LionTech Rocket Labs

USLI Preliminary Design Report 2016-2017

Project Odyssey

The Pennsylvania State University
46 Hammond Building State College, PA 16802
September 30, 2016

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List of Acronyms

A&R	Avionics and Recovery
CATO	Catastrophe At Takeoff
CFD	Computational Fluid Dynamics
EHS	Environmental Health and Safety
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
FOPS	Fragile Object Protection System
GPS	Global Positioning System
HPCL	High Pressure Combustion Lab
LTRL	LionTech Rocket Labs
MDRA	Maryland Delaware Rocketry Association
MSDS	Material Safety Data Sheet
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
PPE	Personal Protective Equipment
PSC	Pittsburgh Space Command
PSU	The Pennsylvania State University
RSO	Range Safety Officer
STEM	Science Technology Engineering Math
STTR	Small Business Technology Transfer
TRA	Tripoli Rocket Association
UPAC	University Park Allocation Committee
USLI	University Student Launch Initiative

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1. General Information

1.1 Important Personnel

Adult Educator

Michael Micci - micci@psu.edu - (814-863-0043)

Safety Officer

Laura Reese - ler5201@psu.edu

Team Leader

Luke Georges - lag5461@psu.edu

NAR Contact

Robert DeHate, President, Animal Motor Works, Inc. - rocketflier@gmail.com
LionTech Rocket Labs Mentor, NAR L3 Certification - #75198

NAR Sections: Pittsburgh Space Command (PSC) #473

1.2 Team Roster and Structure

Lion Tech Rocket Labs has approximately 88 active members, ranging from freshman to senior undergraduates and graduate students. However, it is unexpected that all of these students will be able come to the competition due to travel expenses and necessary accommodations. The team is divided into administrative and technical branches for managing resources and completing tasks.

Administrative

The administrative branch is composed of the President, Vice-President, Treasurer, Secretary, Outreach Chair, Webmaster and Safety Officer. These individuals are responsible for actively providing space for the technical branch to be able to function and managing the team as a whole. The position holder and their respective duties are shown in Table 1.

Table 1: Administrative Infrastructure

Name	**Position**	**Proposed duties**
Luke	President	Communicates with project stakeholders, organizes meetings and keeps team on schedule. Guides team in the overall design and construction of the systems.
Evan	Vice President	Assists President in managerial tasks, meetings with stakeholders and team. Coordinates integration between subsystems.
Justin	Treasurer	Arranges fundraising events, communicates with sponsors and manages funds for the project
Sam	Secretary	Records information discussed in meetings and communicates with the general body of the club in the form of reminders and meeting recaps via email
Brian	Outreach	Organizes events for the club to engage with the community and share experience, knowledge and passion in STEM fields
Tanay	Webmaster	Manages team website, uploads project deliverables and meeting notes
Laura	Safety Officer	Ensures team follows safety regulations and implements safety plan

Technical

The technical branch is responsible for the design, fabrication, testing, and flight operations of the payloads and flight vehicle. The technical branch is divided in to four main subsystems: Avionics and Recovery, Payload, Propulsion, and Structures. Table 2 displays the officer positions and subsystem duties within the technical branch. Because the team is large, a description of what each subsystem's duties are is given in place of a description of each member's duties. The officers themselves take a leadership role in the subsystems; they guide, teach and work alongside their team to complete their duties. The general members of the club are spread out among each of the four subsystems, under the technical officers.

Table 2: Technical Infrastructure

	Position	Duties
Evan	A&R Leadership	Avionics and Recovery creates the avionics bay for the flight vehicle, tests altimeters, ejection charges and parachutes. On launch days A&R ensures proper parachute packing and successful vehicle recovery.
Gretha		
Torre	Payload Leadership	Payload designs and creates science packages for the project. These tend to involve computing and electrical components within the flight vehicle. Payload ensures these packages are functioning properly when preparing for launch.
Dan		
Alex P.	Propulsion Leadership	Propulsion selects motors for the vehicle, performs flight analysis and drag estimates. Propulsion is normally in charge of motor handling and insertion on launch days.
Trevor		
Alex B.	Structures Leadership	Structures designs and creates the flight vehicle, tests materials and ensures all necessary components of the vehicle are compatible and flight ready. Structures is in charge of final assembly of the rocket for launch.
Kurt		
Anthony		
Kartik		

2. Summary

2.1 Team Summary

Team – LionTech Rocket Labs
Address – 46 Hammond Building, University Park, PA 16802
Mentor – Robert DeHate - NAR L3CC - #75198

2.2 Vehicle Summary

Size and mass

The Launch vehicle for project Odyssey was designed in order to maximize reliability and safety while including the desired payloads and characteristics. To achieve these goals, several design characteristics were chosen. The outer diameter of the airframe was determined to be 6.079”, constructed using Blue Tube airframe and couplers. The length of the launch vehicle was also increased to 147 Inches, while the weight of the launch vehicle now is determined to be 39.5 pounds.

Motor choice

The motor selection process is based off of the mission performance criteria outlined in the NASA USLI 2016-17 handbook and preliminary uses Open Rocket to simulate flight characteristics. Through this motor selection process The Cesaroni L-1350 was selected.

The recovery system will allow the rocket to land safely and within the kinetic energy limits of 75ft-lbs. This rocket will have a dual-deployment landing system where the drogue will be deployed at apogee and the main will be deployed at 700ft above the ground. The avionics bay consists of two independent altimeters with corresponding power supplies, switches, and charges. In order to not overwhelm the body of the rocket, one of the altimeters will set off the ejection charge at a delay. The avionics bay will be contained in a coupler in the center of the rocket with parachutes on both ends of it. The rocket will have a 36” Classical Elliptical as the drogue parachute and a 96” Iris Ultra as the main parachute.

2.3 Payload Summary

LTRL will fly two payloads during the USLI competition: the Fragile Object Protection System (FOPS) and Kiwi, an autonomous coaxial helicopter that will be launched from the rocket at apogee and navigate towards a predetermined location.

Summary of the Payload Experiment

Due to high accelerations and impacts during rocket flight, fragile objects stored within the vehicle are particularly vulnerable to break or bend. LTRL’s FOPS aims to protect these fragile objects from potential damage caused by vehicle flight.

LTRL’s second payload, an autonomous coaxial helicopter called Kiwi, will be launched from the rocket at apogee. Kiwi will then stabilize itself and autonomously navigate to a predetermined location. It will be equipped with an onboard GPS and emergency parachute system to ensure Kiwi descends in accordance with the kinetic energy requirements.

2.4 Milestone Review Flysheet

Milestone Review Flysheet

Institution	The Pennsylvaina State University
Milestone	PDR

Vehicle Properties

Total Length (in)	147
Diameter (in)	6.079
Gross Lift Off Weigh (lb)	39.5
Airframe Material	Blue Tube 2.0
Fin Material	Fiberglass (1/8")
Coupler Length	12 inches

Stability Analysis

Center of Pressure (in from nose)	110 inches
Center of Gravity (in from nose)	89.7 inches
Static Stability Margin	3.33
Static Stability Margin (off launch rail)	2.25
Thrust-to-Weight Ratio	7.68
Rail Size and Length (in)	1515 rail, 144 in
Rail Exit Velocity	76.6 ft/s

Recovery System Properties

Dogue Parachute

Manufacturer/Model	Fruity Chutes/ Classic Elliptical			
Size	36"			
Altitude at Deployment (ft)	5280			
Velocity at Deployment (ft/s)	0			
Terminal Velocity (ft/s)	65.7			
Recovery Harness Material	Kevlar			
Harness Size/Thickness (in)	0.5			
Recovery Harness Length (ft)	20			
Harness/Airframe Interfaces	Closed 1/2" Steel Eyebolts, 1/4" Steel Quick Links			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	548.2	604.2	438.5	

Recovery Electonics

Altimeter(s)/Timer(s) (Make/Model)	Stratologger SL100/CF
Redundancy Plan	Two independent altimeters (Stratologger SL100/CF), e-matches, power sources, black powder charges
Pad Stay Time (Launch Configuration)	3 hours

Motor Properties

Motor Designation	4263-L1350-CS-0
Max/Average Thrust (lb)	348.23/ 303.27 lb
Total Impulse (lbf-s)	962 lbf-s
Mass Before/After Burn	7.87/ 4.20 lb
Liftoff Thrust (lb)	101.16
Motor Retention	Slimline Retainer w/ Tailcone

Ascent Analysis

Maximum Velocity (ft/s)	668 ft/s	
Maximum Mach Number	M 0.6	
Maximum Acceleration (ft/s^2)	255 ft/s^2	
Target Apogee (From Simulations)	5315 ft	
Stable Velocity (ft/s)	337.6 ft/s	
Distance to Stable Velocity (ft)	310 ft	

Recovery System Properties

Main Parachute

Manufacturer/Model	Fruity Chutes/ Iris Ultra			
Size	96"			
Altitude at Deployment (ft)	700			
Velocity at Deployment (ft/s)	65.7			
Terminal Velocity (ft/s)	17.8			
Recovery Harness Material	Kevlar			
Harness Size/Thickness (in)	0.5			
Recovery Harness Length (ft)	30			
Harness/Airframe Interfaces	Closed 1/2" Steel Eyebolts, 1/4" Steel Quick Links			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	41.5	45.7	33.2	

Recovery Electonics

Rocket Locators (Make/Model)	Garmin Astro 320 GPS Beacon
Transmitting Frequencies	***Required by CDR***
Black Powder Mass Drogue Chute (grams)	7.4
Black Powder Mass Main Chute (grams)	7.76

Milestone Review Flysheet

Institution	The Pennsylvania State University	**Milestone**	PDR

Autonomous Ground Support Equipment (MAV Teams Only)

Capture Mechanism	Overview
Container Mechanism	Overview
Launch Rail Mechanism	Overview
	Include Description of rail locking mechanism
Igniter Installation Mechanism	Overview

Payload

Payload 1	Overview
	Due to high accelerations and impacts during rocket flight, fragile objects stored within rocket are particularly vulnerable to break or bend. LTRL’s fragile object protection system aims to protect these fragile objects from potential damage caused by vehicle flight by enveloping them in a non-Newtonian fluid suspended in a foam lined chamber via rubber bands.
Payload 2	Overview
	LTRL's second payload, a coaxial helicopter called Kiwi, will be launched from the rocket at apogee. Kiwi will then stabilize itself and autonomously navigate to a predetermined location. It will be equipped with an onboard GPS and emergency parachute.

Test Plans, Status, and Results

Ejection Charge Tests	LTRL will conduct ground tests for the ejection charges before subscale launch at a local facility. There will also be a ground test on the day of subscale launch and before a full scale launch. The amount of black powder needed for ejections will be estimated using models before initial ground testing but will be refined after the ground tests.
Sub-scale Test Flights	First Subscale test launch is scheduled for early November
Full-scale Test Flights	Fullscale test flights have not been scheduled yet

3. Changes Made Since Proposal

3.1 Vehicle Design

Since the initial project proposal, several refinements were implemented to the launch vehicle regarding its size and mass. For instance, the outer diameter of the airframe was increased to 6.079” from 5.50” to allow for increased volume for payloads such as the planned Kiwi payload. Blue Tube was maintained as the airframe material to keep the thrust-to-weight ratio within a manageable range, although planned material testing and validation will determine if Blue Tube is the most efficient choice. The length of the launch vehicle was increased to 147 inches in order to accommodate increased size for Kiwi and parachutes needed to maintain kinetic energy requirements. Along with increased length, the weight of the launch vehicle was increased to 39.5 pounds due to the launch vehicle’s increased length, diameter, and payload masses. This resulted in needing a higher impulse motor than in the proposal design. Lastly, the portion of the airframe surrounding FOPS was altered from Blue Tube to Acrylic for its translucent properties in order to have visual confirmation of the success of FOPS.

3.2 Recovery System

Since proposal, there have been more accurate mass estimations which has allowed initial parachute selection. The main parachute will be the 96” Iris Ultra and the drogue will be a 36” Classic Elliptical. Both parachutes will be Fruity Chutes brand since they have been very reliable in previous launches.

The altimeters will be StratoLoggerCF rather than the Stratologger 100. They are the newest version of the previous altimeters and are expected to be at least as accurate as the SL100. The Stratologger CF altimeters will undergo rigorous testing to ensure their precision and accuracy.

3.3 Payloads

The payload subsystem has made two changes to the payloads since proposal. Because the non-Newtonian fluid must be put into the protective chamber prior to the fragile object, the plastic bag containing the object will be on a pulley system so that it can be brought to the top of the chamber and the fragile object can be loaded into it. Additionally, due to the difficulty and danger of guiding the entire rocket, a small coaxial helicopter drone, Kiwi will guide itself to a location determined prior to launch. The drone will be stored in the body of the rocket and released at apogee.

3.4 Project Plan

In terms of funding and the budget there has been both an increase in expected funding and decrease in expected cost. This allows more room in the budget for new tools and better resources to work on the project than previously thought. There have been no changes to the project timeline at this stage of the project. If anything, the project is ahead of schedule in some areas; however, not by enough to warrant adjustment of the timeline. The general tasks outlined initially are proving to guide the project well so far.

4. Vehicle Criteria

4.1 Mission Statement

LionTech Rocket Labs believes in providing an opportunity to be a part of high powered rocketry and engineering design processes to any students who are interested, regardless of background or experience.

LTRL is strives to excel in the USLI competition using previous experiences combined with new innovations and ideas; however, the success of the organization is not directly tied to this. Instead, the success of the organization is based on:

- Members gaining valuable experience in rocketry, teamwork and outreach
- Outreach activities spreading information about both the club and STEM fields
- Conducting innovative design and research to improve the club and project

4.2 Vehicle Design

Systems Level Structural Design Study:

For the structural design of the launch vehicle, there were several possibilities for each subsystem in terms of materials or other considerations. Each of these possibilities had reasons in favor and opposing each alternative. Figure 1 illustrates the fullscale design incorporating all subsystems of the launch vehicle.

Figure 1: Fullscale Assembly

Nosecone

For the nosecone of the launch vehicle, the material could have been chosen as plastic or fiberglass. A plastic nosecone would constitute less weight; the durability of plastic was determined to be insufficient as compared to fiberglass. Fiberglass would have superior durability and strength, although at an increased cost. The tip of the nosecone could be fiberglass or a separate aluminum component, where an integrated fiberglass nosecone tip would be much lighter than a solid aluminum tip. However, the ductility and structural stiffness of the aluminum tip outweighed that of fiberglass. The shape of the nosecone could be selected as an Ogive nosecone, a variant of the Haack series, or a Von Karman nosecone shape. An Ogive shape would be easily modeled virtually but would lead to a higher coefficient of drag when compared to either of the other possibilities. In addition, another Haack series shape could have been chosen over a Von Karman using another C value during calculations. Unfortunately, other Haack series shapes yield higher drag coefficients, whereas the Von Karman shape is mathematically formulated to produce the lowest drag. In addition, the only Haack series that is commercially available is the Von Karman Series nosecone. A Von Karman nosecone shape would result in decreased overall drag for the launch vehicle but would be more difficult to model as it incorporates the mathematical definition of the exterior.

The selected launch vehicle nosecone is made of fiberglass and has a Von Karman shape for better aerodynamics [6]. Refer to Figure 2 for a dimensioned drawing of the nosecone.

The specifications for the nosecone is as following:

- 5.5:1 length to diameter ratio
- 5.5-inch outer diameter
- 30.25-inch length
- inch shoulder (5.4-inch diameter)
- 48 ounces (including all the components housed within nosecone)

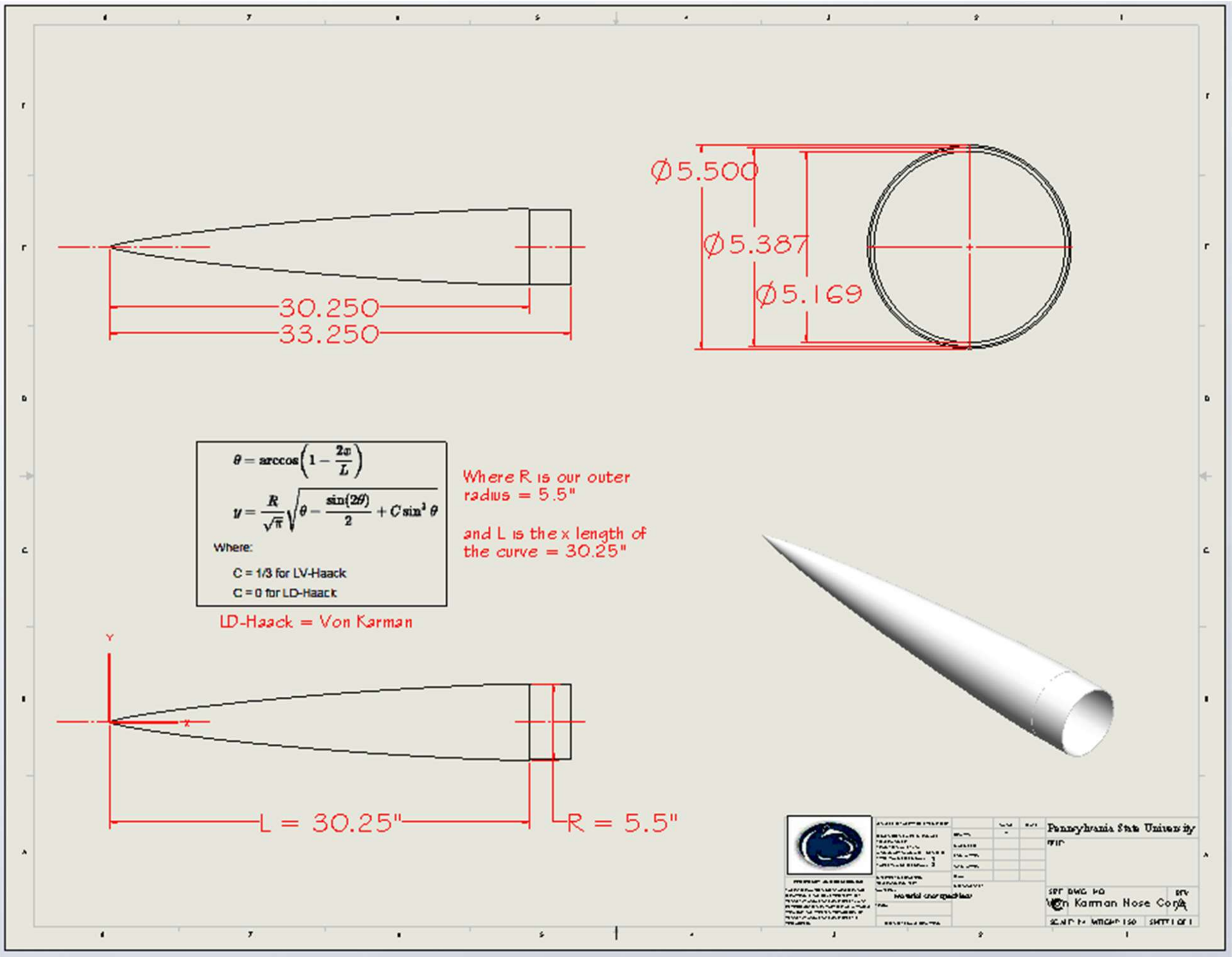


Figure 2: Engineering drawing of Von Karman Nose Cone

Transitions & Acrylic

For transitions between the fiberglass nosecone and acrylic, as well as between the acrylic and blue tube 2.0 airframe sections, additive manufacturing materials of ABS or PLA could be chosen. The primary benefit of ABS includes its superior strength, although ABS is more difficult to print, making it more prone to warping and unwanted imperfections within the parts. In addition, the 3D-Printed components could be loaded, structural members. There seems to be no significant advantage to direct loading, and compared to indirect loading, the distribution of stresses off of the 3D-printed components would lead to increased longevity of the 3D-printed components.

Alternatives to the acrylic airframe section surrounding FOPS include blue tube 2.0 and fiberglass. The advantages of fiberglass included decreased required weight, and blue tube 2.0 offered decreased cost. However, both material alternatives did not offer the ability to have prompt visual confirmation of the status of FOPS.

Nosecone to acrylic transition

The final choice for the transition will be a 3D-printed PLA thermoplastic. The transition section will not be loaded as there is a coupler inside to support it. The forward transition is epoxied in place and screws are inserted through the acrylic, transition, and into the nosecone shoulder to hold the three components in position. Refer to Figure 3 for a dimensioned drawing of the forward transition.

