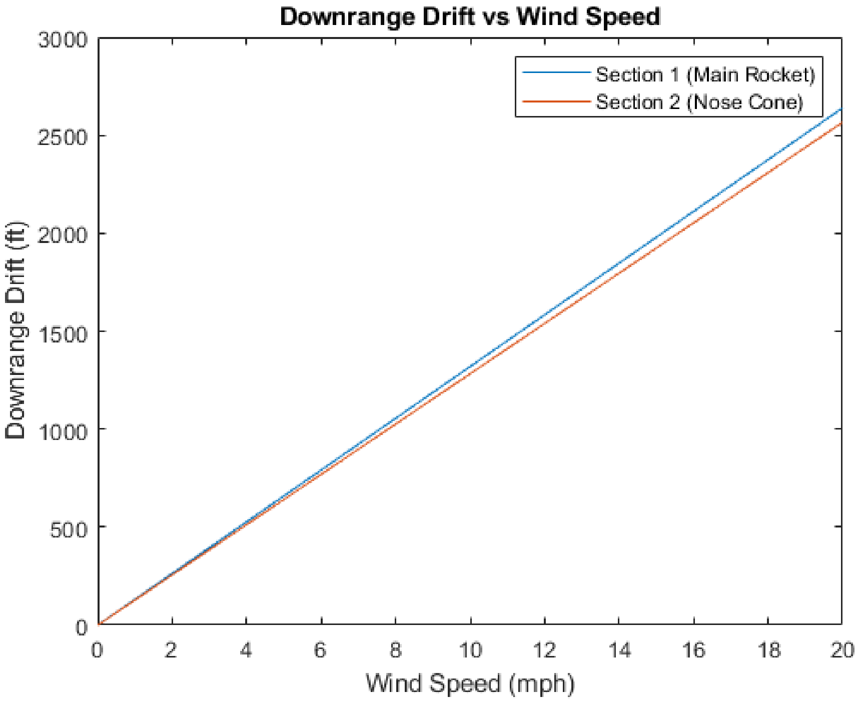


Figure 5.3.4.2 Downrange Drift Plot

Based on this data, and our maximum downrange drift restriction of 2500’, our limit for wind speeds at launch is 27.866667 ft/s, allowing us to launch in a wide range of wind conditions.

6. Payload Criteria

6.1. UAV (Unmanned Aerial Vehicle)

6.1.1. UAV Structure Rational

The main body of the UAV is made from 2mm thick carbon fiber plate due to its high strength and stiffness to weight ratios and ease of manufacturability of parts via waterjet parts not requiring intricate hand layup methods. The size of the electronics were brought together into an “I” configuration saving space and weight allowing the arms of the UAV to fold. This saved space allows the propeller arms to fold alongside the body without adding additional width which is largely beneficial due to the constraints of the fixed body diameter of the launch vehicle.

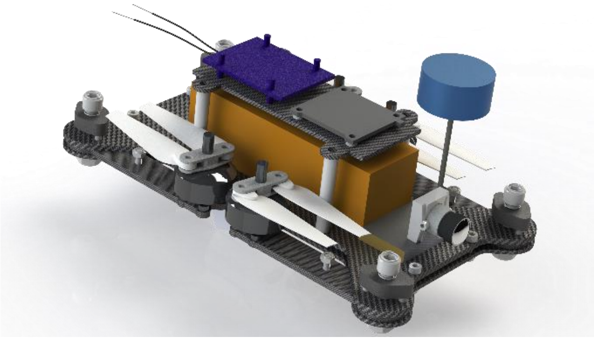


Figure 6.1.1.1 UAV Payload in Stowed Configuration

The propeller arms will be held in place by mechanisms discussed in the **Error! Reference source not found.** Section. Once this mechanism releases the arms, they will unfold under spring tension provided by rubber bands that are wrapped around the pivot points and secured on mounting screws. Upon reaching the appropriate opening angle, locking pins will slide from above into holes on the arms under spring force and prevent further rotational motion of the arm. An alternate considered design used servos string tension to open the arms, we decided against this as it would add extra complexity to the design and would weigh more.

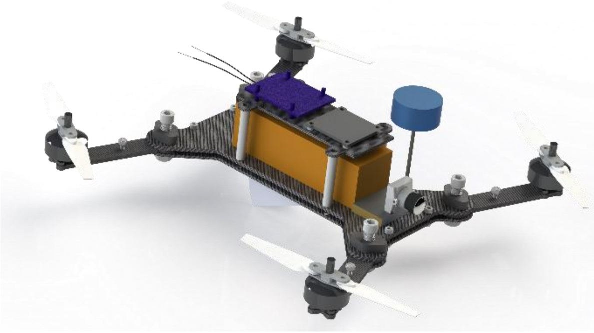


Figure 6.1.1.2 UAV Payload in Flight Configuration

The landing legs for the UAV became a challenge to find a mounting spot which could provide adequate stability and cleared any of the crucial retention system components for the full mission. The landing legs need to pass through the Retention Sled with enough clearance that they won't get caught when the UAV takes off from the plate. The landing leg length also changed depending on how far from the center of the UAV they were mounted. Legs mounted closer to the center could be longer and legs that were closer to the outside of the UAV could not be as long because they would intersect with the bottom walls of the retention system. To account for any fitment issues we would eventually encounter, we chose to use 2mm stainless steel rods. These rods can be bent into position and have a spring force that forces it to be in the open position. The slightly absorbent landing legs will help if the pilot preforms a less than ideal landing.

6.1.2. **UAV electronics**

To develop an effective payload quadcopter, our electronics package has to balance cost, reliability, and performance with a strong emphasis on limiting its overall weight.

One of the first major electronics choices was the need to choose a flight controller. We ended up choosing the “Diatone Mamba F722S Stack - 506 50A Dshot1200 6S ESC”. To do this we wanted a flight controller which supported a flight firmware called BetaFlight. We decided to use BetaFlight as our flight controller’s firmware because it is known as an easy to use and very reliable for quadcopters. BetaFlight enables us to run programs that can automatically stabilize the quadcopter in case of unexpected turbulence. We chose this specific controller from Diatone Mamba because it had a wide range of connection ports and included an ESC board which is required for controlling each of the quadcopter’s four motors. Overall, the Diatone Mamba was a great combination of versatility and performance for the given price. Using this flight controller should simplify the entire electronics package for the UAV.

Figure 6.1.2.1 Diatone Mamba F722S Stack - 506 50A Dshot1200 6S ESC

Image Source: Diatone Mamba

After choosing a flight controller, we needed to choose motors so we could determine the overall battery requirement and thus the overall weight of the UAV. We predicted that the UAV would weigh a maximum of two pounds. We predicted that we would need each of the four motors to be of the 2400Kv classification. With 2400Kv race motors, the propellers will be spinning fast enough that we create enough thrust that the quadcopter can quickly translate to a location and lift a substantial amount of collected material if needed. We choose the T-Motor F40 Pro III 2400Kv Racing Motor because it has great thrust performance for its power efficiency.

Figure 6.1.2.2 T-Motor F40 Pro III 2400Kv

Image Source: T-Motor F40

We chose to use the Infinity 2200Mah 4S 85C Graphene Tech lipo Battery as it balances our requirements for size and flight time. While our flight controller can use a 6s battery, we determined that a 6s battery would be too big and too heavy to warrant the extended flight time. We determined that the next best option would be a 4s lipo battery which comes in a much more manageable size package. A 4s battery is also advantageous because we don't have to insert a capacitor between the battery and the flight controller's ESC board. 4s batteries are often cheaper because they are more widely used in remote control hobbies.

Figure 6.1.2.3 Infinity 2200Mah 4S 85C Graphene Tech LiPo Battery

Image Source: Infinity Batteries

To control our UAV, we needed a receiver. We chose the FrSky R-XSR S.Bus/CPPM 8/16 Channel Micro Receiver because of its size, price, and reliability in the UAV community. The receiver has two antennas which increase the reliability of the connection with the pilot's transmitter. The size enabled us to mount it tucked away and thus further decrease the size of the whole UAV.

Figure 6.1.2.4 FrSky R-XSR S.Bus/CPPM 8/16 Channel Micro Receiver

Image Source: FrSky

Controlling the UAV is accomplished by a handheld remote-control transmitter. We chose the FrSky Taranis X9 Lite RC Transmitter because of its compatibility, programmability, and price. The transmitter allows us to create programable switches which are used for the soil sampling mechanism. This controller is also compatible with our receiver as they are both FrSky products of the X generation. Being a FrSky product, the price was much lower than some competitors.

Figure 6.1.2.5 FrSky Taranis X9 Lite RC Transmitter

Image Source: FrSky

To help with the automation and guidance of the UAV, we included a GPS module. This module needed to be lightweight and small to fit on the UAV. We chose the Matek SAM-M8Q GPS Module because it uses a plate antenna which sacrifices the antenna’s signal reliability for form factor. The plate antenna offers an adequate amount of GPS accuracy for locating the drone for telemetry and automation.

Figure 6.1.2.6 Matek SAM-M8Q GPS Module

Image Source: SAM-M8Q U-blox

For our pilot to control the UAV with accuracy, we needed to include an FPV system so the pilot can see from the UAV’s perspective. The first component in the FPV system is the camera. We decided to use the RunCam Micro Eagle - Lumenier Edition (White) which is a widely used FPV camera for quadcopters. This camera is notable for its combination of fast processing speed with consistent high-quality video output. A fast and high-quality camera is crucial because the pilot needs to be able to respond to the UAV’s movements with a little time delay process as possible. A lagging video signal can make the UAV very difficult to control and predict.

Figure 6.1.2.7 RunCam Micro Eagle - Lumenier Edition (White)

Image Source: RunCam

After the video is created by the camera and ready to output, the video signal needs to go into the video transmitter. The TBS Unify Pro32 HV 5.8GHz Video Transmitter (MMCX) was chosen as our video transmitter. This transmitter is desirable because it complies with the 5.8GHz transmitter constraints. The Unify Pro32 also has a variable transmission power capability so it can provide a very reliable and interference-free video to the pilot. The Unify Pro32 is also one of the recommended FPV video transmitters for our flight controller.

Figure 6.1.2.8 TBS Unify Pro32 HV 5.8GHz Video Transmitter (MMCX)

Image Source: TBS Unify

The last component of the FPV system was the FPV antenna. The antenna is needed to reliably transmit the video signal to the UAV's pilot. The antenna needed to have an MMCX connection to attach to our transmitter. We chose a Right Hand Circular Polarized antenna which would offer a reliable and steady signal regardless of the UAV's orientation relative to the pilot. The XILO AXII MMCX 5.8GHz Antenna (RHCP) antenna was chosen because of its lightweight form factor. The weight of this component is key as the top of the antenna will be suspended above the rest of the UAV. The location means that the center of gravity will be higher and thus destabilizing the UAV.

