LionTech Rocket Labs

USLI Critical Design Review Report 2016-2017

Project Odyssey

The Pennsylvania State University
46 Hammond Building State College, PA 16802
January 13, 2017

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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
RDPC	Recovery Descent Profile Calculator
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

List of Variables

C_d = Coefficient of Drag
D = Drag
V = Velocity
KE = Kinetic Energy
m = mass
M_t = total mass under parachute descent
M_m = mass of heaviest component descending under parachute
g = acceleration due to gravity on the surface of the Earth
T = Thrust
ρ = Air density (assumed 0.002378 slugs/ft^3)
A = Area of the rotor
V_{tip} = The velocity at the tip of the rotor
C_{lavg} = The average coefficient of lift
Ω = Rotation rate in rad/s
r = Radius
V_f = Forward velocity
V_{fnd} = Non-dimensional forward velocity

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Section 1: General Information

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

Alex Balcher NAR L2 Certification - alex.balcher@gmail.com
- #96148SR

NAR Sections: Pittsburgh Space Command (PSC) #473

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
Scott	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
Torre	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 **Gretha**	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.
Torre **Dan**	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.
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.
Kurt **Anthony** **Kartik**	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.

Section 2: Summary of CDR Report

1: Team Summary

Team – LionTech Rocket Labs
Address – 46 Hammond Building, University Park, PA 16802
Mentor – Alex Balcher – NAR L2 – #96148SR

2: Vehicle Summary

Size and mass

The current launch vehicle design will result in a launch vehicle with an overall length of 147 inches, and a total mass of 30.81 pounds without the motor and 38.69 pounds with the motor at launch. These values are smaller than expressed in previous reports due to the shrinking of several components, allowing for a reduction necessary airframe length. The outer diameter of the airframe will be 6.079" and will be constructed out of Blue Tube 2.0.

Motor choice

The motor selected for full scale is the Cesaroni L1350 motor. This motor provides the rocket with an apogee of 5231 ft and an off the rail velocity and stability of 75.8 ft/s and 2.65 calibers respectively.

Recovery system

The recovery system will utilize a dual-deployment landing system where the drogue will be deployed at apogee and the main will be deployed at 700ft above the ground. This landing system along with properly sized parachutes will allow the rocket to land within the kinetic energy limit of 75ft-lbs. The avionics bay consists of two independent altimeters with corresponding power supplies, switches, and charges one of which will be for redundancy. In order to not overwhelm the body of the rocket, one of the altimeters will set off the ejection charges 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 an 18" Classical Elliptical as the drogue parachute and a 72" Iris Ultra Standard as the main parachute.

Rail Size

The launch vehicle will use a 1515 rail. It is capable of launching on an 8-foot launch rail, however for safety and increased off the rail stability and velocity the rail length chosen is 12-feet

3: Payload Summary

Summary of the Payload Experiment

The two payloads LTRL is flying in this competition are FOPS, Fragile Object Protection System, and Kiwi, a gyrocopter.

FOPS uses a protection bay filled with non-Newtonian fluid, a solution of cornstarch and water, to protect the unknown fragile object from the forces of rocket flight. The object will be suspended in the fluid using flexible plastic, re-sealable bag connected to each end of the protection bay via elastic bands. The launch vehicle will also contain and launch an autonomous autogyro (Kiwi), which will guide itself to a predetermined location using an on-board GPS.

4: Milestone Review Flysheet

Milestone Review Flysheet

Institution	Pennsylvania State University	**Milestone**	CDR
Vehicle Properties		**Motor Properties**	
Total Length (in)	147	Motor Manufacturer	Cesaroni
Diameter (in)	6.079	Motor Designation	L1350
Gross Lift Off Weigh (lb)	38.69	Max/Average Thrust (lb)	Avg: 303.4
Airframe Material	Blue Tube 2.0	Total Impulse (lbf-s)	962
Fin Material	G10 FR4 Fiberglass	Mass Before/After Burn	2616g/1270g
Drag	0.628	Liftoff Thrust (lb)	340
Stability Analysis		**Ascent Analysis**	
Center of Pressure (in from nose)	115	Maximum Veloxity (ft/s)	675
Center of Gravity (in from nose)	91.75	Maximum Mach Number	0.61
Static Stability Margin	3.8	Maximum Acceleration (ft/s^2)	259
Static Stability Margin (off launch rail)	2.65	Target Apogee (From Simulations)	5231
Thrust-to-Weight Ratio	7.83	Stable Velocity (ft/s)	95
Rail Size and Length (in)	1.5/144	Distance to Stable Velocity (ft)	3.5
Rail Exit Velocity (ft/s)	75.8		
Recovery System Properties		**Recovery System Properties**	
Drogue Parachute		**Main Parachute**	
Manufacturer/Model	Fruity Chutes Elliptical	Manufacturer/Model	Fruity Chute Iris Ultra
Size	18" Diameter	Size	72" Diameter
Altitude at Deployment (ft)	5280	Altitude at Deployment (ft)	700
Velocity at Deployment (ft/s)	-	Velocity at Deployment (ft/s)	95
Terminal Velocity (ft/s)	95	Terminal Velocity (ft/s)	19.52
Recovery Harness Material	Kevlar	Recovery Harness Material	Kevlar
Harness Size/Thickness (in)	0.5	Harness Size/Thickness (in)	0.5
Recovery Harness Length (ft)	30	Recovery Harness Length (ft)	40
Harness/Airframe Interfaces	1/2" Steel Eye Bolt	Harness/Airframe Interfaces	1/2" Steel Eye Bolt

Kinetic Energy of	Forward Body	Aft Body	Section 3	Section 4	Kinetic Energy	Nose/Body Tube	Avionics Bay	Booster	KIWI

Each Section (Ft-lbs)	1651	2728		

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	StratoLogger CF
Redundancy Plan	Single level redundancy for drogue and main event
Pad Stay Time (Launch Configuration)	2 hours

of Each Section (Ft-lbs)	51.42	49.64	52.44	9.22

Recovery Electronics	
Rocket Locators (Make/Model)	Garmin Astro 320
Transmitting Frequencies	MURS (151.820 MHz - 154.600 MHz)
Pyrodex Mass Drogue Chute (grams)	5
Pyrodex Mass Main Chute (grams)	4

Section 3: Changes Made Since PDR

1: Vehicle Design

Upon the transition from sub-scale to full-scale, several changes were made to the structure of the rocket to boost stability and flight performance as well as contribute to structural integrity sufficient for vehicle criteria. For example, fin shape was altered and fin brackets were designed to best reduce the effects of fin flutter. Other changes were made to internal components such as increasing the size of couplers to reduce the risk of failure at section interfaces. These changes are elaborated upon in the upcoming design sections.

2: Recovery System

General:

The main changes since PDR are the sizes of the parachutes and the design of the avionics board. The avionics board is now more compact and LTRL has confirmed the ability to successfully 3-D print boards. The design of the board is included later in this report and parachute sizing is also covered in depth.

Parachute Sizing:

A more thorough look was taken at parachute sizing. The coefficients of drag used in the model to predict the subscale flight recovery were found by doing simple drop test experiments with the parachutes. However, these numbers proved to be inaccurate, as shown by the comparison between the predicted descent profile and the actual descent profile of the subscale launch. The parachute sizes are now smaller and will drift less.

Avionics Board:

Since PDR, the design for the avionics board has been finalized. The final design for the avionics board will consist of a 3-D printed board in a new configuration in order to account for design concerns addressed in PDR. The new configuration is a triangular structure with three all-thread rods in which the altimeters will rest on the top of a horizontal platform, while the batteries lie underneath this platform. This configuration was decided upon in order to add additional strength to the avionics coupler as a whole, by using three all-thread rods, as well as to hold all components of the avionics board more securely. In addition, the plane that batteries are in is now horizontal which eliminates the safety concern of the battery terminal being removed. Specifically, this configuration will eliminate the concerns that launch and deployment event forces can dislodge the battery terminals from the electrical harness.

3: Payloads

The method of loading FOPS has been changed from inserting the specimen into a chamber filled with dilatant to inserting the specimen into an empty chamber and then allowing an on-board reservoir to fill the chamber. The second payload will be a gyrocopter instead of a coaxial helicopter. The details of the new design can be found later in the report. Additional safety features are included in the gyrocopter that were not included in the coaxial helicopter.

4: Project Plan

The project plan has been updated to more accurately reflect the plans for the second half of the project. In addition, the plan now has a greater level of detail compared to PDR. The timeline now includes meeting times, as well as timelines for each subsystem rather than a broad timeline for the entire project. The system level timelines provide more detail and better represent the actual activities of the club. Furthermore, a Google Calendar was created for the club. The calendar is accessible by all leads and allows them to record what was accomplished in each meeting and plan what needs to be completed in future meetings. This will allow better record keeping and for easier access to information pertaining to what each subsystem has done and when.

Section 4: Design and Verification of the Launch Vehicle

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

2: Final Design Decisions

Motor Selection

The motor selected for full scale is the Cesaroni L1350 motor. This motor was chosen because it offers the closest apogee to the target apogee amongst the three candidate motors. Furthermore, 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.

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 619 oz and has a thrust to weight ratio of approximately 7.83.

The L1350 motor achieves a 5231 ft apogee and an off the rod velocity of 75.8 ft/s 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. Motor testing is discussed in more detail in section 7.1. The manufacturer's thrust curve, as shown in Figure 1, displays a thrust curve without any extreme peaks and maintains close to the average thrust of approximately 303 lbs. 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.

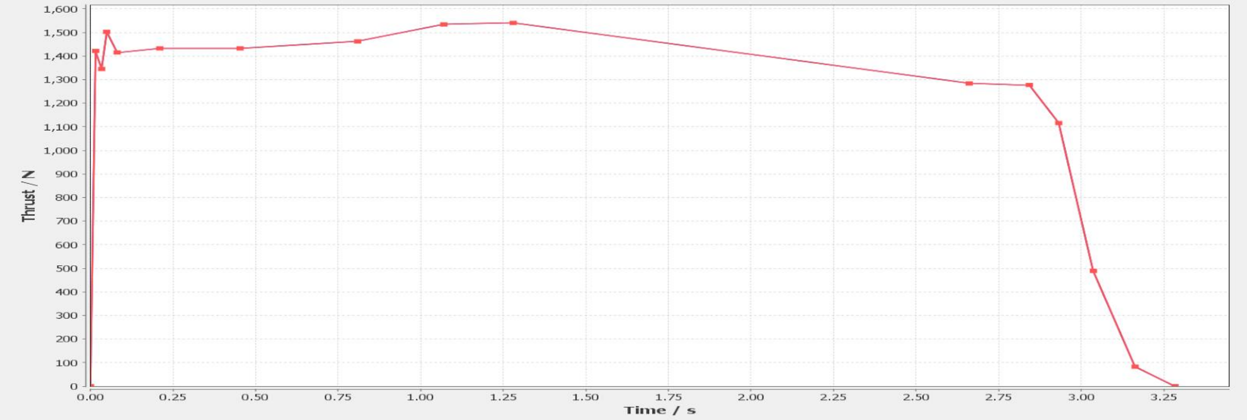


Figure 1: Thrust Curve for the Cesaroni L1350 motor

Nosecone

For the final design of the launch vehicle, the nosecone material was chosen to be fiberglass. This is due to the fact that in comparison to plastic, fiberglass has superior durability necessary to withstand both predicted and unforeseen forces that could act on the nosecone. This superior durability and strength makes fiberglass the superior option, even taking into account the increased cost and weight of the component. In addition, the nosecone tip was chosen to consist of a separate aluminum component over an integrated fiberglass tip. An aluminum tip has superior ductility and structural stiffness in comparison to a fiberglass counterpart. In addition, a separate aluminum component would allow to easy replacement of the component should it experience any structural or aerodynamic imperfections, instead of having to replace the entire nosecone. The profile of the nosecone was chosen to be the Von Karman shape over an ogive profile. This is due to the Von Karman's mathematical formulation to have a lower overall drag coefficient than an Ogive profile [1]. Because of this, the launch vehicle has increased aerodynamic performance. The only drawback to the Von Karman profile is its greater overall length in comparison, necessitating an increase in length and thus weight of the nosecone component, but this consideration is well worth the decrease in drag coefficient.

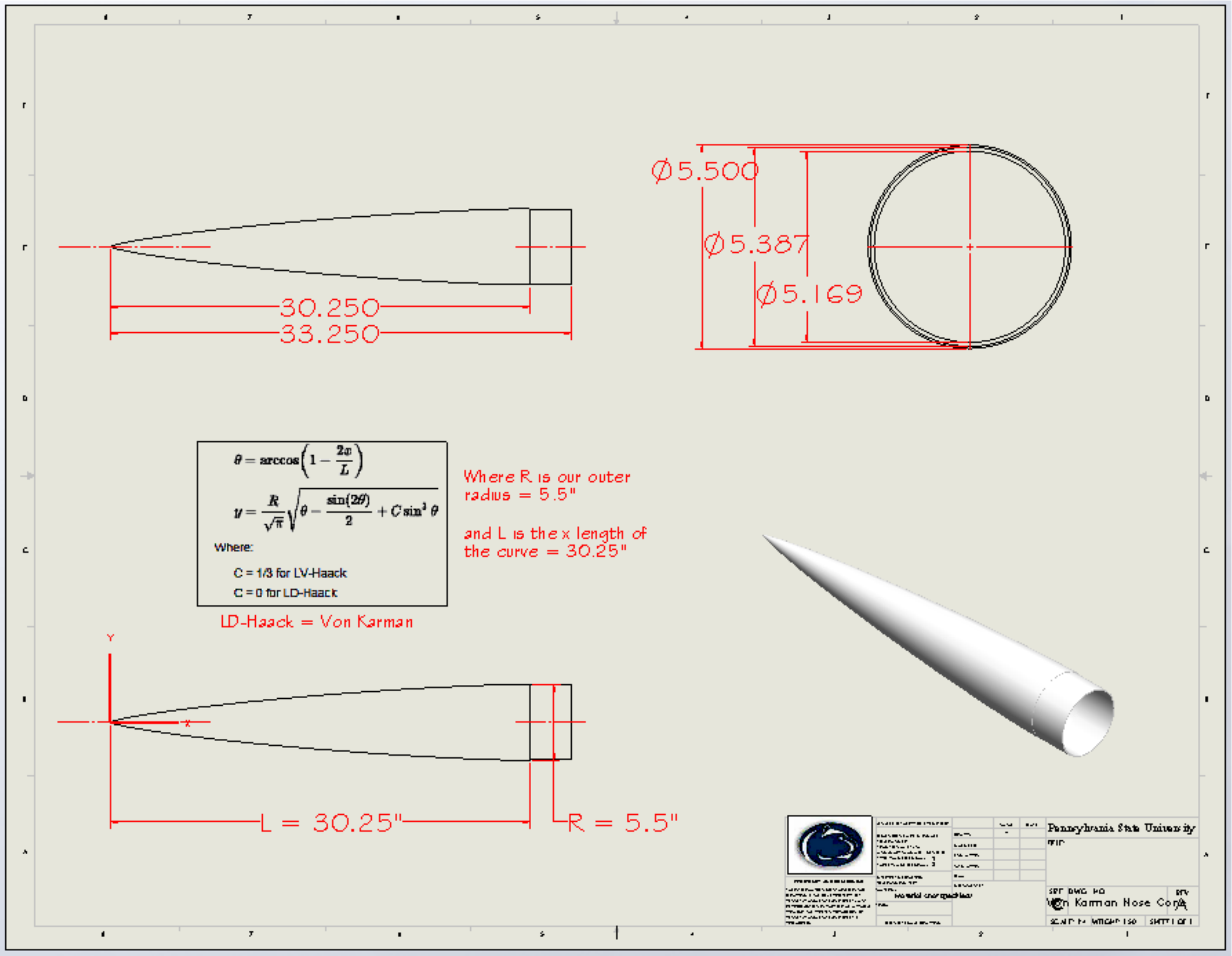


Figure 2: Von Karman Nose Cone Engineering Drawing

The dimensioned drawing of the nosecone is shown in Figure 2. The overall specifications for nosecone are as follows:

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

Transitions and Acrylic

The final material choice for both the nosecone to acrylic transition, and the acrylic to main body tube transition, will be a 3D-printed PLA thermoplastic. No viable superior material option to PLA thermoplastic was found for printing the components using the techniques of additive manufacturing, or 3D-Printing. This was primarily due to the ease of manufacturing PLA thermoplastic parts and the readily available resources for 3d-printing using PLA thermoplastic. Experiences using PLA thermoplastic for components in the past year has resulted in adequate durability and strength, given expected loads during flight and recovery.