The specifications for the transition is as following:

- 1.5-inch length
- 5.5-inch forward diameter and 5.75-inch aft diameter
- 1.49 ounces

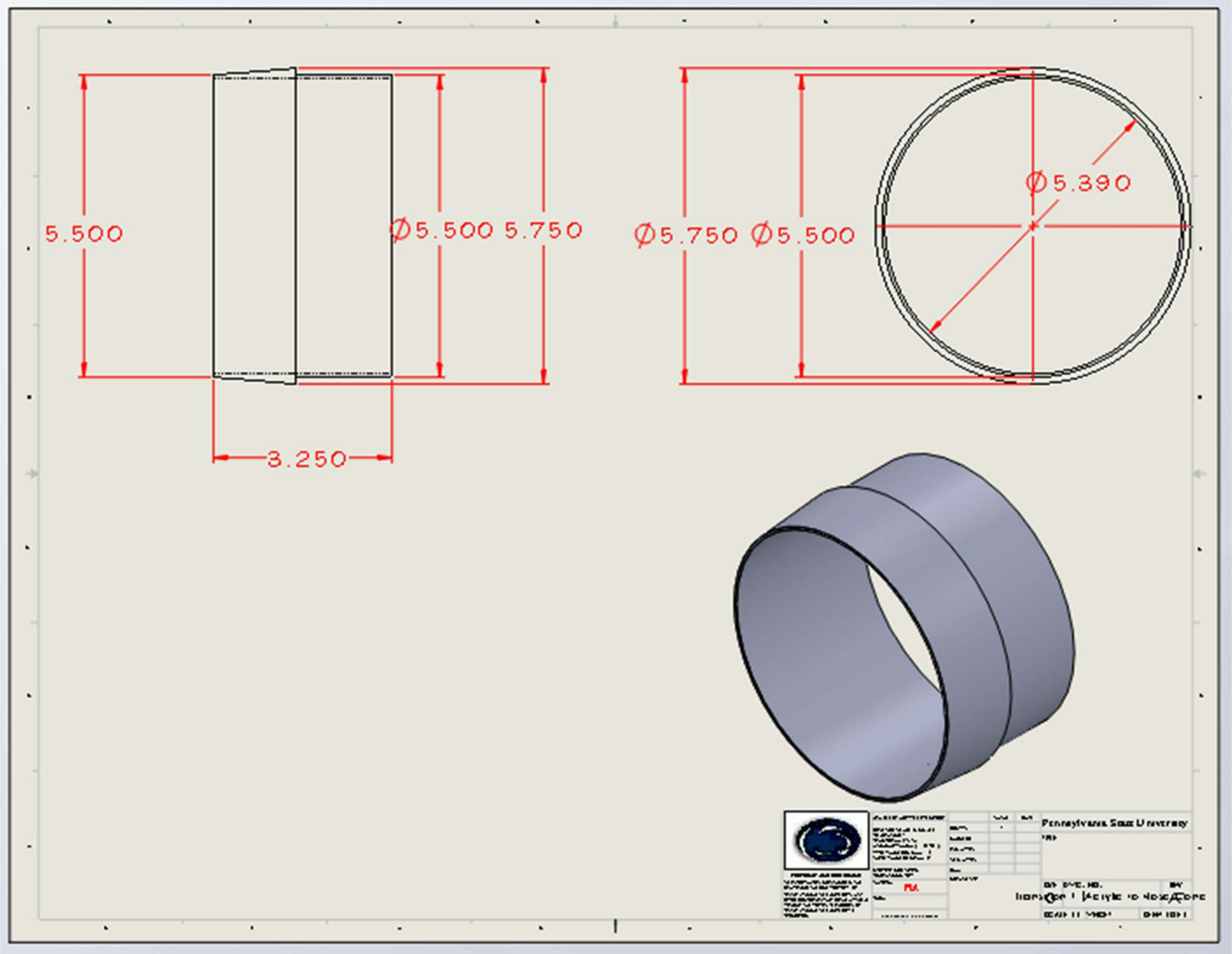


Figure 3: Engineering Drawing of Nosecone-Acrylic Transition

Acrylic

This airframe section contains the FOPS payload assembly. It also contains the transition stabilizing coupler made from blue tube 2.0. Refer to figure XXX in the FOPS payload description for renderings of the acrylic section.

The specification for the acrylic section is as following:

- 12-inch length
- 5.75-inch outer diameter
- 65.9 ounces

Acrylic to Main Body Tube transition (external and internal)

This section will be a 3D-printed PLA thermoplastic. This transition tube will be supported by a blue tube 2.0 coupler. The aft transition is epoxied in place and screws are inserted through the acrylic, transition, and into the transition stabilizing coupler to hold the three components in position. Refer to Figure 4 for a dimensioned drawing of the forward transition.

The specifications are as following:

- 3-inch length
- 5.75-inch forward diameter and 6.079-inch aft diameter
- 3.13 ounces

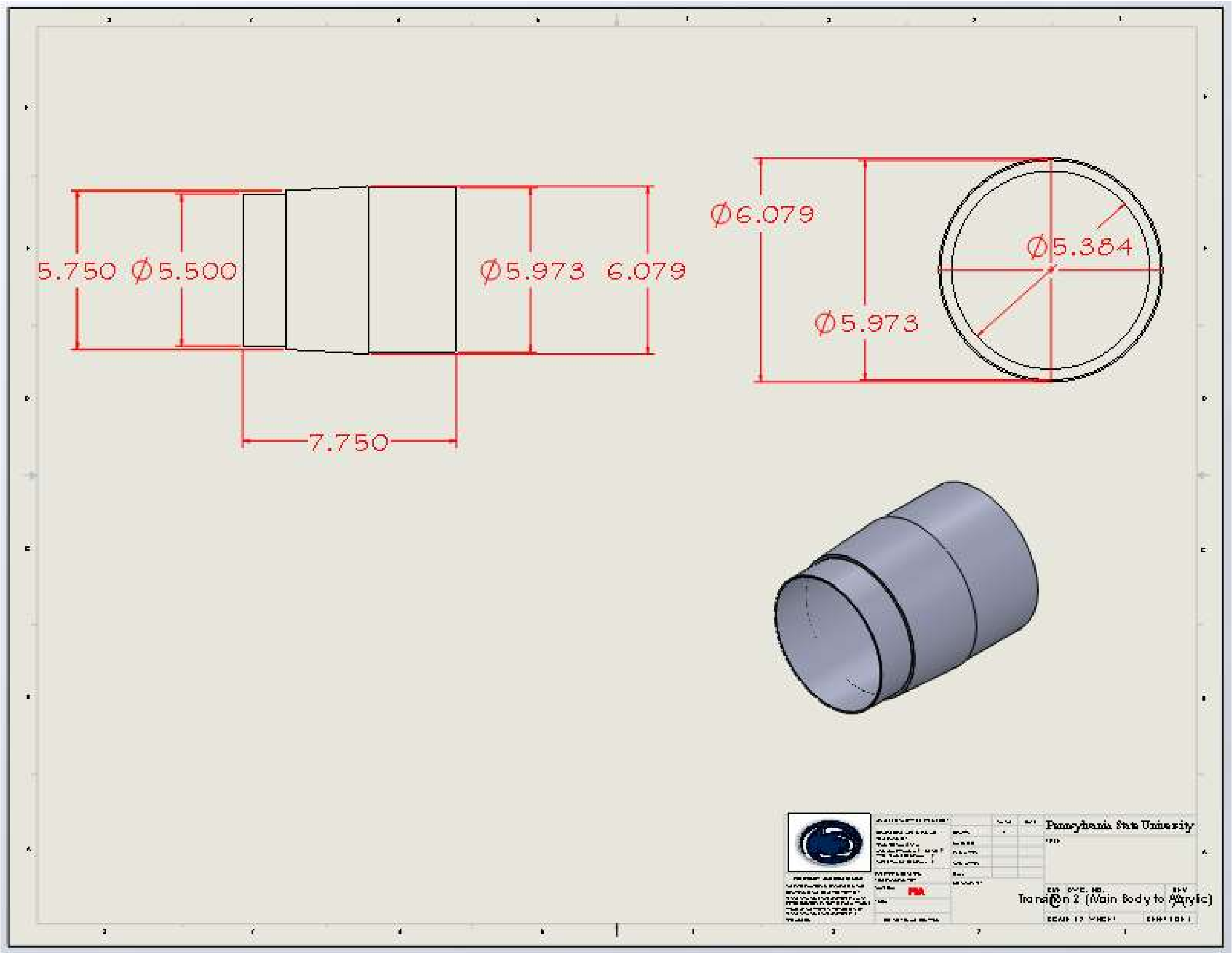


Figure 4: Engineering Drawing for Acrylic to Main Body Tube Transition

Airframe

For the main airframe of the launch vehicle, an alternative to the current blue tube 2.0 constriction was fiberglass. Advantages of fiberglass included current member's previous experience with the material over the past few years, as well as increased strength. From previous experiments carried out, fiberglass was determined to have fairly high tensile strength, even with nontrivial stress concentrators. Moving forward, there are comparable tests planning to take place to obtain data for blue tube 2.0. These results will be factored in when those experiments are performed. However, the main detractors from fiberglass as airframe material was the increased expense and safety considerations while cutting airframe components. A selection matrix for these two materials can be found below in Table 3.

Table 3: Selection Matrix for Launch Vehicle Airframe Material

		Fiberglass		blue tube 2.0	
Attributes	Weights	Rating	Weighted	Rating	Weighted
Cost	35%	2	0.7	3	1.05
Strength	20%	3	0.6	2	0.4
Mass	20%	1	0.2	3	0.6
Handling	20%	2	0.4	4	0.8
Looks	5%	3	0.15	2	0.1
Total	100%		2.05		2.95

The main body tube is made up of blue tube 2.0. It contains the main parachute and shock cord. The main separation point is between the main body tube and acrylic airframe section with shear pins between those points. Screws are inserted through the airframe and into the Avionics bay to hold the two sections together.

The specifications are as following:

- 30-inch length
- 6.079-inch outer diameter
- 87.5 ounces

Avionics Bay

The specifications are as following:

- 6-inch length
- 6.079-inch outer diameter
- 112 ounces (mass includes all internal components)

Drogue Body Tube

This airframe section is made up of blue tube 2.0 and contains the drogue parachute, shock cord, and the KIWI payload. Screws are inserted through the drogue body tube into the avionics bay to hold them in place. The drogue separation point is between the drogue body tube and booster section with shear pins between these sections.

The specifications are as following:

- 30-inch length
- 6.079-inch outer diameter
- 92.5 ounces (mass includes everything housed in drogue body tube)

Booster Body Tube and Coupler

The section is made up of blue tube 2.0. The booster section holds to inner tube aligned through centering rings. The drogue body tube to booster coupler has a length of 8in and 5.973in outer diameter.

The specifications for the booster are as following:

- 30 inches length.
- 6.079 outer diameter
- 28.7 ounces

Airframe Testing

To verify that the launch vehicle is capable of withstanding the expected loads during launch and landing, material testing is to be completed prior to full-scale construction. This testing will require the use of the Learning Factory at Penn State to create an apparatus which requires machining of parts. In previous years, LionTech Rocket Labs has tensile tested G12 fiberglass as seen in Figure 5.

The greatest failure mode for the airframe is in tension where screws are used to hold them together. During testing, aluminum bulk plates were attached to the 3-inch diameter G12 fiberglass tube using four and six screws on each respective bulk plate. The whole specimen was then attached to the tensile test machine using two aluminum rods 0.77 inches in diameter, as seen in Figure 5.

Figure 5: Tensile Testing Setup for G12 Fiberglass Specimen

The tensile test machine continuously applied axial load until specimen failure. Data obtained from the tensile testing machine resulted in a yield force of approximately 3,780 pounds, as noted in Figure 6.

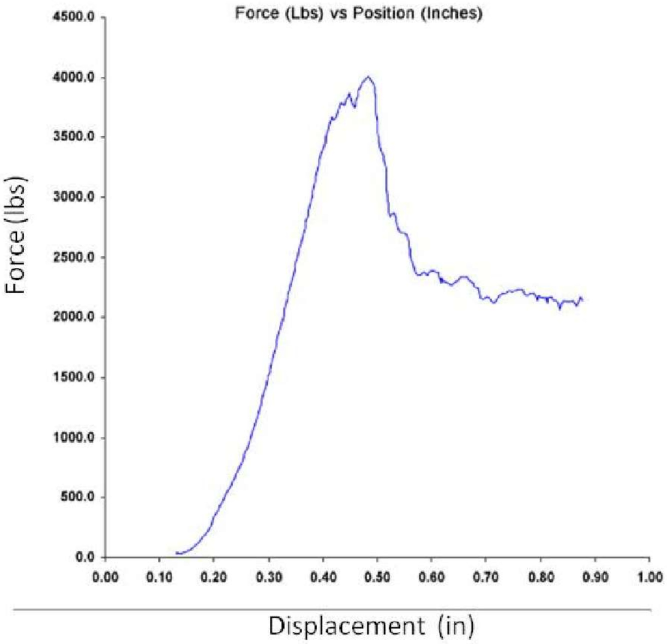


Figure 6: Force vs. Displacement of 3-inch diameter G12 Fiberglass Specimen

This yield force resulted in a corresponding yield stress of approximately 42.7 ksi, as calculated in Figure 7. This is due to the fact that the failure of the specimen occurred on the side of the fiberglass that had 4 screws, increasing the stress at those points.

$$\sigma_f = \frac{yield\ force}{Area} = stress\ at\ failure$$

$$\sigma_f = \frac{3782\ pounds * 2}{\pi * 0.188in * 4screws * 0.075in}$$

$$\sigma_f = 42.69\ ksi$$

Figure 7: Calculation of Yield Stress from Tensile Test Data

Camera Cover

The camera cover had to be a durable design that could easily perform the task of housing a camera utilizing additive manufacturing to achieve ease of manufacturability, a potential alternative design where a rectangular section was removed from the airframe and a 3D-printed cover was inserted using integrated clips. The benefits of this design would be the ability to efficiently repair and replace the camera cover itself. The camera cover was shaped to an airfoil to decrease drag and improve flight performance. However, the accurate fit between the airframe and 3D-printed cover would be prone to geometric error, resulting in potential gaps in the airframe. The figure below illustrates the differences between the alternative and current designs, respectively.

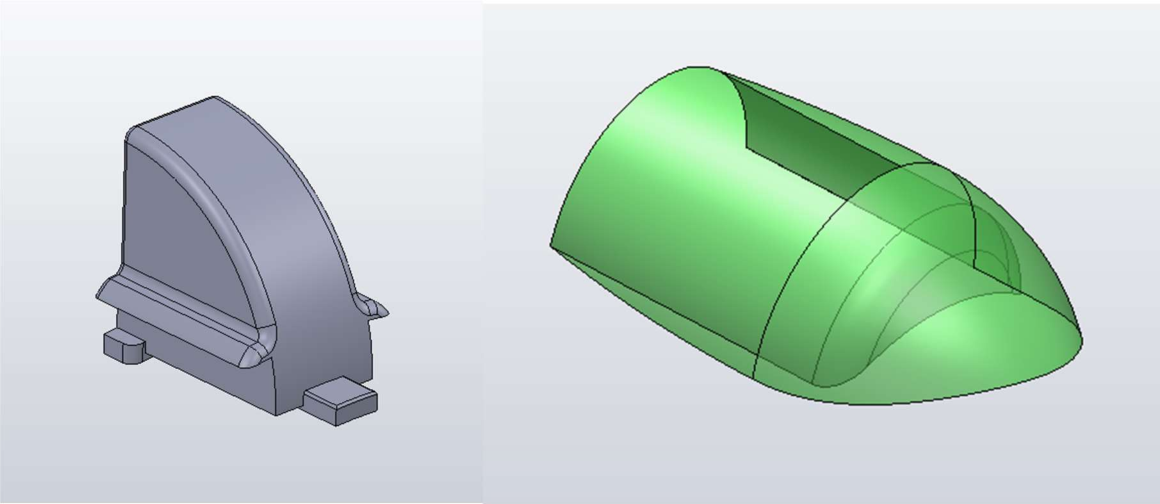


Figure 8: Last Year's Camera Cover Design (Left) VS. New Design (Right)

The chosen camera cover is made of 3D-printed PLA thermoplastic and supports the camera which sits externally on the rocket. There will be a small hole in the airframe to allow the camera's power and data wires to traverse inside the main body. Figure 9 shows a dimensional drawing of the camera cover.

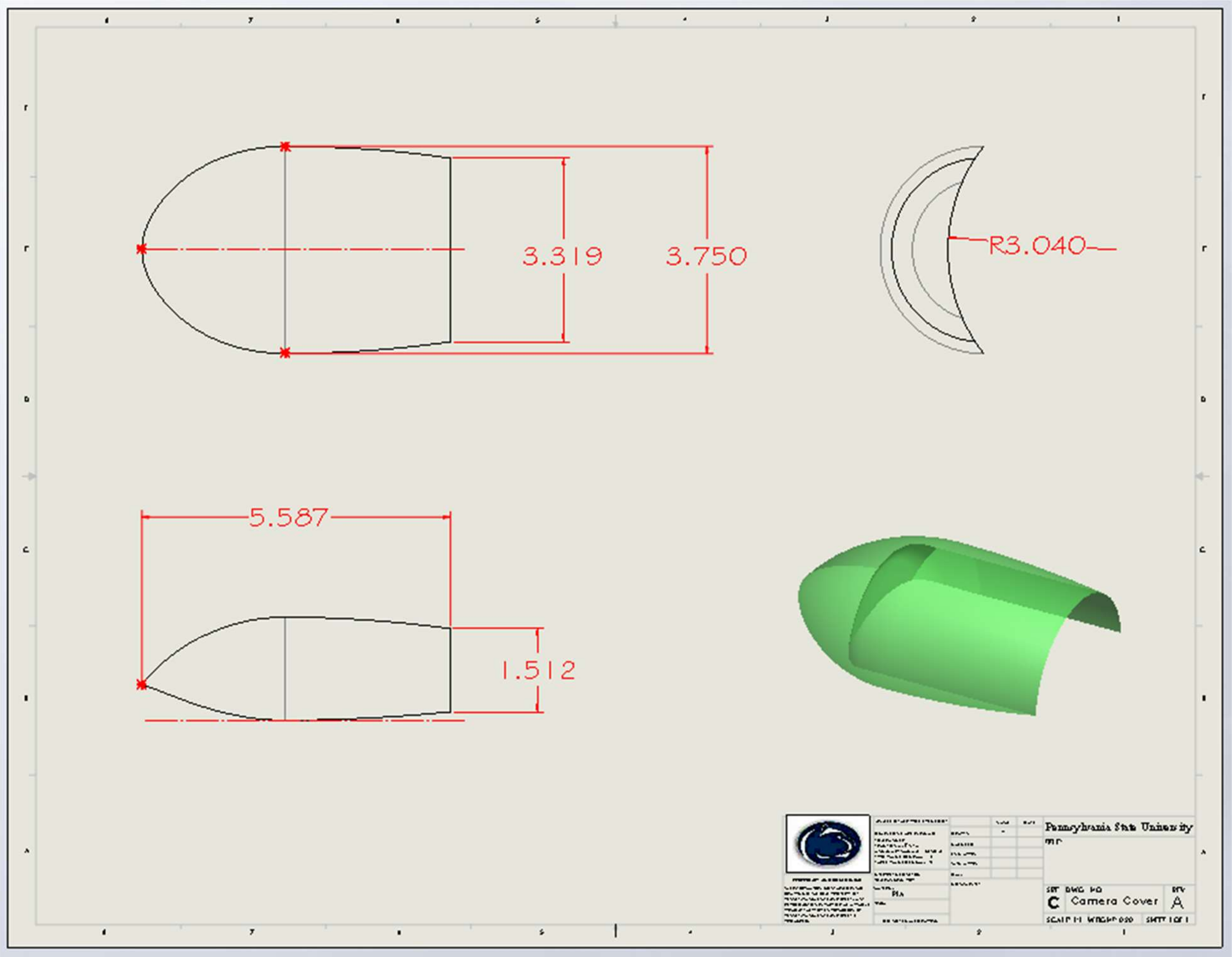


Figure 9: Engineering Drawing of Camera Cover

Bulkheads & Centering Rings

Bulkheads act to segregate sections of the launch vehicle as well as provide anchorage for shock cord and parachutes. Potential alternatives for bulkhead materials included fiberglass and plywood. Fiberglass would provide increased strength; however, fiberglass would have greater mass. Plywood would prove to be lighter as well as less hazardous to sand if necessary, though plywood certainly would have decreased strength.

Similar to bulkheads, centering rings could have fiberglass and plywood as potential materials. Fiberglass would have inherently increased strength, but at the cost of increased mass. Plywood as a centering ring material would unfortunately result in decreased strength. However, plywood would not only provide decreased mass, but would provide more surface area for the adhesion of epoxy due to its thicker geometry.

The bulkheads are made up of plywood and sequester sections of the launch vehicle. Because of this thicker material choice, the higher surface area results in higher epoxy adhesion. A rendering that displays the centering ring locations in the motor section is shown in Figure 10.

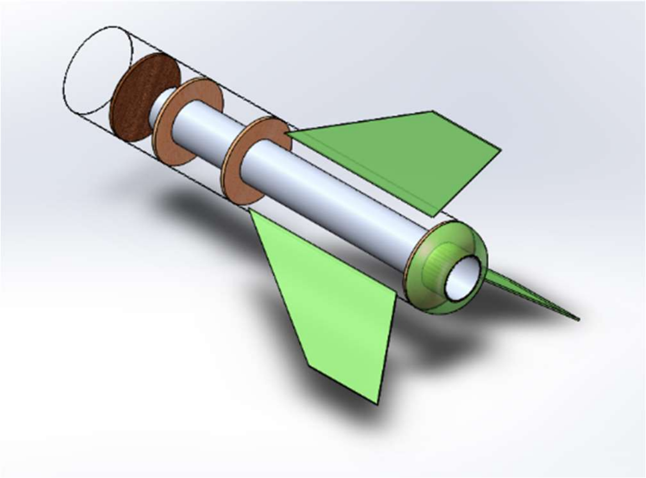


Figure 10: Booster Section Rendering

Fin Brackets

Fin brackets had two possibilities for materials, implementing either machined aluminum or additive manufacturing using thermoplastics. Aluminum fin brackets would offer superior strength and durability in comparison to thermoplastic. However, the aluminum component would have to be screwed to the airframe, with the screws proving difficult to access once centering rings are adhered into place. Thermoplastic fin brackets would have decreased strength in comparison to aluminum, but the benefits would include a lighter mass and accelerated manufacturing of components. This accelerated and less costly production using additive manufacturing would allow for design feedback loops for rapid iterations of designs.

The fin brackets will be 3D printed which requires further testing. Refer to Figure 11 for a dimensioned drawing of the fin brackets in their initial design phase.