Figure 6.1.2.9 XILO AXII MMCX 5.8GHz Antenna (RHCP) antenna

Image Source: XILO

6.1.3. Sampling mechanism

As the primary objective of the mission payload, the successful collection of 10 ml of sample material is critical. To insure this is achieved, our team designed a sampling mechanism that we felt best matched our requirements. We chose our design based on 3 main design features, these features being the design complexity, and form factor.

Design and Analysis

Our chosen sampler design is composed of a shovel/scoop for collecting sample material that is attached to the output shaft of an electric gearmotor that is in turn fixed to the bottom of our UAV by a mounting plate. The scoop is capable of rotating in one axis (pitch relative to the UAV), in both directions. The scoop sweeps past the bottom of the landing legs, ensuring that the scoop swings through a large amount of the sample material to insure ample access to sample material. In the closed configuration, the scoop nests inside of a pocket built into the mounting plate, ensure collected material cannot fall out of the scoop while in flight.

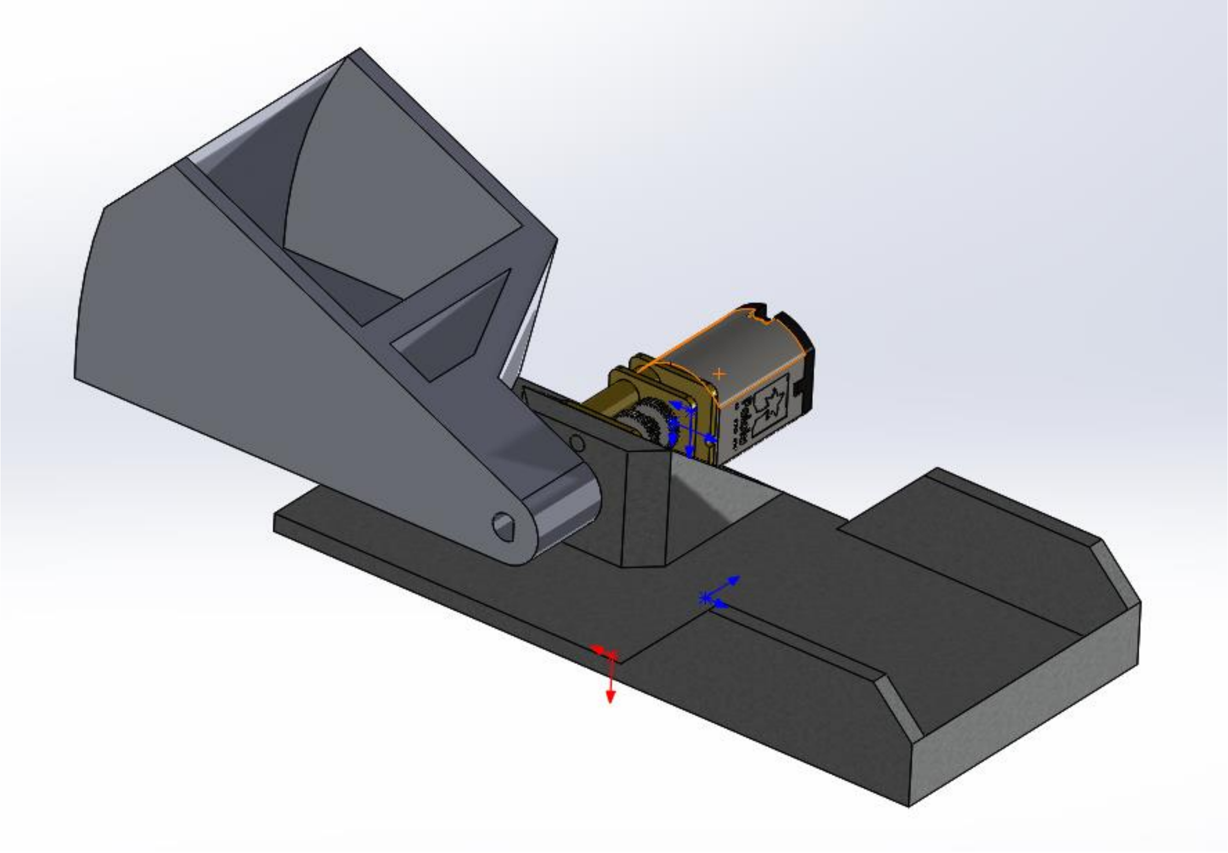


Figure 6.1.3.1 Sampler Open Isometric View

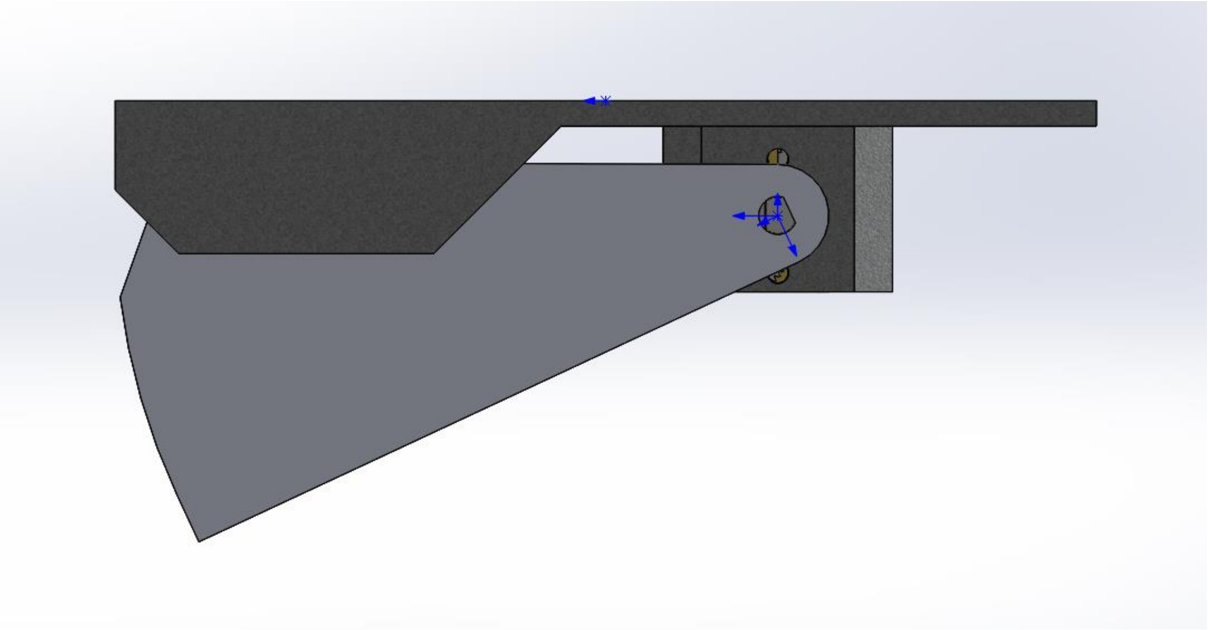


Figure 6.1.3.2 Sampler Closed Side View

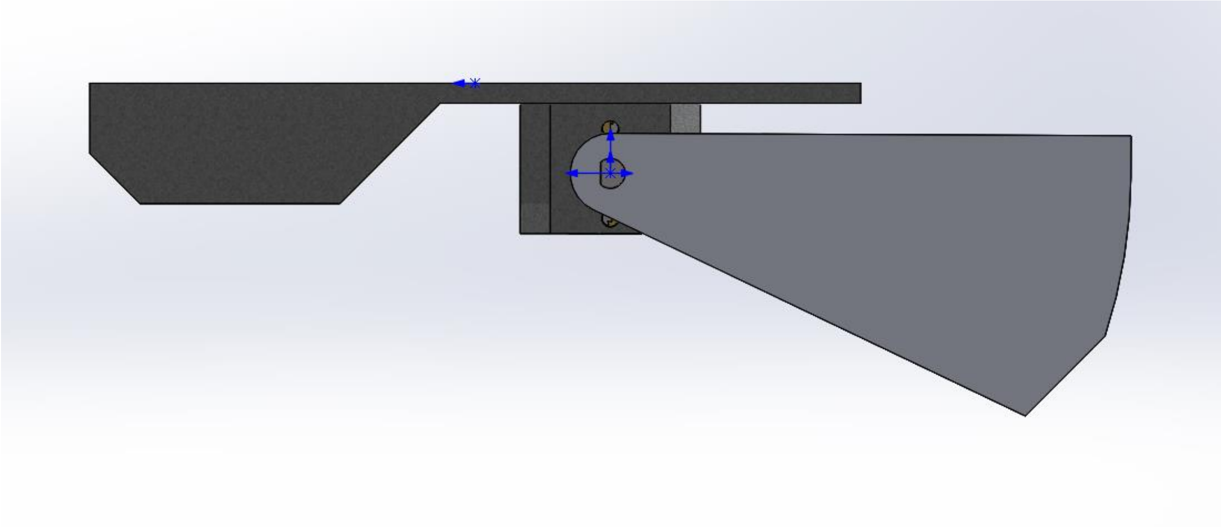


Figure 6.1.3.3 Sampler Open Side View

This design was chosen over alternative options, such as an auger/core drill, or multi arm claw, based on how well it met the three main design requirements. Firstly, this design is extremely simple, with only one moving member, the scoop, and 3 components. This is important as it means this mechanism will be easier to build and service and has less failure modes than the alternative designs. As well the single arm scoop was the most compact design, in terms of vertical height usage. This is important as due to the way the UAV is held within retention system, vertical space under the drone is limited to 1.5”. This height would be difficult to achieve with an auger system.

We plan to build a prototype system and test the overall design as well as different scoop designs on a similar material to the announced plastic pellets. In this testing we hope to optimize our sampler design and find any possible unforeseen issues with our design and the sample material. This will insure that by the CDR we have a tried and tested sampling system.

6.2. Payload Retention System

6.2.1. Retention Sled

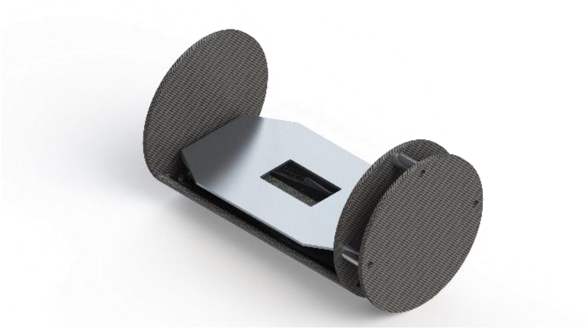


Figure 6.2.1.1 Retention Sled (Disengaged)

The leading design for the payload retention sled consists of three carbon-fiber discs (fore, intermediate, and aft) connected by a carbon-fiber spar and circular standoffs, respectively. The payload retained between the fore and intermediate sled discs by mounting it atop a scissor lift. The main structural elements of the retention sled are three .19685" carbon fiber discs and a 9” NylonX spar. The spar is bolted to the fore and intermediate sled discs and houses the scissor lift that supports and secures the payload. The intermediate and aft sled discs are separated and secured by three 1” circular standoffs. Carbon fiber and NylonX were chosen for the discs and spar because of their light weight and high strength. These parts must endure the stress imparted by launch and landing without major deformation or fracture without being too massive, which would move the launch vehicle’s center of mass too far forward.