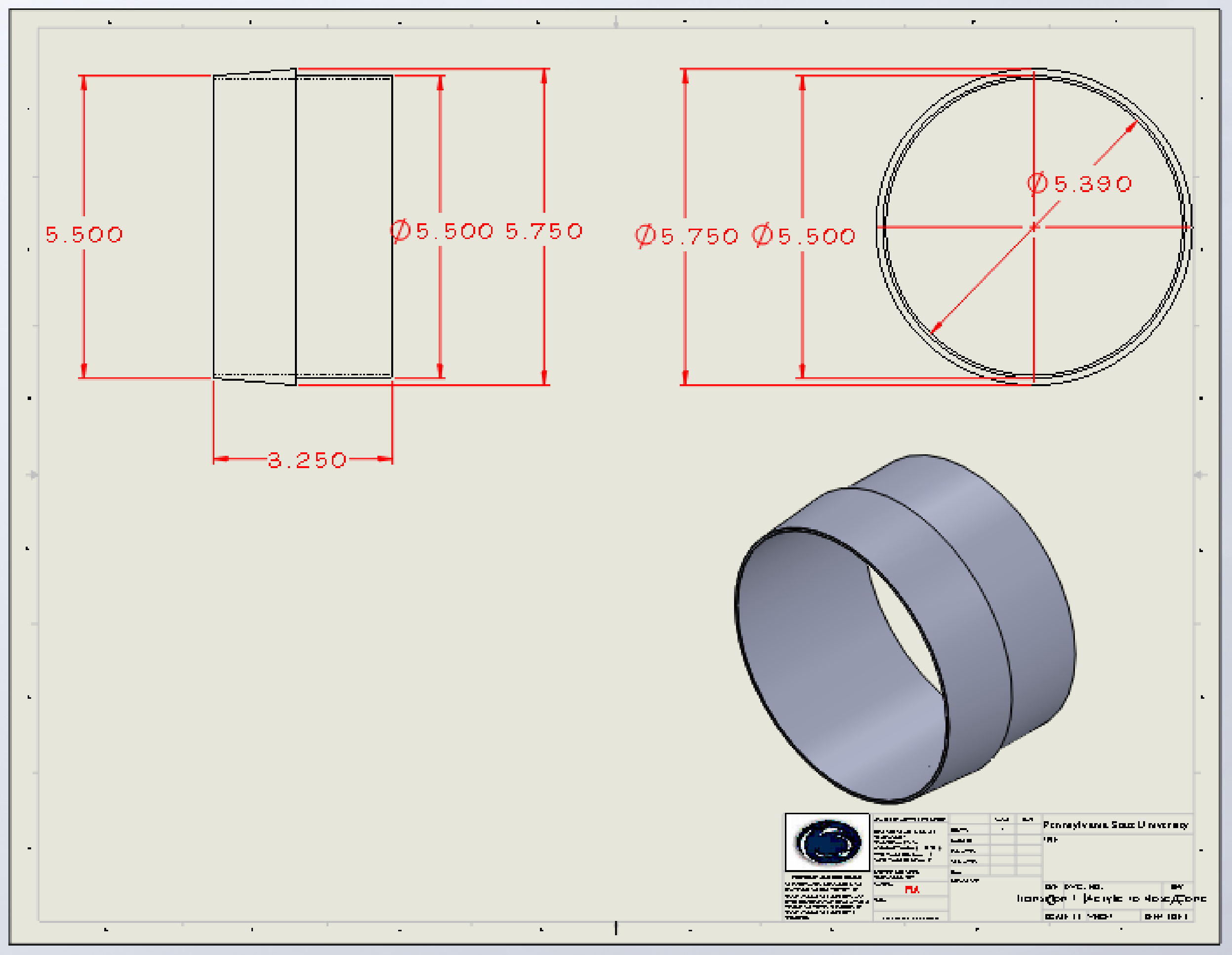


Figure 3: Dimensioned Drawing of the Nose Cone to Acrylic Transition

The forward transition is shown and dimensioned in Figure 3. The specifications for this transition are as follows:

- 1.5-inch exposed length
- 1.75-inch shoulder length
- 5.5-inch forward diameter and 5.75-inch max diameter
- 1.49 ounces

The acrylic section of the vehicle contains the FOPS payload assembly. It also contains the transition stabilizing coupler made from blue tube 2.0. Refer to Figure 25 in the FOPS payload description for renderings of the acrylic section. The specification for the acrylic section is as follows:

- 12-inch length
- 5.75-inch outer diameter

- 65.9 ounces

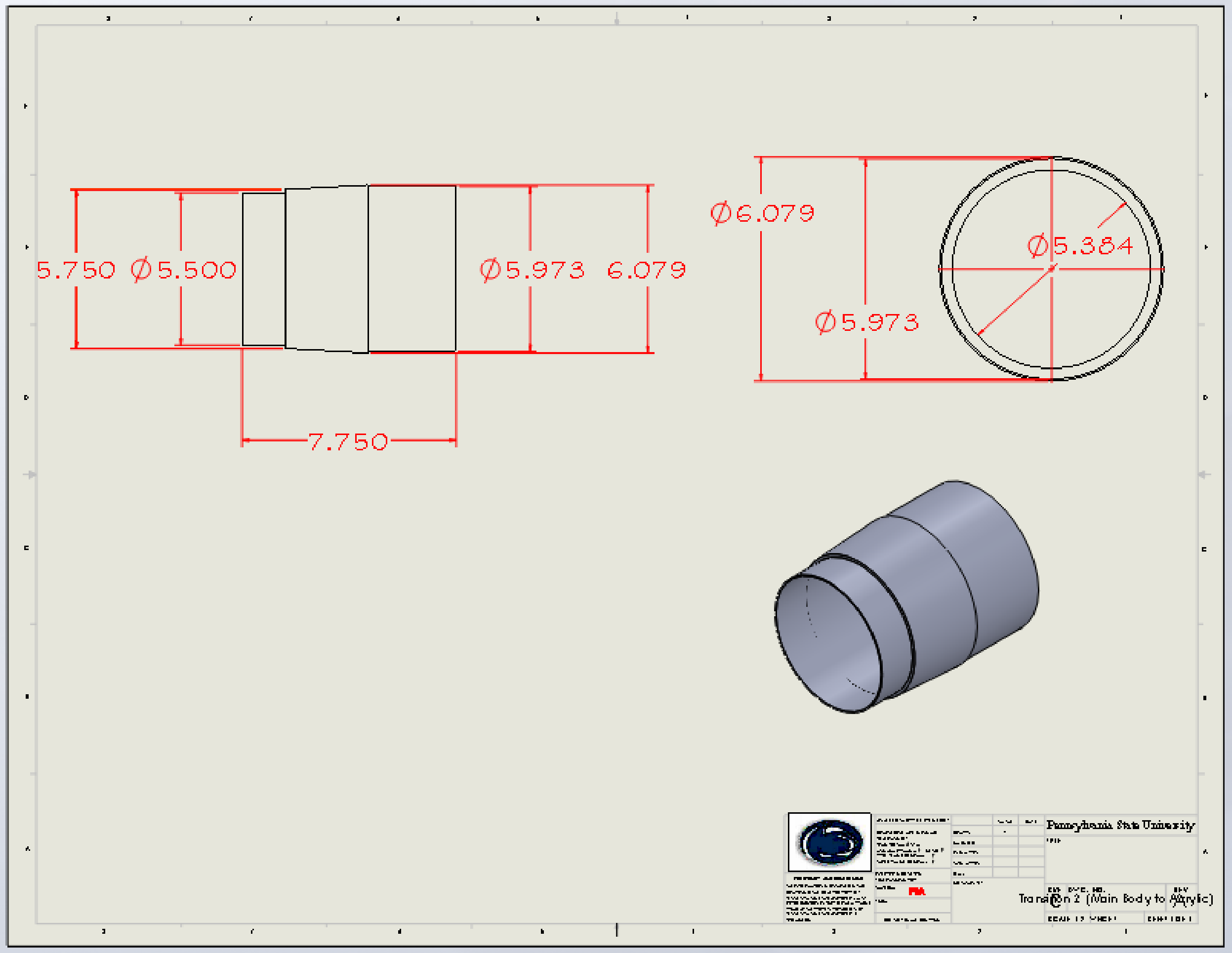


Figure 4: Dimensioned Drawing of the Acrylic to Main Body Tube Transition

The acrylic to main body tube transition is shown in Figure 4. This section will compose of a 3D-printed PLA thermoplastic section. PLA thermoplastic will be used for the same reasons as given in the previous 'Nosecone to Acrylic transition' section. The specifications for this transition are as follows:

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

Airframe

The airframe for the launch vehicle will be constructed from Blue Tube 2.0. This option was primarily chosen over fiberglass due to results of a selection matrix constructed during the preliminary design phase. The selection matrix 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

Due to the performance with the given metrics and weightings, Blue tube 2.0 can be surmised to be the overall superior option when choosing a material for the airframe of the launch vehicle, especially in the metrics of price and handling, which includes the level of safety achievable for cutting and sanding the material.

In addition to the aforementioned selection matrix, material testing on Blue Tube 2.0 Airframe will take place in order to determine its tensile strength. This test methodology has been previously used in an experiment on a tubing section of G12 Fiberglass, and results were obtained as to the tensile yield force and corresponding yield stress of the airframe specimen. Similar testing will be performed on a specimen of Blue Tube 2.0 with an outer diameter of 6.079 inches. Specifications for the previous Fiberglass test can be found below in section 3.4.1.

The main separation point of the airframe will be between the main body tube and acrylic airframe section with shear pins between those points. Screws will be inserted through the airframe and into the Avionics bay section to secure the two sections together.

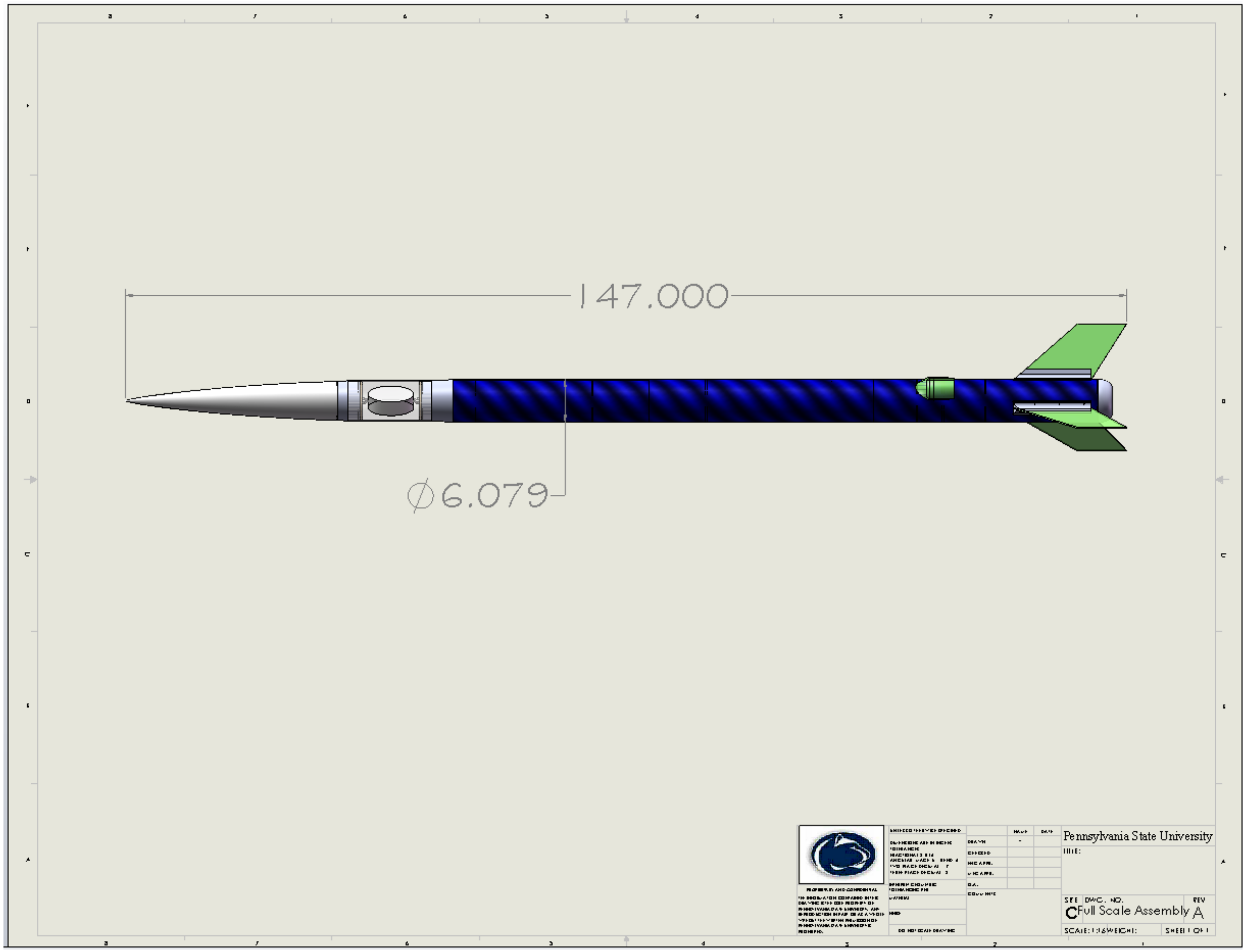


Figure 5: Dimensioned Drawing of the full-scale Vehicle Assembly

The full launch vehicle assembly is shown in Figure 5. The airframe aft of the acrylic to body transition is split into several parts, the forward section, avionics bay, drogue section, drogue to booster coupler, and the booster section.