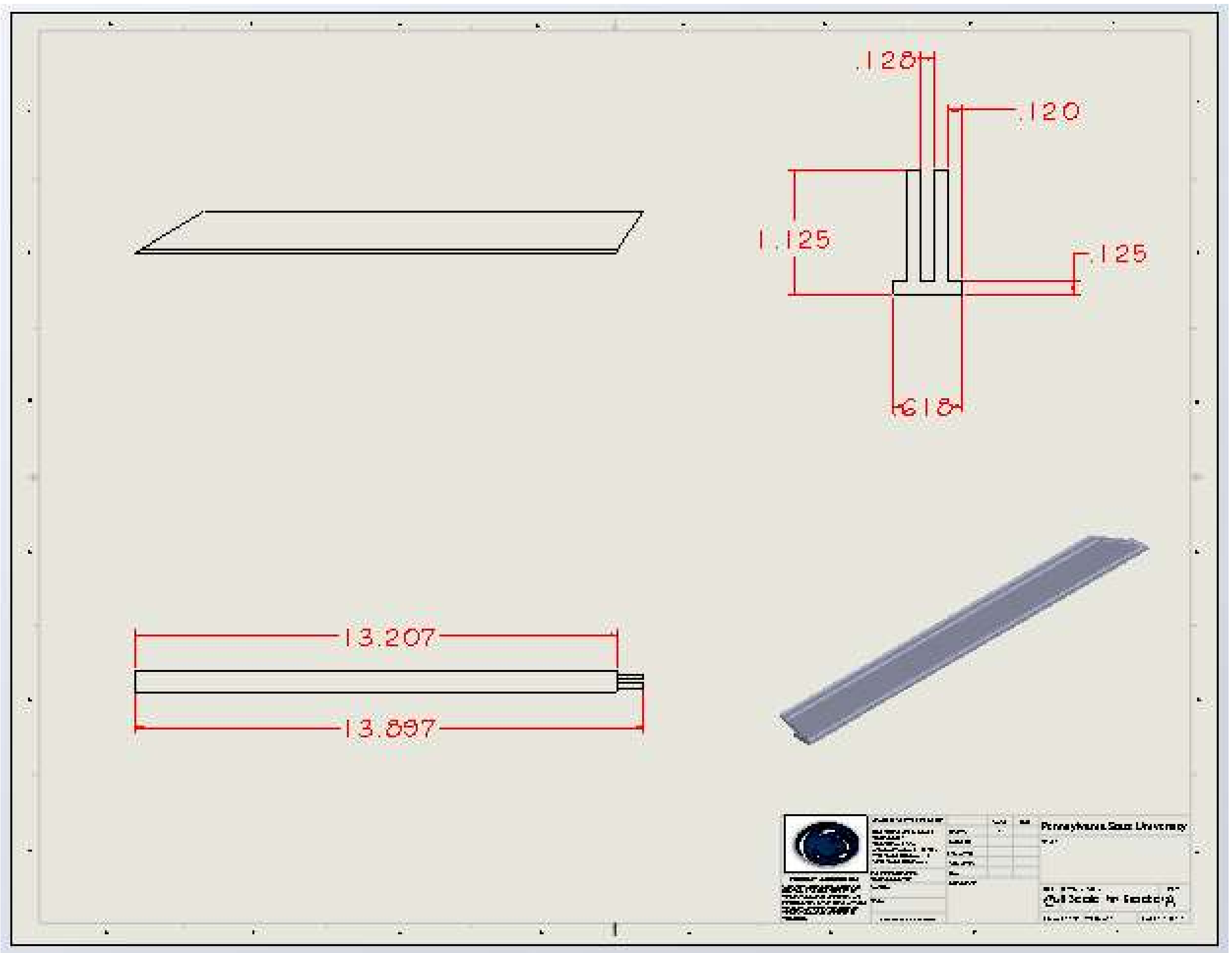


Figure 11: Engineering Drawing of Fin Brackets

Fins

The fins act to impose stability by moving the center of pressure towards the aft end of the rocket. When considering fin material, the desired characteristics are to be durable, lightweight, inexpensive, and easily constructed. In drafting the current launch vehicle design, two thicknesses of fins were readily available, which were ⅛” and 1/16”. The current design incorporates ⅛” thick fins, though 1/16” were also available. Benefits of 1/16” fins would be decreased mass, although a considerable drawback would be the potential for a flutter during flight.

The specifications are as following:

- 1/8-inch thickness
- fiberglass construction
- 3 fins

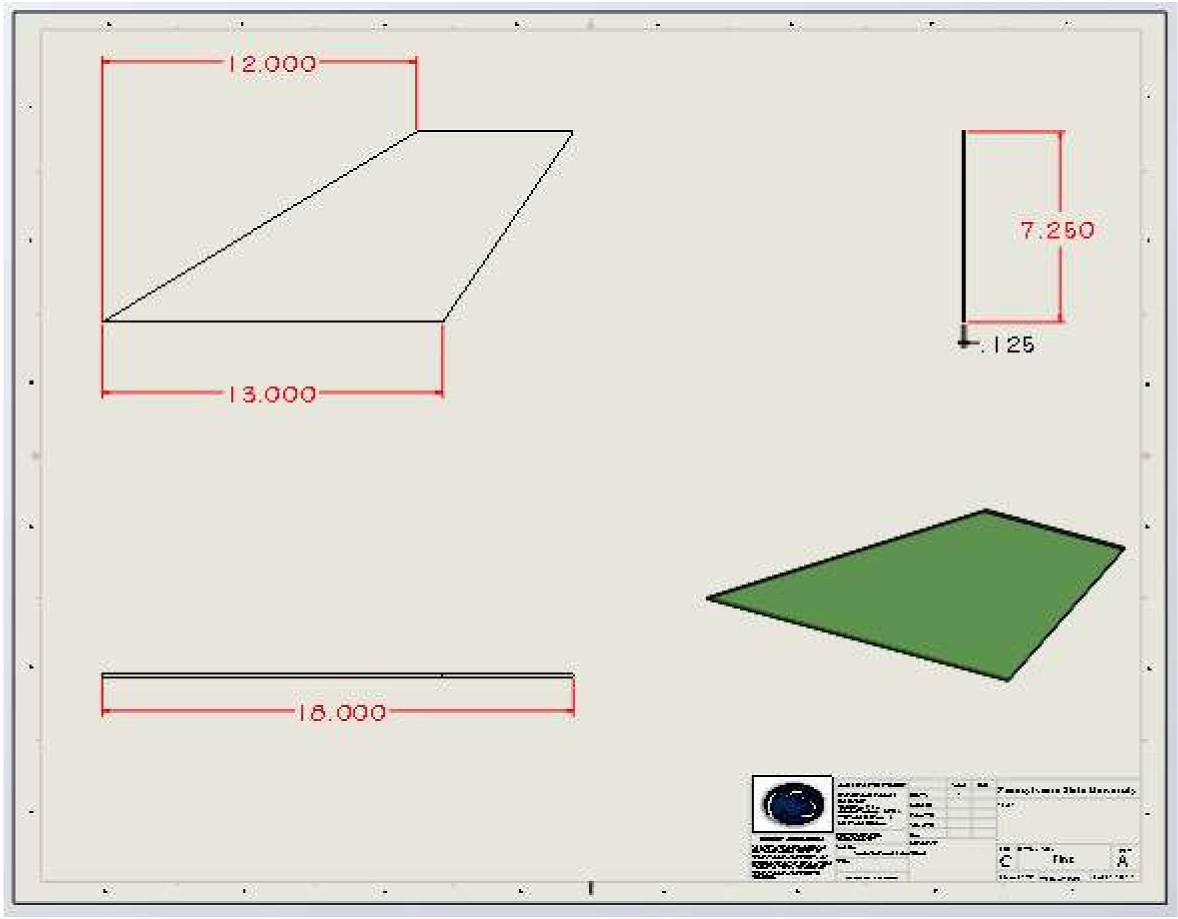


Figure 12: Engineering Drawing of Fins

Motor Retainer

Finally, the launch vehicle’s motor had two main options of a traditional snap ring or a tail cone. Retaining the launch vehicle’s motor with a snap ring would be a significantly lighter option and would prove less costly. However, such a small component would have a higher risk for misplacement at a launch site as well as have a more difficult installation into the rocket on site. A tail cone would have significantly more mass than a snap ring retainer. However, a tail cone would provide improved retention of the motor by distributing forces across the tail cone, motor tube, and centering rings. Due to the tail cone being attached directly to the airframe the motor retention would be far more reliable. In contrast, a snap ring would concentrate loads on the motor tube and centering rings only. In addition, benefits of a tail cone would be improved aerodynamics from reduced turbulent fluid flow behind the launch vehicle during flight.

The motor tube is made up of blue tube 2.0 and holds the Motor retainer which is attached to the tail cone.

The specifications for the booster are as following:

- 26 inches' length.
- 3.1in Outer diameter
- Total Mass: 87.4 ounces

The tail cone is attached to the motor retainer and gives improved retention, and aerodynamics. Refer to Figure 13 for a dimensioned drawing of the tail cone.

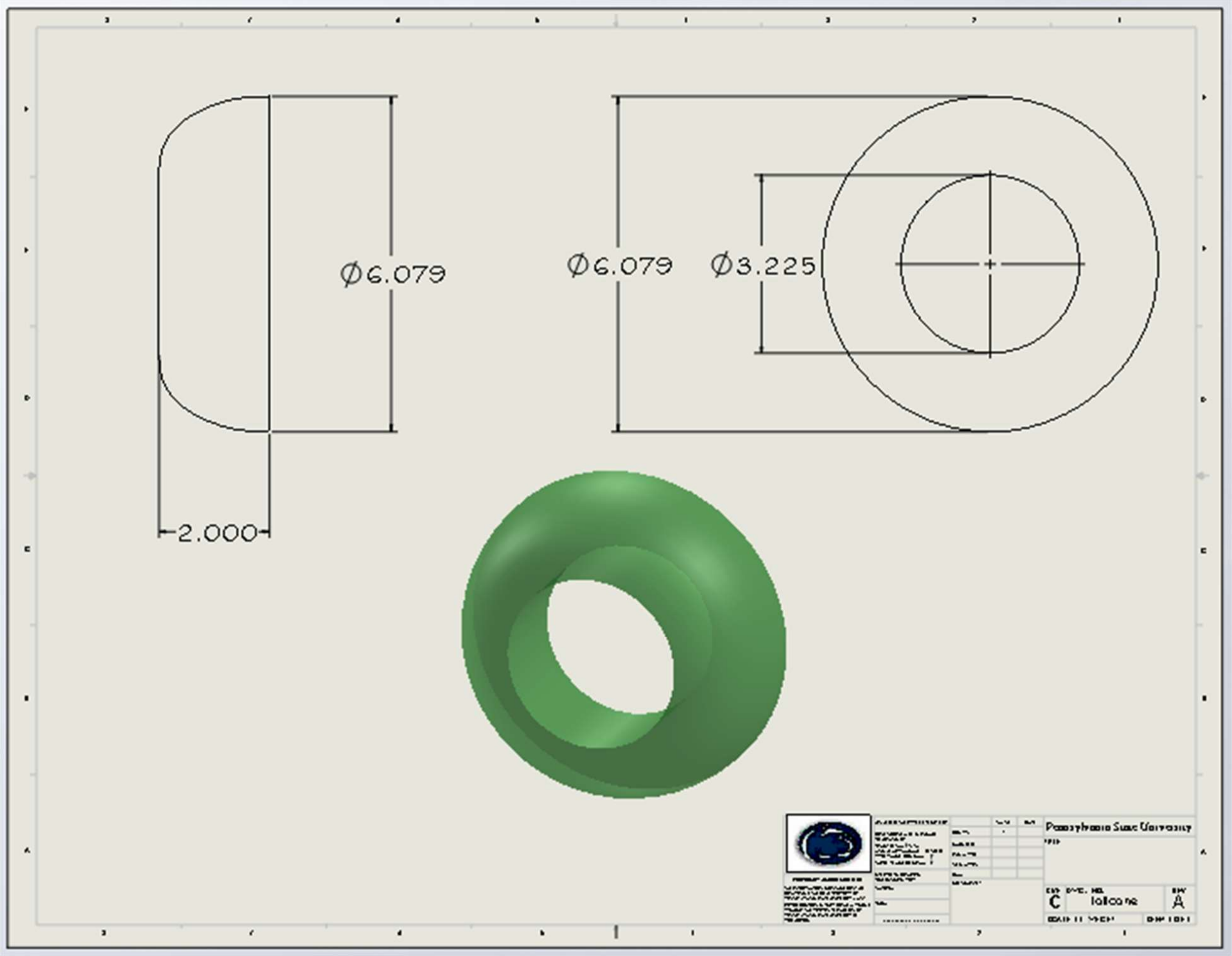
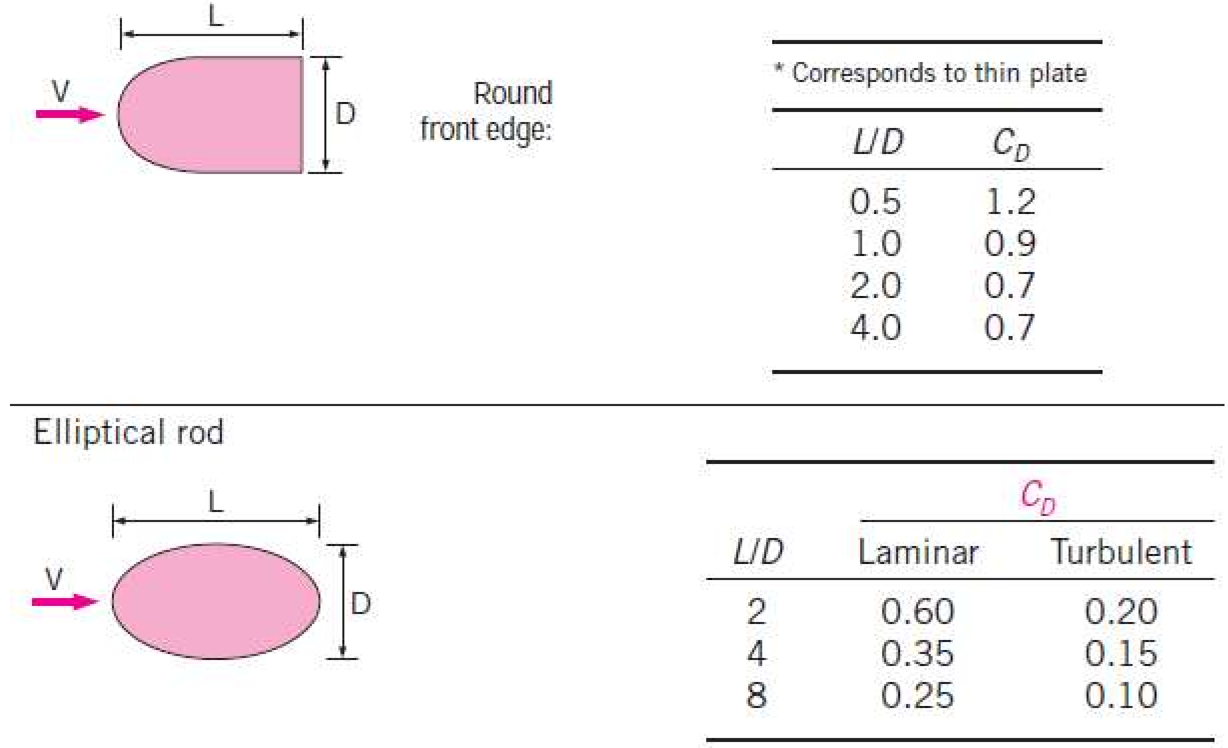


Figure 13: Engineering Drawing of Tail cone

A comparison of the fluid flow behind different geometries can be found in Figure 14. Modeling both geometries gives similar results to those shown below, with a much lower coefficient of drag with a rounded trailing edge.



L/D	C_D
0.5	1.2
1.0	0.9
2.0	0.7
4.0	0.7

* Corresponds to thin plate

Elliptical rod

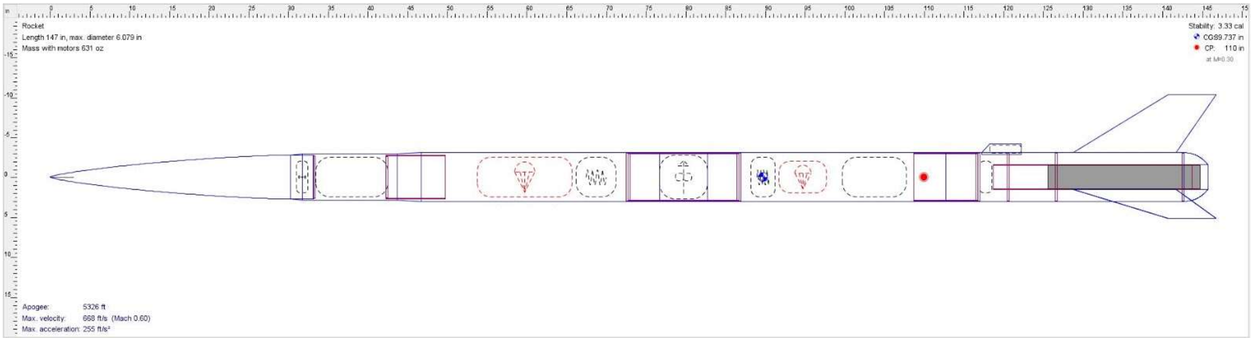
	C_D	
L/D	Laminar	Turbulent
2	0.60	0.20
4	0.35	0.15
8	0.25	0.10

Figure 14: Comparison of Geometries and Comparable Drag Coefficients [5]

4.3 Stability Analysis

Fullscale Stability

The current OpenRocket model has a calculated center of gravity location about 89.7 inches from the tip of the nosecone and a center of pressure of 110 inches from the nose cone, as seen in Figure 15.


Rocket
Length 147 in, max. diameter 6.079 in
Mass with motors 631 oz

Stability: 3.33 cal
CG:89.737 in
CP: 110 in
at M=0.30

Apogee: 5326 ft
Max. velocity: 668 ft/s (Mach 0.60)
Max. acceleration: 255 ft/s²

Figure 15: Fullscale OpenRocket Model

This puts the center of gravity about 20.3 inches forward of the center of pressure, which corresponds to a static stability margin of 3.33 calibers and 2.25 calibers off the launch rail.

Figure 16 describes the center of gravity, center of pressure, and the stability margin from lift off until the stability becomes relatively constant.

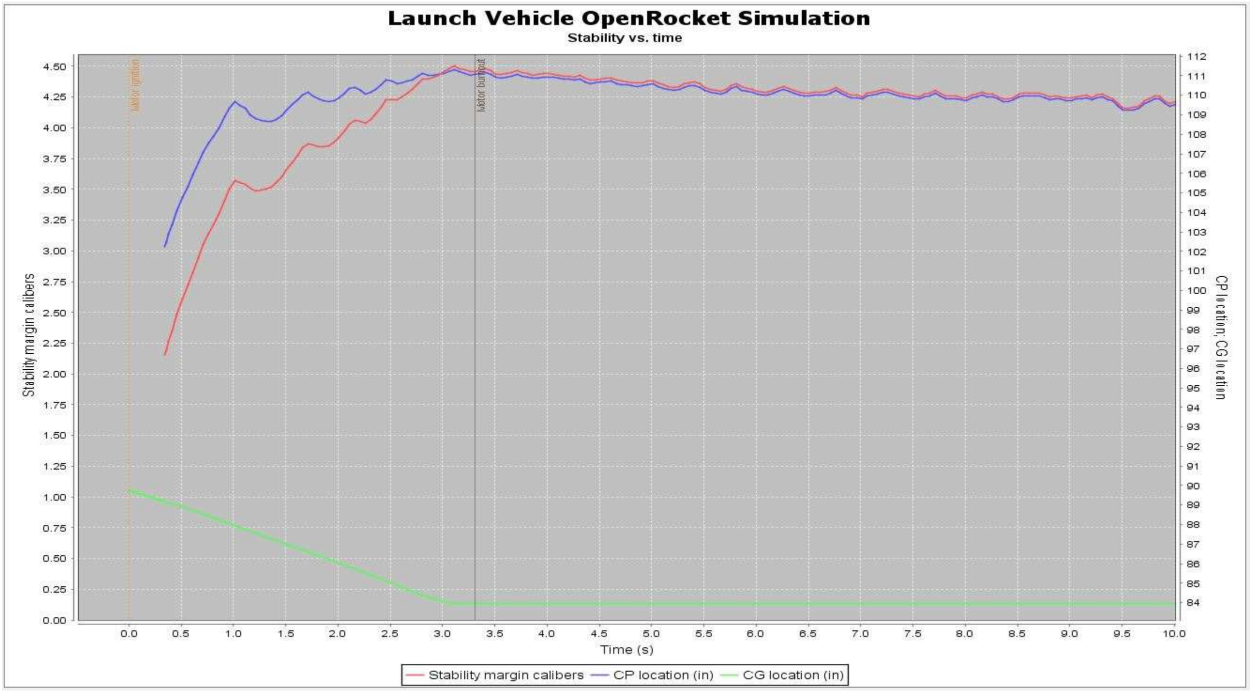


Figure 16: Fullscale OpenRocket Stability Simulation

Subscale Stability

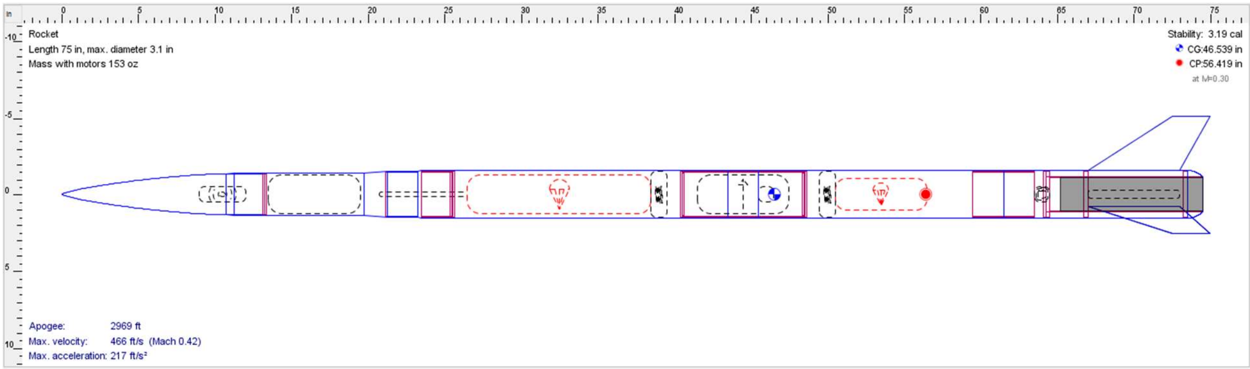


Figure 17: Subscale OpenRocket Model

The sub-scale launch vehicle will contain many of the same features found in the full-scale rocket and is currently under construction. A subscale launch is currently scheduled for November 13th. Figure 17 illustrates the OpenRocket design of the sub-scale rocket. There will be two ejection events which will separate at the aft transition section and the booster coupler. The diameter of the rocket is 3.1 inches, length is 75 inches. The motor has a diameter of

54mm, all these dimensions and considerations gives the mass of the rocket to be 153 ounces. The open rocket model for the subscale has a calculated CG location 46.5 inches from the tip of the nosecone and a center of pressure of 56.4 inches from the nose cone. This provides a static stability margin of 3.19 calibers and an off the rail stability margin of 2.05.