Figure 6.2.1.2 Retention Sled (Engaged)

The main functionality of the payload retention sled is to protect and secure the payload during flight, and to deploy the payload for flight once the upper airframe has landed. The payload will be secured to the scissor lift by a motorized retention system attached to the scissor lift platform. This system will clamp down on the payload to secure it during flight and sled deployment. The scissor lift itself will consist of three scissors and one L16-R Miniature Linear Servo (1.9685" stroke, 150:1 gear ratio), as well as a platform to hold the payload and its retention system. This actuator was chosen for its high gear ratio and compact form, both of which are ideal for extending the scissor lift plus a relatively heavy payload. Four of these servos were used in last year's payload, which eliminates the need to buy more servos and provides three extra servos in case the first breaks down. The scissor members are 8" long and machined out of 0.1" thick 6061-T6 aluminum alloy for their strength compared to their size. The members are attached to the platform, and as the linear servo extends, the platform will rise. The platform is machined out of 0.5" thick 6061-T6 aluminum alloy, although the platform is primarily 0.1" thick, with 0.4" scissor rails on the underside. This material was chosen for its stiffness, so the payload retention system is not compromised during flight. The platform is designed to attach to the scissor members, house the payload retention mechanism, and to fit around the payload itself. An alternate design had a payload capsule that housed a tall UAV payload that rotated perpendicular to the airframe before the capsule opened, clamshell-style. This design was determined to be too complex to implement in the timeframe provided. This design would also present significant challenges in orienting the payload vertically for deployment and rotating it outwards. For these reasons, we chose the current design over the alternate one.

6.2.2. Retention Rotation Mechanism

The leading design for the payload rotation mechanism consists of three circular 0.197" carbon-fiber plates in series, mounted to the interior of the nosecone. The aft plate provides structural support and serves as a mounting location for the rotation system's electronics and battery. The mid plate mounts the rotation mechanism, a Hitec HS-785HB Servo with a circular horn hub. This servo was chosen due to its output power and torque, and due to its use in the payload retention system's lead screw. 2" aluminum standoffs connect the aft and mid plates, the former of which is secured to the inner neck of the nosecone by epoxy. The fore plate is the rotation plate, mating the servo horns to the payload sled. Bearings mounted around the perimeter of this plate allow for smooth rotation within the nosecone. Carbon fiber was chosen for the plates due to its strength and weight, as the assembly must be able to endure flight and impact forces but not significantly weigh down the nose of the rocket.

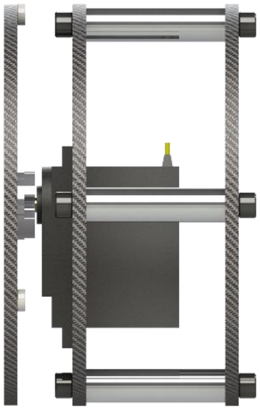


Figure 6.2.2.1 Side View of Retention Rotation Mechanism

Also considered mounting the rotation mechanism to the pusher plate that is being driven by the lead screw, on the opposite side of the sled from the nosecone. This would consolidate mechanisms in the upper airframe and would allow for both Hitec HS-785HB Servos to use the same power supply.

The payload rotation mechanism's purpose is to ensure that the payload is vertically oriented before release, allowing the UAV to take off. As orientation of the payload within the airframe after landing is not predetermined, accelerometer information must be used to determine the payloads facing. After the payload is driven out of the airframe via lead screw, the payload rotation mechanism will use its servo to orient the payload sled. Safe release of the payload is then possible.

6.2.3. Payload Retention Driver

Figure 6.2.3.1 Payload Retention Driver Side View

The leading design for the retention system driver consists of a continuous rotation servo driving a 0.25"-20 threaded lead screw which translates the sled out of the airframe for rotation. The driver assembly in composed of 3 main sections, The motor/leadscrew interface section, the electronics section, and the upper airframe bulkhead section. The motor/leadscrew section is composed of 2 (two) 0.197" carbon fiber plates which act as the mount for the continuous rotation servo and for the bushing mount for the leadscrew, the leadscrew is driven by a Hitec HS-785HB Servo which was chosen for its exceptional output power and stall torque along with its packaging size.

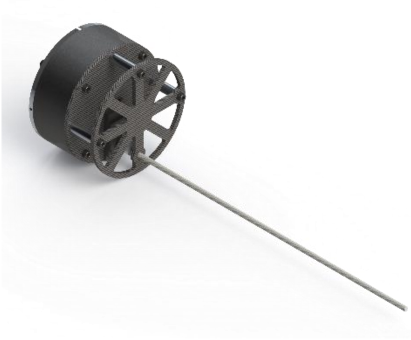


Figure 6.2.3.2 Payload Retention Driver Isometric View

Behind is the electronics section mechanically this section acts as the intermediary between the motor and the bulkhead and structurally composed of a 3d printed PLA (Polylactic Acid) shell, inside of which are the major electronic components detail in Payload Electronics. Behind that is the bulkhead section which acts as the interface between the upper airframe and recovery system. The primary component is the 0.25" 6061-T6 aluminium bulkhead which secures the shock cord to upper airframe through a "I" bolt. The bulkhead is secured in place through 4 (four) 0.25" bolts which pass through the airframe. Alternate designs consisted of a spring-loaded ejector, but we decided on the current design because it was deemed to be safer and more consistent

6.2.4. Payload Electronics

The electrical components to be housed within the retention system bay will be very similar to those in the electronics bay. The Arduino Nano along with a LoRa transceiver and GPS board will act as the driving electronics for the payload retention system. Though this unit will also have the ability to broadcast its data, it will primarily act as a listener for the signal to activate the lead screw motor and deploy the UAV after receiving permission to do so once landing is safely confirmed. This will be powered by the same two cell LiPo battery as the electronics bay and a buck-boost converter to regulate power to the HS-785HB servo motor. The electronics of the orientational system bay housed within the nosecone of the launch vehicle will be identical to those of the retention system with the only difference being the replacement of the GPS with a gyroscope for sensing the orientation of the retention system in order to properly command its servo motor to properly orient the UAV sled to allow for its successful deployment.

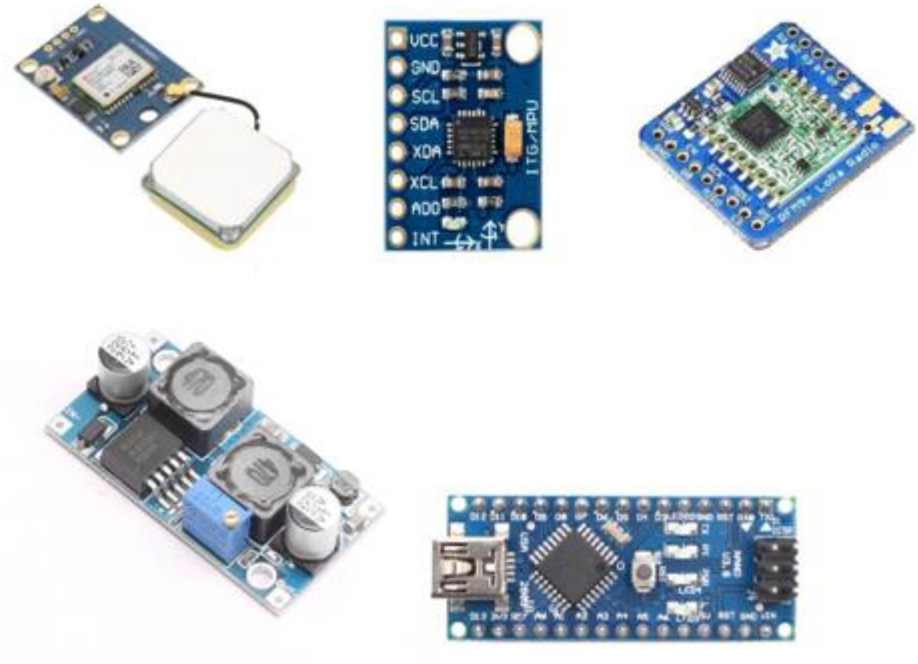


Figure 6.2.4.1 Payload Electronics

7. Safety

Safety is the number one priority of the WPI USLI team. Throughout this document we have carefully analyzed all the threats and malfunctions the students and machinery involved in this project could face. This includes but is not limited to, hardware, electrical, mechanical, environmental and personal hazards. The safety officer is primarily in charge of managing safety procedures and is responsible for enforcing safety rules, verifying the safety of all students, and creating and following checklists to ensure all aspects of the launch vehicle and payload are safe for use and handling.

7.1. Project Risk Overview

Project Risk Overview analyzes the risks that could affect the project as a whole. The risks are ranked based on their probability and on their effect on timing, budget and design. For each risk there are mitigation methods that we will use to lower the chance of the risk occurring.

Project Risk Probability Definitions	
Rating	Description

A	The risk is expected to have negative effects if it is not mitigated.
B	The risk is likely have negative effects if it is not mitigated
C	The risk may have negative effects if it is not mitigated.
D	The risk is possible but unlikely to have negative effects.

Figure 6.2.4.1 Table Project Risk Probability Definitions

Project Risk Severity Definitions	
Rating	Description
I	Irrecoverable failure.
II	Significant loss of money, time, or major design overhaul.
III	Minor loss of money, time, or minor design overhaul.
IV	Negligible effect to design, timeline, and budget.