The specifications for these sections are as follows:

Forward Airframe Section

- 28-inch length
- 6.079-inch outer diameter
- 59.7 ounces

Avionics Bay Coupler

- 4-inch length
- 6.079-inch outer diameter
- 66.5 ounces (mass includes all internal components)

Drogue Airframe Section

- 32-inch length
- 6.079-inch outer diameter
- 81.5 ounces

Drogue to Booster Coupler

- 12-inch length
- 5.973-inch outer diameter
- 11.7oz

Booster Section

- 32-inch length
- 6.079-inch outer diameter
- 135 ounces

Bulkheads and Centering Rings:

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.

Camera cover:

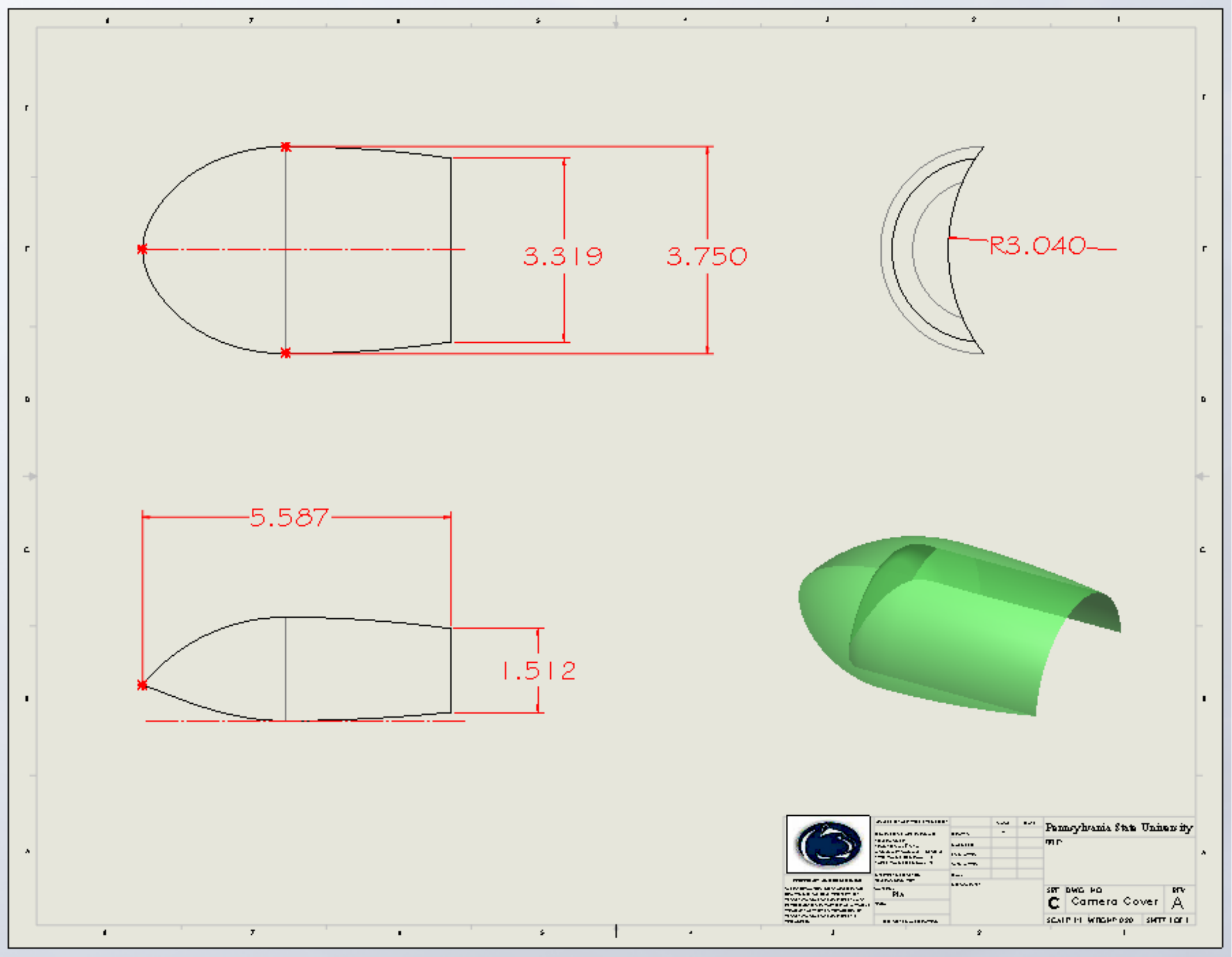


Figure 6: Dimensional Drawing of the Down-Body-Camera Cover

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. A dimensional drawing of the camera cover is shown in Figure 6.

Fin brackets:

The fin brackets will be 3D printed and one is shown in Figure 7.

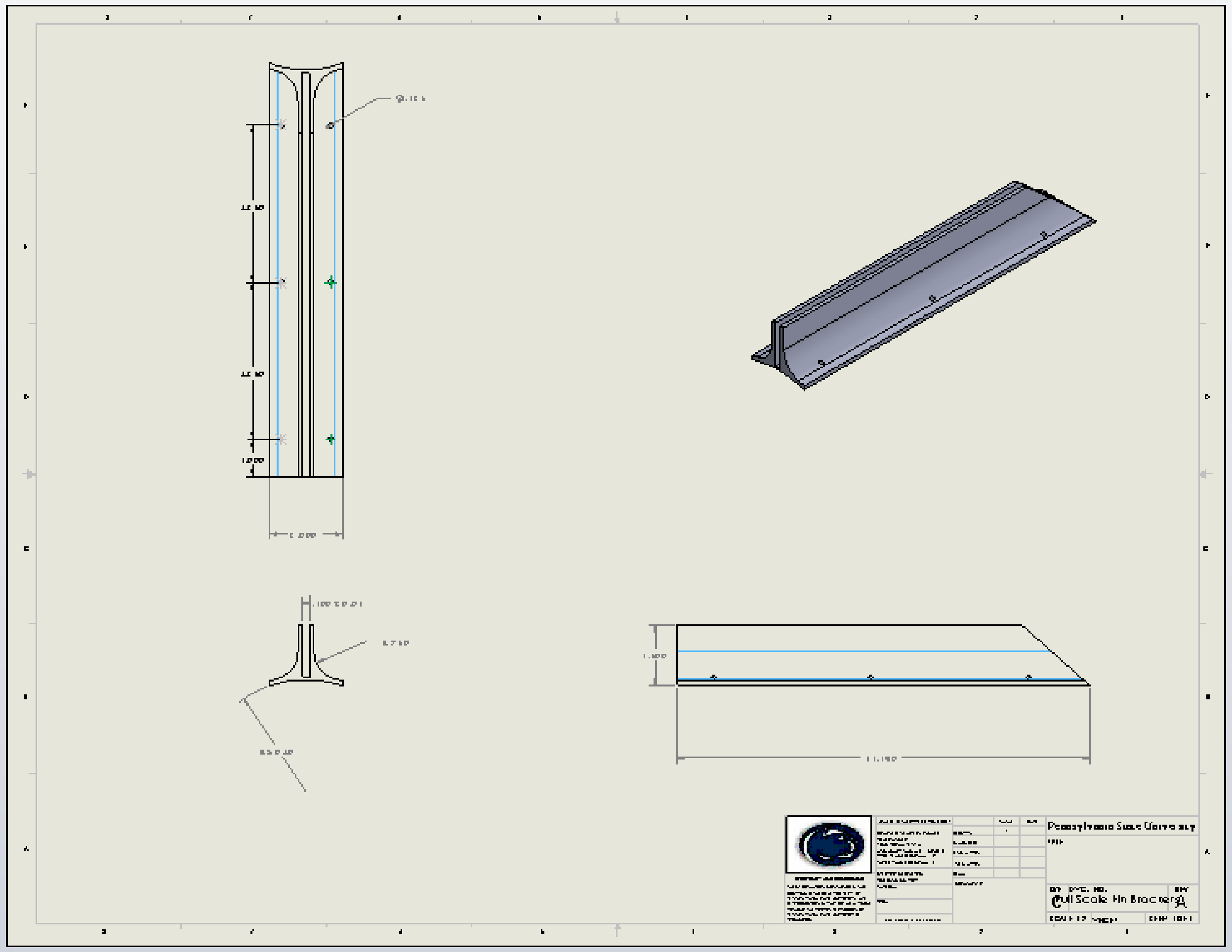


Figure 7: Dimensioned diagram of a Fin Bracket

Fins:

Refer to Figure 8 for a dimensioned drawing of the fins. The specifications are as following:

- 3/16” thick
- Fiberglass Construction
- 3 fins

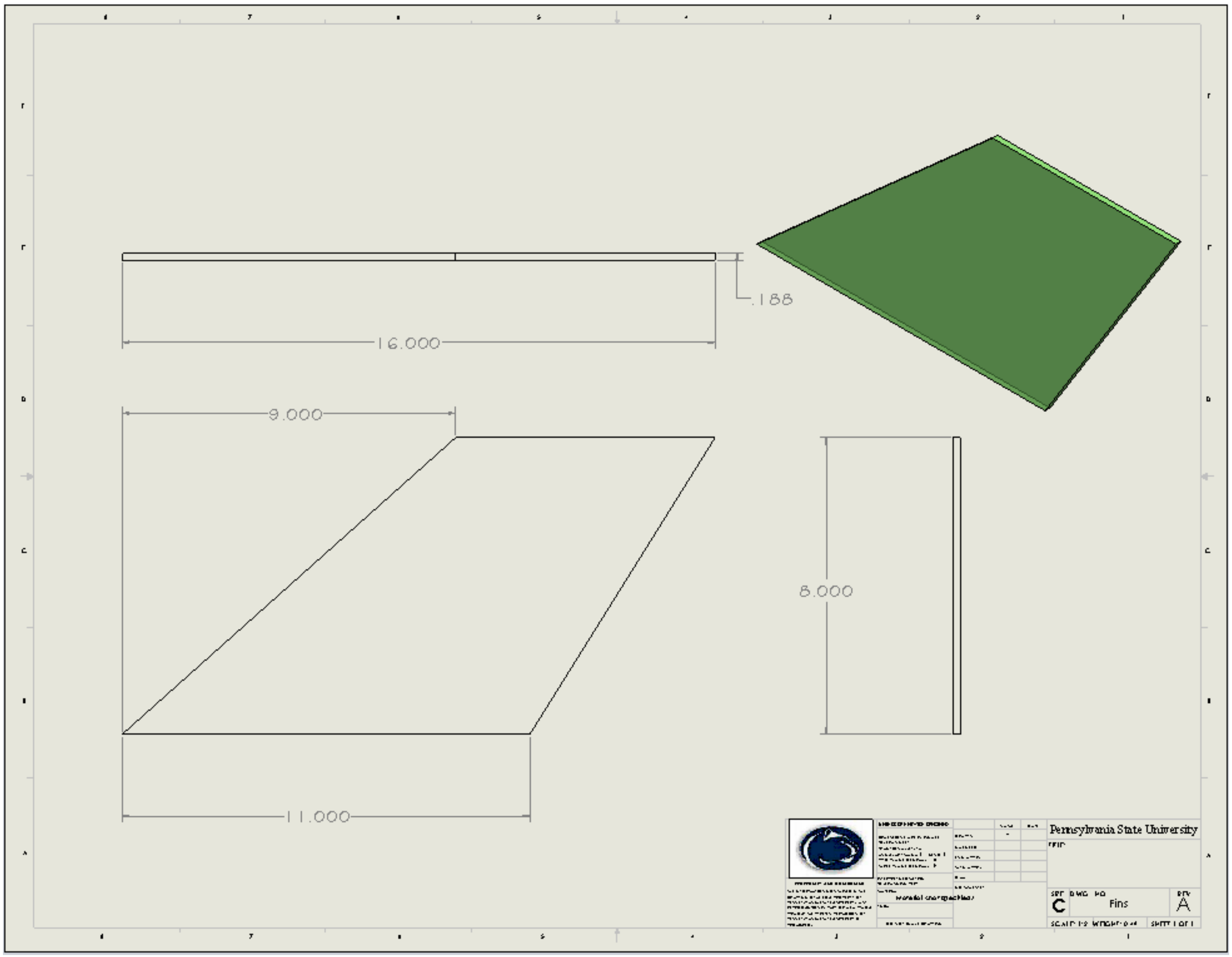


Figure 8: Dimensioned drawing of a Fin

Tail cone:

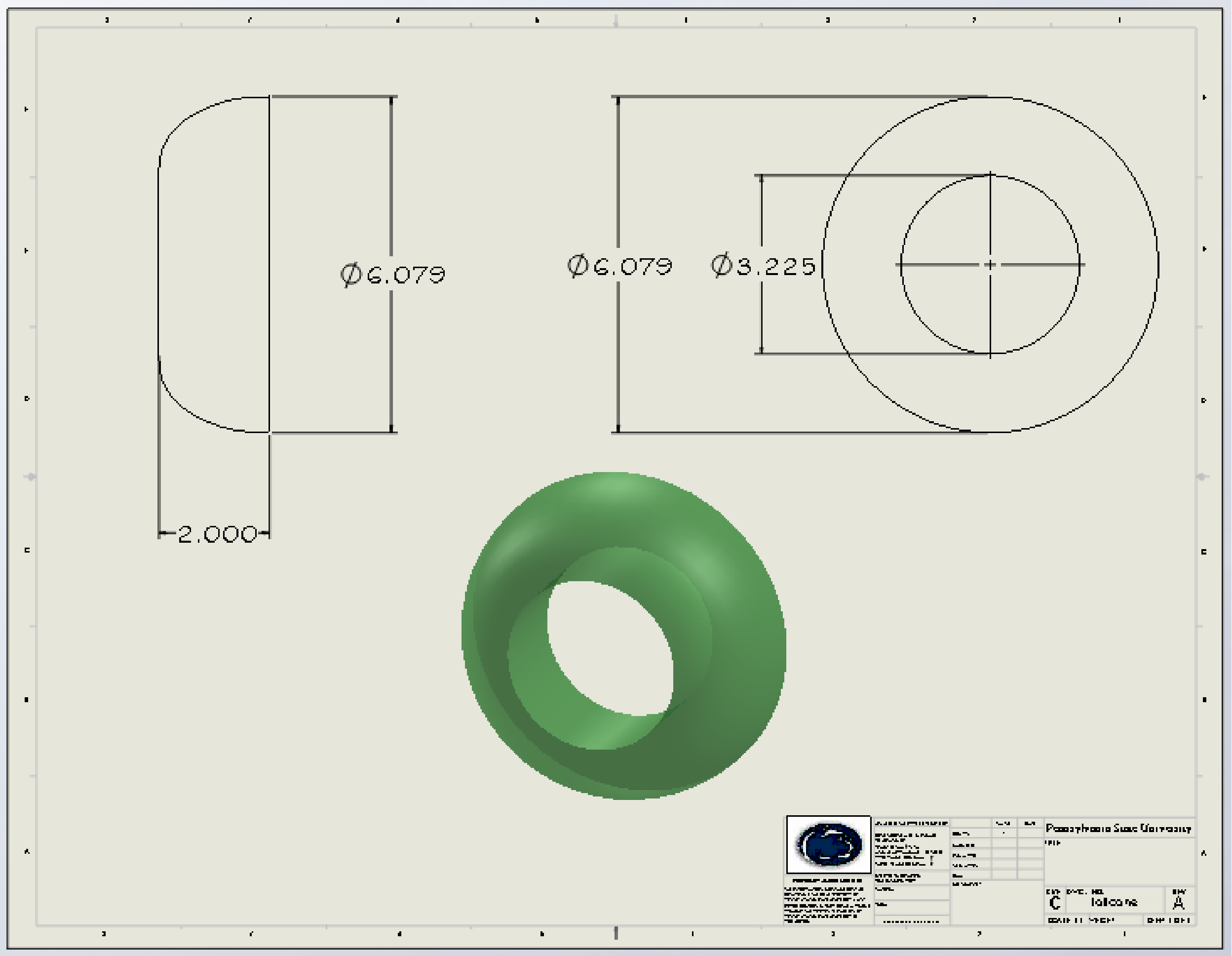
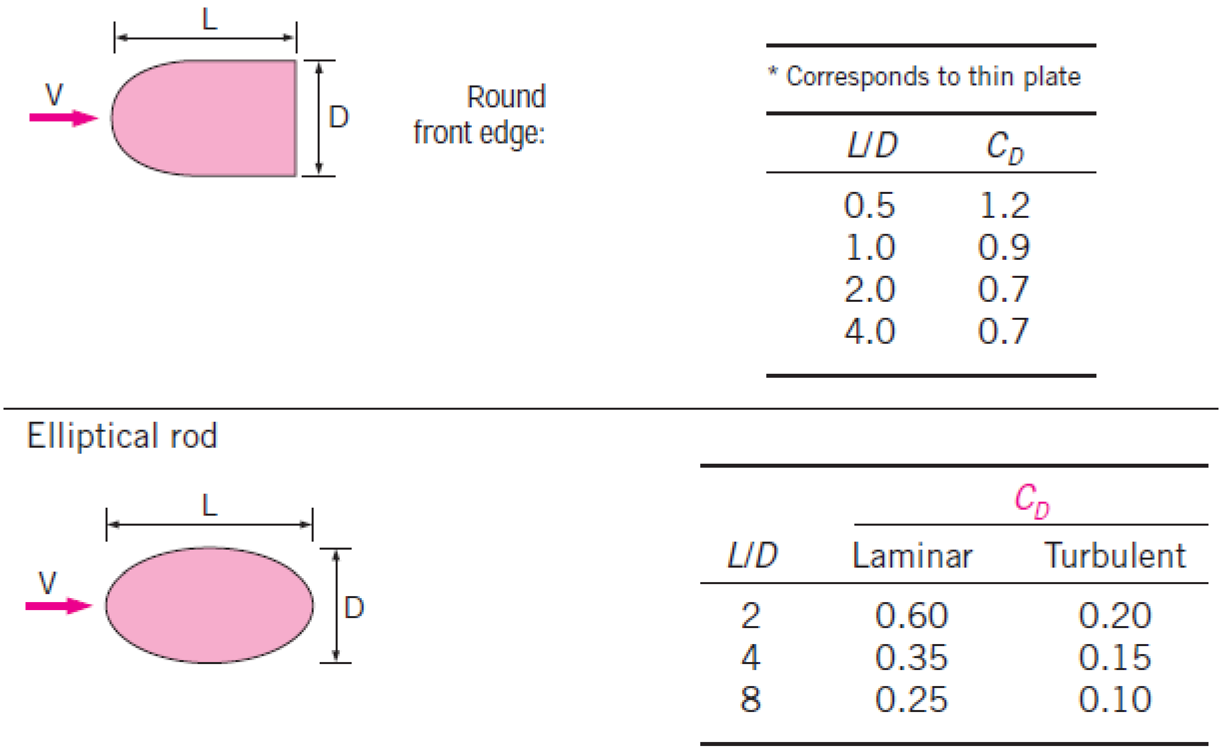


Figure 9: Dimensioned Drawing of the Tail Cone

Figure 9 is a dimensioned drawing of the tail cone. The tail cone is attached to the motor retainer and gives improved motor retention, and aerodynamics for the launch vehicle.



Round front edge:

* Corresponds to thin plate

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

Elliptical rod

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

Figure 10: Comparison of Geometries and Comparable Drag Coefficients

A comparison of the fluid flow behind different geometries can be found in Figure 10. Without a tail cone the launch vehicle is better represented by the rounded leading edge flat plate. With the tail cone adding a rounded taper to the aft of the vehicle, the vehicles geometry becomes closer to that of the elliptical rod. The elliptical rod has a 50% lower drag coefficient than the rounded flat plate at a reference L/D of 4. Modeling both geometries gives similar results to those shown in Figure 10, with a much lower coefficient of drag with a rounded trailing edge.

System level design review

Table 4: System Level Requirement Verification

	Verification	Verification	Status
1.4	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Materials and construction methods used by the club will allow for the repeated use of the vehicle. Full-scale test flights of the launch vehicle will be completed.	Full-scale design of the launch vehicle has been completed, construction of the launch vehicle will begin in the coming days.
1.5	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The flight vehicle's design will consist of four sections in total. Three attached sections will consist of a forward payload section, a drogue parachute section, a booster section. Kiwi will also serve as an independent section.	The Design of the launch vehicle has been completed.
1.6	The launch vehicle shall be limited to a single stage.	The vehicle contains a single stage three grain motor.	Simulation using OpenRocket has been completed, including only one stage of thrust.
1.7	The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	Vehicle is easily assembled and disassembled by using screws and couplers to fit each section together, as well as attaching necessary payloads to the airframe.	The launch vehicle design has been finalized, and includes procedures to allow for efficient assembly of the launch vehicle.
1.14	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	The launch vehicle has a stability margin of 2.65 when exiting a 12 foot rail.	Simulation using OpenRocket has been completed, resulting in an acceptable rail exit stability.
1.15	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The launch vehicle will have a velocity of 75.8 when exiting a 12-foot rail.	Simulation using OpenRocket has been completed, resulting in an acceptable rail exit velocity.

Suitability of shape and fin style for mission

The fin shape for the launch vehicle is suited for the loads expected during the duration of the mission. The launch vehicle will feature tapered swept fins that are 3/16 of an inch in thickness. The design of the fins would allow for reduced fin flutter over other fin designs. The fins will protrude only 7.1 inches beyond the main airframe, and the thickness of the fins has been increased to 3/16 of an inch from ⅛ of an inch in the preliminary design. These factors, in addition to the fin brackets extending along the entire length of the fins, the fin flutter potential should be greatly reduced. The New England Rocketry Association has developed an algorithm using Microsoft Excel to calculate fin flutter velocity. Figure 11 and Table 5 below show this methodology and the corresponding equations used.

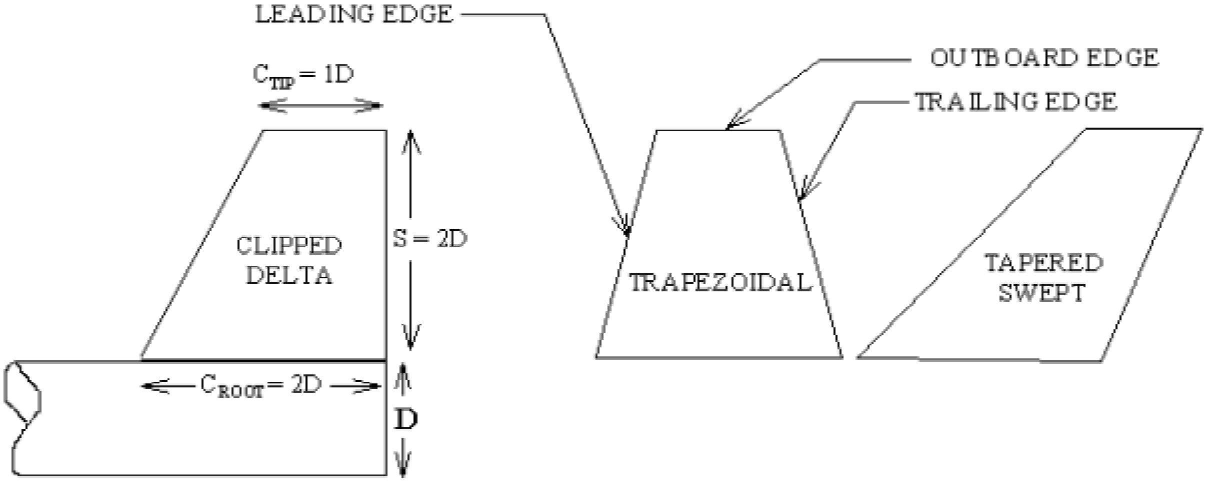


Figure 11: Fin Planform Dimension References

Table 5: Fin Flutter Speed Calculations and Relevant Equations

This program calculates the fin flutter velocity. It must be greater than				
the maximum rocket velocity. If not, the fins are liable to come off!				
Enter parameters: b,C,c,t,h – in Column C by replacing placeholder values				
Notes:				
*Correct units are given in Column D				
*Shear Modulus of fiberglass = 425,000 psi				
* The Altitude of Max Velocity, h, can be obtained from a plot in RockSim of				
altitude vs. velocity				
Shear Mod	**G=**	425,000	psi	
Fin span	**b=**	8.0000	in	

Root chord	**C=**	11.0000	in	
Tip chord	**c=**	7.0000	in	
Fin thickness t =	**t=**	0.1875	in	
Alt of Max V	**h=**	3375	ft	
Computations				
*************************				
S=0.5*(C+c)*b	S=	72.0000		
AR = ((b)^2)/S	AR=	0.8889		
r = c/C	r =	0.6364		
T=59-0.00356*h	T=	46.9850		
P(pressure)	P=	13.0051		
Sound speed a=		1103.8114	feet/sec	
Denom1 [= (1.337)*((AR)^3)*(P)*(1 + r)]		19.9825		
Denom2 [= 2*(2+AR)*(t/C)^3)]		0.00002861		
*************************				
Sound Speed*SQRT(G/(Denom1/Denom2))				
Fin Flutter Velocity Vf =	**Vf =**		**861.1**	**ft/sec**
Max Rocket Velocity MRV =	**MRV=**		674	**ft/sec**
Fin Flutter Velocity Vf > MRV Maximum Rocket Velocity				

Proper use of materials in fins, bulkheads, and structural elements

The materials used to construct the launch vehicle are appropriate in order to allow for mission success. The main airframe sections, as well as coupler components, will be constructed from Blue Tube 2.0, which will be able to provide ample structure to the launch vehicle and its enclosed components. The Acrylic airframe section will have a ⅛ inch wall thickness, which will give proper structure to the fore portion of the airframe and protect the FOPS payload. The airframe transition components as well as the fin brackets will be created from 3D-printed PLA, which through use on previous launch vehicles will be able to provide adequate resistance to expected forces throughout the duration of the flight. Both internal and external bulkheads will be constructed of birch plywood, and will provide capacious support when mounted to the airframe and coupler components. Finally, the chosen fin material is G10 Fiberglass sheet which will be 3/16 inches thick, which should provide sufficient structural integrity.

Verification of sufficient motor mounting and retention

The motor mounting for the launch vehicle will be provided by a motor retainer and 3 centering rings spaced along the motor retainer for support. The motor retainer will be constructed out of Blue Tube 2.0, while the centering rings will be constructed out of birch plywood. There is not a motor retention block present in the final design since there will be a bulkhead placed in the aft portion of the camera section, which will be placed just fore of the motor retainer. This bulkhead will perform adequately in the role of a motor retention block in place of a dedicated motor retention block.

Mass Estimates

Table 6 contains a list of mass estimations for everything making up the fully assembled launch vehicle.

Table 6: Mass Estimates of Launch Vehicle by Subsystem

Part	Mass (ounces)	# of items	sub-total mass
Structures			
Nosecone with aluminum tip	40	1	40
Acrylic	18.2	1	18.2
Body tube, main	24.3	1	24.3
Body tube, drogue	27.7	1	27.7
Booster body tube	27.7	1	27.7
Bulkhead, inner transition	2.04	1	2.04
Bulkhead, inner	3.33	3	9.99
Bulkhead, outer	3.28	3	9.84
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	11.7	1	11.7
AV bay body tube	3.46	1	3.46
AV Bay coupler	16.4	1	16.4
Motor Inner tube	10.8	1	10.8
Centering ring	1.81	3	5.43
Fin set	43.3	1	43.3
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)	55	-	55
Hardware	12	-	12
Payload			
Helicopter Payload	19	1	19
FOPS	40	1	40
Avionics & Recovery			
Drogue Parachute	7.72	1	7.72
Shock cord, drogue	12	1	12
Avionics Bay	28	1	28
Shock cord main	16	1	16
Main parachute with blanket	19.4	1	19.4
GPS	6	1	6
Total (ounces)	-		493
Total (pounds)	-		30.81

3: Subscale Flight Results

The subscale launch vehicle was tested on November 13th at the NAR certified Pittsburg Space Command club field in Grove City PA. The temperature on that day was a high of 54 degrees and low to intermediate erratic winds. Figure 12 shows the results of a simulation with these conditions that yielded a similar flight profile to the actual flight data shown in Figure 13.