4.4 Mass Budget

Part	**Mass (ounces)**	# of items	sub-total mass
Structures			
Nosecone w/ aluminum tip	40	1	40
Acrylic	18.2	1	18.2
Body tube, main	30.5	1	30.5
Body tube, drogue	28.7	1	28.7
Booster body tube	28.7	1	28.7
Bulkhead, inner transition	2.04	1	2.04
Bulkhead, inner	3.33	3	9.99
Bulkhead, outer	3.28	4	13.12
Transition, nose cone to payload	1.49	1	1.49
Transition, payload to main body	3.13	1	3.13
Transition stabilizing coupler	4.38	1	4.38
Coupler, drogue to motor	7.81	1	7.81
AV bay body tube	5.73	1	5.73
AV Bay coupler	13.7	1	13.7
Motor Inner tube	10.8	1	10.8
Centering ring	1.81	3	5.43
Fin set	27.6	1	27.6

Tail cone	6.66	1	6.66
Motor Retainer	1.89	1	1.89
Camera/cover	9.75	1	9.75
Ballast (10% Dry weight)	45.9	-	45.9
Hardware	12	-	12
Payload			
Helicopter Payload	8	1	8
FOPS	40	1	40
Avionics & Recovery			
Drogue Parachute	11.4	1	11.4
Shock cord, drogue	30	1	30
Avionics Bay	28	1	28
Shock cord main	22	1	22
Main parachute with blanket	31.7	1	31.7
GPS	6	1	6
Total (ounces)	-		504.62
Total (pounds)	-		31.53875

4.5 Propulsion System

As of now, the primary motor allows for the closest apogee to the target. The alternatives either undershoot the target significantly, or reach an altitude that result in disqualification with the current mass estimations of the rocket. Alternative motor choices offer variable flight characteristics, allowing for variance in gross liftoff weight and success reaching the target apogee (5280 ft).

The current design of the propulsion system involves the alternatives of using the L1395, and L1355 motors. These are the leading alternatives because of the fact that they are the motors closest in impulse to the primary motor and will allow for adjustments made to the mass of the vehicle. Based on experience and observation of other manufacturers, Cesaroni motors are preferable to the other alternatives.

The launch vehicle's propulsion subsystem delivers the vehicle, and payloads to the target apogee (5280 ft). Components of the propulsion system include a solid ammonium perchlorate based motor in accordance with the USLI 16-17 handbook guidelines, with an accompanying liner, an aluminum retainer and retaining hardware, O-rings, and a nozzle. Launch is initiated with the use of an electronic match to ignite the propellant.

Review of Motor Alternatives

Three potential rocket motors were selected. These three motors that are shown in Table 4 are organized into a Primary and Secondary ratings. The primary motor is the current motor that the rocket will utilize and the secondary motors are designated in the event of a need for mass increase or decrease. The currently selected primary motor is the L1350, which is a 67% L-Class motor that utilizes a variant of ammonium perchlorate composite propellant known as C-Star. The current weight of the rocket with the primary motor inside of it is 631 oz and has a thrust to weight ratio of approximately 7.68.

The primary motor achieves about 5315 ft apogee based on the current rocket configuration in OpenRocket. This software is used as an estimate along with the manufacturer motor specifications until the motor characteristics are clarified through static motor testing at The Penn State University High Pressure Combustion Lab. The manufacturer's thrust curve, as shown in Figure 18, displays a thrust curve without any extreme peaks and maintains close to the average thrust. This is a desired thrust curve because it will be easier to model due to the lack of extreme peak thrust with respect to the average thrust. The thrust curve also displays a total impulse of 962 lbf-s and an engine burn time of about 3.25 seconds.

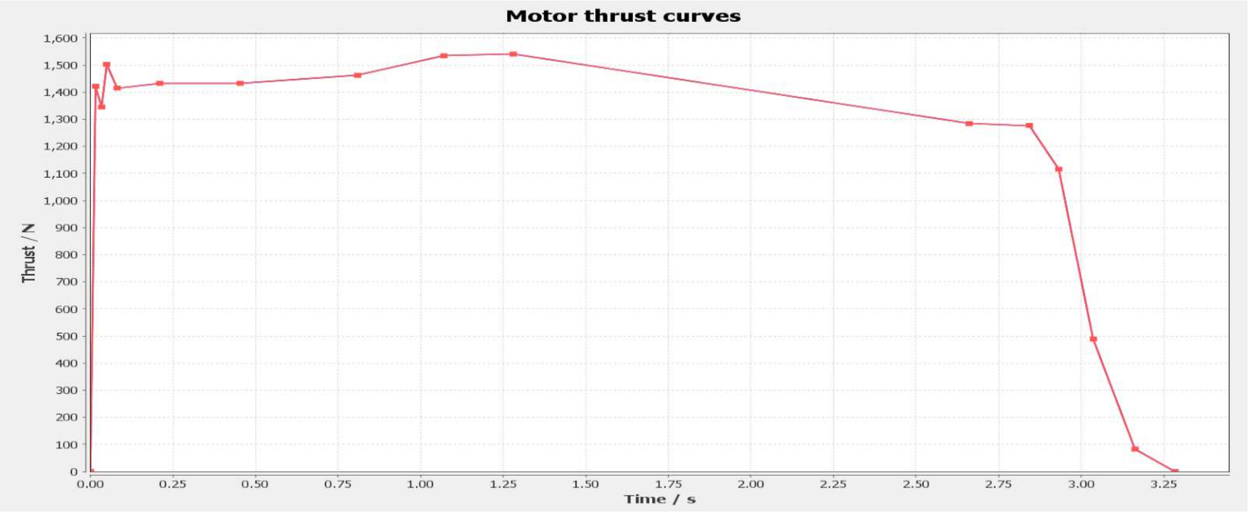


Figure 18: L1350 Thrust curve

Table 4: Rocket Motor Flight Characteristics

Designation	Rating	Apogee (ft.)	Velocity off rail (ft./s)	Impulse (lbf-s)	Weight (oz.)
Cesaroni L1350 (3 Gr.)	Primary	5315	76.6	962	125.92
Cesaroni L1395 (4 Gr.)	Secondary	6090	73.6	1100	152.48
Cesaroni L1355 (4 Gr.)	Secondary	4649	73.7	905	174.4

Evident from the Table 4 the alternative motor choices are simulated to achieve a target apogee a significant margin away from the target of 5280 ft. These however are the closest motors in impulse to the primary motor that are manufactured by Cesaroni Technology Inc. Reliability and safety are two of the most important characteristics when selecting motors, and based on prior experience and observation, Cesaroni motors have been consistent in this regard.

These alternatives have been selected in the event of a substantial change to the gross vehicle weight. With the current mass estimate these motors are secondary, but may fall into use later in the design process.

4.6 Recovery System

The recovery system has a few main components including the avionics board, the avionics bay structure, the parachutes and their harnesses, the actual avionics equipment, the electronic shielding, the separation points of the rocket, and the method of parachute mechanism.

The avionics board is the board onto which the avionics equipment, including the altimeters and the batteries, is mounted. Historically, the A&R subsystem has constructed these boards from fiberglass which is very strong but also heavy and has safety hazards associated with construction. A&R has recently been working on the design of an additively manufactured board. Such a board would boast advantages such as low mass and precision, but has drawbacks such as manufacturing limitations. Attempts at printing current board designs have so far led to failure, likely as a result of thermal warping of the part. Printing an avionics bay, while challenging, presents the opportunity to reduce the length of the avionics bay, thus further reducing the mass of the rocket. However, PLA, one of the stronger and more common 3-D printing filaments, is susceptible to heat. Its glass transition temperature is between 50 and 60 degrees Celsius [1], which the rocket can certainly reach on a hot day in Alabama while waiting on the launch pad. Testing will have to be done to ensure that the mechanical properties of PLA are still sufficient should the rocket reach these temperatures. These two concepts are compared in Table 5, where the 3-D printed board edges out the fiberglass board. For now, the 3-D printed board will be the focus the design. However, should the 3-D printed board fail to materialize, the fiberglass board is a viable alternative that the subsystem has ample experience working with. Figure 19 shows SolidWorks models of both the fiberglass board and the 3-D printed board.

Table 5: Trade study comparing the fiberglass avionics board with a 3-D printed design

		Fiberglass Board		**3-D Printed Board**	
Category	Weight	Score	Weighted	Score	Weighted
Cost	1	1	1	1	1
Legacy	1	3	3	1	1
Strength	3	3	9	2	6
Precision	3	1	3	3	9
Complexity	2	2	4	1	2
Mass	3	1	3	3	9
Thermal Resistance	2	3	6	1	2
Total			29		30

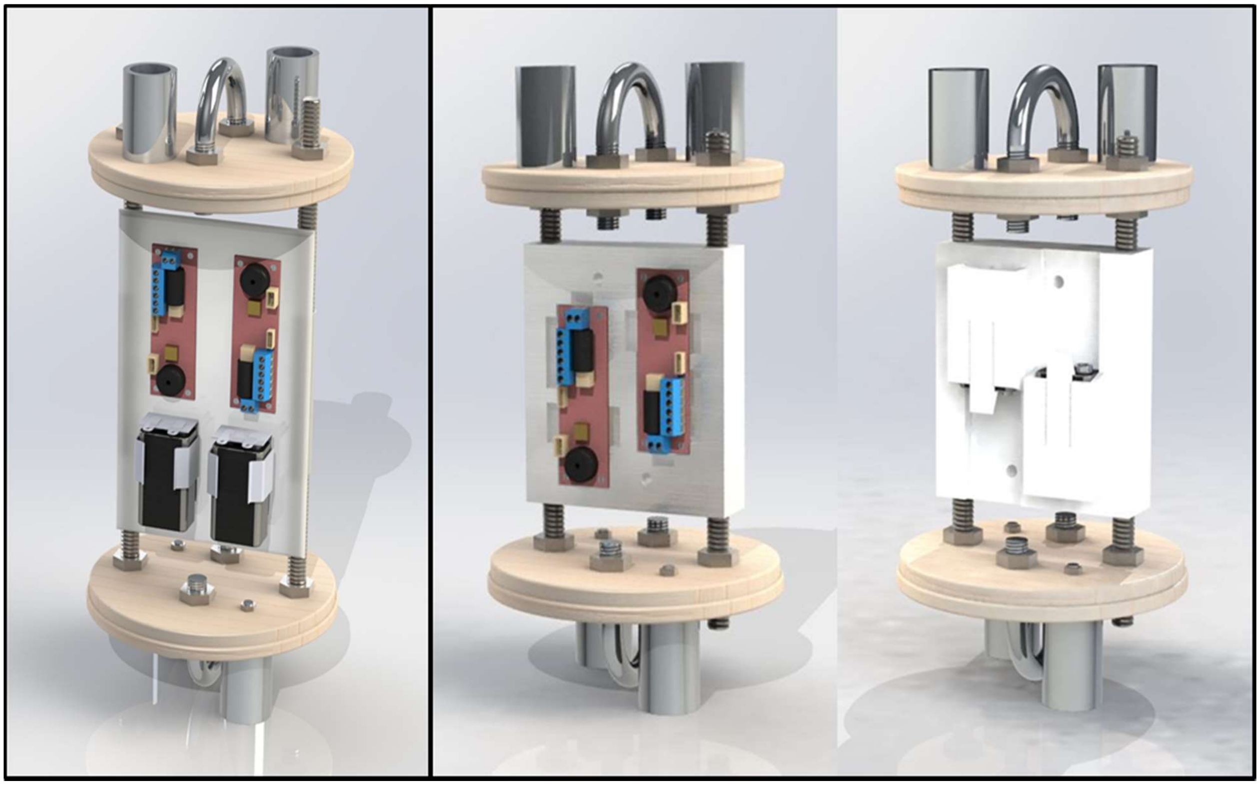


Figure 19: Fiberglass board (Left) vs 3-D printed board (right)

The avionics bay is usually located in a coupler in the center of the rocket between two body tubes. Therefore, the outer shell of the bay is determined by the material chosen for the entire structure, which the Structures subsystem has determined is Blue Tube for this year's design. However, A&R must still make some other decisions about the structure of the avionics bay, including the material of the bulkheads and the material of the all-threads. Some simple calculations can be done to determine if steel all threads are necessary or if aluminum threads are sufficient. For these calculations, the descent profile from Valkyrie, LTRL's rocket in the 2016 competition, will be used. Valkyrie exhibited a velocity of roughly 75 ft/s immediately before main parachute deployment. Valkyrie also had a 120" diameter main parachute. To find a conservative estimate for maximum force exerted on the avionics bay during recovery, a scenario involving full and immediate main parachute deployment can be used. Using Equation 1 [2] and assuming standard sea level conditions and a coefficient of drag of 2, the drag of the parachute can be calculated to be 1045 lbf.

$$D = \frac{1}{2} C_d \rho V^2 \pi r^2 \tag{1}$$

The all threads must be capable of withstanding this force during deployment. Typically, two ⅜" all threads are used. The stress in each all thread can easily be calculated by dividing the force by the area. This stress works out to be 4731 psi. This is far below the yield strength of Aluminum 6061-T6 which is 40,000 psi [3]. This works out to be a factor a safety of

8.5. Therefore, Aluminum 6061-T6 is the clear choice for the structure, especially with a density of about one third that of steel.

The bulkhead construction material selection is essential as they are at high risk of failure due to the stress from deployment. Despite its drawbacks, fiberglass it extremely strong and has a long history in the A&R subsystem in fullscale rockets without structural failure. Wooden bulkheads, on the other hand, are much easier to construct and lack many of the safety issues involved with construction with fiberglass. Table 6 shows the selection matrix used to decide between these two options.

Table 6: Selection matrix for choosing bulkhead material.

		Fiberglass Bulkhead		**Wooden Bulkhead**	
Category	Weight	Score	Weighted	Score	Weighted
Cost	1	1	1	3	1
Legacy	1	3	3	3	3
Strength	3	3	9	2	6
Precision	3	1	3	2	6
Complexity	2	2	4	3	6
Mass	3	1	3	3	9
Total			23		29

Table 6 shows that a wooden bulkhead is a better option for the bulkheads. However, further testing will have to be done to ensure the wooden bulkhead is strong enough to withstand deployment.

The A&R subsystem maintains a selection of parachutes of all different sizes to meet the needs of any of the team's launches. Parachutes are chosen to sufficiently slow descent velocity to a safe kinetic energy level. The selection method for the parachutes is described in detail in the following section, Parachute Sizing Estimation

The avionics equipment consists of the altimeters and the power source for the altimeters. The power source is dependent on what the power needs of the altimeter are. Altimeters selection is vastly narrowed by legacy components and cost. Stratologger SL 100 altimeters have been used extensively in the amateur rocket community and by LTRL with great success. LTRL also owns three such altimeters, making it the primary candidate for the fullscale use. However, as the SL 100 has been commercially replaced by the nearly equivalent SL CF altimeter, the team has started to acquire these new altimeters for use. Because of their ruggedness, reliability, and affordability, these altimeters will be used for the recovery system. The main advantage of the new altimeter is its slightly lower weight of 0.07 ounces [4]. Both of these altimeters can be used with a simple 9V battery.

Electronic shielding, most often Faraday Cages, are used to shield the electronics in the avionics bay from outside interference to prevent accidental ignition of the separation charges. Such cages usually consist of a fine wire mesh encircling the avionics bay. The A&R subsystem has historically simply cut a mesh sheet, rolled it into a cylinder, and put in into the coupler of the avionics bay. However, this has led to difficulties during avionics bay assembly as the points where the mesh sheet was cut are often jagged and can cut hands when reaching into the avionics bay. This assembly also makes it difficult to insert and take out components from the bay, as they often get snagged on the mesh. Therefore, a new idea has been proposed for the construction of the Faraday Cage. One team member proposed the idea of 3-D printing a thin sleeve that the mesh can slide into, therefore keeping the mesh to a well-defined geometry and separating it from the rest of the avionics bay. This concept allows for a much cleaner, safer, and modular design that will be adopted in the fullscale rocket.

The rocket separation points are largely fixed to the interface between the body and the nose cone and the interface between the bottom body tube and the booster section. This is opposed to the separation points being located at points directly adjacent to the avionics bay. The reason these separation points are chosen to for parachute ejection assurance. If the separation points are adjacent to the avionics bay, then the separation charges, located on the bulkheads of the avionics bay, will push the parachute further into the body tubes. While the velocity of the components separating most likely will pull the parachute out, this is an additional risk that can be avoided by placing the separation points at the right locations. The separation points could be located adjacent to the avionics bay if dangling charges are used to ensure the charges force the parachute from the body tube, but this method also has added complications, especially during assembly. An additional advantage of having one of the separation points at the interface between the booster section and the body tube is that the body tube remains connected to the avionics bay instead of the booster section, which is usually one of the most massive parts of the rocket already, thus reducing the necessary parachute size to maintain a safe landing velocity.

The last major recovery system component is the parachute deployment mechanism. The main choices for this component are black powder ejection, Pyrodex ejection, and CO_2 cartridge ejection. Each system has its own advantages and disadvantages and are weighed in Table 7, which highlights the selection process of the deployment mechanism based on various important selection criteria.

Table 7: Selection Matrix for the parachute deployment mechanism

		Black Powder		**Pyrodex**		**CO_2 Cartridge**	
Category	Weight	Score	Weighted	Score	Weighted	Score	Weighted
Cost	1	3	3	3	3	2	2
Legacy	3	3	9	2	6	1	3

Reliability	3	3	9	2	6	2	6
Member Experience	2	3	6	2	4	1	2
Form Factor	1	2	2	2	2	1	1
Complexity	2	3	6	2	4	1	2
Safety	3	1	3	2	6	3	9
Total			38		31		25

The leading choice for the deployment mechanism is the black powder, mostly due to its legacy and reliability. Further testing will likely have to be done to narrow the choices. Specifically, testing could focus on recreating previous conditions in which the Pyrodex and CO_2 failed to attempt to understand how to make those systems more reliable.

Parachute Size Estimation

The parachute size needed to safely land the rocket while remaining below the kinetic energy limit can easily be calculated using Equation 2.

$$V = \sqrt{\frac{2 * KE}{m}} \tag{2}$$

$$D = \sqrt{\frac{M_m M_t g}{C_d KE \rho \pi}} \tag{3}$$

Then, this velocity can be inserted into the terminal velocity equilibrium equation, Equation 3, to find the diameter needed for the main parachute. The computer calculations used to find the necessary diameters is shown in Appendix A: MATLAB Recovery Model. Figure 20 shows the plot for necessary diameter of the main vs. kinetic energy at landing calculated with the MATLAB code.

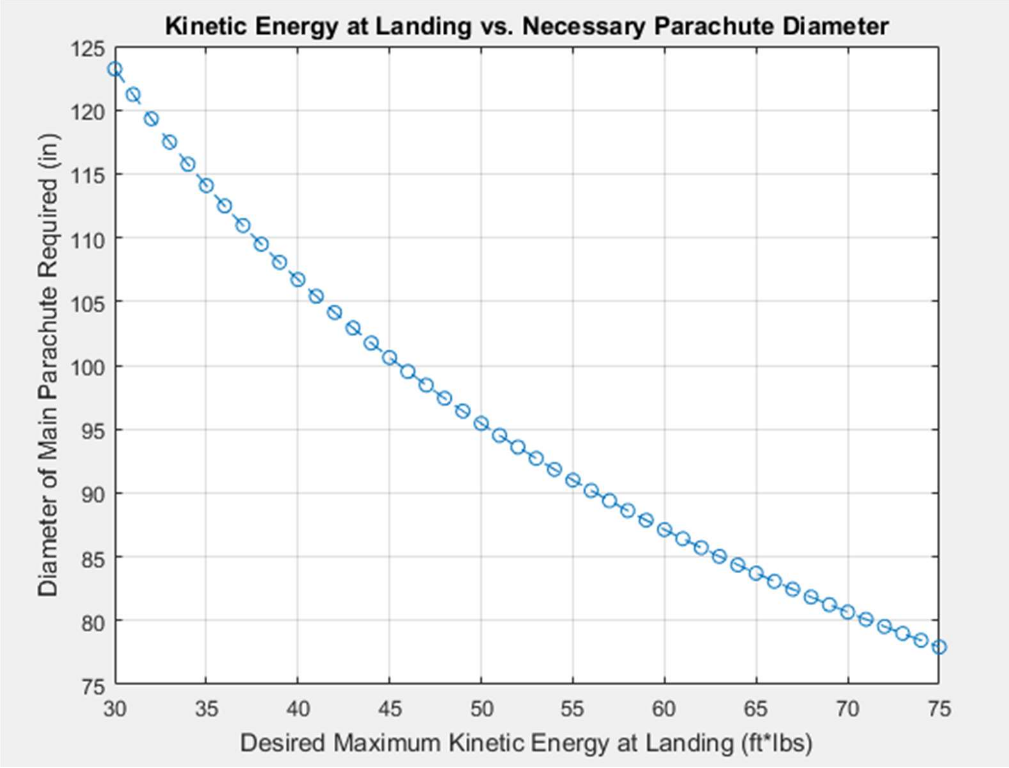


Figure 20: Diameter of the main parachute vs. desired kinetic energy at landing

Proof of Redundancy

The avionics system design includes multiple layers of redundancy. First and foremost, there are two altimeters. Each altimeter is linked to its own separate main and drogue charge. Each altimeter is also powered by its own battery. Therefore, even with the failure of a battery, altimeter, e-match, or charge ignition in one of the systems, the other system is completely independent and should still operate correctly. The deployment charges are also staggered so that they do not go of simultaneously, a precaution taken to avoid overpressure events. In addition to these measures, the 36” drogue chute was chosen so that, in off chance of a main parachute deployment failure, the rocket still lands at a reasonable velocity, 60 ft/s, in comparison to a velocity on the order of 100 ft/s for a 24” drogue parachute. This effectively cuts the energy of the landing in half in this emergency scenario, as well as gives spectators more time to see the rocket during descent and prepare for its landing.

4.7 Mission Performance Predictions

A fullscale flight simulation was done using the Cesaroni L1350 rocket motor and open rocket software. This simulation, as shown in Figure 21, displays the vertical altitude, velocity and acceleration of the rocket with respect to time. The simulation shows a smooth ascent and descent to and from apogee. The maximum velocity achieved is 668 ft/s and estimated apogee is 5,315 ft. This is above the target apogee, but OpenRocket is only a simulation used to determine rocket motors that fit the needs of the rocket. The target apogee of exactly 1 mile will be achieved through altering the rocket's mass very slightly and improving the model of drag calculation and thrust curve for more accurate apogee calculation. Improvements to modeling the rocket's flight will be made via static motor testing at The Penn State University High Pressure Combustion Lab and experimental data from wind tunnel testing using a closed-circuit wind tunnel. The OpenRocket simulation adequately demonstrates the viability of the Cesaroni L1350 rocket motor in conjunction with this rocket design to meet the performance requirements of this competition.