Figure 6.2.4.2 Table of Project Risk Severity Definitions

Project Risks Overview					
Risk	Probability/ Severity	Schedule Impact	Budget Impact	Design Impact	Mitigation
Destruction of Full Scale	AI	Disqualification from the competition. The team will have to reorganize the schedule to compensate to build a new full-scale rocket	The budget would have to be increased to compensate for the construction of a new launch vehicle. The team may not be able to afford to construct a	The design would need to be altered to prevent another full-scale destruction	Test all aspects of the full-scale launch vehicle to ensure they work correctly. Analyze and test all electronics within the launch vehicle. Do not expose the rocket to any hazardous environments

			new launch vehicle		
Full Scale launch fail	AII	If no damage was done to the rocket, minor time delays to reschedule the launch. Two-three-week delays to reorder parts and rebuild the rocket. Additional time to edit the design.	The budget could be affected significantly (up to 2000$), depending on the number of repairs that need to be done	The design will be altered to avoid future launch fail	Analyze results of a subscale launch and simulations to ensure that the rocket will not fail at launch. Follow all the instructions given by the RSO (Range Safety Officer) and all NAR regulations
Destruction of payload in testing.	AII	Two-three-week delays to reorder parts and rebuild the payload	The budget could be affected significantly (up to 500$), depending on the number of repairs that need to be done	Significant design changes will be made to ensure that the payload does not fail again	Use of simulations and separate testing of the UAV and the retention system before test launches
Damage to construction material	AIII	Small to hefty schedule impact depending on damaged material	Little impact on budget due to the use of school owned tools May need to buy more of the material	May need to use different methods or materials for construction	Use construction material carefully and sparingly
Sub-scale launch fail	BII	The sub-scale launch will have to be rescheduled, causing minor delays. One-two-week delays to reorder parts and rebuild the sub-scale. Additional time to edit the design.	The budget will be affected in a minor to significant way (up to 1500$), depending on the damage	The design will be altered to avoid future launch fail	Use simulations to ensure that the sub-scale rocket will not fail at launch. Follow all the instructions given by the RSO and all NAR regulations
Unexpected expenses (higher than	BII	Little schedule impact unless a shortage of funds	Budget may have to be supplemented	May impact supplies able to order due to	Keep a detailed budget and account

expected shipping, parts, travelling costs		results in an incomplete order of needed parts	and more money would have to be raised to offset any additional costs	looking for cheaper options to offset the more expensive ones	for shipping when budgeting
Parts lost in shipment to the competition	DI	-Limited to unrecoverable schedule impact	-May need to use extra funds from budget to pay for parts lost	-May need to use different parts to replace those lost	-Use a more reliable shipping company
Damaged or delayed during shipping	DII	Limited to unrecoverable schedule impact	May need to use extra funds from budget to pay for parts damaged	May need to use different parts to replace those lost	Pack the launch vehicle and payload very carefully
Injury	CIII	Delays may occur due to ensuring the injured member's safety and determining the cause of the injure and ways of mitigating it	No impact	No impact	The team will follow all safety procedures, consult the Material Safety Data Sheets (MSDS) and follow the NAR requirements
Launch Cancellation	DIV	The launch may be rescheduled to a rain date NASA has scheduled	No impact	No impact	There is no mitigation due to this decision being up to NASA. Completion of design and construction will ensure the team is prepared for any potential launch date

Figure 6.2.4.3 Table of Project Risk Overview

7.2. Personnel Hazard Analysis

Personnel Hazard Analysis focuses on finding possible hazards that can occur, hazards analyzed in the Personnel Hazard Analysis may cause harm to team members and bystanders. The risks are ranked by their probability and severity. The purpose of the Personnel Hazard Analysis is to identify causes of each hazard and develop ways of mitigation and control to ensure everybody is safe.

Personnel Hazard Probability Definitions	
Rating	Description
A	The hazard expected to occur if it is not mitigated.
B	The hazard is likely occur if it is not mitigated
C	The hazard may occur if it is not mitigated.
D	The hazard is possible but unlikely to occur.

Figure 6.2.4.1 Table of Personnel Hazard Probability

Personnel Hazard Severity Definitions	
Rating	Description
I	Significant chance of death or permanent injury.
II	Possibility of major injuries requiring hospitalization or permanent minor disability.
III	Chance of injury requiring hospitalization or period of minor disability.
IV	May cause minor injury which may require first aid.

Figure 6.2.4.2 Table of Personnel Hazard Severity Definitions

Personnel Hazard Analysis						
Section	Hazard	Cause	Effect	Probability/Severity	Mitigation & Controls	Verification

Machining/building	Power Tool Injury	Improper training or human error during the use of power tools	Injuries include, but are not limited to cuts, scrapes, amputation	CII	Members will receive proper training and will have access to instructions on how to operate each tool and will wear proper PPE (Personal Protective Equipment) specific to each tool. If an injury does appear a member will be given proper medical help.	Safety officer or a member of the safety team is present during the use of potentially dangerous tools to ensure proper usage and PPE.
	Tool Injury	Improper training or human error during the use of tools	Injuries include, but are not limited to cuts, scrapes, amputation, crush injury	CII		
	Caught in a machine	Loose items of clothing/jewelry/hair/gloves getting pulled into a machine	Partial or complete destruction of an item pulled in; injuries as severe as amputation	CII	Members will not be allowed to use machines while wearing loose items of clothing/jewelry/gloves or having long hair that are not contained.	Safety officer or a member of the safety team present during the machining process to ensure members aren’t wearing loose items.
	Fire	Human error, short circuit or any other event that causes a fire to start	Burns, inhalation of toxic fumes death	DI	Members will only work in facilities with proper fire safety systems installed.	Safety officer or member of the safety team will be present to ensure proper use of machines and will inspect the area for clear indications of emergency exits
	Electric Shock	Coming in contact with an exposed wire	Burns, death from electrocution	DII	Members will inspect all wires before working with them.	Analysis of wires
	Debris from machine	Improper securing of the material/object that is being machined	Injuries include, but are not limited to eye injuries,	CIV	Members will be properly trained to use the machines and will wear proper PPE specific to each machine.	Safety officer or a member of the safety team is present during machining to ensure proper usage and PPE.

			cuts, crush injuries			
Chemical	Exposure to epoxy	Improper PPE worn during construction	Eye and skin irritation; prolonged and reputative skin contact can cause chemical burns	AIII	During work with epoxy members will wear proper PPE including safety goggles, gloves, clothes that protect the skin from coming in contact with the material	MSDS sheet for epoxy will be consulted to make sure members are wearing proper PPE
	Exposure to carbon fiber/ fiberglass dust and debris	Sanding, using a Dremel tool, machining carbon fiber/ fiberglass	Eye, skin and respiratory tract irritation	BIII	During work with carbon fiber/ fiberglass members will wear proper PPE including safety goggles, gloves, long pants and long sleeve shirt.	MSDS sheet for each material will be consulted to make sure members are wearing proper PPE
	Exposure to black powder	Loading charges for stage separations or any other contact with black powder	Serious eye irritation, an allergic skin reaction; can cause damage to organs through prolonged and repetitive exposure	BIII	Only people who are trained in working with black powder will be allowed to handle it. They will wear proper PPE. Clothing that has black powder on it will be washed in special conditions.	Safety officer will ensure that unauthorized members do not work with black powder. MSDS sheet for black powder will be consulted to make sure members are wearing proper PPE
	Fire	Chemical reaction, explosion or any other event in which a chemical catches fire	Burns, inhalation of toxic fumes, death	DI	Members will only work in facilities with proper fire safety systems installed.	Safety officer or member of the safety team will be present to ensure proper use of chemicals and will inspect the area for clear indications of emergency exits. Chemicals that are in use will be kept track of to inform

						firefighters in case of a fire.
	Exposure to LiPo	LiPo battery leakage	Chemical burns if contacts skin or eyes	DIII	The battery will not be dismantled and will be checked for leaking before use.	Analysis of the battery
	Exposure to APCP	Motor damage	Eye irritation, skin irritation	DIII	Members will wear proper PPE while handling the motor	MSDS sheet for APCP will be consulted to make sure members are wearing proper PPE
Launch	Injuries due to recovery system failure	Parachute or altimeter failure	The rocket/ parts of the rocket go in freefall and injure personnel and spectators in the area causing bruising and possible death	BI	Parachutes will be properly packed, the altimeter will be calibrated correctly, the amount of black powder in separation chares will be weighted on an electronic scale	Wind, instability in thrust
	Injuries due to the motor ejection from launch vehicle	Motor installed and secured improperly	Motor and other parts of the rocket go in freefall and injure personnel and spectators in the area causing burns and possible death	CI	The motor will be installed by a certified mentor	Safety officer will ensure that the motor is installed by a certified mentor, prior to the launch the rocket will be inspected following a checklist
	Injuries from premature ignition of separation charges	Improper installation of igniters, stray voltage	Severe burns	CI	The battery will be switched off during installation of the igniters, black powder in separation charges	Safety officer will ensure that all safety procedures are followed during

					will be weighted on an electronic scale	the installation of the charges
	Injuries due to a premature motor ignition	Improper storage of the motor, damage of the motor or early ignition	Severe burns	DI	Motor and igniters will be bought from official suppliers, properly installed by a certified mentor and ignited by the RSO	Safety officer will ensure that installation of the motor and ignition are done by certified personnel
	Injuries due to unpredictable flight path	Wind, instability in thrust	The rocket goes in unexpected areas and could injure personnel or spectators	DI	The rocket will not be launched during strong winds, the rocket design will be tested through simulations to make sure that it is stable during flight	Weather conditions will be assessed, the rocket will be launched only if the RSO considers the weather safe. Multiple simulations will be run to ensure that the rocket is stable

Figure 6.2.4.3 Table of Personnel Hazard Analysis

7.3. Failure Modes and Effects Analyses (FMEA)

The FMEA ranks failure modes based on probability and severity for the hardware components of the launch vehicle and the payload. Their possible causes and effects have been considered, as well as methods of mitigation and verification of the systems to avoid these failure modes.

FMEA Probability Definitions	
Rating	Description

A	The failure is expected to occur if it is not mitigated.
B	The failure is likely occur if it is not mitigated
C	The failure may occur if it is not mitigated.
D	The failure is possible but unlikely to occur.

Figure 6.2.4.1 Table of FMEA Probability

FMEA Severity Definitions	
Rating	Description
I	Complete loss of the item or system.
II	Significant damage to the item or system. Item requires major repairs or replacement before it can be used again.
III	Damage to the item or system which requires minor repairs or replacement before it can be used again.
IV	Damage is negligible.

Figure 6.2.4.2 Table of FMEA Severity Definitions

Launch Vehicle FMEA					
Hazard	Cause	Effect	Probability/ Severity	Mitigation & Controls	Verification
Drogue parachute does not deploy	The parachute may not be packed properly, or it might be too tight of a fit in the airframe.	The rocket would descend at a dangerous free fall velocity. If the main parachute deploys at this speed, the airframe will most	BI	The drogue parachute will be properly sized and also have multiple	Testing of the recovery system and full scale testing

		likely be severely damaged.		systems to deploy it.	
Parachute detaches from launch vehicle	Improper installation of the recovery system	This would result in the complete destruction of the rocket and payload upon ground impact. It could also injure personnel on the ground due to debris upon impact.	BI	Proper installation of the recovery system and select correct sizes of hardware to handle ejection forces.	Testing of recovery system and full scale testing
Main parachute does not deploy	The parachute may not be packed properly, or it might be too tight of a fit in the airframe.	If the drogue parachute deploys, then the rocket would still fall at a high speed, leading to minor damage. If the drogue parachute also does not deploy, then the entire rocket would be destroyed upon impact of the ground.	BII	The main para chute will be properly sized and also have multiple systems to deploy it.	Testing of the recovery system and full scale testing
Melted or damaged parachute	The parachute bay is not properly sealed , or the parachutes aren’t packed correctly.	This could prevent the parachutes from slowing the rocket’s descent rate, resulting in the possible loss of the rocket and payload.	BII	Proper protection and packing of the parachutes.	Testing of recovery system and full scale testing
Shock cord tangles	Parachutes are not packed properly	Could decrease the parachutes’ effectiveness, resulting in the loss of the rocket and payload upon ground impact.	BII	Properly pack the parachutes	Testing of recovery system and full scale testing
Electronics bay is not secured properly	Electronic bay does not fit tightly into the airframe	Potential electronics and recovery failure	BII	Manufacture the electronics bay to fit accurately in the airframe	Full scale testing
Motor ejected fr om launch vehicle	The motor is secured improperly.	The motor could possibly go into freefall during flight. If it is still ignited it may harm	CI	The motor will be installed by a certified mentor. The motor retention	Full scale testing