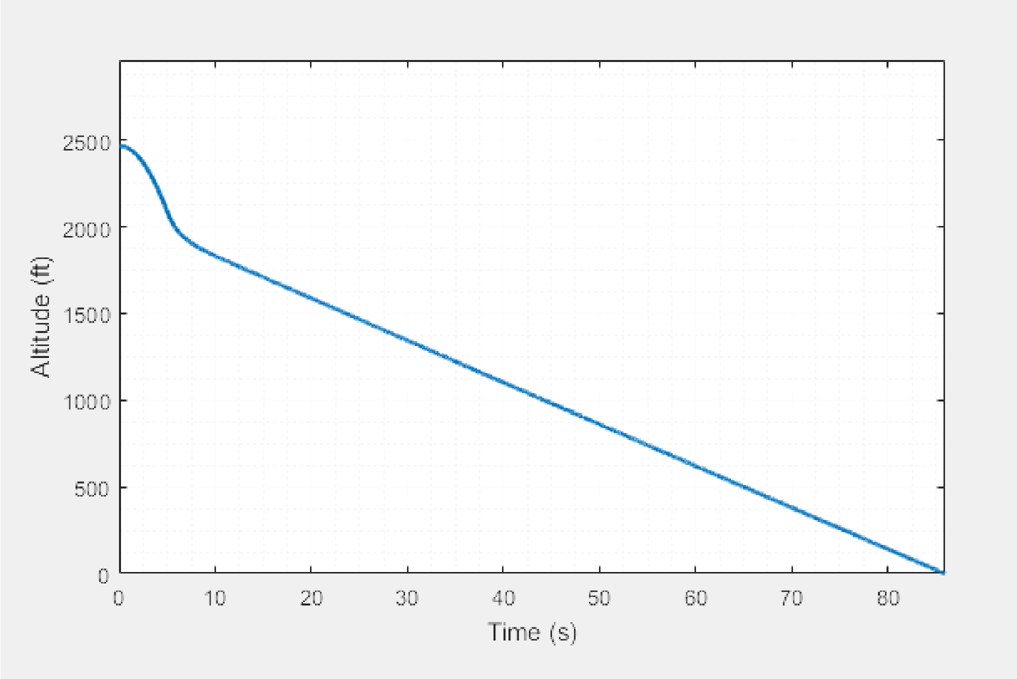


Figure 12: Altitude results from subscale simulation

Avionics Results

A StratoLogger 100 model commercial altimeter was included in the avionics bay of the subscale for deployment of the parachutes and for recording the flight profile. The altimeter recorded a flight apogee of 2467 ft. A couple seconds after apogee the drogue deployed. The momentum from the drogue deployment also deployed the main parachute. This was attributed to using an insufficient number of shear pins on the main parachute coupler. Figure 13 shows the flight profile of the rocket during descent.

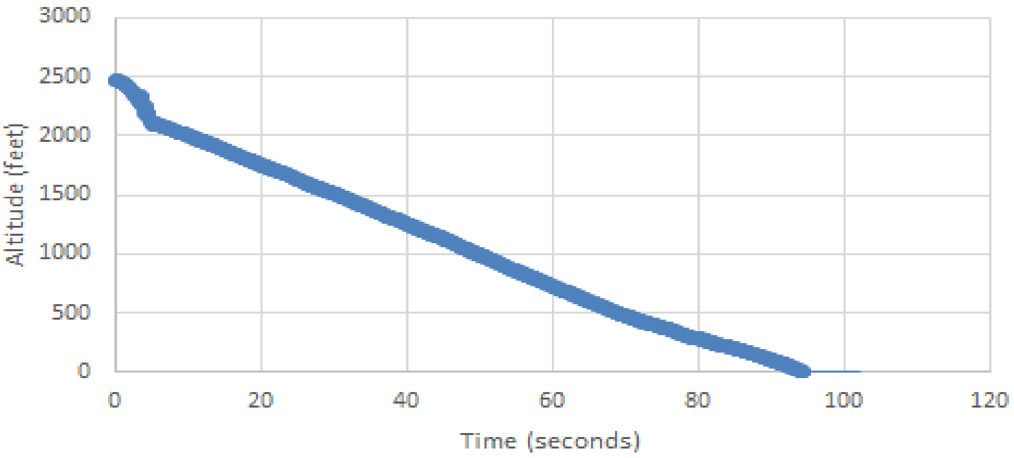


Figure 13: Flight Profile of the subscale during descent

The observed descent time was 95 seconds while the predicted descent time was around 85 seconds. The difference in these times may be accounted for by taking a closer look at the coefficient of drag of the parachutes. It is likely that the parachutes coefficients of drag were higher in reality than those used in the model.

The coefficient of drag used in the simulation for the drogue was 0.88. The coefficient of drag for the main used in the simulation was 1.5. These were found by dropping objects with known masses with these parachutes from a known height and observing the descent time. This method of collection for the coefficients of drag lends to some inaccuracies. Therefore, for the full scale, coefficients of drag will be determined by the manufacturer data or more careful experimentation.

The issue of unintentional main deployment at apogee will be resolved by using more shear pins and conducting more thorough ground testing.

Propulsion Results

Using OpenRocket, the coefficient of drag was predicted to be 0.628 for both the subscale and full scale rocket. The predicted apogee of subscale was 2969 ft, and the flight apogee was 2467 ft. There are several possible reasons for such a large discrepancy in the apogee such as winds and last minute changes to the rocket. Due to this discrepancy it is unclear if the OpenRocket coefficient of drag prediction is accurate or if any other prediction method would yield accurate results without being able to account for more variables. Section 7.1 discusses another method to experimentally determine the coefficient of drag.

Payload Results

FOPS did not adequately protect the fragile object during the subscale launch. The design will compensate for this failure by adjusting the shape of the plastic bag used so that the shape of the bag fits better inside the protection chamber, minimizing additional stress caused by the bag. An on-board reservoir will be used to fill the chamber after the insertion of the object(s).

Scaling Factors and Decisions

When scaling the sub-scale up to full-scale, our scaling factors were determined based upon manufactured blue tube and acrylic materials. The only variable held constant is the thickness of the blue tube, again by virtue of manufactured pre-sets. Some altercations needed to be made to the scaled fins to accommodate a new stability. Several of the internal components are scaled as well, such as the Avionics Bay and Couplers.

Error between predictions and test results

In terms of the vehicle’s structure and its effect on flight performance, error between actual and predicted flight data is likely due to flight conditions or incorrect mass statements of internal components still under construction such as our Kiwi payload. Some other sources of error would be with additional weight of adhesives and fasteners, or imperfect (symmetrical) geometry when manufactured.

Sub-scale flight and its effect on full-scale design

The flight of our subscale launch vehicle and its flight data has confirmed our overall design. With said data we are able to pursue full-scale design and flight projections.

4: Recovery Subsystem

Components of the Recovery System

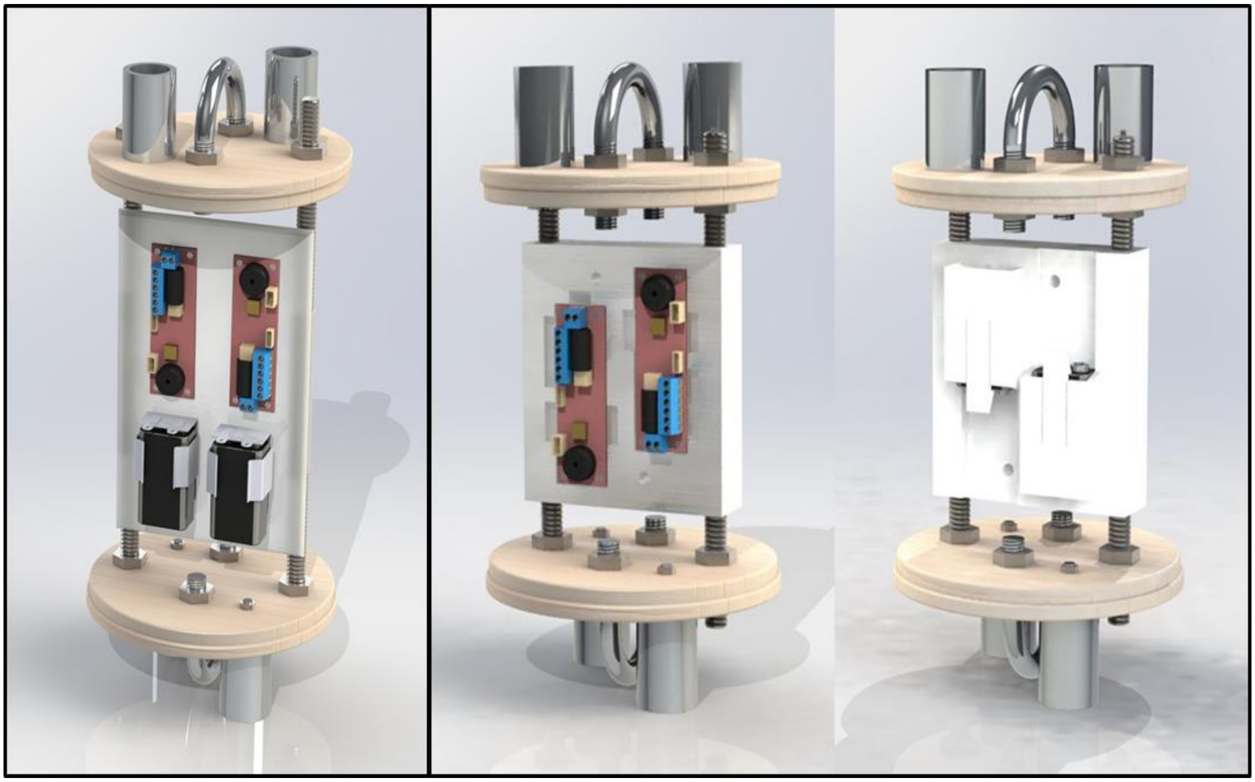
The components of the recovery system are the avionics board, the avionics bay structure, the parachutes and their corresponding harnesses, the altimeters, the faraday cage, and the method of parachute deployment.

The altimeters and their corresponding power supplies are mounted onto the avionics board. In previous competitions, A&R has used fiberglass sheets for the avionics board due to its strength and durability. This comes at a cost of weight and safety hazards involved with cutting and sanding fiberglass. An alternative to fiberglass is to 3-D print the board. The 3-D printed board is significantly lighter and would be a more effective use of space. 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 7, where the 3-D printed board edges out the fiberglass board.

Table 7: 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

To test if an additively manufactured avionics board is viable, a small board was printed for use on the subscale. This board performed without incident, verifying the choice of going with an additively manufactured board. The full-scale rocket will use a 3-D printed board due to this selection matrix and the success of the subscale launch. The 3-D printed boards are strong and secure enough to withstand the forces exerted during the parachute deployment events and the heat endured while waiting on the launch pad. The different design options are shown in Figure **14** where the left is made out of fiberglass and the right is the 3-D printed board.



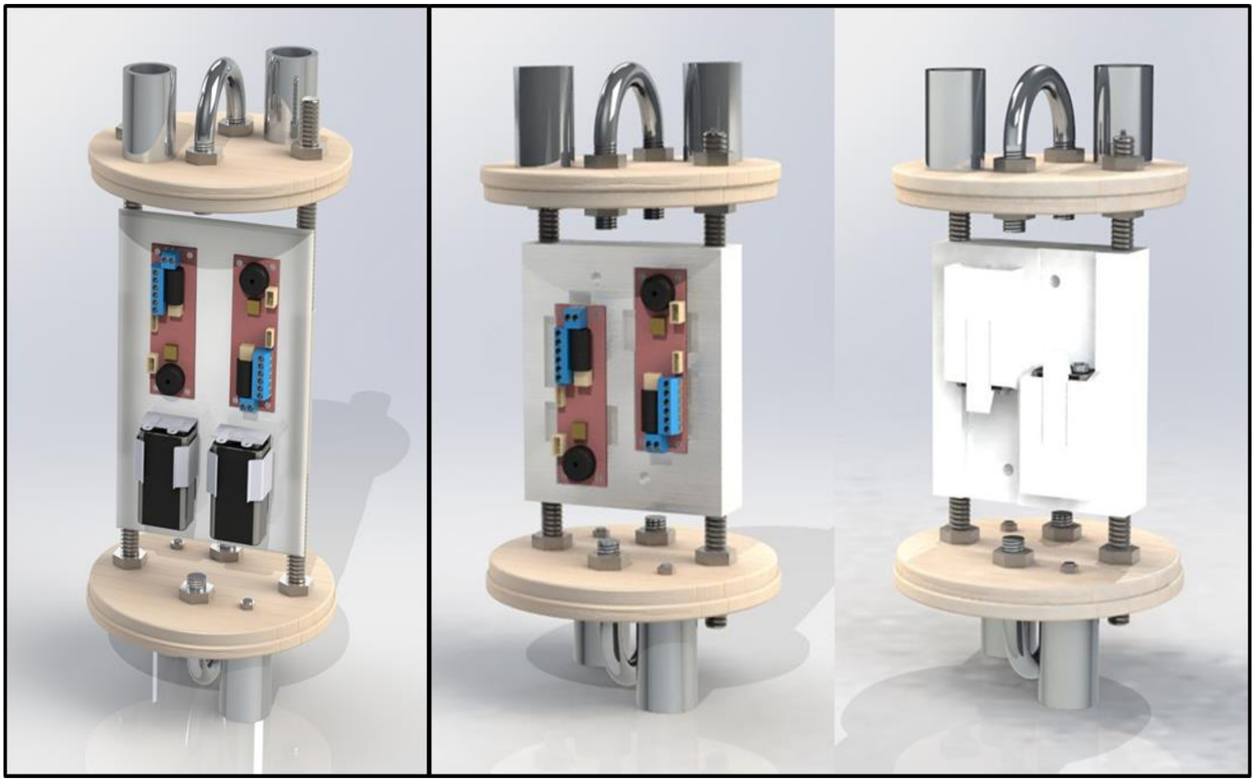


Figure 14: Fiberglass board (Left) vs 3-D printed board prototype (right)

Ultimately, a triangular design was created for use in the full scale. This design can be seen in Figure 15.