Figure 21: L1350 flight simulation

Calculation of Kinetic Energy at Landing

At landing, the predicted velocity of the rocket is 17.8 ft/s, as shown in Figure 22. This velocity was also calculated by the MATLAB code in Appendix A. This code runs a recovery model in which the force balance between gravity and drag is integrated in time with separate phases for drogue and main. The model also assumes that the parachutes do not deploy instantaneously, but rather in a linear fashion, as the area increases linearly with respect to time until the deployment time is complete. The finer parameters of the model, such as the coefficient of drag of the drogue, are based on experimental results from the fullscale launch at the USLI competition in April 2016. While the model is not perfect, the A&R subsystem plans on improving the model in the coming months by further experimental analysis and calculations.

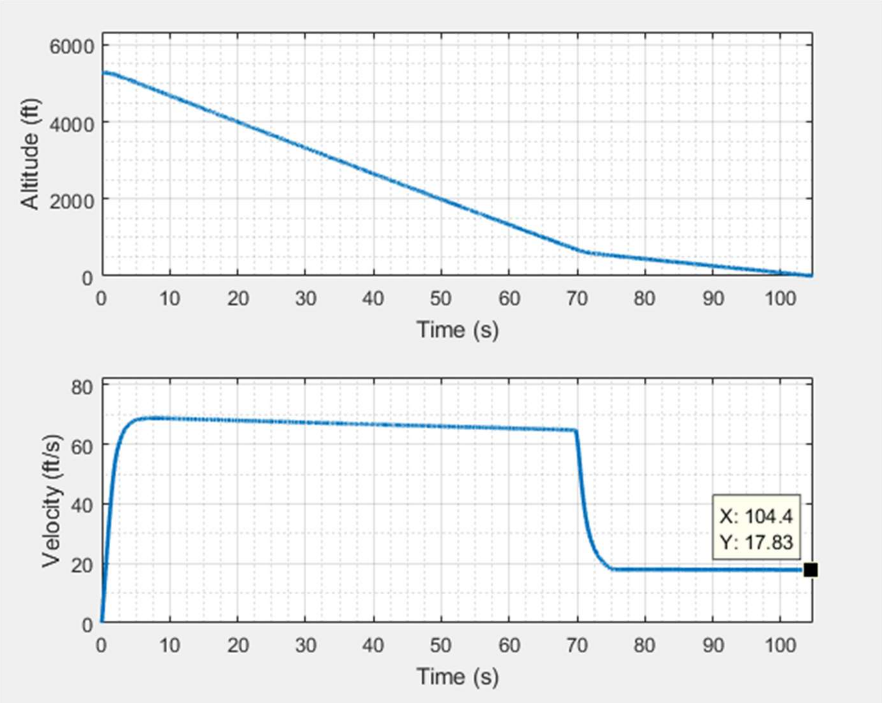


Figure 22: MATLAB model of the rocket descent vs time

Using the velocity of the rocket during landing, it is easy to calculate the kinetic energy of each section. This can be done by simply done by using the kinetic energy equation. The kinetic energy results are shown in Table 8.

Table 8: Kinetic Energy of each component upon landing

Section	Weight (lbf)	Kinetic Energy (ft*lbs.)
Nosecone	8.40	41.5
Central Body	9.26	45.7
Booster Section	6.72	41.5

Drift Calculations

The drift of the rocket can simply be calculated by multiplying the descent time by the wind velocity. This was also performed in the recovery model in Appendix A. The estimated drift distance is shown in Figure 23. The distances at the specific wind velocities are given in Table 9.

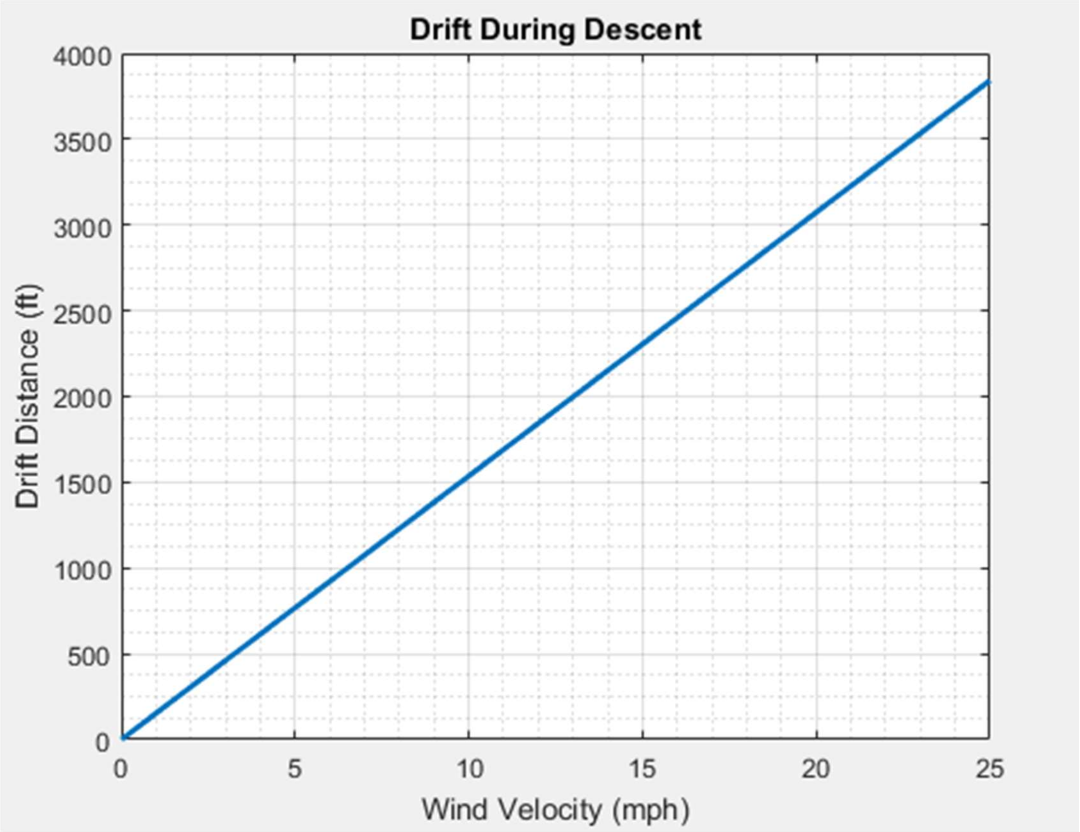


Figure 23: Drift distance estimates vs wind velocity of the fullscale during descent.

Table 9: Estimated drift distances at wind velocities between 0 and 20 mph.

Wind Velocity (mph)	Drift Distance (ft)
0	0
5	768.4
10	1537
15	2305
20	3774

5. Safety

5.1 Components Required and Impact of Risks or Delays

In order to design and manufacture a rocket with scientific payloads and a recovery system many components are needed. LTRL is divided into four subsystems to effectively and efficiently complete the project.

- The structures subsystem primarily works on the design and manufacture of the rocket and its components. The biggest risk involved is not getting parts on time. The materials used for the structure of the rocket are ordered rather than made in house. Due to the uncommon nature of high-powered rocketry these parts distributors can take a long period of time to get orders in. Consequently, if manufacturing is delayed other subsystems can be delayed as they are unable to test their designs with the vehicle.

- The payload subsystem works on the science packages housed within the rocket. Payload must design their projects to fit in the rocket and survive the flight and landing. These parts are usually the most fragile, complicated and expensive of the vehicle. As such, ensuring these parts are not damaged and are reusable is very important as replacing them may not be possible without going over-budget. Additionally, codes and models used must be tested for accuracy of results. In the event that models are not correct the science package could fail.

- Propulsion selects and tests motors, runs flight simulations and does drag analysis on the vehicle. For this subsystem one large risk during preliminary design is a mass change resulting in the need to switch motors. If motors were already purchased, then they are rendered useless and a waste of funding. Regardless, in the event of a motor change, the subsystem needs to redo its analysis and selection of a motor which can set the project behind schedule.

- Lastly, Avionics and Recovery handles the parachutes, altimeters and uses models to calculate drift and descent characteristics. If the recovery system does not work perfectly the vehicle, payload and safety of people at the launch are at risk. Losing the vehicle and payload would set the project back immensely in terms of both time and budget

5.2 Preliminary Checklists

Recovery Preparation

Checked and initialed by two Recovery subsystem members and the Safety Officer

Recovery Subsystem Members

____

____

Safety Officer

____

Key Switch	OFF Position
Batteries	OUT
Bay	Wired
Batteries	Installed
Bay	Assembly
E-matched	Assembled
Gun Powder	Measured

Note: Drogue - 7.4 grams black powder
Main – 7.76 grams black powder

Measured Charge	Added to blast cap
Wadding	Added to blast cap
Recovery Harness	Assembled
Parachutes	Folded
Nomex Blankets	Fixed to Shock Cord
Folded Chute	Powdered
Recovery Harness and Chutes	Inserted into body tube
Rocket	Assembled
Shear Pins	Installed

Structures Preparation

Checked and initialed by two Structures subsystem members

Structures Subsystem Members

____

____

Avionics Bay	Screwed to Main and Drogue Sections
FOPS	Placed in the Acrylic Section
Nose Cone	Screwed to Acrylic Transition Coupler
Acrylic to Main Transition	Shear pinned to Main Section
Booster Section	Shear pinned to the drogue section
Motor Retainer	Screw on tail cone

FOPS Preparation

Checked and initialed by two Payload subsystem members

Payload Subsystem Members

____

____

Fragile Specimen(s) .... Received
Specimen(s) .... Placed into protective bag
Shear thickening bag .... Sealed
Materials bag .... Centered within payload bay
Bulkheads .... Attached to materials bay
Materials bay .... Connected to rocket body

Kiwi Preparation

Checked and initialed by two Payload subsystem members
Payload Subsystem Members

____

____

Electrical Connections .... Secure
Power Switch .... In the ON Position
Rotors .... Unobstructed by the padding and vehicle walls
Kiwi vehicle .... Properly padded and inserted into the rocket
Kiwi vehicle .... Secure

Motor Preparation

Checked and initialed by one Propulsion subsystem member and one NAR certified member
Propulsion Subsystem Member

____

NAR Certified Member

____

Smoke Trail Grain Assembly .... Loaded into forward closure
Forward Closure .... O-Ring inserted
Nozzle Holder .... O-Rings inserted
Nozzle .... Inserted into nozzle holder
Lower Retaining Ring .... Sealed on bottom of casing
Nozzle/Nozzle Holder Assembly .... Inserted into casing
Casing Liner .... Inserted into casing
Motor Grains (3) .... Inserted into casing liner and spaced with O-rings
Forward Insulating Disk .... Inserted into casing
Forward Closure/Smoke Trail Grain Assembly .... Inserted into casing
Upper Retaining Ring .... Sealed on top of casing
Closure Wrench .... Used to firmly tighten both retaining rings
Motor Casing .... Installed in motor retainer

Exterior Closure .... Sealed on base of casing

5.3 Personnel Hazard analysis

All team members have taken Penn State's lab safety course containing information safety regulations for working with hazardous materials. Safe working habits will be enforced when working on any project. The team safety officer is responsible for ensuring all team members are informed of any hazards and abide by the guidelines for accident avoidance. New hazards will be introduced over the lifetime of the project, so briefing sessions will be held prior to handling of the new hazardous material or object.

Table 10 shows several examples of hazards and their respective mitigations. The likelihood and impact of each hazard is ranked on a scale of 1-5. The necessary PPE for hazard mitigation have been purchased, and their locations are known to team members. As part of launch day activities, all team members present are informed of potential safety issues at high-power rocket launches, proper safety oriented conduct and range safety regulations.

Table 10: Personnel Hazard Analysis

Hazard	Cause	Effect	Likelihood	Severity	Mitigation
Blue tube and sheet machining and sanding	Inhalation of small particulates	Dust particles can cause respiratory irritation	3	2	Use face mask and shop vacuum, maintain adequate ventilation
Power Tool Use	Flying debris	Cuts, possible eye injury	2	3	Wear safety glasses, follow tool safety instructions
Black Powder	Material is a fire hazard and explosive	Fire, personal injury, equipment damage	2	5	Only qualified people are permitted to handle these materials. Use only in small quantities and away from sparks and statics.

Pyrodex	Material is a fire hazard and explosive	Fire, personal injury, equipment damage	1	4	Only qualified people are permitted to handle these materials. Use only in small quantities and away from sparks and statics.
Paints, Adhesives and Solvents	Inhalation of aerosol and solvent vapors	Skin and or respiratory irritation	2	2	Use PPE and adequate ventilation
Motor misfire or unfired ejection charges	Possible unexpected explosions	Personal injury, equipment damage	1	5	Wait for a safe period of time, disarm ignition sources.
Unstable or dangerous rocket flights at launches	Rocket hitting personnel or equipment	Injury to personnel or equipment	2	5	Obey launch officials, pay attention during launch, pre-launch safety briefings
Improperly loaded equipment during transport	Equipment moves during transport	Damage to equipment, possible injury to personnel	2	3	Proper packaging and securing of all transport equipment

Hazard Research

Hazardous materials and potentially dangerous situations will be encountered during the project duration. In order to create a safe environment for everyone involved in the construction of the rocket and payloads, safety precautions relevant to the hazards encountered are in place. These safety procedures were developed by consulting the Material Safety Data Sheets (MSDS) attached to the end of this report in Appendices B and C. All NAR regulations pertaining to high power rocket safety are followed. Operator's manuals are also available to members to consult prior to using any unfamiliar equipment. More experienced individuals will be in the lab during construction, so no one is ever in a situation where they are unsupervised while using a tool for which they are not properly trained to use.

5.4 Failure Modes and Effects Analysis

To ensure a safe and effective launch, an assessment of possible failures has been made. By analyzing the cause of the failure, precautionary steps will be taken to reduce the risk of failure. Table 11 shows the preliminary set of failure modes. The likelihood and impact of each failure mode is ranked on a scale of 1-5.

Table 11: Failure Modes and Effects Analysis

Failure Mode	**Cause**	**Effect**	**Likelihood**	**Impact**	**Mitigation**
Rocket					
Motor does not stay retained	Ejection charges push motor out of rear of rocket	Motor does not remain in rocket	1	5	Use of active motor retention, Use of lower impulse motor
Cascading fracture of body tube	Body tube fractures due to extreme stress around bolt hole	Catastrophic failure of airframe	1	4	Simulation of expected stresses, materials testing
Crack along outer seam of body tube	Body tube cracks due to torsional stress and bending moment	Functional/structural inadequacy	2	3	Simulation of expected stresses, materials testing
Body tube fracture crack	Body tube cracks due to materials defect and/or	Aerodynamic inconsistency and/or structural failure	2	2	Visual inspection

	repeated impacts				
Unwanted separation of coupler from body tube	Premature shear pin failure	Undeployed parachutes, uncontrolled descent	3	2	Visual inspection , pre-flight check
Fracture crack in coupler	Torsional stress and/or bending moment	Aerodynamic inconsistency and/or structural failure	2	2	Simulation of stresses, materials testing
Nosecone tip removal	Extreme impact	Aerodynamic instability, instability, sky debris	1	4	Simulation of expected stresses, material testing
Fin fracture crack	Extreme or repeated impact, bending moment	Aerodynamic instability, structural failure	2	2	Simulation of expected stresses, material testing
Fins separate from the fin brackets	Insufficient epoxy strength, loosening of bolts	Sky debris	1	5	Simulation of expected stresses, material testing, pre-flight check
Fin brackets loosening from the body tube	Insufficient epoxy strength	Aerodynamic instability, structural failure	1	3	Visual inspection, pre-flight check
Fin brackets separate	Insufficient epoxy strength	Sky debris	1	5	Simulation of expected stresses,

from body tube					materials testing, pre-flight check
Fracture crack in bulkheads	Material Defect, stress on eyebolt threads, insufficient epoxy strength	Structural Failure, pressure leakage	2	5	Visual Inspection, Pre-flight check
All-threads shear	Insufficient all thread strength	Unwanted separation of rocket	1	5	Simulation of expected stresses, visual Inspection, Pre-flight check
Airframe zippers	During ejection shock cord cuts into body tube	Rocket body is damaged	2	3	Deploy parachute precisely at apogee with altimeters
Payload					
Payload causes sudden change in center of gravity for the rocket	Shifting shear thickening liquid causes a sudden change in center of gravity for the rocket	Rocket becomes unstable	1	3	A set amount of shear thickening liquid will be used. Any liquid will be suspended in the center of the fragile materials protection bay, and will be located close to the natural center of gravity
Kiwi loses balance and is no longer able to	Kiwi loses balance	Kiwi guided section free falls to the ground	3	4	Kiwi will be made with an overall density low enough to ensure a low terminal velocity

sustain flight					during free fall. The design of Kiwi will use ballast to prevent sudden attitude change
Drive shaft failure occurs while Kiwi is in flight	Drive shaft failure	Kiwi guided section free falls to the ground	2	4	Kiwi will be made with an overall density low enough to ensure a low terminal velocity during free fall
Kiwi loses GPS contact	Kiwi loses GPS contact	Kiwi guided section does not reach proper location	1	5	In case of directional failure, Kiwi will be programmed to descend at a low velocity
Kiwi gets tangled in parachute cords	Kiwi gets tangled in parachute cords	Kiwi guided section free falls to ground, other rocket section also does not descend under parachute	2	4	Care will be taken in the packing of Kiwi in the rocket body to ensure ease of exit without interference. In case of entanglement, Kiwi will be designed to be light enough to ensure paracord operation
Payload Integration					
Integration Failure	Lack of communication	One or more subsystems do	2	4	Hold weekly subsystem leads

	between subsystems	not function properly when integrated			meetings to promote cross subsystem communications
Launch Support Equipment					
Motor does not ignite	Motor does not ignite on launch day	Rocket does not lift off pad	2	5	Use recommended igniters. Store motors properly to avoid oxidation.
Launch Operations					
Motor CATOs	Motor casing or components rupture	Damage to rocket	1	5	Inspect motor grains prior to installation. A certified member will assemble the motor with another observing.
Premature airframe separation	Drag separation or internal pressure causes separation	Airframe separates without parachute deployment	1	3	Pressure relief holes and use of nylon shear pins
Recovery System Failure	Parachutes do not deploy, resulting in excessive ground impact energy	Damage to rocket	2	5	Ground test ejection system to verify parachute and helicopter deploy. Employ redundant ejection altimeters.
Recovery					

Drogue chute fails to deploy	Drogue chute either does not leave the tube or does not unravel	Possible damage to body of rocket, possible zippering of body when the main parachute deploys	2	3	Ground test recovery system for optimal ejection strength
Main chute fails to deploy	Main chute either does not leave tube or does not unravel	Rocket lands to quickly, damage to body of rocket	2	4	Maintain sufficient airflow to deeply main chute from deployment bag
Main chute deploys first	Main chute deploys at apogee	Rocket will drift fairly far depending on wind	3	3	Proper labeling of wires, ground test, use correct number of shear pins
Main and drogue become tangled	Main chute gets deployed below drogue and tangles	Parachutes would not open properly, rocket would descend too quickly	2	4	Use adequate length of recovery harness
Ejection charges do not ignite	No parachute deployment, ballistic descent	Rocket body damage, rocket descends at terminal velocity	2	5	Use fresh batteries for each launch, check altimeter for continuity, have redundant altimeter
Ejection charges	Ejection occurs before/after apogee	Would affect flight but	2	3	Properly sized vent holes

ignite early/late		rocket would still land safely			
Parachute gets burned	Ejection charges damage parachute	Would burn a hole in the parachute and it would not function properly	1	3	Use Nomex/Kevlar chute protector
Recovery harness burns	Ejection partially or fully burns through harness	Weakness connection between the body and parachutes and could cause untethering of a part	1	4	Use heat resistant recovery harness material
Recovery harness attachment breaks	Bulkhead, U-blot or harness breaks	Part of the rocket becomes detached and descends too quickly	2	3	Adequately sized recovery harness, flight test
High kinetic energy at landing	Rocket lands at an excessive velocity	Potential damage to body of rocket	2	4	Accurate estimate, OpenRocket
Avionics					
Altimeter does not detect pressure change	No data is recorded and ejection charges are not fired	Parachutes will not deploy, rocket will descend too quickly,	1	5	Properly sized vent holes away from airflow obstructions,

		damage to body of rocket			redundant altimeters
Loss of power	Battery dies or wires become unattached	Parachutes will not deploy, rocket descends too quickly, damage to body of rocket	2	4	Use fresh batteries that can withstand rocket accelerations, redundant altimeters
Altimeter overheats	The altimeter will not function	Parachutes will not deploy, rocket descends too quickly, damage to body of rocket	1	5	Properly sized vent holes, redundant altimeters

5.5 Environmental Concerns

One of the main environmental concerns includes the disposal of toxic substances, due to use of such substances in rocket construction. All toxic substances will be disposed in accordance with local laws and regulations by Penn State Environmental Health and Safety (EHS). During a launch, measures will be taken to minimize changes to the local environment due to the emission of hot, toxic gases from the rocket motor during launch. A safe radius around the pad will be cleared of combustible materials. High winds during rocket flight could adversely impact the landing guidance system. Table 12 below summarizes this risks, ranking the likelihood and impact on a scale of 1-5.

Table 12: Environmental Hazards

Environmental Hazard	Cause	Effect	Likelihood	Impact	Mitigation
Solvent, paint or other toxic substance released to environment	Improper disposal of used chemicals	Potential contamination of environment	2	3	Call Penn State EHS
Motor gases	Hot, toxic gases released during takeoff	Contamination of environment, air pollution hazard	4	2	Follow all launch safety regulations
High winds (>10 mph) during recovery	High wind makes operation of recovery helicopter system difficult	Rocket section is driven off course and lands in hazardous location	3	4	Emergency parachute to safely land rocket, launch in low wind conditions

5.6 Overall Project Risk Management

There are several concerns with the overall project, mostly related to budget and personnel management. These are presented in Table 13 below.