		personnel in the vicinity or destroy the launch vehicle. It could also create free falling debris that could cause harm.		system will also be inspected prior to launching the rocket.	
Fins break off during ascent	Large aerodynamic forces or poor fin design	Rocket cannot be relaunched	CI	Mount fins properly onto the airframe	Material testing of the fins and full scale testing
Airframe separates during ascent	Improper connection of airframe sections; large aerodynamic forces cause the airframe to separate	Rocket cannot be relaunched	CI	Couplers are tight enough within the airframe to keep the airframe sections attached during ascent	Complete analysis of coupler and material strength testing
Altimeter failure	Loss of power, low battery, disconnected wires, destruction by black powder charge, or burnt by charge detonation	Incorrect altitude readings and altitude deployment; can result in potential loss of rocket and payload	CI	There will be a backup altimeter with a second power source in case the main altimeter fails. There will also be a set of backup black powder charges connected to the backup altimeter. Both altimeters will also be tested before launch.	Altimeter testing and full scale testing
Altimeter switch failure	Switch comes loose during launch or component failure	Incorrect altitude readings and altitude deployment; can result in potential loss of rocket and payload	CI	Test switches before launch	Altimeter testing and full scale testing
Electronics bay failure	Loss of power, disconnected wires, destruction by	Altimeter or recovery system failure	CII	Test the electronic bay	Full scale testing

	black powder charge, or burnt by charge detonation			and altimeter before launch	
Descent too fast	Parachute is too small	Potential damage or loss of rocket and payload	CII	Properly size parachute; test recovery system before launch	Full scale testing and testing of recovery system
Motor Misfire	Damaged motor or damage to ignitor prior to launch.	Significant to unrepairable damage to the rocket and possibility of harm to personnel	DI	The motor is only handled by a certified team mentor. If there is a misfire, the team will wait at least 60 seconds before approaching the launch vehicle and will follow the instructions of the RSO.	Full scale testing
Premature motor ignition	Damaged motor or accidental early ignition.	Possibility to harm personnel in vicinity during ignition.	DI	The motor will be replaced. It will be properly installed by a certified mentor and inspected by the RSO.	Full scale testing
Shock cord is severed	Faulty shock cord, weak cord from repeated testing, destruction by black powder charge, or burnt by charge detonation	The parachutes would detach from the rocket, leading to the loss of the rocket and payload.	DI	The shock cord will be properly sized to handle ejection loads. It will also be inspected before the parachutes are packed. A Nomex blanket will protect the shock cord from fire damage and	Testing of recovery system and full scale testing

				the black powder charges will be measured carefully.	
Fins do not keep the rocket stable	Damaged fins	Predicted apogee is not reached	DI	Use OpenRocket simulations to make sure the fin design will keep the rocket stable	Subscale and full scale testing
Fins break off during landing	High impact during landing; point stresses on fins	Rocket cannot be relaunched	CIII	Avoid fin designs with weak points and test fins with forces of final descent velocity	Material testing of the fins and full scale testing
Descent too slow	Parachute is too large	Landing outside of max drift zone	CIII	Properly size parachute; test recovery system before launch	Full scale testing and testing of recovery system
Pressure not equalized inside airframe	Vent holes are too small	Altimeters do not register accurate altitude	CIII	The vent holes will be drilled accurately	Inspection and full scale testing

Figure 6.2.4.3 Table of Launch Vehicle FMEA

Payload and retention system FMEA						
Function	Hazard	Cause	Effect	Probability /severity	Mitigation & Controls	Verification
Payload Retention	Payload retention failure	Retention system is loose and is unable to stay secure within the airframe.	Retention system fails to release payload and fails the mission. Retention system	AI	Write a checklist for retention security at launch. Take extra measures during the design process to ensure that the retention system is properly secure.	Ensure that retention system is properly secured before launch.
	Retention system fails to release payload					

	Retention system becomes insecure	Incorrectly estimated payload weight. Improper retention system installation. Payload retention design flaw	damages the inside of the rocket body and the payload if left insecure. Retention system falls from rocket during flight. Retention system is damaged and rendered unusable		Ensure that electronics telling the retention system to release the payload are in working condition	Test electronics that release payload before launch
Payload Ejection	Retention system is improperly oriented after landing preventing ejection	There could be a false ejection signal, faulty assembly of retention system, payload retention design flaw or electrical failure	The payload is ejected while still inside the rocket body, damaging the rocket and payload, the payload is ejected forcibly and is destroyed	AI	We will take protection measures for the UAV to ensure it will not be damaged during ejection and design the ejection to ensure the UAV is not ejected forcefully	We will create a checklist to test if the ejection works as intended and test the ejection before launch day to ensure it works properly
	Payload Ejection failure					
	Payload becomes damaged during ejection process					
UAV loss of control during flight	UAV electronics fail	This could be caused by a faulty battery, high winds or hazardous weather conditions, loss of connection with radio	The drone is destroyed and unable to complete its mission, the uncontrolled UAV damages the environment or the people in the surrounding	CI	We will design the UAV to be able to handle extreme conditions, ensure the radio signal of the remote is able to reach the UAV at distance, ensure the UAV can take off from multiple orientation	We will check the charge of the battery, perform multiple test flights of the UAV before the launch,
	UAV propellers fail					
	Loss of battery					
	Loss of communication between UAV and remote control					

	UAV is not able to handle environmental conditions Unstable takeoff conditions	signal from remote control, faulty electronics, faulty design or assembly of UAV prior to competition	area, the UAV flies into the rocket and damages the airframe		-choose a battery that has a long life and is not likely to be faulty	practice UAV take-offs, test the UAV in high winds
Faulty/low battery	Battery is not charged before launch Battery dies before UAV takeoff Battery dies while UAV is midair Battery dies while soil sample is being collected	Purchase of a faulty battery, the battery is drained before competition	The UAV is unable to takeoff and complete its mission, the UAV falls midflight and is damaged or broken, the UAV falls midflight and harms someone in the process, the UAV falls midflight and damages the environment	BII	We will choose a battery that has a long battery life and is not prone to being faulty and keep the battery in places where the battery will not be drained	We will check the battery charge before the launch
Electronics catch fire	Battery catches fire Improper wiring causes ignition Overheating causes ignition	Overheating of the internals of the payload during launch or outside temperature, faulty battery, incorrect wiring leading to an ignition, ignition within rocket that impacts	The rocket catches on fire and burns during launch, the rocket becomes ballistic and could hurt the environment or people in the crowd, the drone is destroyed and unable to complete its mission	DI	We will design the retention system and UAV to be properly ventilated to prevent overheating and wire the UAV in such a way that is least likely to cause a fire	We will not overexert the UAV and cause it to overheat and check the security of the wires before launch

		the security of the payload				
Soil Collection device	Soil collector becomes damaged during flight	Faulty radio signal from remote control, faulty assembly of soil collection device, faulty design of soil collection	Soil collector is unable to complete its task and fails the mission, soil collector prevents the UAV from properly taking off, soil collector becomes stuck within the retention system and prevents ejection	DIII	We will design the soil collection device, so it is properly contained within the UAV, and design the collection device so it is compatible with the soil sample	We will ensure that the collector is not dull or stripped before launch, and test the collector on multiple soil samples before launch day
	Soil collector becomes damaged during use					
	Soil collector becomes stuck					
Soil Collection container	soil container is unable to contain soil	The soil collection container becomes broken during launch, the collector is broken inside the retention system, faulty assembly of the container to the UAV, faulty design of the container	The soil container is unable to properly hold soil and fails the mission, soil container is unable to open and release sample	DIII	We will design the container so it closes completely and cannot get stuck	We will test the container to make sure it works before launch day and use several different soil types to test on container
	soil container becomes damaged during flight					
	soil container becomes damaged during use					
	soil container becomes stuck					

Figure 6.2.4.4 Table of Payload and Retention System FMEA

7.4. Environmental Concerns

Environmental Concerns table is focused on negative effects natural conditions can have on the rocket and vice versa. Each concern is assigned a rank based on its probability and severity, and for each concern we listed a way of mitigating it to minimize the risk.

Environmental Conditions Probability Definitions	
Rating	Description
A	The condition is expected to have negative effects if it is not mitigated.
B	The condition is likely have negative effects if it is not mitigated
C	The condition may have negative effects if it is not mitigated.
D	The condition is possible but unlikely

Figure 6.2.4.1 Table of Environmental Conditions Probability Definitions

Environmental Conditions Severity Definition	
Rating	Description
I	The condition may cause death or permanent disability to personnel or loss of the system.
II	The condition may cause major injuries or significant damage to the system.
III	The condition may cause injury or minor damage to the system.
IV	The condition may cause minor injury or negligible damage to the system.

Figure 6.2.4.2 Table of Environmental Conditions Severity Definition

Environmental Concerns				
Phase	Environmental Condition	Effect	Probability/ Severity	Mitigation

Launch	Inclement Weather	Unsafe alterations to launch vehicle's trajectory and launch vehicle itself.	AI	The team will not launch in inclement weather.
	High Temperature	Overheated motors or energetics could start a fire and light any flammable objects in the area. This could also be a danger to circuits	CI	The electronics will be inspected and tested to prevent shorts and anything else that could cause overheating. Motors will be safely installed and arranged in a way to prevent them from stalling or being affected by other things that may overheat them.
	Trees	Due to winds or an unpredicted flight path, the launch vehicle or payload could end up hitting or landing in a tree.	CII	The launch vehicle will be aimed in a direction with wind in mind and far from any trees to ensure the best chance of avoiding trees.
	Fire	High temperature exhaust from the motor has a chance to light flammable objects on fire if they are too close	DI	The vehicle will be launched on a launch rail with a blast deflector. The area will be cleared of flammable materials.
	Birds	If the launch vehicle hits a bird, it could damage the launch vehicle and alter its trajectory depending on the size of the bird. It will also harm the bird.	DII	The launch vehicle will not be launched while there are birds too close to it.
	Water/Rain	If the launch vehicle lands in water or gets significantly wet in any way, it could cause the BlueTube2.0 to warp or electronics. It may also disturb animals or plants within the body of water it lands.	DII	The launch vehicle will not be launched near a significantly large unfrozen body of water, nor in severe or prolonged rain.
	Strong Winds	Unsafe alterations to launch vehicle's trajectory.	BIV	Alter course and adjust trajectory to prevent launch vehicle's landing from leaving the exclusion zone. If the RSO deems the winds to be too high, the team will wait for the winds to die down.