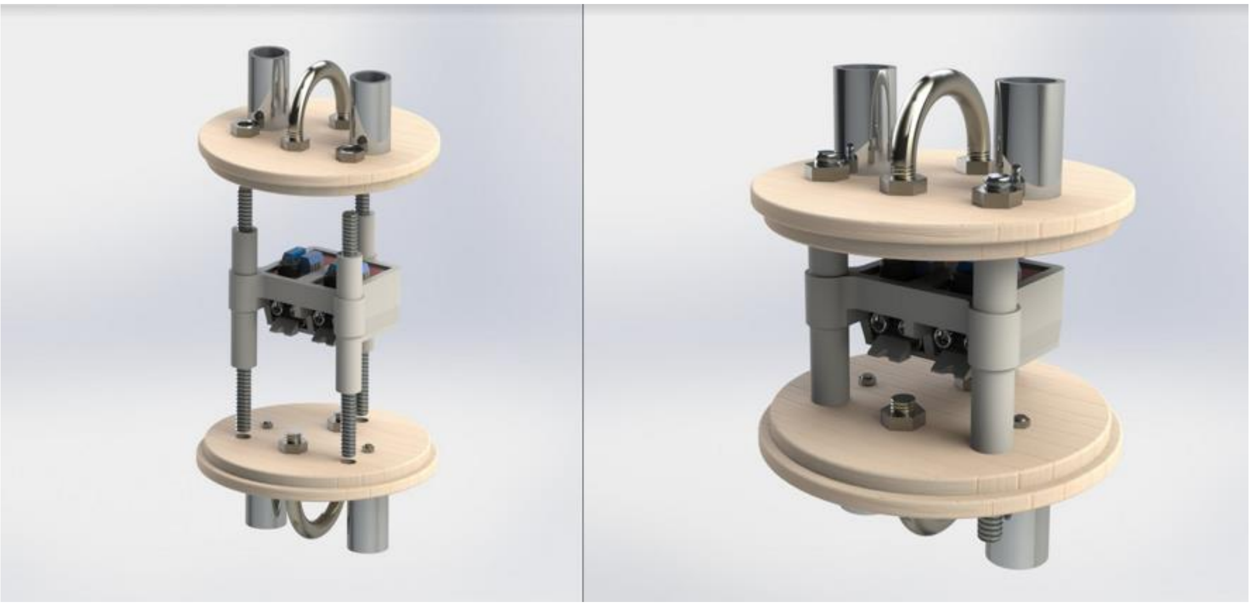


Figure 15: Full-scale 3-D printed board

This triangular design was the result of over four design interactions and improvements. Early problems with the printing of the material were overcome and the final design is compact, safe, and highly integrated into the rocket. Figure 16 shows a successfully printed avionics board.

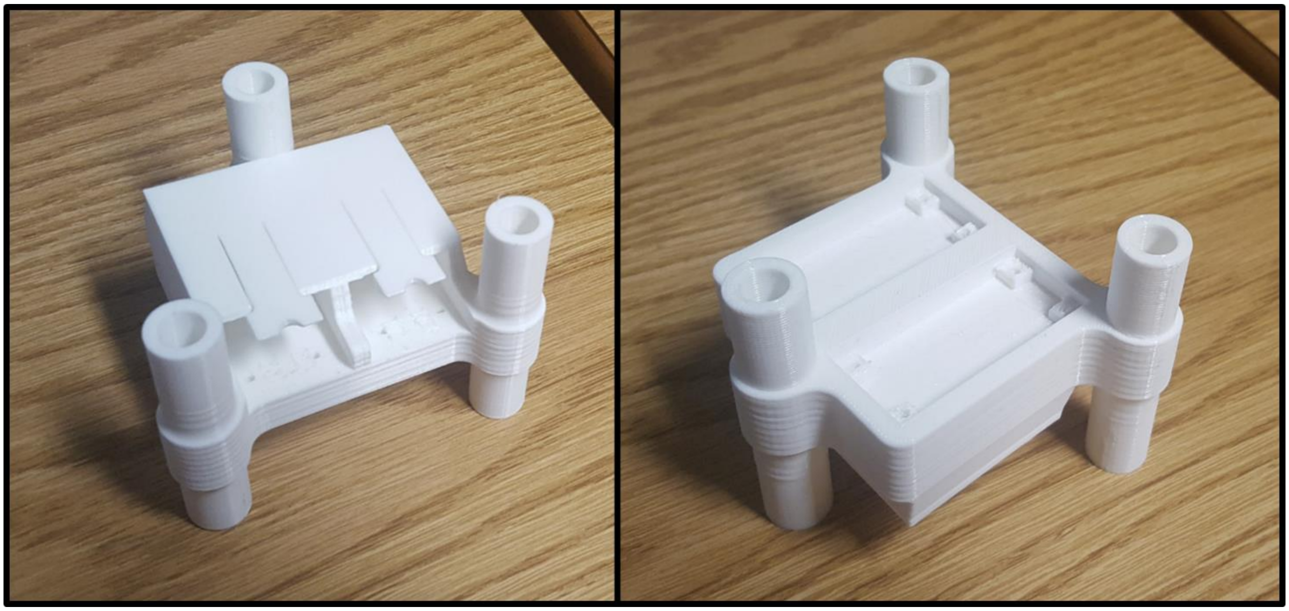


Figure 16: Full Scale 3-D Printed Avionic Board

Since the avionics bay will be housed in a coupler, there will be all-threads and bulkheads to hold the avionics board in place and protect it from the ejection charges. There are two options for the all-threads, aluminum and steel. Aluminum all-threads are lighter than steel but also not as strong. In 2016, LTRL launched a rocket, Valkyrie, of similar height and weight using aluminum all-threads. Hence, data from that launch can be used to determine if aluminum all-threads are strong enough for this year's rocket. 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.

$$D = \frac{1}{2} C_d \rho V^2 \pi r^2 \qquad (1)$$

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 will be used in the full-scale rocket.

For the bulkhead, the two options are wood and fiberglass. In most previous launches, fiberglass bulkheads have been used. However, fiberglass bulkheads have several drawbacks and wooden ones are better as long as they are strong enough. From previous launch data, wooden bulkheads have been shown to be strong enough to withstand the forces from parachute deployment. Using table 6, it is clear that wooden bulkheads are a better choice for the rocket and hence they will be used in the full-scale rocket.

Table 8: Selection matrix for choosing bulkhead material.

		Fiberglass Bulkhead		**Wooden Bulkhead**	
Category	Weight	Score	Weighted	Score	Weighted
Cost	1	1	1	3	3
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		33

The switches, altimeters, and the power supply are the avionics equipment. The two switches in the full-scale rocket will be 1” diameter key switches. Those switches have been used in the vast majority of rockets that LTRL has built in the past two years and have never failed. The wires that connect the key switches to the altimeters will be soldered onto the key switches to ensure that they remain connected. The altimeters used will be two SL CF altimeters because of their reliability, ease of use, and affordability. These are an upgraded model of the previous altimeters LTRL has used which were the StratoLogger SL 100 altimeters that were very reliable and lead to many successful launches. The SL CF altimeters weigh 0.07 ounces [4]. Each altimeter will use a fresh 9V battery as its power supply.

The Faraday Cage is a crucial component of the avionics coupler because it protects the electronics in the avionics bay from any interference. This prevents the accidental deployment of the separation charges at the launch pad around other rockets. Traditionally, that Faraday Cage was a thin mesh metal sheet that was rolled and fit into the coupler. However, this made it difficult to access the avionics equipment and attach the key switch. It would also scratch the avionics bay and any hands that tried to adjust the bay. For the full-scale rocket, there will be a 3-D printed sleeve that a thin sheet of aluminum can slide into and remain undisturbed (Figure 17). The sleeve allows the assembly of the avionics bay and coupler to be easier and ensures that the Faraday Cage is not shifted. Additionally, the bulkheads will have a layer of aluminum on the inside to further protect the electronics.

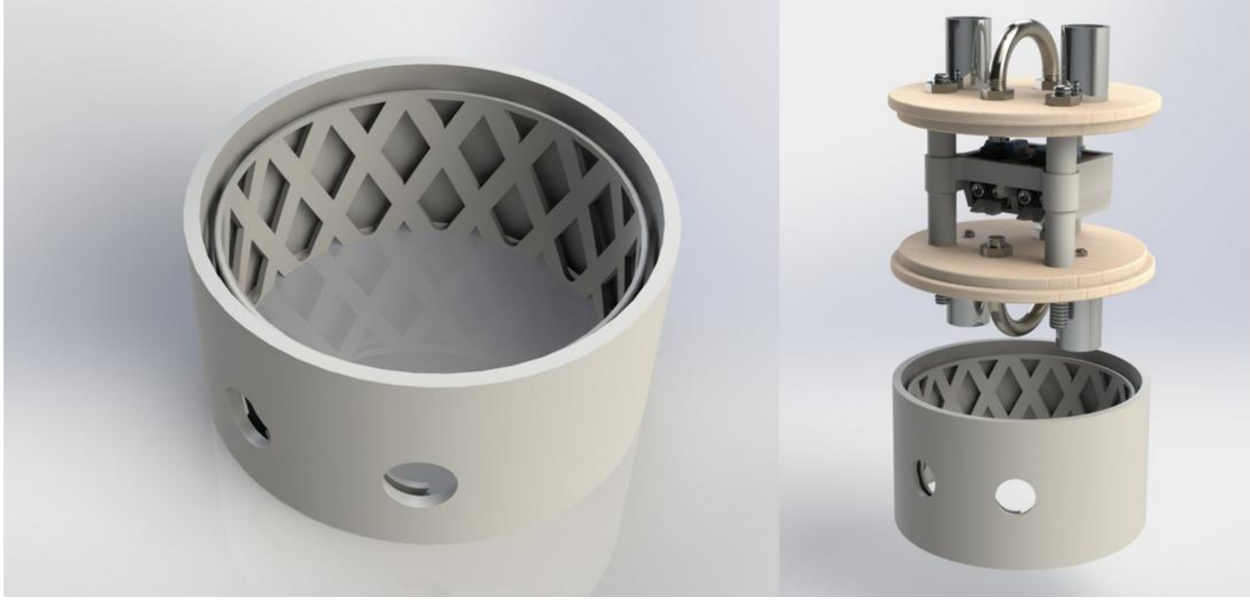


Figure 17: Sleeve for Faraday Cage Assembled Avionics Bay

The parachutes chosen for the full-scale rocket are an 18” Fruity Chutes Classic Elliptical for the drogue parachute and a 72” Fruity Chutes Iris Ultra Standard for the main parachute. These parachutes were chosen because they will allow the rocket to descend within the kinetic energy limit of 75 ft-lbs without drifting more than 2500’. More information about the parachute selection is in the following section, Parachute Sizing Estimation.

The rocket separation points in the full-scale rocket are 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

9, which highlights the selection process of the deployment mechanism based on various important selection criteria.

Table 9: 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 full-scale rocket will use black powder because of its reliability and the team's familiarity with it. The team has calculated the amount for black powder needed for each section using models but will confirm if it is the proper amount through ground tests and test launches.

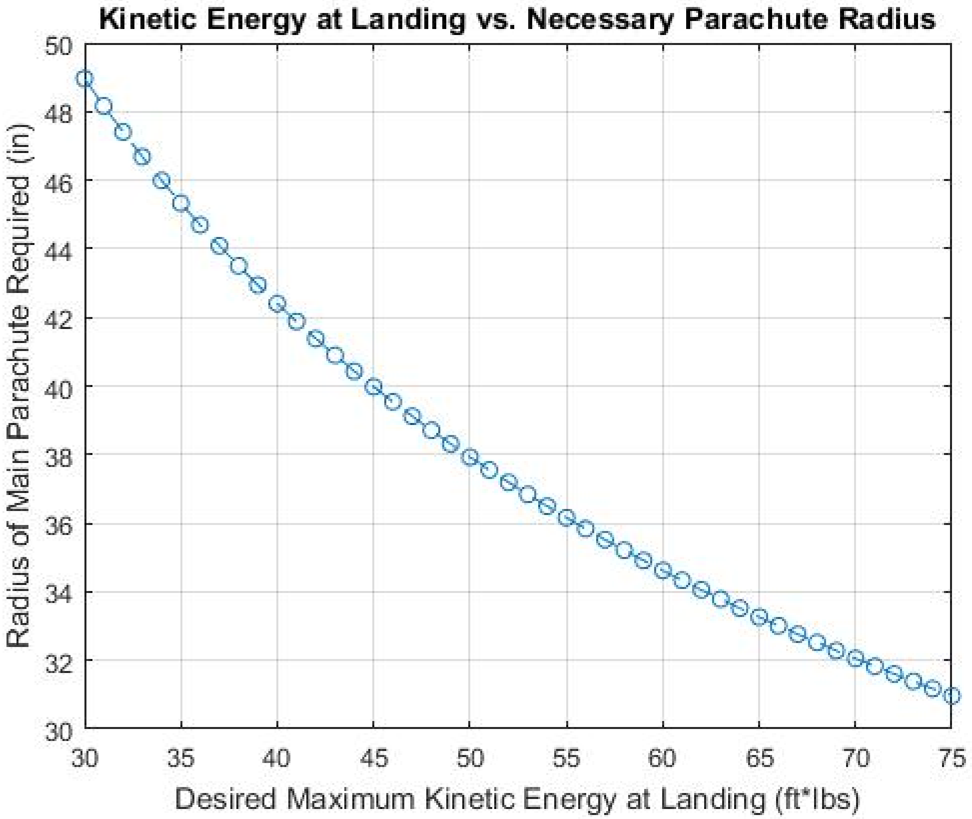
Parachute Size Estimation

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.



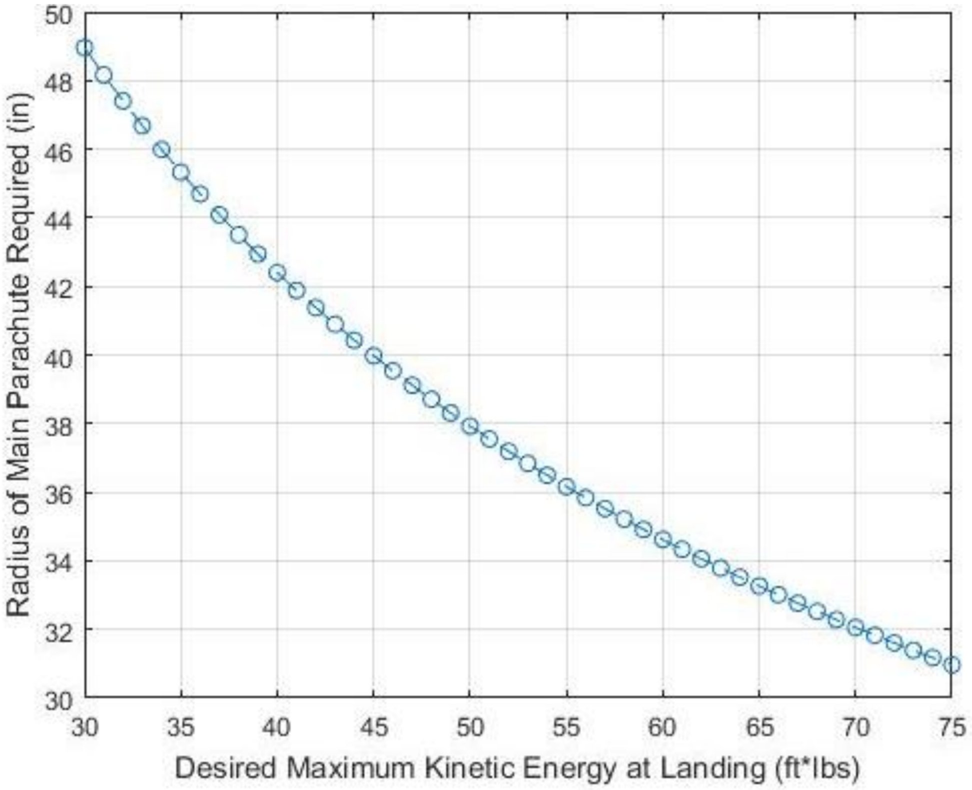


Figure 18 shows the plot for necessary diameter of the main vs. kinetic energy at landing calculated with the MATLAB code.