Table 13: Overall Project Risks

Risk	Cause	Effect	Likelihood	Impact	Mitigation
Labor leaves/graduates	Seniors graduate or students stop attending meetings	There are no longer enough students available to perform the necessary work	High	Medium	Recruitment at beginning of each semester. Team building activities.
Club loses funding	One or more sources can no longer provide funding	There is not enough money to pay for transportation or necessary parts/equipment	Low	High	Dedicated member to track expenses and make funding contracts possible.
Project falls behind schedule	Team fails to build critical components in a timely manner	Major milestones are not met in time	Medium	Medium	Weekly status meetings, follow project plan
Failure to acquire transportation	Transportation to Alabama not acquire	Team is unable to travel to the competition	Low	High	Have plan to carpool if necessary
Injury of team personnel	Hazards outlined in Table 10	Team member is injured	Low	High	Inform and enforce team safety
Project over budget	Testing/fabrication/ travel costs exceed expectations	Project cost exceeds amount of money projected.	Low	Medium	Compare prices from different vendors, avoid

					excess shipping costs
Damage during testing	Accident/malfunction during testing	Catastrophic damage to rocket	Medium	Medium	Ground testing, maintain stock of spare parts
Club loses facilities	University revokes club access to lab	Club loses access to 46 Hammond	Low	High	Maintain clean environment and proper storage of materials
Parts are unavailable	Parts needed for rocket are not available commercially	Rocket cannot be completed using planned parts	Low	Medium	Use non-exotic materials and check for Availability. Order parts far in advance
Theft of equipment	Parts or testing equipment get stolen	Rocket construction becomes more difficult, excess cost to the club	Low	Medium	Only subsystem leaders and officers will have card access to the LTRL lab

6. Payload Criteria

6.1 Payload Objectives

The fragile object protection payload aims to protect an unknown material of unknown dimensions from the forces that induced by rocket acceleration. The experiment that LTRL will perform with this payload will test the adequacy of a non-Newtonian fluid to protect a fragile object within a rocket. If the fragile object is unharmed by vehicle flight, and the protection system remains intact throughout the flight, the experiment will be deemed a success.

The objective of Kiwi is to stabilize after ejection from the rocket and navigate to a predetermined location. Kiwi will test a custom autonomous navigation and stabilization system as its experiment. For Kiwi to be considered successful, it will need to stabilize itself and land within 5 feet of the specified location without the use of its parachute.

6.2 System Level Design Review

Table 14: Design Factors for FOPS

Potential Designs	Positive Factors	Negative Factors
Shear Thickening Liquid with Open Cell Foam	Can envelop and fully disperse forces across a fragile specimen, offers good acceleration dispersal	Vulnerable to slow creep, which is particularly prevalent during the wait until launch; any specimen must be protected from potential liquid damage
Magnetic suspension	No physical contact with specimen	Requires strong magnets and a magnetic container, electric power
Accelerometer/reel acceleration dampening system	Allows for most control over specimen protection from acceleration	Requires electric power and advanced control mechanisms
Spring/elastic suspension	Simplest mechanical system	Least control, high acceleration due to elastic response

Shear Thickening Liquid

Using a shear thickening liquid provides two distinct advantages. A STL is able to conform to the surfaces of a specimen and provide a more distributed load than solid suspension mechanisms. While not under force, an STL is also able to conform to any specimen shape, which allows for a wide variety of specimens to be protected. However, specimens can still drift within the shear thickening liquid, requiring some kind of holding mechanism which could lower the efficacy of the STL. Shear thickening liquid is also incompressible, meaning that a specimen of unknown volume

Magnetic Suspension

Magnetic suspension of specimens has been proven to work with paramagnetic materials. Force can be exerted on a specimen without physical contact. However, the amount of control necessary for dynamic stability is particularly difficult to achieve. There is also no damping in a purely magnetic system.

Accelerometer System

An accelerometer-controlled reel system provides the most amount of control by allowing the specimen to undergo controlled movement. Unlike the elastic band design, no elastic response will be present, which reduces the stresses on a specimen due to acceleration. However, such a system would require electricity to run, which is a concern due to the long time the system could be waiting, as well as the power required to run motors and reels. The internal mechanisms required to reduce the acceleration on the specimen would also require a large amount of space inside the rocket, and complex internal mechanisms.

Elastic Suspension

Elastic bands which connect the specimen container to the rocket body are the simplest solution to the issue of acceleration exerting forces on a specimen. However, the elastic bands will also produce high accelerations at maximum extensions. A system with more damping would provide better protection from acceleration.

Table 15: Design Factors for Kiwi

Potential Helicopter Designs	Positive Factors	Negative Factors
Single Rotor Helicopter	Simplest design	Not very efficient
Coaxial Helicopter	Energy efficient Fits nicely inside vehicle	Complex
Quadcopter	High stability	Not energy efficient Hard to fit inside vehicle
Potential Computer Choice	**Positive Factors**	**Negative Factors**
Raspberry Pi	High processing power Most adaptable controller	Large size Higher complexity for programming
Arduino Leonardo	Small Easy to program	Less processing power

Single Rotor

A single-rotor helicopter is the most familiar design, with the most research and component availability. The single-rotor design is also very compact, and suitable for a rocket body. However, single-rotor helicopters also require a tail rotor which requires a separate motor and provide the least control of all design options.

Coaxial

A coaxial helicopter retains the compact design of a single-rotor helicopter, without the additional space required to have a tail rotor. More control is afforded by having a single point of force, and dual-blade designs produce force more efficiently than single-rotor designs or quadcopters. However, the internal mechanisms for coaxial rotors are more complex than either of the other options, and are less available.

Quadcopter

Quadcopters provide the most stability and control of any design options. However, control comes at the cost of power required to sustain thrust with four separate rotors. The space required for four rotors with distinct mounting points also necessitates a folding design, which adds a layer of complexity to building a quadcopter.

Raspberry Pi

The Raspberry Pi provides more processing power than its competitors, however it is heavier and more difficult to program. Because of the size of the helicopter and due to limitations put in place by the size of the rocket, the weight of the microcontroller will be a big factor to determine if it can be used in the payload.

Arduino Leonardo

The Arduino Leonardo is smaller than the Raspberry Pi, however it does not provide as much processing power as its alternative. Because of the complicated nature of the programs necessary for this payload to successfully complete this mission, processing power cannot be compromised.

6.3 Leading Design

Fragile Object Protections System

The materials protection bay will connect the front of the rocket to the rear section. Connections will be directly attached to the acrylic body of the protection bay. By using the materials bay as the structural support, no internal structures which would interfere with the ability of the rocket to protect its payload. U-bolts will connect the materials bag to the bay bulkheads. U-bolts in the bulkhead will act as mounting points for elastic bands, which will suspend the materials bag in the center of the bay. By being suspended in the bay, the shear thickening liquid will be most able to control the acceleration on the fragile specimen. Chunks of open-cell foam will allow for expansion of the materials bag with the addition of the specimen, while still being able to distribute loads across the surface of the specimen. By having distinct chunks of open-cell foam, the normal forces on the specimen will be lower than if a continuous piece of foam were used. The shear thickening liquid inside the bay will distribute loads directly across the surface of the specimen, and is the least likely of any holding system to cause a bending force on the specimen. Figure 24 below shows the assembled FOPS bay:

Figure 24: Assembled view of FOPS

The black bag contains the non-Newtonian fluid and the specimen. The bag is suspended in the center of the bay to minimize collisions with the sides of the bay. The bag is secured via rubber bands to U-bolts in the bulkheads. Figure 25 below goes into detail about the dimensions of the components of FOPS. As seen in the figure, the materials bag is large enough to contain the unknown object that will be received on launch day.

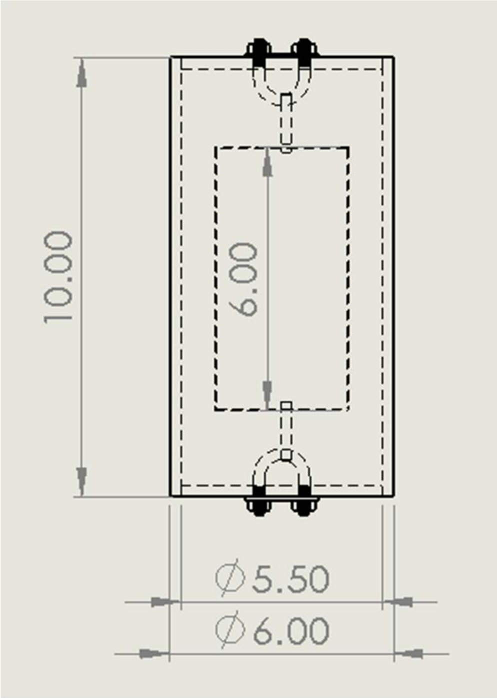


Figure 25: Dimensioned drawing of materials protection payload

Kiwi

The coaxial helicopter will be chosen as the vehicle of Kiwi because it is the most energy efficient and easily fits inside the rocket since it does not have a tail rotor. The Raspberry Pi will be used as the flight computer for Kiwi. This microcontroller is the best option despite its size because it, unlike the Arduino, gives Kiwi all of the processing power it needs to complete its mission.

6.4 Precision of Instrumentation

Due to the distinct success or failure states of FOPS, precision of instrumentation is not applicable. There are no measurements in this experiment. FOPS is a very repeatable experiment as the setup of the protection chamber will be exactly the same for all flights. Additionally, the periods of highest stress on the system (takeoff, rocket separation at apogee, and landing) are similar in each rocket flight provided the rocket systems work as expected. There is no need for a recovery system specifically for this payload.

The precision of instrumentation for Kiwi will be determined by the distance between where it lands and the predetermined target. The repeatability of measurement is decreased by environmental factors, the most notable of which is wind. Strong winds will lower the helicopter’s stability and make maneuvering extremely difficult. However, environmental factors should be the only factors which reduce the repeatability of the experiment. The recovery system for Kiwi comprises a GPS for autonomous navigation and locating purposes. Kiwi will also be equipped with a small parachute system in case of flight system failure to ensure that it is in accordance with the kinetic energy requirements.

7. Project Plan

7.1 Requirements Compliance

Requirement Verification

Vehicle Requirements

Requirement Number	Method of Verification	Verification
1.1	Demonstration	The onboard payload will be delivered to an apogee of 5,280 feet above ground level in a test launch.
1.2	Inspection	The vehicle shall carry at least one commercially available, barometric altimeter for recording the official altitude.
1.2.1	Inspection	The official altitude shall be reported via a series of beeps from the official scoring altimeter post launch.
1.2.2	Inspection	The vehicle will have a second altimeter to provide dual redundancy for all deployment charges.
1.2.3	Inspection	At the LRR, a NASA official will mark the altimeter that will be used for the official scoring.
1.2.4	Inspection	At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.
1.2.5	Inspection	All audible electronics, other than the official scoring altimeter shall be capable of turning off.
1.2.6.1-4	Inspection	All competition scoring rules as listed in the handbook are understood and shall be followed.
1.3	Inspection	All recovery electronics shall be powered by commercially available 9V batteries.
1.4	Demonstration	Materials and construction methods used by the club allow for the repeated use of the vehicle.

		Demonstrated by the multiple launches required by the test vehicle.
1.5	Demonstration	Flight vehicle's design consist of three sections to contain the parts for payload, avionics and recovery, and propulsion respectively as seen by the separation points during launch.
1.6	Inspection	The vehicle contains a single stage three grain motor.
1.7	Demonstration	Vehicle is easily assembled and disassembled by using screws and couplers to fit each section together.
1.8	Demonstration	The launch vehicle shall be capable of being prepared for launch in a period of 4 hours. And capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.
1.9	Testing	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. Engine firing will be tested by propulsion prior to first flight.
1.10	Demonstration	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch. Demonstrated through launch of subscale.
1.11	Inspection	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

1.11.1	Testing	(As of PDR the selected motor is the L1350) Final motor choices shall be made by the Critical Design Review
1.11.2	Inspection	In the event the motor needs to be changed after CDR it shall be approved by the NASA Range Safety Officer (RSO)
1.12.1	Analysis	The minimum factor of safety shall be 4:1 with supporting design documentation included in all milestone reviews.
1.12.2	Analysis	The low-cycle fatigue life shall be a minimum of 4:1.
1.12.3	N/A	Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank. The design does not contain any pressure vessels.
1.12.4	N/A	Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when. The design does not contain any pressure vessels.
1.13	Testing/Analysis	Current selection is rated at an impulse of 4280 Ns (67% of the maximum L class motor 5120 Ns allowed for use in university competition)
1.14	Simulation	The stability margin at point of static exit currently sits at 2.25 calibers, exceeding the 2.0 required stability margin. These stability margins were simulated using OpenRocket.
1.15	Simulation	The vehicle will have a minimum velocity of 76.6 ft/s at rail exit. (Min allowable is 52 ft/s)

1.16	N/A	A subscale launch for the vehicle is currently scheduled for November 13th, 2016.
1.16.1	Simulation/Inspection	Subscale design will resemble a 1:2 scale of the full size launch vehicle as shown in the OpenRocket models.
1.16.2	Inspection	The subscale shall carry an altimeter for apogee altitude reporting.
1.17	N/A	A checklist shall be made to ensure that the sub requirements of 1.17 shall all be followed
1.18	Inspection	No structural protuberance will be located forward of the burnout center of gravity.
1.19.1	Inspection	The vehicle will not include forward canards.
1.19.2	Inspection	The launch vehicle shall not utilize forward firing motors.
1.19.3	Inspection	The launch vehicle shall not utilize motors that expel titanium sponges.
1.19.4	Inspection	The launch vehicle shall not utilize hybrid motors.
1.19.5	Inspection	The launch vehicle shall not utilize a cluster of motors.
1.19.6	Analysis	The launch vehicle shall not utilize friction fitting for motors, instead utilizing a tail cone for motor retention
1.19.7	Analysis	The launch vehicle will reach approximately Mach 0.6, below the Mach 1 maximum requirement. This value was simulated using OpenRocket. Value will also be verified after test launches.

1.19.8	Simulation	The vehicle ballast will not exceed 10% of vehicle weight. The current simulation includes a 10% ballast.

Recovery System Requirements

Requirement Number	**Method of Verification**	**Verification**
2.1	Demonstration	A drogue will deploy at apogee and a main will deploy at 700ft. Demonstrated through full-scale launch.
2.2	Demonstration	LTRL will ground test ejection charges before any subscale or fullscale launch. There will be ground tests before any initial launches.
2.3	Analysis	The parachutes will be correctly sized so that each component of the rocket lands within the kinetic energy constraint of 75ft-lbs. The current parachute selection has the rocket well under the kinetic energy limit.
2.4	Inspection	The recovery system wiring will be completely independent of any payload components.
2.5	Inspection	There will be two independent altimeters, power supplies, and ejection charges for redundancy.
2.6	Demonstration	Motor ejection will not be used to separate the rocket. The altimeter will control the ejection charges.
2.7	Inspection	Each altimeter will have a separate key switch that will be accessible from the outside of the rocket.
2.8	Inspection	Each altimeter will have an independent battery.
2.9	Demonstration	Each key switch will be able to stay in the on position while on the launch pad.

2.10	Demonstration	Removable sheer pins will be used to keep the rocket together for both parachute compartments until the ejection charges cause separation.
2.11	N/A	There will be a GPS unit installed that will constantly send the position of the rocket.
2.11.1	Inspection	All parts will be tethered but if any are not, they will have independent GPS units.
2.11.2	Inspection	The GPS unit will be functional on launch day. There will be a spare GPS unit in case of any electronic failures before the launch.
2.12	Inspection	The recovery system electronics will be in a faraday cage as to not interfere with any component of the rocket or other rockets.
2.12.1	Inspection	The recovery system will be in a coupler without any other payloads or electronic components.
2.12.2	Testing	The faraday cage will protect the recovery system from any interference. Testing before launch will confirm this requirement.
2.12.3	Testing	The faraday cage will protect the recovery system from any interference. Testing before launch will confirm this requirement.
2.12.4	Testing	The faraday cage and being in its own coupler will protect the recovery system from any interference. Testing before launch will confirm this requirement.

Experimental Requirements

Requirement Number	**Method of Verification**	**Verification**

3.1.1	Inspection	The rocket will carry a fragile specimen protection experiment as a payload.
3.1.2	Demonstration	At the launch, an additional autonomous coaxial helicopter payload will be flown in the rocket, but will not be submitted for scoring.
3.1.3	Inspection	The coaxial helicopter payload will be included in reports so that the safety of the project can be reviewed by overseeing engineers.
3.1.3	Inspection	The coaxial helicopter payload will be equipped with its own GPS.
3.1.3	Analysis	The coaxial helicopter payload will be equipped with an emergency parachute system to ensure that it comes down in accordance with the kinetic energy requirements.
3.4.1	Demonstration/ Analysis	A chamber filled with dilatant will house a flexible bag, which will contain and protect the fragile materials. The chamber will be suspended by elastic bands in order to provide gross acceleration dissipation.
3.4.1.1	Demonstration	All specimens will be placed in separate bags and inserted into the dilatant, which will cushion each specimen individually.
3.4.1.2	Analysis	The cushioning provided by the dilatant, combined with the acceleration dissipation of the elastic bands will ensure that any material placed inside the chamber will be able to survive the accelerations and shocks of launch, landing, and recovery.
3.4.1.3	Inspection	A sealable materials bag inside the chamber will allow for insertion of specimens, while the dilatant will allow for objects to be of unknown size and shape.

3.4.1.4	Testing/Inspection	All dilatant for cushioning will be permanently housed inside the rocket during preparation, with enough volume left inside the bay between the elastic regions and materials chamber to permit for displacement due to specimen volume. All specimens will be sealed in watertight bags.
3.4.1.5	Inspection	The material chamber will be large enough to house a 3.5” by 6” cylinder.
3.4.1.6	Analysis	The mass of the objects will be accounted for in the estimations of flight, as well as the accelerative forces on the materials chamber.

Safety Requirements

Requirement Number	**Method of Verification**	**Verification**
4.1	Demonstration	The team will use launch and safety checklists. The team will demonstrate the use of launch and safety checklists during all launches.
4.2	N/A	Laura Reese is listed as safety officer
4.3	N/A	The safety officer will perform all responsibilities as listed.
4.3.1	Inspection	The safety officer will monitor the team with an emphasis on safety.
4.3.1.1	Inspection	The safety officer will monitor the team during design of the vehicle and launcher.
4.3.1.2	Inspection	The safety officer will monitor the team during construction of the vehicle and launcher.

4.3.1.3	Inspection	The safety officer will monitor the team during assembly of the vehicle and launcher.
4.3.1.4	Inspection	The safety officer will monitor the team during ground testing of the vehicle and launcher.
4.3.1.5	Inspection	The safety officer will monitor the team with an emphasis on safety during the subscale launch tests.
4.3.1.6	Inspection	The safety officer will monitor the team with an emphasis on safety during the full-scale launch test.
4.3.1.7	Inspection	The safety officer will monitor the team with an emphasis on safety during the launch day.
4.3.1.8	Inspection	The safety officer will monitor the team with an emphasis on safety during the recovery activities.
4.3.1.9	Inspection	The safety officer will monitor the team with an emphasis on safety during educational activities.
4.3.2	N/A	The safety officer will implement all procedures developed by the team for construction, assembly, launch and recovery activities.
4.3.3	N/A	The safety officer will managed and maintain current versions of the team's hazard analyses, failure modes analyses, procedures and chemical inventory data.
4.3.4	N/A	The safety officer will assist in the writing and development of the team's hazard analyses, failure modes analyses and procedures.
4.4	N/A	The team's mentor is Robert Dehate.
4.5	N/A	The team will abide by the rules and guidance of the RSO.

4.6	N/A	The team will abide by all rules set forth by the FAA.

General Requirements

Requirement Number	**Method of Verification**	**Verification**
5.1	Demonstration	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.
5.2	Demonstration	The team provided a project plan including project milestones, budget and community support, checklists, personnel assigned, educational engagement events, risks, and mitigations. The team will follow the project plan.
5.3	N/A	Foreign National Team members will be identified to NASA by Preliminary Design Review.
5.4	Demonstration	The team members attending the launch will be identified by Critical Design Review.
5.4.1	N/A	Only actively engaged team members will come to launch week activities.
5.4.2	N/A	One mentor will come to launch week activities.
5.4.3	N/A	At most two adult educators will come to launch week activities.
5.5	Demonstration	The team will engage at least 200 participants in educational, hands-on science and math related activities throughout the year and write reports on these events.

		The reports will be submitted at most two weeks after the activity.
5.6	Inspection	The team has developed a website for the competition. The website will be kept up to date throughout the competition.
5.7	Demonstration	Teams will post, and make available for download, the required deliverables to the team website by the due dates specified in the project timeline.
5.8	Demonstration	All reports shall be delivered in pdf format.
5.9	Demonstration	Every report shall include a table of contents outlining major sections and their respective sub-sections.
5.10	Demonstration	Every report shall include page numbers at the bottom of the page.
5.11	Demonstration	The team shall provide proper video conference equipment needed to perform a video teleconference with the review board.
5.12	Demonstration	The flight vehicle will be capable of launching using the launch pads provided by the launch service provider.
5.13	Demonstration	The team will meet the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards.

Derived Requirements

Each subsystem, as well as the safety officer, derived project specific requirements as listed below. These are an extension beyond the general requirements given and will be used by the club to target specific aspects of the project.