	Sand	If the launch vehicle lands in sand or has sand blown into it, it could disrupt or get stuck in small components.	DIII	The launch vehicle will not be launched near a significantly sandy area.
Payload Teleoperation	Plants and Animals	Losing control of the UAV could result in it damaging plants and possibly any animals in the area.	CIII	A proper connection will be ensured prior to activating the UAV and there will be a failsafe in the case of a dropped connection or loss of control.
Payload Retention System	Obstruction	A plant, rock, or other object could get in the way of the retention system deploying and get damaged or prevent the system from functioning.	DIV	The retention system will be designed to deploy slowly in order to minimize potential damage to it and to any surroundings.

Figure 6.2.4.3 Table of Environmental Concerns

8. Project Plan

8.1. Requirements Verification

8.1.1. General Requirements

Ref	Description	Verification Method	Verification Status
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	The team will demonstrate minimal use of past work in documentation and will not allow adult mentors to contribute beyond general advising.	IN PROGRESS
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The team will demonstrate a maintained project plan by including it in documentation and reviewing it at every officer meeting.	IN PROGRESS

1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	The team will demonstrate this by notifying NASA of foreign nationals.	VERIFIED
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.13). 1.4.3. No more than two adult educators.	The team will demonstrate this by maintaining a list of active members and submitting a list of those who choose to attend the competition to NASA.	NOT VERIFIED
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event. A sample of the STEM Engagement Activity Report is on page 35.	The team will demonstrate this taking attendance at events and submitting STEM Engagement Activity Reports on time.	IN PROGRESS
1.6	The team will establish a social media presence to inform the public about team activities.	The team will demonstrate this by consistently posting content on social media.	IN PROGRESS
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	The team will demonstrate this by submitting documentation on time.	IN PROGRESS
1.8	All deliverables must be in PDF format.	The team will demonstrate this by ensuring all deliverables are PDFs	IN PROGRESS

		and end in a .pdf file extension.	
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	The team will demonstrate this by utilizing Microsoft Word's automatic table of contents feature.	IN PROGRESS
1.10	In every report, the team will include the page number at the bottom of the page.	The team will demonstrate this by utilizing Microsoft Word's automatic page numbering feature.	IN PROGRESS
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	The team will inspect audio and visual equipment prior to presentations to ensure they are in working order.	NOT VERIFIED
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the launch field. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on launch day wind conditions.	The team will demonstrate this by designing and constructing the launch vehicle using 1515 rail buttons.	IN PROGRESS

1.13	Each team must identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year,and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.	The team will demonstrate this by including the information of its mentor in documentation.	VERIFIED

8.1.2. Vehicle Requirements

Ref	Description	Verification Method	Verification Statu
2.1	Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team’s altitude score during Launch Week.	The team will demonstrate this by declaring a target altitude in the PDR.	VERIFIED
2.2	The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.	The team will preform an analysis of the launch vehicle to ensure that its apogee is within the specified range. This will also be demonstrated in the full scale launch.	IN PROGRESS

2.3	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and their official target altitude on launch day. This altimeter may also be used for deployment purposes (see Requirement 3.4)	The team will demonstrate this by utilizing a Strattologger in all flights of the vehicle.	NOT VERIFIED
2.4	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	After test flights, a post launch inspection will be conducted by the Safety Officer to determine if the vehicle could be relaunched.	NOT VERIFIED
2.5	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute. 2.5.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length. 2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	The team will demonstrate this by including dimensions for shoulders in documents and listing all independent sections.	IN PROGRESS
2.6	The launch vehicle will 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 will create a pit crew consisting of members from both the rocket and payload divisions. Prior to the competition, a the pit crew will be tested to ensure that its members can prepare the vehicle for launch within a maximum of 2 hours and a goal of less than 30 minutes.	NOT VERIFIED

2.7	The launch vehicle and payload will 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, although the capability to withstand longer delays is highly encouraged.	An analysis of the electronics will be performed to ensure that the batteries are enough to stay active for a minimum of 2 hours with a goal of 3 hours.	NOT VERIFIED
2.8	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	The team will utilize only commercially available APCP solid motors and will demonstrate this capability at test launches.	NOT VERIFIED
2.9	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The launch vehicle will never be connected to anything other than a 12-volt direct current firing system during test launches to demonstrate its independence of external ground support equipment.	NOT VERIFIED
2.10	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR). 2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone. 2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The team will demonstrate this by declaring the final motor in the CDR and only purchasing that motor from a licensed vendor.	NOT VERIFIED

2.11	The launch vehicle will be limited to a single stage.	The team will demonstrate this by including only one motor in all designs as specified in documentation.	NOT VERIFIED
2.12	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-sec- onds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).	The motor declared in the CDR will not by greater than an L class motor.	NOT VERIFIED
2.13	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. 2.13.2. 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. 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The team will demonstrate compliance with this requirement by never including pressure vessels in designs or on the launch vehicle.	NOT VERIFIED
2.14	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	An analysis of the rocket will be performed using an OpenRocket simulation to ensure its static stability margin is greater than 2.0.	NOT VERIFIED
2.15	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	The team will demonstrate this by detailing any structural protuberances in the documentation.	NOT VERIFIED

2.16	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	An analysis of the vehicle will be performed using an OpenRocket simulation to ensure it exits the rail at 52 fps.	NOT VERIFIED
2.17	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets. 2.17.1. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model. 2.17.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude. 2.17.3. The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project. 2.17.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	The team will demonstrate this by including the design of the subscale in documentation along with submitting telemetry gathered by the vehicles electronics in the CDR.	NOT VERIFIED

2.18.1	Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight: 2.18.1.1. The vehicle and recovery system will have functioned as designed. 2.18.1.2. The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project. 2.18.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply: 2.18.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass. 2.18.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass. 2.18.1.4. If the payload changes the external surfaces of the rocket (such as with camera hous- ings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	The team shall demonstrate compliance with this requirement by including flight telemetry and photos of the vehicle, before and after, of all flights in documentation. Flight videos will be posted to the team's social media.	NOT VERIFIED

	2.18.1.5. Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances (such as weather). 2.18.1.6. The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle. 2.18.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO). 2.18.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement. 2.18.1.9. Vehicle Demonstration flights must be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.		

2.18.2	Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria must be met during the Payload Demonstration Flight: 2.18.2.1. The payload must be fully retained until the intended point of deployment (if applicable), all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair. 2.18.2.2. The payload flown must be the final, active version.2.18.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required. 2.18.2.4. Payload Demonstration Flights must be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	The team will demonstrate this by including photographs of the mission in documentation, posting video on social media. An inspection of the payload will be preformed to determine if it sustained any damage during flight.	NOT VERIFIED

2.22	Vehicle Prohibitions 2.22.1. The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability. 2.22.2. The launch vehicle will not utilize forward firing motors. 2.22.3. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) 2.22.4. The launch vehicle will not utilize hybrid motors. 2.22.5. The launch vehicle will not utilize a cluster of motors. 2.22.6. The launch vehicle will not utilize friction fitting for motors. 2.22.7. The launch vehicle will not exceed Mach 1 at any point during flight. 2.22.8. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast). 2.22.9. Transmissions from onboard transmitters will not exceed 250 mW of power (per transmitter). 2.22.10 Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams. 2.22.11. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The team will demonstrate this by not utilizing any of these prohibited items and by not including any of them in documentation.	IN PROGRESS

8.1.3. Recovery Requirements

Ref	Description	Verification Method	Verification Status
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. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO. 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. 3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.	The team will demonstrate this requirement at launch by utilizing the drogue parachute and main parachute correctly.	IN PROGRESS
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.	The team will conduct the necessary ejection tests.	IN PROGRESS
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	The team will verify using MatLab and will also use the Strattologger velocity to verify kinetic energy.	NOT VERIFIED
3.4	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The team will demonstrate this requirement at launch by including two Stratologgers.	NOT VERIFIED
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	The team will demonstrate this by using a two cell LiPo battery to power each altimeter	IN PROGRESS
3.6	Each altimeter will 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.	The team will demonstrate this requirement on the launchpad by including two rotary switches.	VERIFIED

3.7	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The team will demonstrate this at launch by using rotary switches, which cannot switch off due to flight forces.	NOT VERIFIED
3.8	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The team will demonstrate this by including design plans in documentation to show that the payload and recovery systems are completely independent.	NOT VERIFIED
3.9	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	The team will demonstrate this at launch by using removable shear pins for each parachute.	NOT VERIFIED
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads.	The team will analyze this using MatLab.	NOT VERIFIED
3.11	Descent time will be limited to 90 seconds (apogee to touch down).	The team will analyze this using OpenRocket	NOT VERIFIED
3.12	3.12. 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. 3.12.1. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device. 3.12.2. The electronic tracking device(s) will be fully functional during the official flight on launch day.	The team will demonstrate this by including a GPS in every independent section.	NOT VERIFIED

3.13	3.13. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing). 3.13.1. 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. 3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics. 3.13.3. 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. 3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The team will conduct tests to ensure electronics do not experience interference and will demonstrate this at all launches.	NOT VERIFIED

8.1.4. Payload Requirements

Ref	Description	Verification Method	Verification Status
4.2	Teams will design a system capable of being launched in a high-power rocket, landing safely, and recovering simulated lunar ice from one of several locations on the surface of the launch field. The method(s)/design(s) utilized will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will	The team will design a payload and retention system, then iterate on the design with data gathered from freestanding and onboard testing. After test launches, it will be inspected to ensure that	IN PROGRESS

	provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.		
4.3.3	The recovered ice sample will be a minimum of 10 milliliters (mL).	The team will design a sample recovery mechanism capable of shifting 10 mL of coarse grain material. The team will demonstrate its ability in a test prior to its integration with the launch vehicle.	NOT VERIFIED
4.3.4	Once the sample is recovered, it must be stored and transported at least 10 linear feet from the recovery area.	The distance from the recovery area that the UAV travels will be measured using a measuring tape.	NOT VERIFIED
4.3.5	Teams must abide by all FAA and NAR rules and regulations.	Operation of the UAV will be overseen by either the Safety Officer of Payload Lead to ensure rules and regulations are followed.	NOT VERIFIED
4.3.6	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Any ground deployments must utilize mechanical systems.	The team will demonstrate this by only utilizing electrically powered systems in the payload and retention mechanisms.	NOT VERIFIED

4.3.7	Any part of the payload or vehicle that is designed to be deployed, whether on the ground or in the air, must be fully retained until it is deployed as designed.	The team will design a mechanism that retains the payload on a sled in the upper airframe that can only be actuated by a lead screw, which will not be activated until cleared for deployment.	NOT VERIFIED
4.3.7.1	A mechanical retention system will be designed to prohibit premature deployment.	The team will design a mechanical retention system consisting of a sled, lead screw, rotating mechanism, and corresponding servos that will be housed entirely within the upper airframe.	NOT VERIFIED
4.3.7.2	The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.	The team will conduct shake tests and drop tests of the payload and retention system. The payload and retention system will also be flown on a flight test.	NOT VERIFIED
4.3.7.3	The designed system will be fail-safe.	The team will conduct tests of the payload and retention system mechanisms in a controlled environment to determine failure conditions.	NOT VERIFIED
4.3.7.4	Exclusive use of shear pins will not meet this requirement.	The team will demonstrate this by not utilizing shear pins in the design	NOT VERIFIED

		of the payload retention system.	
4.4.1	Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event.	The team will demonstrate this by remotely controlling the payload retention system.	NOT VERIFIED
4.4.2	Unmanned aerial vehicle (UAV) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAV.	The team will not design the payload to be deployed during descent as detailed in documentation.	NOT VERIFIED
4.4.3	Teams flying UAVs 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).	Operation of the UAV will be overseen by either the Safety Officer of Payload Lead to ensure rules and regulations are followed.	NOT VERIFIED
4.4.4	Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	The team will mark the number using a printed label.	NOT VERIFIED