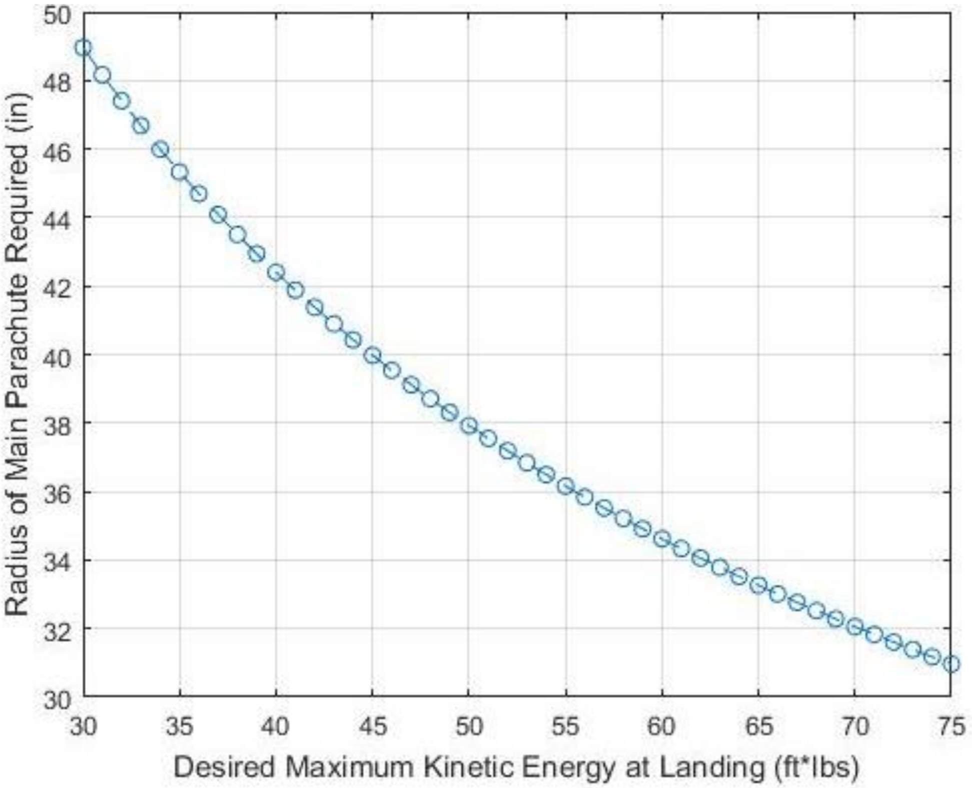


Figure 18: Diameter of the main parachute vs. desired kinetic energy at landing

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. The redundancy ensures that the parachutes will deploy and that the rocket will not have ballistic descent.

5: Mission Performance Predictions

Motor Performance Analysis

Figure 19 shows the flight profile simulation from ignition to landing. The altitude, vertical velocity, and vertical acceleration are simulated over time. In Figure 19, it can be observed that the predicted altitude will be just under 5250 ft, this apogee prediction includes the maximum ballast weight allowed in the rocket. Which, will allow for fine tuning the apogee if there are greater winds than in the model, which were 4.47 mph with a small average deviation and medium turbulence level.

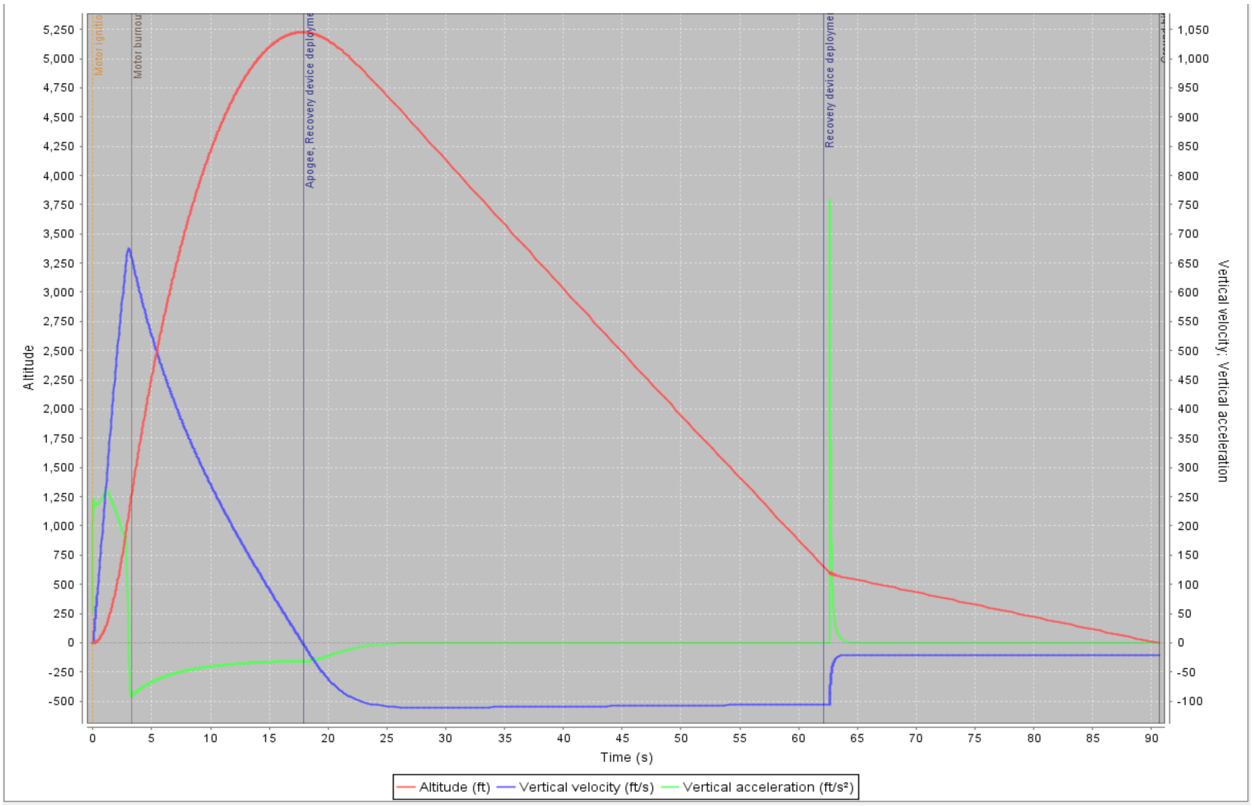


Figure 19: Full-scale Flight Simulation

It is known that OpenRocket over-predicts drag during simulations, therefore it can be assumed that the actual apogee would be higher. Two methods will be used to compensate for this over prediction, discussed in section 7.1.

Figure 20 shows the OpenRocket simulation for the L1350 motor thrust curve. It can be observed that features in Figure 20 resemble those in the manufacturers thrust curve in Figure 1. For example, the time and magnitude of peak thrust in both plots are between 1500 and 1550 Newtons at 1 to 1.25 seconds. Additionally, there are similar distinct graphical features such as the spike at ignition which both show to be approximately 1500 Newtons. Finally, there is a second feature at approximately 2.75 seconds which shows the thrust approaching a constant value of about 1300 Newtons before quickly decreasing. These multiple correlations show reasonable agreement between the provided information and the predictions.

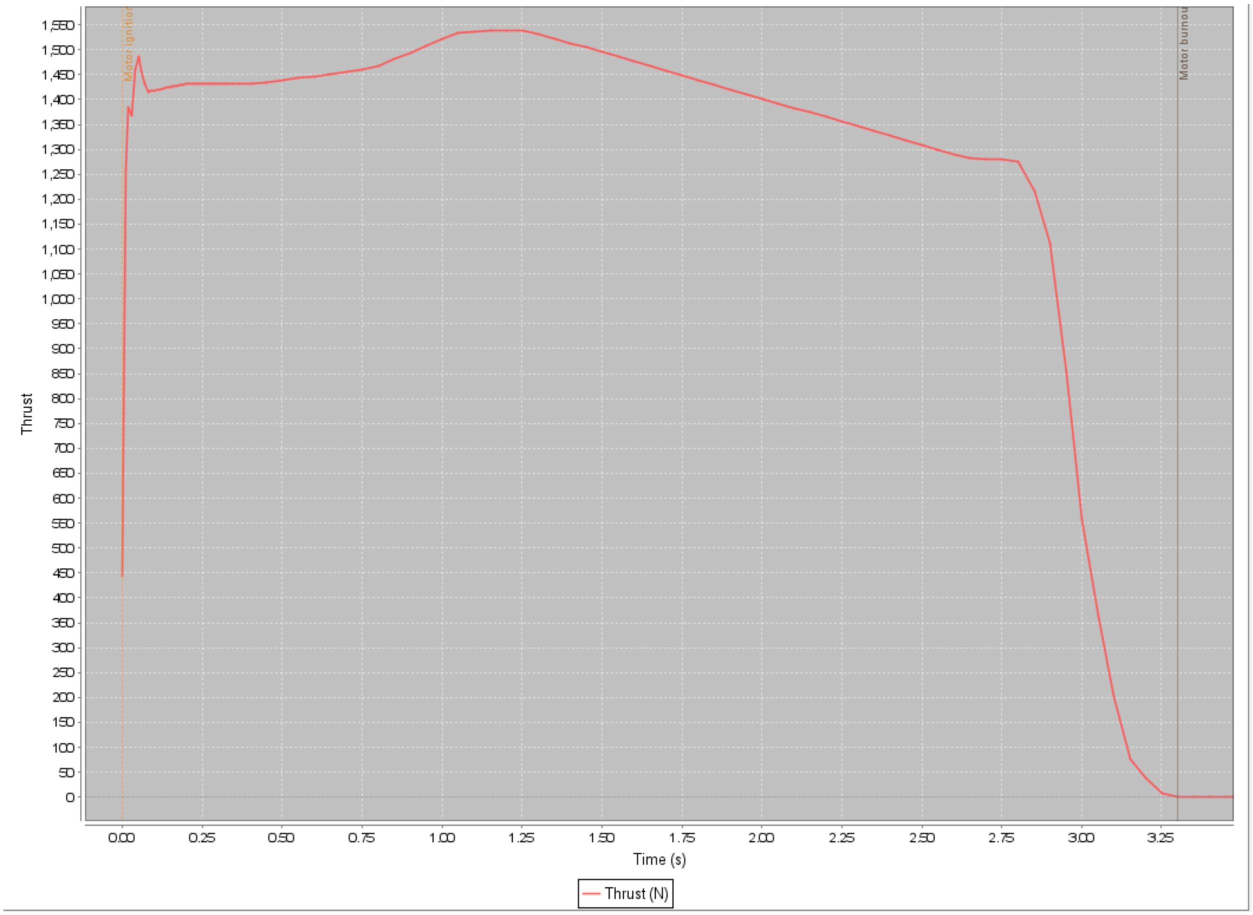


Figure 20: OpenRocket Thrust Curve Simulation

Stability Analysis

The current OpenRocket model has a calculated center of gravity location about 91.75 inches from the tip of the nosecone and a center of pressure of 115 inches from the nose cone, as seen in Figure 21.

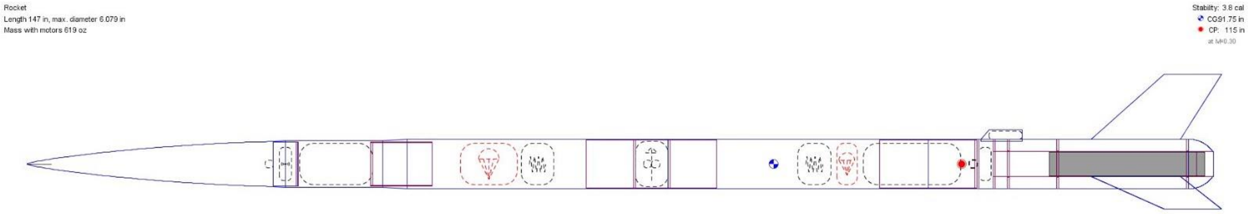


Figure 21: Full-scale OpenRocket Model

This puts the center of gravity about 23.25 inches forward of the center of pressure, which corresponds to a static stability margin of 3.8 calibers, 2.65 calibers off a 12 ft launch rail and 2.56 calibers off an 8 ft launch rail. Figure 22 and Figure 23 describes the center of gravity, center of pressure, and the stability margin from lift off until the stability becomes relatively constant when launched from 12 ft or 8 ft launch rails respectively.