Derived Requirements

1. PAYLOAD

1.1 Fragile material is recovered from the bay is the same condition as received	Testing	Test the materials protection system with various fragile objects vulnerable to bending, breakage, collapse, and liquid damage
1.2 No materials will leave the materials bay until recovery	Inspection	Perform pre-flight check on rocket and during material bay loading
1.3 The protection payload does not cause the vehicle to become unstable.	Inspection/Analysis	Observe the vehicle's flight during subscale and full-scale test launches.
1.4 Kiwi becomes stable upon exit of the rocket.	Inspection/Analysis	Observe Kiwi's flight during subscale and full-scale test launches by on board camera.
1.5 Kiwi lands within 5 feet of the landing point.	Testing	Measure the distance between Kiwi's landing site and launch site.
2. Avionics and Recovery		
2.1 Redundant altimeter will be at a delay to not overwhelm the body	Demonstration	The redundant altimeter will be at a slight delay.
2.2 There will be backup electronics in case of failure on launch day	Demonstration	The team will have backup altimeters and GPS units in case of failure before launch.
2.3 Pressure port will be adequately sized	Testing	There will be ground testing and test launches to ensure that the pressure port is a proper size.
2.4 Structural materials will be strong enough to maintain integrity throughout descent and landing	Testing	There will be estimations and testing done to ensure the integrity of the structure throughout parachute ejections and landing.
3. Propulsion		
3.1 Modeling for prediction of target apogee	Analysis	Assessments will be conducted to minimize point loss in the target altitude category.
3.1.1 Validation of manufacturer's data	Testing	Static motor testing will be conducted to accurately model vehicle flight.
3.1.2 Vehicle Drag Assessment	Testing	Wind tunnel drag modeling will be conducted on a subscale model of the final launch vehicle to calculate an accurate coefficient of drag.
3.2 Handling and risk mitigation	Testing	Retaining hardware will be assessed using 3D scanning to inspect for deformation. Motors and igniters

		stored safely and handled appropriately at all times.
4. Safety		
4.1 Team members take safety course	Demonstration	All team members will complete the Penn State lab safety course
4.2 Lab safety plan in place	Demonstration	An official university Unit Safety Plan will be completed to ensure a safe lab environment
5. Structures		
5.1 Improve aerodynamics of launch vehicle	Testing	Components will be selected to maximize aerodynamic efficiency.
5.2 Materials testing for airframe selection	Testing	Airframe materials will be evaluated for tensile strength to verify structural integrity.
5.3 Launch vehicle fins will be removable	Demonstration	Fins on launch vehicle will be able to be removed without disassembly of the launch vehicle.
5.4 Visually confirm payload status	Inspection	Launch vehicle will contain transparent section of airframe to obtain visual status of FOPS.

7.2 Budget

Line Item Expenses

Table 16: Projected Line Item Expenses

Fullscale			
Structures			
J-B Weld Adhesive 8270, Fast Hardening, 10 Ounce Tube	2	$20.12	$40.24
6” Blue Tube	1	$66.95	$66.95
6” Blue Tube Full Length Coupler	1	$66.95	$66.95
5.5” Blue Tube Coupler	1	$18.95	$18.95
Centering Rings 75mm (fits Blue Tube) to 6.0" (2 Pack)	2	$13.55	$13.55
Structural Fiberglass (FRP) Sheet 1/8" Thick, 12" x 12"	2	$10.17	$20.34
6” Von Karman nose cone	1	$116.33	$116.33
Optically Clear Cast Acrylic Tube, 6" OD x 5-3/4" ID, 1' Length	1	$47.98	$47.98
Bulkheads	6	$8.93	$8.93
75mm motor tube	1	$29.95	$29.95
Freight Charges(Predicted)	1	$50.00	$50.00
Payload			
Raspberry Pi camera	1	$27.00	$27.00
Helicopter/ Helicopter parts funds	1	$100.00	$100.00
Misc. (jumpers, wires, switches, LED’s)	1	$30.00	$30.00
A&R			
StratoLoggerCF Altimeter	2	$54.95	$109.90
GPS	1	$100.00	$100.00
Subscale			
Structures			
J-B Weld Adhesive 8270, Fast Hardening, 10 Ounce Tube	2	$20.12	$40.24
Blue Tube 75/48	1	$29.95	$29.95
ARR Blue AC-75x48" FLC	1	$31.95	$31.95
Mad Cow 2.6" 4:1 VK Fiberglass	1	$28.95	$28.95
Bulkhead - 75mm (1/pk)	5	$3.83	$19.15
Bulkhead - 2.56" BT-80 (1/pk)	2	$2.99	$5.98

Bulkhead - 2.6" (Thick/Thin) BT-80 (1/pk) 1/4" Ply	1	$2.99	$2.99
ARR Blue Coupler AC- 2.56"	1	$9.25	$9.25
Structural Fiberglass (FRP) Sheet 1/8" Thick, 12" x 12"	2	$10.17	$20.34
Optically Clear Cast Acrylic Tube 2-3/4" OD x 2-1/2" ID, 1' Length	1	$40.04	$40.04
Freight charges	1	$48.81	$48.81
Propulsion			
Cesaroni L1350 (3 Gr.)	3	$209.00	$627.00
Cesaroni J290	3	$77.21	$231.64
75mm Pro75-3G Casing	1	$187.00	$187.00
Miscellaneous Equipment			
Sharpie Fine Point Permanent Markers, 12-Pack	1	$6.75	$6.75
GREAT GLOVE NM50015-L-BX Nitrile Powder Free 4-5 mil General Purpose, Large, Blue (Pack of 100)	1	$8.74	$8.74
Loew Cornell 1021254 Woodsies Craft Sticks, 1000-Piece	1	$4.05	$4.05
Blue Sky 100 Count Plastic Cups, 5 oz. Clear	1	$5.24	$5.24
Dremel Cutoff Wheel 1-1/2	2	$22.99	$45.98
Safety Glasses Intruder Multi Color Clear Lens	1	$11.99	$11.99
3M 8000 Particle Respirator N95, 30-Pack	2	$13.95	$27.90
Label Maker	1	$24.99	$24.99
Soldering iron	1	$23.97	$23.97
Solder and Flux kit	1	$18.67	$18.67
Silicone	1	$6.58	$6.58
Duct Tape	2	$7.98	$15.96
Misc.(Bolts, Nuts, Washers, All-threads)	1	$50.00	$50.00
Iris Ultra 84" Compact Parachute	1	$345.00	$345.00

Budget and Funding Plan

The projected expenditures for the 2016-2017 school year are included in Table 17. This table lists all expected costs for the club.

- The fullscale and subscale sections include the cost of building materials for the rocket plus additional supplies for material testing. The given subscale cost is final as all parts have been purchased, while the fullscale shows a line-item estimate from Table 16.
- Propulsion encompasses all motors needed for subscale and fullscale flights as well as additional motors of multiple sizes for motor testing. The specific motors are listed in Table 16 and the cost given reflects an estimate based upon these line-items.
- Travel costs are mainly attributed to the Alabama trip during spring semester, however additional funding is required to cover fuel costs for other test launches throughout the school year.
- Outreach costs must also be considered and can include travel to outreach locations as well as any supplies needed for the event.
- Miscellaneous equipment includes all tools, equipment, and supplies needed for construction of the rocket. The current cost encompasses all parts shown in the line-item estimate as well as an additional $500.00 for unexpected costs in the future.

Table 17: Updated Annual Expenses

Expected Costs: 2016-2017	
Fullscale	$847.04
Subscale	$277.65
Propulsion	$1,045.64
Travel	$5,000.00
Outreach	$300.00
Miscellaneous Equipment	$1,095.82
Total	$8,566.15

Funding for the USLI competition will be mainly provided through various academic sponsors who provide the club with financial aid. Table 18 describes the expected funding from these various sources.

- The Aerospace Department of Penn State has been the main sponsor of LTRL and they will continue to support the club this year. They have agreed to provide a donation of $5,000.00.
- University Park Allocation Committee (UPAC) is another organization that is dedicated to supporting Penn State clubs. They offer funding for club-associated travel and are the main source of income for travel and housing costs for the USLI competition.
- Yearly dues and fundraising opportunities gathered throughout the school year will also provide funding on the scale of around $1,500.00.
- The Boeing Company has supported the club in the past and has agreed to give a donation of $500.00 for this school year.

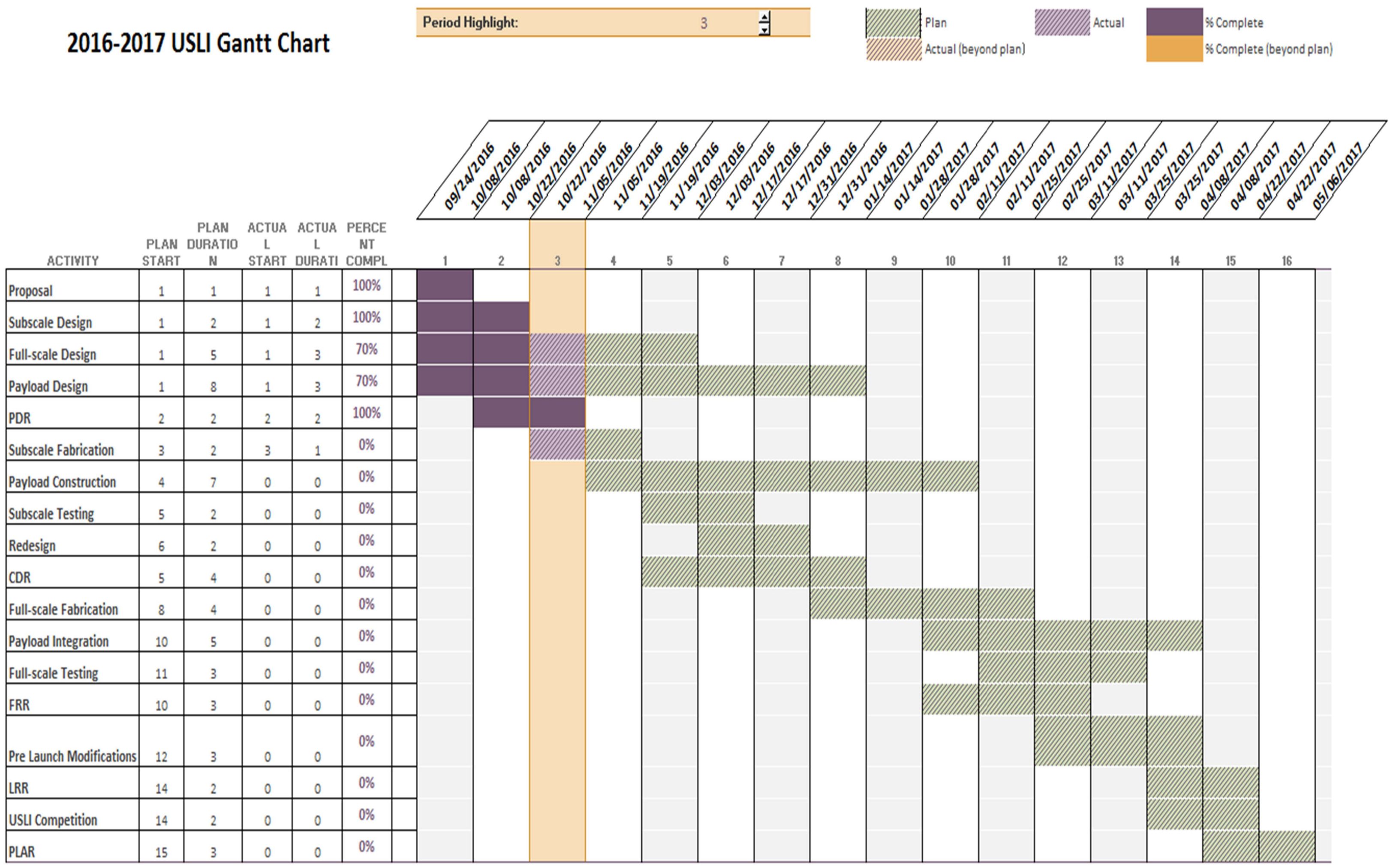
The club will continue to pursue additional sources of income in order to ensure completion of the competition as well as develop relationships with additional departments at Penn State. The Mechanical Engineering Department at Penn State is interested in supporting the club due to the large number of mechanical students. The club hopes to solidify this relationship in order to provide further funding this year as well as plan ahead for future years. The College of Engineering and Engineering Undergraduate Council (EUC) are two groups that have been contacted and seem interested in helping fund the club. Again, the club plans to develop relationships with these groups in order to diversify the funding pool.

Depending on the amount of success in acquiring additional sponsors, the club may expand its goals in order to maximize the use of additional funding. Examples include more club launches, like the Battle of the Rockets, which will allow for increased student participation, learning, and development. Increased research opportunities within rocketry is another area that with more funding could greatly expand the reach and influence of the club.

Table 18: Expected Income

Expected Income 2016-2017	
Aerospace Engineering Department	$5,000.00
UPAC	$3,500.00
Club Fundraising	$1,500.00
The Boeing Company	$500.00
Total	**$10,500.00**

7.3 Timeline



2016-2017 USLI Gantt Chart

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATI	PERCENT COMPL
Proposal	1	1	1	1	100%
Subscale Design	1	2	1	2	100%
Full-scale Design	1	5	1	3	70%
Payload Design	1	8	1	3	70%
PDR	2	2	2	2	100%
Subscale Fabrication	3	2	3	1	0%
Payload Construction	4	7	0	0	0%
Subscale Testing	5	2	0	0	0%
Redesign	6	2	0	0	0%
CDR	5	4	0	0	0%
Full-scale Fabrication	8	4	0	0	0%
Payload Integration	10	5	0	0	0%
Full-scale Testing	11	3	0	0	0%
FRR	10	3	0	0	0%
Pre Launch Modifications	12	3	0	0	0%
LRR	14	2	0	0	0%
USLI Competition	14	2	0	0	0%
PLAR	15	3	0	0	0%

Works Cited

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[4] PerfectFlite, "SL100 Altimeter," in PerfectFlite Altimeters, 2015. [Online]. Available: http://www.perfectflite.com/sl100.html. Accessed: Oct. 28, 2016.

[5] Y. A. Çengel and J. M. Cimbala, Fluid mechanics: Fundamentals and applications. Boston, MA: McGraw-Hill Higher Education, 2006, sec. Drag Coefficients of Common Geometries, p. 573.

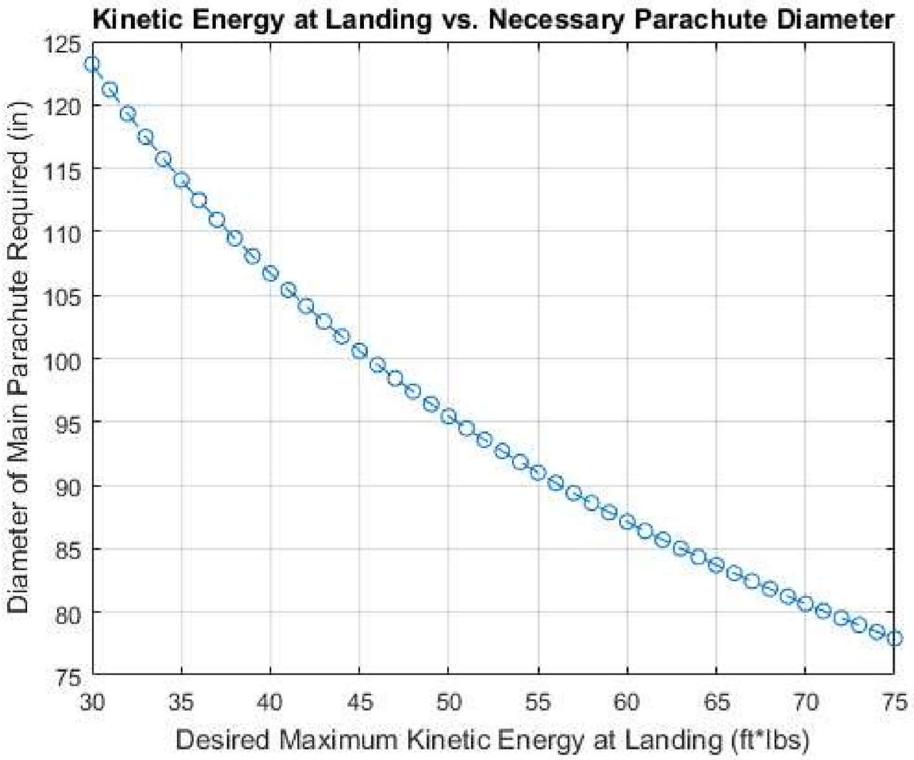
[6] G. Crowell Sr., The Descriptive Geometry of Nosecones. Instituto de Fisica de Sao Carlos, 1996. [Online]. Available: https://web.archive.org/web/20110411143013/http://www.if.sc.usp.br/~projetosulfos/artigos/NoseCone_EQN2.PDF. Accessed: Oct. 22, 2016.

Appendix A: MATLAB Recovery Model

Contents

Calculate necessary area of Parachute to meet certain KE on landing

```
clc, clear, close all
%Gravitational accelteration units: m/s^2
g = 9.81;
%Density in kg/m^3
rho = 1.225;
%Temperature in fahrenheit
initialTemp = 10;

keMax = 75;

%Coefficient of drag of drogue, main, and tumbling rocket respectively
Cdd = 0.88;
Cdm = 1.5;
Cdr = 0.3;

%These should be in kg

mass(1) = 3.81;%For the fore
mass(2) = 4.199;% For the avionics bay
mass(3) = 3.048; %For the booster
mass(4) = 1.52; %Main parachute
mass(5) = 1.174;%Drogue parachute

maxMass = max(mass);
totMass = sum(mass);

radiusMainM = ones(1,10);
keMatFtLbs = (30:1:75);
keMatJoule = keMatFtLbs*1.3358;

for i = 1:length(keMatJoule)
radiusMainM(i) = sqrt((maxMass*totMass*g)/(Cdm*keMatJoule(i)*rho*pi));
end

radiusMainFt = 3.281*radiusMainM;
radiusMainIn = radiusMainFt * 12;

figure(1);
plot(keMatFtLbs,2*radiusMainIn,'--o')
title('Kinetic Energy at Landing vs. Necessary Parachute Diameter');
xlabel('Desired Maximum Kinetic Energy at Landing (ft*lbs)');
ylabel('Diameter of Main Parachute Required (in)');
grid on;
```