8.1.5. Safety Requirements

Ref	Description	Verification Method	Verification Status
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	The team will demonstrate that by including the checklists in the FRR reports	NOT VERIFIED
5.2	Each team must identify a student safety officer who will be responsible for all items in sections 5.3. - 5.6.	The team demonstrated in the proposal that the safety officer, Veronika Karshina, has been chosen to be responsible for items in sections 5.3. - 5.6.	VERIFIED

5.3.1.	The role and responsibilities of the safety officer will include, but are not limited to: Monitor team activities with an emphasis on safety during: 5.3.1. Design of vehicle and payload 5.3.2. Construction of vehicle and payload components 5.3.3. Assembly of vehicle and payload 5.3.4. Ground testing of vehicle and payload 5.3.5. Subscale launch test(s) 5.3.6. Full-scale launch test(s) 5.3.7. Launch day 5.3.8. Recovery activities 5.3.9. STEM Engagement Activities	Safety officer will demonstrate compliance with this rule by being present at all events listed in section 5.3. and emphasizing safety during these events	IN PROGRESS
5.3.2.	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officer will demonstrate that by using checklists and signing off steps after verifying their completion during completing construction, assembly, launch, and recovery activities	NOT VERIFIED
5.3.3.	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The safety officer will demonstrate that by providing hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data in proposal, PDR, CDR or the FRR	IN PROGRESS
5.3.4.	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures	The team will demonstrate that by leaving the safety officer responsible for writing and developing the hazard analyses, failure modes analyses, and procedures	IN PROGRESS

5.4.	During test flights, our team will abide by the rules and guidance of the local rocketry club’s RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club’s President or Prefect and RSO before attending any NAR or TRA launch.	The team will demonstrate that by creating and following a checklist that will include abiding to rules and guidance of the RSO	NOT VERIFIED
5.5.	Teams will abide by all rules set forth by the FAA.	The team will inspect the design and the rocket/payload to ensure that FAA regulation are met. The team will follow a checklist before launch to ensure that all rules set forth by the FAA are met	NOT VERIFIED

8.1.6. **Team Derived Vehicle Requirements**

Ref	Requirement	Justification	Verification Method	Verification Status
LV.1	The vehicle must have a ballast system.	The rocket will weigh more than in simulations, so it must weigh more than in simulations in order to reach its target apogee.	The team will test this in test launches.	IN PROGRESS
LV.2	The vehicle's fin can must be assembled using bolts rather than epoxy.	Will reduce shipping prices via flat-packing and will increase ease of maintenance.	The team will confirm this by checking quotes from shipping companies.	NOT VERIFIED
LV.3	The vehicle must reuse last years nose cone	Reduction of costs to fit within budget.	The team will test this by checking budget estimates.	NOT VERIFIED

LV.4	The vehicle must use a two-cell battery	Dimension (smaller more compact and significantly less in diameter), doesn't need as much voltage (doesn't need more than 7.2 v), relatively low C rating (maximum continues discharge rate) Straloggers say it gets damaged more than 5A	The team will test this by checking dimensions.	NOT VERIFIED
LV.5	The airframe must have a 6 inch diameter	In order to reuse the nose cone the team already has, the diameter of this year's rocket must match that of last year.	The team will demonstrate this by seeing fit	NOT VERIFIED
LV.6	Rocket must have waterproof finish	There is a high probability of the rocket landing in snow.	The team will test this by placing Blue Tube in crushed ice.	NOT VERIFIED
LV.7	Material and components must be accounted for before leaving for any launch	All parts, both primary and secondary, as well as tools, must be present for each launch	A launch vehicle checklist will be utilized to ensure required components are accounted for.	NOT VERIFIED
LV.8	The separated airframe will not come into excessive contact while during descent	Avoiding excessive contact will minimize potential damage to airframe components	Shock cord will be measured to a total length of three times the length of the entire launch vehicle, then signed on the construction checklist	NOT VERIFIED
LV.9	All deployable recovery components will be correctly packed	Proper packing of parachutes, nomex blankets and shock cord will ensure a safe deployment and prevent damage to the materials	Parachutes will be packed so that they may be easily deployed, and paired with appropriate nomex blankets and shock cord	NOT VERIFIED

LV.10	Altimeters must be programmed for parachute deployment at apogee and 650ft	Proper deployment of parachutes will result in recovery of the launch vehicle and payload	A primary and redundant secondary altimeter will be used to fire ejection charges	NOT VERIFIED
LV.11	All data-collecting devices will be powered on and transmitting	Failure to power-on pertinent electronics will result in not collecting necessary flight metrics or mission goals	A electronics checklist will be utilized for power on status, and a computer will be set to receive transmissions from any wireless devices onboard the launch vehicle	NOT VERIFIED
LV.12	Launch vehicle will be set up on the launchpad	Only licensed persons shall be allowed to configure the rocket on the launch rail	A level II high powered rocketry certified (NAR or Tripoli) individual will attend all launch events	NOT VERIFIED

8.1.7. Team Derived Recovery Requirements

Ref	Requirement	Justification	Verification Method	Verification Status
RC.1	The recovery system must utilize a Tender Descender.	This needs to be used in order to allow the upper and lower bodies of the launch vehicle to descend separately while having all parachutes stored in the same cavity.	Will be included in design documentation.	IN PROGRESS
RC.2	The recovery system must utilize two Jolly Logic Chute Releases.	This is required so that the parachutes will not deploy on drogue deployment as all parachutes are stored in the same cavity.	Will be included in design documentation.	IN PROGRESS

8.1.8. Team Derived Payload Requirements

Ref	Requirement	Justification	Verification Method	Verification Status
PL.1	The payload and retention system must weigh less than 7 pounds.	In order to keep the upper body below the 75 lbf*ft maximum kinetic energy on landing to comply with requirement 3.3.	Calculate total weight of payload and retention system in Solidworks assembly.	NOT VERIFIED
PL.2	The UAV must have a flight time of at least 4 minutes	In order to ensure completion of the mission increased flight time is required to account for any possible pilot error.	A test flight will be conducted to determine its maximum flight time	NOT VERIFIED
PL.3	The retention system must fit inside of a 26 in long 6 in diameter section of blue tube.	To comply with derived requirement LV.5.	The design of the system will be detailed in documentation. It will be test fit to ensure sizing.	NOT VERIFIED
PL.4	The retention system must autonomously orient and translate the UAV into deployment position	In order to ensure clean and precise release of UAV and ensure mission success	The system will be tested at least 4 different orientations that are at least 30 degrees apart.	NOT VERIFIED
PL.5	The UAV must be able to unfold to a larger size	In order to increase stability of the UAV	The design of the system will be detailed in documentation.	NOT VERIFIED
PL.6	The payload must be deployed post landing	In order ensure the safety of the UAV and retention system upon landing	The design of the system will be detailed in documentation.	NOT VERIFIED
PL.7	The UAV propellers must fold	In order to ensure packing proper packing inside of the rocket frame	The system will be tested to ensure that the propellers correctly unfold on activation.	NOT VERIFIED
PL.8	The soil sampling mechanism must be able to hold at least	In order to ensure we account for possible losses in transit or during the	The volume of the system will be calculated to ensure it is at least 20mL	NOT VERIFIED

	20mL of unknown sample	soil sampling process		

8.1.9. Team Derived Safety Requirements

Ref	Requirement	Justification	Verification Method	Verification Status
SF.1	Solder joints must not be cold solder joints.	Cold solder joints are significantly weaker than a proper joint. This could cause breaks in the joint, creating discontinuities that prevent the electronics from functioning and possibly preventing deployment.	Solder joints on each electrical system will be visually inspected at construction and must be signed off on construction checklists.	NOT VERIFIED
SF.2	Components used, created, and constructed will adhere to all on-campus lab and workshop requirements and regulations.	Regulations enforced by the institution that is allowing us to use their facilities should be adhered to in order to best protect students and help further safety practices.	Team members will be strongly encouraged to become basic users in facilities used in the construction of the launch vehicle and payload. Regulations of these facilities will be strictly abided by.	NOT VERIFIED
SF.3	Prior to travel, any member traveling will need to fill out a travel waiver form.	This is required by WPI to ensure the safety of students on trips.	Prior to travel, members will be checked to ensure they submitted a waiver.	NOT VERIFIED

8.1.10. Team Derived Project Plan Requirements

Ref	Requirement	Justification	Verification Method	Verification Status

PP.1	All construction must occur outside of WPI vacations.	During vacation, most members are not available. Machine shops and labs are closed as lab monitors also leave for vacation.	The team will log construction events and ensure they do not occur during vacation.	IN PROGRESS
PP.2	Money raised from corporate philanthropy will be used to subsidize flights as much as possible.	SGA is able to pay for all travel costs except for airfare. Only out of pocket or donated money can be used for flights.	The team will track sponsorship funds in the budget and ensure they are not used for other expenses.	NOT VERIFIED
PP.3	The team will elect an interim Payload Lead and Rocket Lead between the dates of 1/9/20 and 3/1/20.	Both the Rocket Lead and Payload Lead are unable to attend the competition.	The interim officers will be reported to NASA.	NOT VERIFIED

8.2. Budgeting and Timeline

8.2.1. Full Scale and Subscale Rocket Components

Full Scale							
Component	Specific Item	Quantity	Price	Total	Vendor	Comments	Purchased/ Have
Nose Cone	6” Fiberglass Nose Cone	0	$139.00	$0.00	AMW Pro-X	Already Owned	Yes
Nose Cone	Metal Tip for DX3 Massive	1	$20.00	$20.00	MadCow Rocketry		No
Parachute Deployment	Tender Descender	1	$129.00	$129.00	Tinder Rocketry		Yes
Parachute Deployment	Chute Release	2	$129.95	$259.90	Jolly Logic		Yes
Main Tube	Blue Tube 2.0 6”x0.074”x48”	2	$66.95	$133.90	Always Ready Rocketry	Airframe	No

Centering Rings	Plywood ½”x2’x4’	4	$15.50	$62.00	Home Depot		No
Fin Core	Foam - .125" x 24" x 48" 6PCF Polyurethane Foam	1	$24.00	$24.00	ACP Sales		Yes
Fin Exterior	Carbon Fiber - 5.7 oz. 2x2 Twill Weave Carbon Fiber Fabric 50"	3	$39.00	$117.00	ACP Sales		Yes
Motor Tube	Blue Tube 2.0 54mmx.062”x48”	2	$23.95	$47.90	Always Ready Rocketry	Airframe	No
Inner Tube	Blue Tube 2.0 6’x0.077”x48”	1	$66.95	$66.95	Always Ready Rocketry		No
Motor Case	CTI 75-3 Grain Case	1	$201.99	$201.99	CSRocketry		No
Flight Computer	StratoLogger CF	3	$48.89	$146.70	Perfect Flite		Yes
Arming Switch	Mini On/Off Push-Button Switch	4	$.95	$3.80	Adafruit		Yes
Wiring	Wiring	0	$5.00	$0.00	WPI	Already Owned	Yes
Main Engine	Cesaroni L910 C-Star Rocket Motor	3	$157.99	$437.97	CSRocketry		No
Backup Engine	Cesaroni L645 Green3 Rocket Motor	0	$224.99	$0.00	CSRocketry	Will buy as needed	No
Separation Charges	Black Powder Charges	0	$0.00	$0.00	WPI	Already Owned	Yes
Shear Pins	2-56x1/2” Nylon Screws	0	$10.64	$0.00	McMaster-Carr	Package of 100 Already have	Yes

Rail Buttons	Large Airfoiled Rail Buttons (fits 1.5” rail – 1515)	2	$11.17	$22.34	Apogee Rockets		No
Nomex Blankets	Sunward 18in Nomex Blanket	2	$10.91	$21.82	Apogee Rockets		No
Igniter	Full Scale Igniter	0	$0.00	$0.00	WPI	Already Owned	Yes
Parachutes	24” Drogue	1	$19.00	$19.00	Spherachutes		No
Parachutes	40” Upper	1	$44.00	$44.00	Spherachutes		No
Parachutes	48” Lower	1	$50.00	$50.00	Spherachutes		No
Shock Cord	BlueWater 1" Climb-Spec Tubular Webbing - 30 ft.	1	$13.50	$13.50	REI		No
U-Bolt	U-Bolts	0	$0.00	$0.00	WPI	Already Owned	Yes
Drop Cover	10 ft. x 25 ft. Clear 3.5 mil Plastic Sheeting (2-Pack)	1	$17.98	$17.98	Home Deopt		No
Quick Links	316 Stainless Steel Quick Link	0	$5.08	$0.00	McMaster-Carr	Already Owned	Yes
Swivel Mounts	Swivel 12/0 1500 lb	0	$4.00	$0.00	AMW ProX	Already Owned	Yes
Nuts/Bolts/ Washers	Assorted	0	$15.00	$0.00	McMaster-Carr	Already Owned	Yes
Blue Painters Tape	ScotchBlue 1.88”x60yds	0	$6.58	$0.00	Home Depot	Already Owned	Yes
Gorilla Tape	Gorilla 1-7/8x35yds	0	$8.98	$0.00	Home Depot	Already Owned	Yes

Organizer	15-Compartment Interlocking Small Parts Organizer in Black	1	$11.97	$12.72	Home Depot	2 pack	No
Thrust Plate	Aluminum Plate - Multipurpose 6061 Aluminum	1	$12.53	$12.53	McMaster		Yes
Sleeve and Collar	Aluminum Cylinder - Multipurpose 6061 Aluminum 3-1/8" Diameter	1	$34.85	$34.85	McMaster		Yes
Subscale							
Main Tube	4”x0.062”x48”	2	$38.95	$77.90	Always Ready Rocketry		Yes
Nose Cone	Fiberglass 4" Filament Wound 5:1 Ogive	1	$79.95	$79.95	Madcow Rocketry		Yes
Motor Tube	2.15”x.062”x24”	1	$23.95	$23.95	Always Ready Rocketry		Yes
Inner Tube	4”x0.062”x8”	2	$10.95	$21.9	Always Ready Rocketry		Yes
Wiring	Wiring	0	$0.00	$0.00	WPI	Already Owned	Yes
Parachutes	18” Spherachute	1	$15.00	$15.00	Spherachutes	Drogue	Yes
Parachutes	24” Spherachute	1	$19.00	$19.00	Spherachutes	Upper Main	Yes
Parachutes	30” Spherachute	1	$27.00	$27.00	Spherachutes	Lower Main	Yes
Separation Charges	Black Powder Charges	0	$0.00	$0.00	WPI	Already Owned	Yes

Overhead	Miscellaneous Bits and Shipping	1	$100.00	$100.00	Various		
	316 Stainless Steel Washer for Number 8 Screw Size, 0.174" ID, 0.375" OD	1	$3.45	$3.45	McMaster		Yes
	Low-Strength Steel Hex Nut Zinc-Plated, 8-32 Thread Size	1	$1.65	$1.65	McMaster		Yes
	Button Head Hex Drive Screw Black-Oxide Alloy Steel, 8-32 Thread, 1-1/8" Long	2	$10.82	$21.64	McMaster		Yes
	Button Head Hex Drive Screw Black-Oxide Alloy Steel, 8-32 Thread, 1/4" Long	1	$11.34	$11.34	McMaster		Yes
	Button Head Hex Drive Screw Black-Oxide Alloy Steel, 8-32 Thread, 3/8" Long	1	$14.05	$14.05	McMaster		Yes
	Pull-Out Resistant Screw-to-Expand Inserts for Plastic, 8-32 Thread Size, 1 Fin	1	$6.71	$6.71	McMaster		Yes

Motor Casing	CESARONI 54MM 3-GRAIN CASE	1	$86.87	$86.87	Apogee Components		Yes
Aft Closure	CESARONI 54MM STANDARD REAR CLOSURE	1	$53.52	$53.52	Apogee Components		Yes
Motor	CESARONI - P54-3G CLASSIC (J295)	1	$115.14	$115.14	Apogee Components		Yes
Rail Buttons	STANDARD AIRFOILED RAIL BUTTONS (FITS 1" RAIL - 1010)	2	$7.83	$15.66	Apogee Components		Yes

8.2.2. Payload Components

Payload							
Component	Specific Item	Quantity	Price	Total	Vendor	Comments	Purchased/Have
Processor	Arduino Nano	3	$22.00	$66.00	Arduino		No
UAV Motor	T-MOTOR F40 PRO III MOTOR - 2400KV	4	$26.9	$107.6	Pyrodrone		Yes
High Gauge Wire	22AWG colored wire	1	$15.99	$15.99	Amazon		No
Transceiver	NRF24L01	4	$5.00	$20.00	Amazon		No
FPV Camera	FX798T micro FPV camera	1	$30.00	$30.00	GetFPV	Possible option	Yes
FPV Monitor	4.3” LM403 LCD FPV Monitor	1	$70.00	$70.00	GetFPV	Possible option	No
Controller & Receiver	Flysky FS-i6X	1	$54.00	$54.00	Amazon	Possible option	Yes

3D Printer Filament	Nylon X	1	$70.00	$70.00	-		No
3D Printer Filament	PLA	2	$30.00	$60.00	-		No
Propellers	DJI - Quick-release Folding Propellers for DJI Spark Quadcopter (Pair) - Gray	2	$12.99	$25.98	Best Buy		Yes
	1018 Carbon Steel Precision Acme Lead Screw	1	$23.40	$23.40	McMaster		Yes
	Oil-Embedded Flanged Sleeve Bearing	6	$.81	$4.86	McMaster		Yes
	1/4"-20 Thread Size Flange Nut for Ultra-Precision Lead Screw	1	$17.45	$17.45	McMaster		Yes
	Stainless Steel Ball Bearing	10	$6.61	$66.10	McMaster		Yes
Flight Computer	Diatone Mamba F722S Stack - 506 50A Dshot1200 6S ESC	2	$79.99	$159.98	GetFPV		Yes
3D Printer Bit	All Metal Hotend Kit for Creality CR-10 / CR10S / CR20 / Ender 2, 3, 5 Printers	1	$63.50	$63.50	MicroSwiss		Yes
UAV Chassis	Lumenier 3K Carbon Fiber Sheet - 2mm Thick (200x300mm)	1	$34.99	$34.99	GetFPV		Yes
UAV Chassis	Lumenier 3K Carbon Fiber Sheet - 3mm Thick (200x300mm)	1	$44.99	$44.99	GetFPV		Yes
UAV Battery	INFINITY 2200MAH 4S 85C GRAPHENE	1	$27.99	$27.99	PyroDrone		Yes

	TECH LIPO BATTERY						
UAV Receiver	FRSKY R-XSR S.BUS/CPPM 8/16 CHANNEL MICRO RECEIVER	1	$19.99	$19.99	PyroDrone		Yes
UAV Transmitter	FRSKY TARANIS X9 LITE RC TRANSMITTER - Black	1	$69.99	$69.99	PyroDrone		Yes
UAV FPV Camera	RunCam Micro Eagle - Lumenier Edition (White)	1	$46.99	$46.99	GetFPV		Yes
UAV FPV Transmitter	TBS Unify Pro32 HV 5.8GHz Video Transmitter (MMCX)	1	$49.95	$49.95	GetFPV		Yes
UAV FPV Antenna	XILO AXII Straight MMCX 5.8GHz Antenna (RHCP)	1	$9.99	$9.99	GetFPV		Yes
UAV GPS	Matek M8Q-5883 GPS Module	1	$28.99	$28.99	GetFPV		Yes
Sample Drive Motor	Pololu 1000:1 Micro Metal Gearmotor HPCB 12V	1	$24.95	$24.95	Pololu		Yes
E-bay/ retention system battery	Turnigy nano-tech 370mah 2S 25~40C Lipo Pack	4	$4.25	$17.00	HobbyKing		Yes
Connector wires for the batteries	Male JST Battery Pigtail 12cm Length	1	$2.19	$2.19	HobbyKing		Yes
Wiring the pyro leads from the e-bay	Terminal block	4	$3.55	$14.20	Apogee Components		Yes
Switching e-bay on/off when in rocket	Electronics rotary switch	2	$10.33	$20.66	Apogee Components		Yes

Mounting the altimeters to the e-bay sled	Altimeter mounting posts	3	$3.83	$11.49	Apogee Components		Yes
Interfacing with Stratologgers	DT4U USB Data Transfer Kit	2	$22.46	$44.92	PerfectFlite Direct		Yes
Tracking the location of the rocket	DIYmall 6M GPS Module	2	$17.00	$34.00	Amazon		Yes
Sensing orientation/accel of the rocket	MPU-6050 gyroscope/accelerometer	1	$8.99	$8.99	Amazon		Yes
Wireless comms from the e-bay	900Mhz Antenna Kit and connector	1	$13.50	$13.50	Adafruit		Yes
High frequency data logging	FRAM Breakout board	2	$9.95	$19.90	Adafruit		Yes
Retention system lead screw	Rotary encoders	1	$8.54	$8.54	Amazon		Yes
Payload Retention Motors	HS-785HB Servo	2	$49.99	$99.98	ServoCity		Yes

Budget	
Total Allotted	$4,124.84
Total Spent	$2,349.96
Total Remaining	$1,174.88