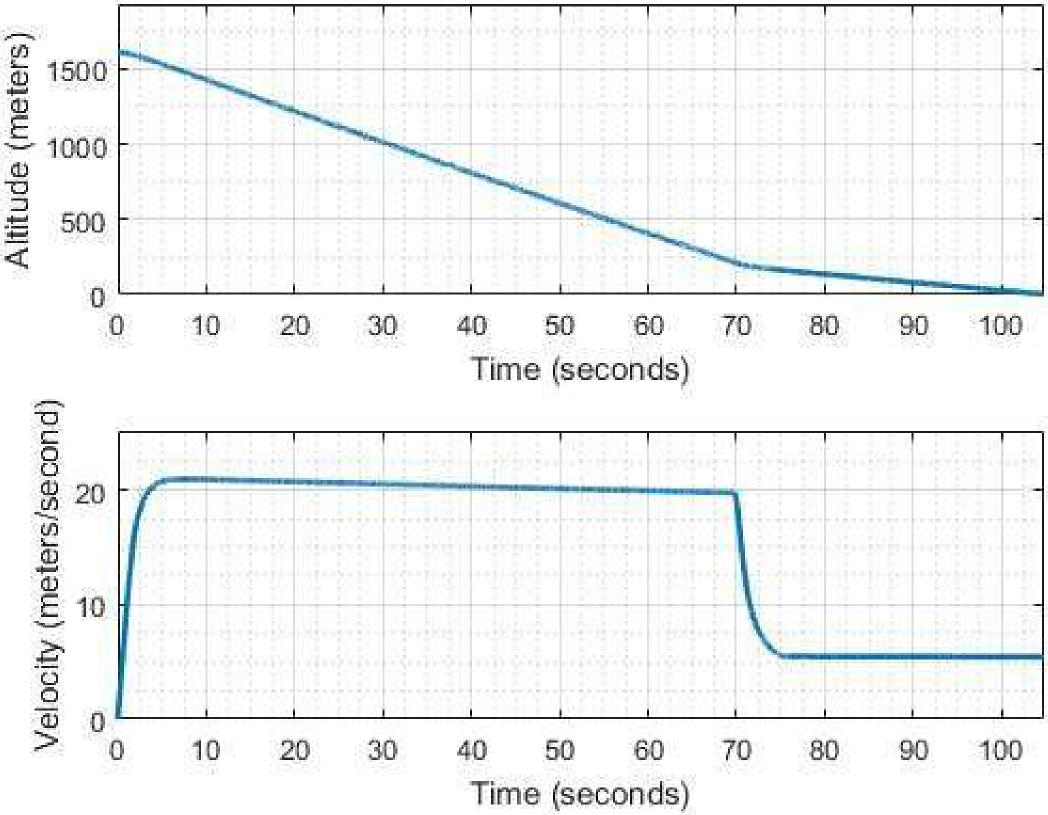


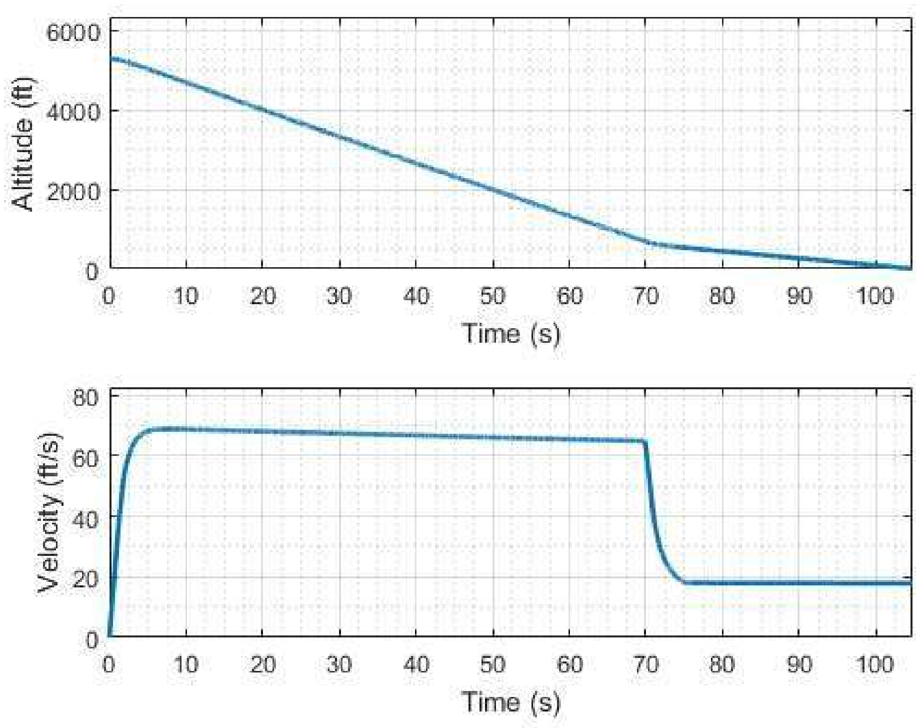
Calculating Force based results

```
Rd_in = 18; %radius of drogue[in]
    Rd = 0.0254*Rd_in; %radius of drogue[m]
Rm_in = 48; %radius of main[in]
    Rm = 0.0254*Rm_in; %radius of main[m]
Rr_in = 4; %simulated radius of "tumbling" rocket parachute[in]
    Rr = 0.0254*Rr_in; %simulated radius of "tumbling" rocket parachute[m]

apogeeft = 5280; %apogee altitude above ground level [ft]
    apogee = 0.3048*apogeeft;
altDrogueft = 5279; %altitude above ground level of drogue deployment[ft]
    altDrogue = 0.3048*altDrogueft;
altMainft = 700; %altitude above ground level of main parachute deployment[ft]
    altMain = 0.3048*altMainft;

% Declare Constants
altLaunchSite = 183; % Altitiude above sea level of the launch site in meters
h = apogee+altLaunchSite; % Initial altitude of the rocket above sea level
h_matrix(1) = h;
time(1) = 0;
dt = .01;
v(1) = 0;
a(1) = g;
i = 1; % Counter variable
Temp = 15; % Temperature in Celcius at ground level.
Weight = totMass*g;

% Deployment time and counter initialization for the main and drogue
```

```
% parachutes
Kd_dep = 0; % Drogue deployment factor, or how many iterations have run since the drogue was
deployed.
Td_dep = 2; % Drogue deployment time (how long it takes) in seconds
Td_dep_elapsed = 0;  % Time elapsed since drogue deployment
Km_dep = 0; % Main deployment factor, or how many iterations have run since the main was depl
oyed
Tm_dep = 5;
Tm_dep_elapsed = 0;

%Drag Calculation
while(h >= altLaunchSite) % Although we are integrating over time, the check is whether the h
eight is still above ground level.
    rho_new = rhocalcestSI(h,Temp); % Calculate the density at the given altitude and tempera
ture
    Dragr(i) = .5*Cdr*rho_new*v(i)^2*pi*Rr^2; % Drag of the rocket body
    Dragd(i) = .5*Cdd*rho_new*v(i)^2*pi*Rd^2; % Drag of the drogue parachute
    Dragm(i) = .5*Cdm*rho_new*v(i)^2*pi*Rm^2; % Drag of the main parachute

        if h > altDrogue + altLaunchSite % Determines which state of descent the rocket is in
 and adjusts accordingly by adding the drags
            Drag = Dragr(i); % If the drogue has yet to deploy, the drag of the rocket is the
 only factor
        elseif h > altMain + altLaunchSite
            Kd_dep = Kd_dep + 1; % Increment drogue deployment factor
            Td_dep_elapsed = Kd_dep*dt; % Use the drogue deployment factor to calculate time
since drogue deployed
            Drag = Dragr(i) + Dragd(i); % Calculate drage when drogue fully deployed

            % This loop only runs right after chute deployment and models
            % the chute as opening in a linead matter
            if Td_dep_elapsed < Td_dep
                Drag = Dragr(i) + (Td_dep_elapsed/Td_dep)*Dragd(i);
            end
        else
            Km_dep = Km_dep + 1;
            Tm_dep_elapsed = Km_dep*dt;
            Drag = Dragr(i) + Dragd(i) + Dragm(i);

            if Tm_dep_elapsed < Tm_dep
                Drag = Dragr(i) + Dragd(i) + (Tm_dep_elapsed/Tm_dep)*Dragm(i);
            end
        end
    i = i + 1; % Increment i, the current index value
    a(i) = (-Drag+Weight)/totMass;
    v(i) = v(i-1)+a(i)*dt;
    delh(i) = v(i)*dt;
    h = h-delh(i);
    h_matrix(i) = h;

    time(i) = time(i-1) + dt;
end

figure(2);
ax11 = subplot(2,1,1);
title('Descent Profile In SI Units');
plot(time,h_matrix-altLaunchSite,'LineWidth',2)
```

```
ylabel('Altitude (meters)');
xlabel('Time (seconds)');
grid on;
grid minor;
axis([0 max(time) 0 max(h_matrix-altLaunchSite)*1.2]);
ax21 = subplot(2,1,2);
plot(time,v,'LineWidth',2);
ylabel('Velocity (meters/second)');
xlabel('Time (seconds)');
grid on;
grid minor;
axis([0 max(time) 0 max(v)*1.2]);
linkaxes([ax11 ax21],'x');

figure(3)
ax12 = subplot(2,1,1);
title('Descent Profile in English Units');
plot(time,(h_matrix-altLaunchSite)*3.281,'LineWidth',2);
ylabel('Altitude (ft)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(h_matrix-altLaunchSite)*3.281*1.2]);
ax22 = subplot(2,1,2);
plot(time,v*3.281,'LineWidth',2);
ylabel('Velocity (ft/s)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(v)*3.281*1.2]);
linkaxes([ax12 ax22],'x');
```

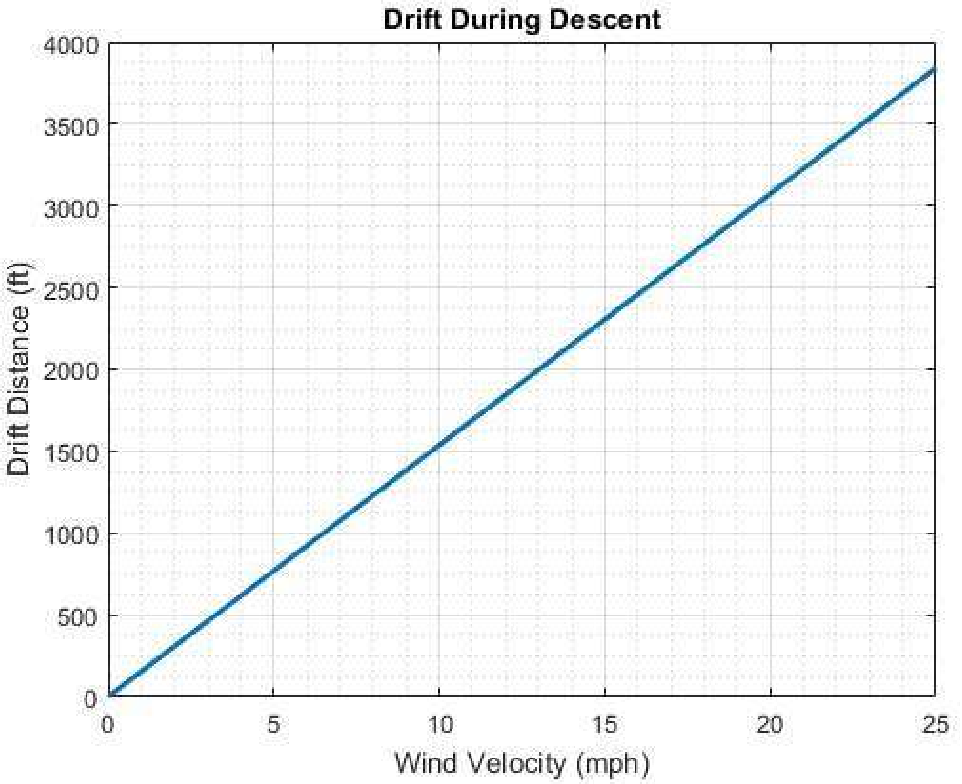

Altitude (meters)
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)
Velocity (meters/second)
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)



Calculate Drift Distance

```
Windmph = 0:1:25; % Velocity of wind[mph]
Windfps = 1.467*Windmph;
Windmps = Windfps*0.3048;

% Calculate drift distance in metric and standard
descentTime = max(time);
driftDistM = Windmps*descentTime;
driftDistFt = Windfps*descentTime;

% Plot drift distance
figure(4)
plot(Windmph,driftDistFt,'LineWidth', 2);
ylabel('Drift Distance (ft)');
xlabel('Wind Velocity (mph)');
grid on;
grid minor;
title('Drift During Descent');

% Output max drift distance
fprintf('The drift distance at a wind velocity of 25 mph is %6.1f ft\n\n', max(driftDistFt));
```

```
The drift distance at a wind velocity of 25 mph is 3842.1 ft
```



Calculating KE of each component at landing

```
vf = v(end); %Find final landing velocity

% Calculate the KE of each component in Joules
KEforeSI = (1/2)*v(end)^2*mass(1);
KEavSI = (1/2)*v(end)^2*mass(2);
KEboostSI = (1/2)*v(end)^2*mass(1);

% Calculate the KE of each component in Ft-lbs
KEforeST = KEforeSI*0.7376;
KEavST = KEavSI*0.7376;
KEboostST = KEboostSI*0.7376;

% Print Results
fprintf('The kinetic energy of the nosecone section is %4.2f ft*lbs\n', KEforeST);
fprintf('The kinetic energy of the avionics bay section is %4.2f ft*lbs\n', KEavST);
fprintf('The kinetic energy of the booster section is %4.2f ft*lbs\n', KEboostST);
```

```
The kinetic energy of the nosecone section is 41.50 ft*lbs
The kinetic energy of the avionics bay section is 45.73 ft*lbs
The kinetic energy of the booster section is 41.50 ft*lbs
```

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Appendix B: MSDS for Black Powder

GOEX
BLACK
POWDER
—THE TRADITION CONTINUES—

Goex Powder, Inc.

Material Safety Data Sheet

MSDS-BP (Potassium Nitrate)

Revised 3/17/09

PRODUCT INFORMATION	
Product Name	Black Powder
Trade Names and Synonyms	N/A
Manufacturer/Distributor	GOEX Powder, Inc.(DOYLINE, LA) & various international sources
Transportation Emergency	800-255-3924 (24 hrs – CHEM TEL)

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully transported, handled, stored, and used following proper safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulations, or ordinances. ALWAYS lock up explosive materials and keep away from children and unauthorized persons. If you have any questions or doubts as to how to use any explosive product, DO NOT USE IT before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

HAZARDOUS COMPONENTS

Material or Components	%	CAS NO.	TLV	PEL
Potassium nitrate	70-76	007757-79-1	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite[1]	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m^3

N/A = Not assigned NE = Not established

---

[1] Not contained in all grades of black powder.

PHYSICAL DATA	
Boiling Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Solubility in Water	Good
Specific Gravity	1.70 – 1.82 (mercury method) 1.92 – 2.08 (pycnometer)
PH	6.0 – 8.0
Evaporation Rate	N/A
Appearance and Odor	Black granular powder. No odor detectable.

HAZARDOUS REACTIVITY	
Instability	Keep away from heat, sparks, and open flames. Avoid impact, friction and static electricity.
Incompatibility	When dry, black powder is compatible with most metals; however, it is hygroscopic and when wet, attacks all common metals except stainless steel. Black powder must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials, and other similar materials, situations, and equipment.
Hazardous decomposition	Detonation produces hazardous overpressures and fragments (if confined). Gases produced may be toxic if exposed in areas with inadequate ventilation.
Polymerization	Polymerization will not occur.

FIRE AND EXPLOSION DATA	
Flashpoint	Not applicable
Auto Ignition Temperature	Approx. Range: 392°F-867°F / 200°C-464°C
Explosive temperature (5 sec)	Ignites @ approx. 427°C (801°F)
Extinguishing media	Water
Special fire fighting procedures	ALL EXPLOSIVES: DO NOT FIGHT EXPLOSIVES FIRES. Try to keep fire from reaching explosives. Isolate area. Guard against intruders. Division 1.1 Explosives (heavily encased): Evacuate the area for 5,000 feet (approximately 1 mile) if explosives are heavily encased. Division 1.1 Explosives (not heavily encased): Evacuate the area for 2,500 feet (approximately ½ mile) if explosives are not heavily encased. Division 1.1 Explosives (all): Consult U.S. DOT Emergency Response Guide 112 for further details.

Unusual fire and explosion hazards	Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

HEALTH HAZARDS	
General	Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulation and ordinances.
Carcinogenicity	None of the components of Black Powder are listed as a carcinogen by NTP, IARC, or OSHA.

FIRST AID	
Inhalation	Not a likely route of exposure. If inhaled, remove to fresh air. If not breathing give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention. Avoid when possible.
Eye and skin contact	Not a likely route of exposure. Flush eyes with water. Wash skin with soap and water.
Ingestion	Not a likely route of exposure. If ingested, dilute by giving two glasses of water and induce vomiting. Avoid when possible.
Injury from detonation	Seek prompt medical attention.

SPILL OR LEAK PROCEDURES	
Spill/leak response	Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in clean up procedures. Carefully pick up spills with non-sparking and non-static producing tools.
Waste disposal	Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with Federal Regulations under the authority of the Resource Conservation and Recovery Act (40 CFR Parts 260-271).

SPECIAL PROTECTION INFORMATION	
Ventilation	Use only with adequate ventilation. (If required)
Respiratory	None
Eye	None
Gloves	Impervious rubber gloves. (If required)
Other	Metal-free and/non-static producing clothes

SPECIAL PRECAUTIONS

- Keep away from friction, impact, and heat and open flame. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials.
- Contaminated equipment must be thoroughly water cleaned before attempting repairs.
- Use only non-spark producing tools.
- No smoking.

STORAGE CONDITIONS

Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

SHIPPING INFORMATION

Proper shipping name	Black Powder	
Hazard class	1.1D	
UN Number	UN0027	
DOT Label & Placard	DOT Label	EXPLOSIVES 1.1D
	DOT Placard	EXPLOSIVES 1.1
Alternate shipping	Limited quantities of GOEX black powder (1# cans only) may be transported as "Black powder for small arms – flammable solid" pursuant to U.S. Department of Transportation 49 CFR.	

The information contained in this Material Safety Data Sheet is based upon available data and believed to be correct; however, as such has been obtained from various sources, including the manufacturer, military and independent laboratories, it is given without warranty or representation that it is complete, accurate, and can be relied upon. GOEX, Incorporated, has not attempted to conceal in any manner the deleterious aspects of the product listed herein, but makes no warranty as to such. Further, GOEX, Incorporated, cannot anticipate nor control the many situations in which the product or this information may be used; there is no guarantee that the health and safety precautions suggested will be proper under all conditions. It is the sole responsibility of each user of the product to determine and comply with the requirements of all applicable laws and regulations regarding its use. This information is given solely for the purposes of safety to persons and property. Any other use of this information is expressly prohibited.

For further information contact:
GOEX Powder, Incorporated
P. O. Box 659
Doyline, LA 71023-0659
Telephone Number: (318) 382-9300
Fax Number: (318) 382-9303

SPECIAL PRECAUTIONS
• Keep away from friction, impact, and heat and open flame. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials. • Contaminated equipment must be thoroughly water cleaned before attempting repairs. • Use only non-spark producing tools. • No smoking.

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

SHIPPING INFORMATION		
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BLACK POWDER

FRICTION TEST
PA

Steel – Snaps
Fiber – Unaffected

IMPACT TEST
PA

16 Inches (10% Point)

ELECTROSTATIC DISCHARGE TEST

Bureau of Mines
0.8 Joules (Confined)
12.5 Joules Unconfined)

STABILITY

75° C International Heat Test – 0.31% Loss
Vacuum Stability – 0. 5cc @ 100° C

BRISANCE – Sand Test 8 gm.

VELOCITY

In the open, trains of black powder burn very slowly, measurable in seconds per foot. Confined, as in steel pipe, speeds of explosions have been timed at values from 560 feet per second for very coarse granulations to 2,070 feet per second for the finer granulations. Confinement and granulation will affect the values.

CHEMICAL DECOMPOSITION

Use water to dissolve the potassium nitrate. By leeching out the potassium nitrate, the residue of sulfur and charcoal is non-explosive but combustible when dry – dispose separately.

SPECIAL REQUIREMENTS:

Black Powder is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

When dry, it is compatible with most metals. However, it is hydroscopic and when wet, attacks all common metals except stainless steel.

CAUTION: Explosives must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials and other similar materials, situations and equipment. Explosives include propellants and pyrotechnics.

Appendix C: MSDS for Pyrodex

Section 1: Identification

Product Identifier: Pyrodex® (a pyrotechnic mixture in either granular or pellet form)

Manufacturer's Name: Hodgdon Powder Company, Inc.

Informational Telephone Number: 1-(913) 362-9455

Address:
6430 Vista Drive
Shawnee, Kansas 66218

Emerg. Phone Number: 1-(800) 255-3924 (Chem Tel)

Recommended Use: for use in muzzleloading reloading and shooting.

Section 2: Hazard(s) Identification

Hazard category:	Signal Word	Hazard statement	Pictogram
Division 1.3	Danger	Explosive, fire, blast or projection hazard	

Target Organ Warning: Above OSHA levels, chronic exposure can cause skin irritation and damage to the respiratory system, and acute exposure can cause skin, eye, and respiratory irritation.

Section 3: Composition/information on ingregients

Component	CAS-Number	Weight %
Charcoal	16291-96-6	8%
Sulfur	7704-34-9	8%
Potassium Nitrate	7757-79-1	30%
Potassium Perchlorate	7778-74-7	30%
Graphite	7782-42-5	<1%

Note: Other ingredients are trade secrets, but can be disclosed per 29CFR1910.1200(i)

Section 4: First-aid measures

Ingestion: * if vomiting occurs, turn patient on side to maintain open airway. Do not induce vomiting. contact a Poison control center for advice on treatment, if unsure.

Eye Contact: * flush eye with water for at least 15 minutes.

Inhalation; * remove patient from area to fresh air.

Skin Contact: * wash the affected area with copius amounts of water. Some persons may be sensitive to product.

Note to Physician: * Treat symptomatically.

Section 5: Fire-fighting measures

Extinguishing media: * For unattended fire prevention, water can be used to disburse burning Pyrodex®. Pyrodex® has its own oxygen supply; flame smothering techniques are ineffective. Water may be used on unburnt Pyrodex® to retard further spread of fire.

Special Procedures: * Pyrodex® is extremely flammable and may deflagrate. Get away and evacuate the area.

Unusual Hazards: * As with any pyrotechnic, if under confinement or piled in moderate quantities, Pyrodex® can explode. Toxic fumes, such as sulfur dioxide are emitted while burning.

Flash Point: not determined

Autoignition Temp: 740 degrees F for Granular; 500 degrees F for Pellets

NFPA Ratings: **Health=1** **Flammability=3** **Reactivity=1**

Advice and PPE for Firefighters:

* Fires involving Pyrodex® should not be fought unless extinguishing media can be applied from a well protected and distant location from the point of fire. Self-contained breathing apparatus (SCBA) and protective clothing must be worn. Wash all clothes prior to reuse.

Section 6: Accidental release measures

Personal precautions, protective equipment and emergency procedures:

* Non-flammable or flame retardant clothing should be worn when cleaning up spilled material. Material is sensitive to ignition from sources such as heat, flame, impact, friction or sparks. Therefore, non-sparking utensils should be used.

Environmental precautions:

* Clean up spills immediately using non-sparking utensils Do not dispose of in the ground.

* Spill residues may be disposed of per guidelines under Secrtion 13: Disposal Considerations.

Section 7: Handling and storage

* Avoid heat, impact, friction and static. Protect against heat effects. Keep away from heat, open flame and ignition sources.

* Absolutely no smoking around open powder or packages. Keep away from combustibles. Avoid electrostatic charges.

* Keep containers closed at all times when not being used. Keep out of reach of children. Open and handle container with care.

* Follow all local, state and federal laws when storing this product.

Section 8: Exposure controls/personal protection

Personal protection for routine use:

* Respiratory protection is not normally needed. If significant dusting occurs, a NIOSH approved dust mask should be worn. Good ventilation is recommended when working with Pyrodex®. Gloves may be worn to protect skin. Safety glasses with side shields are recommended for eye protection. Flame retardant outerwear such as coveralls or lab coat may be worn.

Health Hazards (Acute or chronic): * TLV is unknown for ingestion of dust. Acute oral LD^{50} in rats is calculated to be 4.0 [g/kg body weight].

Signs/Symptoms of Exposure: * Burning or itching of the eyes, nose or skin; shorteness of breath.

First Aid Procedures: * Remove the patient from exposure and if skin contact, wash the affected area with water

Section 9: Physical and chemical properties

Physical State:	Granular solid or pellet	**Soluability:**	Partial in water
Appearance:	Medium to dark grey	**Auto-ignition Temp.:**	740 deg. F (granular)/ 500deg. F (pellets)
Odor:	Slight odor when ignited	**Bulk Density:**	0.75 (g/cc)

Section 10: Stability and reactivity

General Information: * Loading data and the instructions for loading must be observed.

Conditions to Avoid: Avoid heat, impact, friction or static. Protect against heat effects. Keep away from heat, open flame and ignition sources. A violent burn or deflagration cound occur by above mentioned items.

Substances to Avoid: Avoid contact with alkaline substances or strong acids.

Section 11: Toxicological information

* LD_{50} Values-acute oral in rats is calculated to be 4.0 (g/kg body weight)

* TLV unown for ingestion of dust. Some persons may be unusually sensitive to the product.

* Routes of entry include Skin, Inhalation and Ingestion. (Acute Toxicity=Category 4) per Table A.1.1 of 29CFR1910.1200

Section 12: Ecological information

* Do not dispose of powder or residues into any water streams or bodies of water. Avoid spilling powders onto any soils. Clean up any spills promptly.

* No known adverse effects on marine or other aquatic organisms.

Section 13: Disposal considerations

* Care must be taken to prevent environmental contamination from the use of this material. The user has the responsibility to dispose of unused material, residues and containers in compliance with all relevant laws and regulations regarding treatment, storage and disposal for hazardous and non-hazardous waste. Powder can be burned in very small quantities and in very thin layer and must only be ignited from a safe distance.

* Do not dispose of powders down a drain or sewer.

Section 14: Transport information

Label required: Explosive

Highway:

Class or division: 1.3C or 4.1 Flam Solid-(if <100 pounds).
UN Number: UN0499
Shipping Name: Propellant, Solid

Air Transport: **Forbidden!**

Maritime IMDG

Class or division: 1.3C
UN Number: UN0499
Shipping Name: Propellant, Solid

Section 15: Regulatory information

* All products related to Pyrodex® are reported annually as per Community Right-to Know (Tier II). Pyrodex® granular and pellets have been approved by PHMSA and copies of the approvals are on file with Environmental, Health and Safety Manager.

Section 16: Other information

Prepared By: Mark Wendt, Environmental, Health and Safety Manager email: mwendt@hodgdon.com
SDS Creation Date: September 1, 2013
SDS Print Date: September 1, 2013

Disclaimer:

The information provided on this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guide for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered as a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other material or in any process, unless specified in the text.