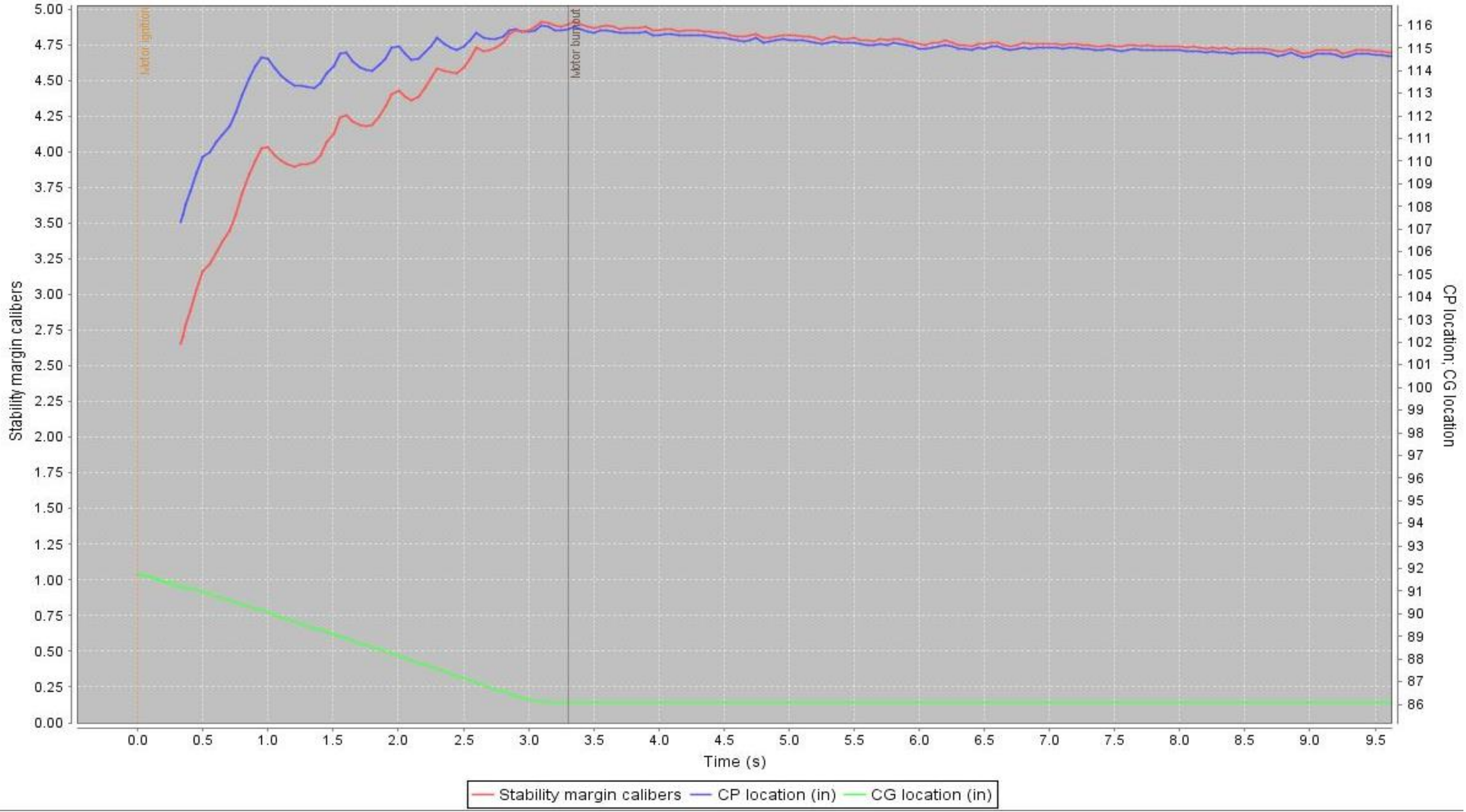


Figure 22: Full-scale OpenRocket Stability Simulation for 12 ft rod

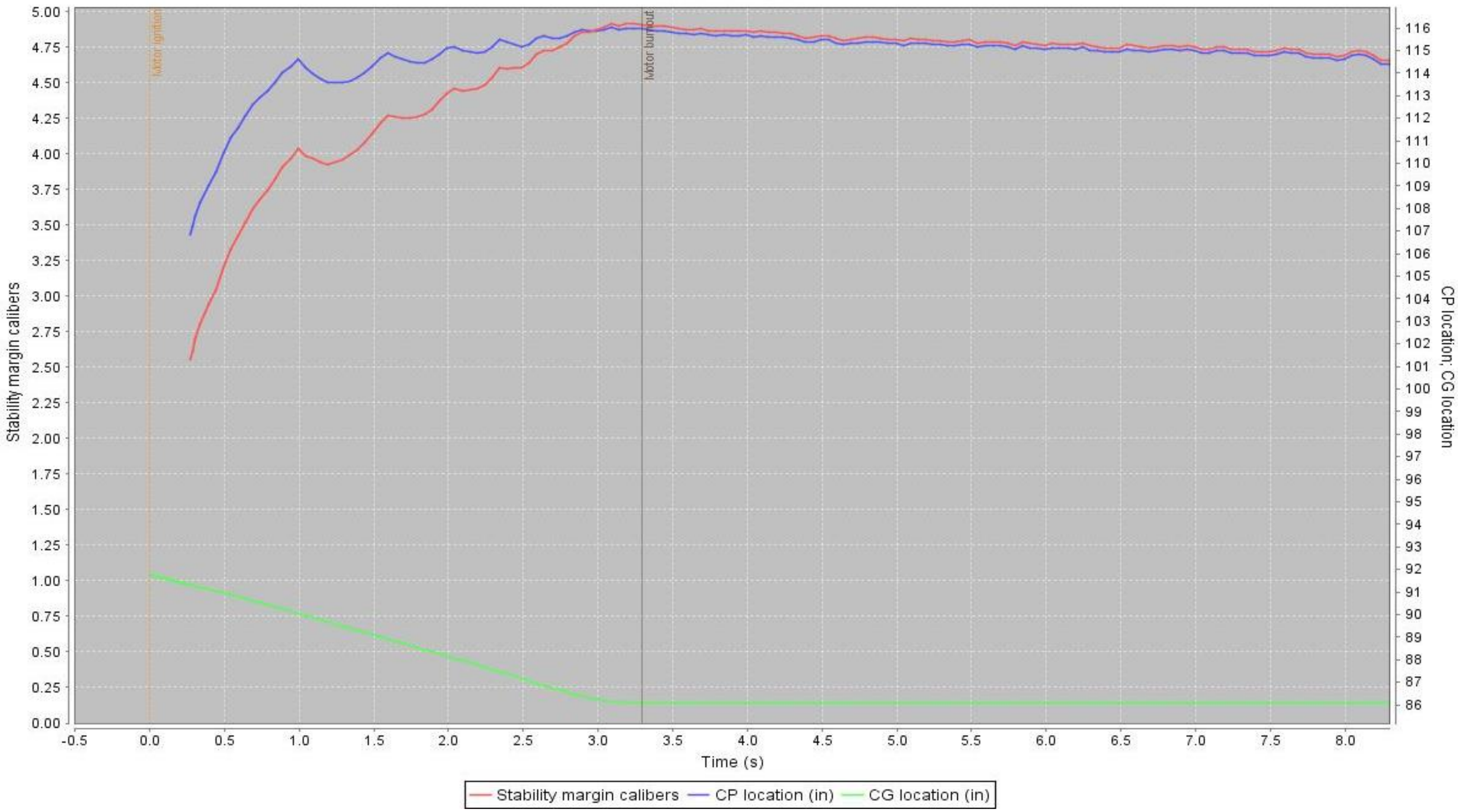


Figure 23: Full-scale OpenRocket Stability Simulation for 8 ft rod

Recovery Predictions

Recovery predictions were made using a computer program developed to estimate necessary parachute sizes and calculate the descent profile of a rocket based on mass and parachute characteristics. This program, dubbed the Recovery Descent Profile Calculator (RDPC) is written in MATLAB and uses a force balance integration method to calculate a descent profile. At each time step, the altitude and velocity are used to find the force of drag the parachutes are exerting on the rocket system. This drag force and the force of gravity are then summed to get a net force, from which the acceleration can be calculated. This acceleration is used to find a velocity at the next time step, after which the process continues until the rocket hits the ground.

Using the selected parachute sizes, RDPC was used to estimate the descent profile of the rocket. Figure X shows the estimates velocity and altitude vs time during descent for the main rocket body.

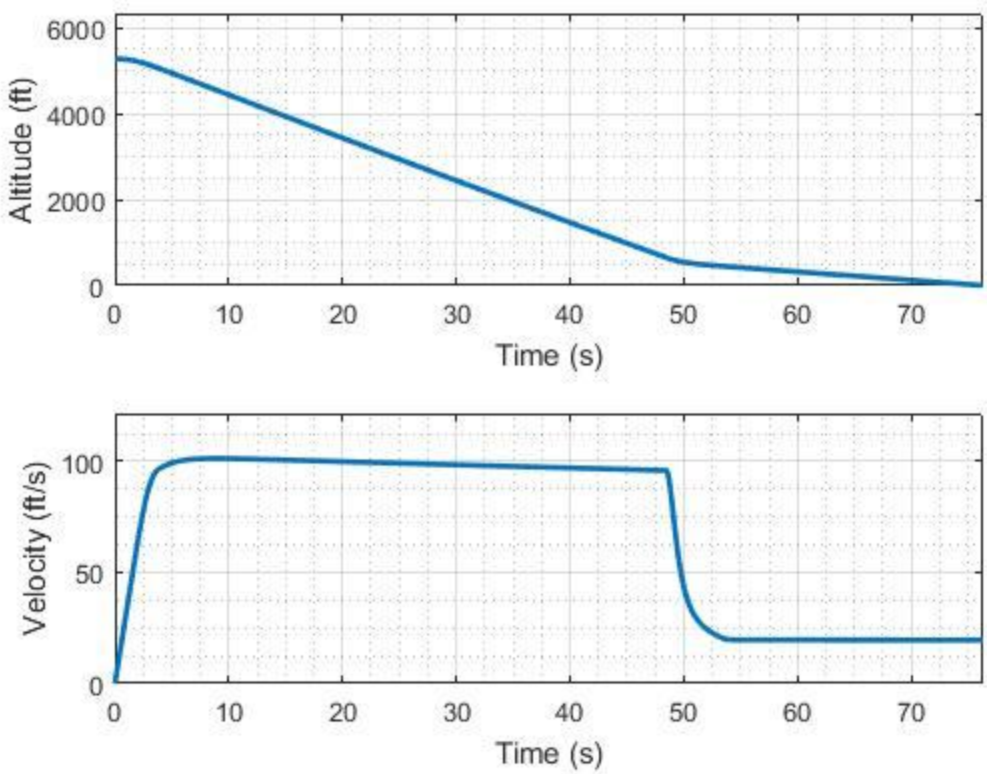


Figure 24: Descent profile of the rocket from RDPC

Kinetic Energy Calculations

Each section of the rocket landing independently is required to have a kinetic energy less than 75 ft-lbs. There are four main components of the rocket that will be landing independently. The mass of each component, the velocity upon landing, and the kinetic energy upon landing calculated from RDPC is shown in Table 10. The Nose Cone, Avionics Bay, and

Booster section will be tethered together and attached to the drogue and main parachute during descent. Kiwi will descent under autorotation of the blades until it reaches 500 feet, at which time the parachute will deploy. Kiwi's landing velocity will be 25.2 feet per second and the kinetic energy of Kiwi will be 9.22 ft-lbs. The highest kinetic energy at landing is the booster section, which will land with approximately 52.44 ft-lbs of energy.

Table 10: Shows the kinetic energy of each rocket component during landing

	Nose Cone & FOPS	Avionics Bay/ Middle Section	Booster Section	Kiwi
Mass (oz)	139	134	142	17
Landing Velocity (ft / s)	19.52	19.52	19.52	25.17
Landing Kinetic Energy (ft-lbs)	51.42	49.64	52.44	9.22

Drift Calculations

The RDPC also calculates the drift distance that the rocket will undergo in certain wind conditions ranging from 0 to 20 mph winds. The main and drogue parachutes were specifically selected to keep the drift within 2500 ft under all wind conditions. Table 11 shows the drift calculated by RDPC during descent under different wind conditions.

Table 11: Drift distance vs wind speed

Wind Speed (mph)	0	5	10	15	20
Drift Distance (ft)	0	559.7	1119	1679	2239

Section 5: Safety

1: Launch Concerns and Operation Procedures

Recovery Preparation

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

Key Switch .... OFF Position
Batteries .... OUT
Bay .... Wired
Batteries .... Installed
Bay .... Assembled
E-matched .... Assembled
Gun Powder .... Measured
Note: Drogue - 4.0 grams black powder
    Main – 5.0 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

Recovery Subsystem Members Safety Officer

___________ ___________

____

Structures Preparation

Checked and initialed by two Structures subsystem members after completion

Rail Buttons .... Aligned and secured to airframe using screw
Avionics Bay ....Fastened to Main and Drogue Sections Using Screws
FOPS .... Placed in Acrylic Airframe 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
Visual Inspection ....Screws tightened and assessed for cracks

Structures Subsystem Members

___________ ___________

FOPS Launch Checklist

Checked and initialed by two Payload subsystem members after completion

Materials Bag ....Sealed
Dilatant..Fills Chamber
Chamber.. Checked for leaks, bolts are secured
Chamber..Secured into rocket **(Structures Lead Signature required)**

Payload Subsystem Members

___________ ___________

Structures Lead

____

Kiwi Launch Checklist

Electrical Connections..Secure
Kiwi Vehicle ....Assembled **(Payload Lead Signature Required)**
Power switch... in the ON Position

Warning: Next step involves explosives and should be conducted away from bystanders and under the supervision of an experienced team member. Wear safety goggles.

Parachute ....Tested
Parachute .... Folded correctly and stowed **(Payload Lead Signature Required)**
WARNING: INCORRECTLY STOWING PARACHUTE MAY LEAD TO UNCONTROLLED DESCENT
Parachute Door .... Latched and secure
Radio ....Connection Established
Rotors .... Unobstructed by the padding and vehicle walls
Kiwi vehicle .... Properly padded and inserted into the rocket
Kiwi vehicle .... Secured

Payload Subsystem Lead

Vehicle: ___________ Parachute: ___________

Motor Preparation

Checked and initialed by one Propulsion subsystem member and one 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

Propulsion Subsystem Member	NAR Certified Member and Cert Level
__________	__________ __________

Setup on Launcher

Rail	Pull to horizontal position
Rail	Clean with WD 40 before placing Rocket
Rocket	Slide the rail buttons carefully through the rail guides
Launcher	Set the rail with the Rocket to the desired angle
Motor	place the charges into the motor

Ignition Insertion

Performed by one Propulsion subsystem member and one Propulsion subsystem lead.

E-match	Twist the leads together if not done
Ignition circuit	Check to make sure it is deactivated
Nozzle Cap	Thread E-match ignition end through the side hole, from outside to inside
E-match	Feed through nozzle up to top of the motor
Nozzle Cap	Place over end of nozzle, securing E-match in place
E-match leads	Separate two leads to at least one foot in distance
E-match leads	Connect each lead to the ignition circuit
E-match leads	Ensure that the leads will not contact each other

Troubleshooting

Problem	Resolution
Altimeter does not turn on	1. Put key switch in off position and try to turn it on again. If it still does not turn on, go to step 2. 2. Disconnect and reconnect the power supply and all of the wires connected to the power supply and key switch. Then turn the key switch into the on position. If it still does not turn on, go to step 3. 3. Replace the altimeter. There will be several back-ups on launch day.
Altimeter does not emit continuity beeps	1. Turn the altimeter off and on again and wait for continuity beeps. If it still does not emit continuity beeps, go to step 2. 2. Ensure that the altimeter is wired correctly and has power. If it still does not emit continuity beeps, go to step 3. 3. Remove and replace the altimeter.
Parachute does not fit in rocket	1. Unpack the parachute 2. Pack the parachute more tightly 3. Cover the parachute with Nomex chute protector 4. Apply baby powder onto the chute protector 5. Place parachute and the chute protector in the rocket
Failure to ignite.	1. Wait for the RSO to give the all clear. 2. Remove AND Disconnect the E-match. 3. Check launch circuit for continuity. 4. Inspect the E-match. 5. If the E-match ignited disassemble the motor while checking to see if it was correctly assembled. 6. Inspect the fuel grains for damage or irregularities. Replace if necessary. 7. If no problem was found consider consulting the RSO or the mentor. 8. Reassemble and reinstall the motor. 9. Try launching again.
Motor cannot be properly assembled	1. Fully read the instructions twice. 2. Completely disassemble the motor. 3. Reassemble the motor step by step exactly as the instructions state. 4. If problem persists contact the RSO/Mentor/Motor Vendor.

Post flight inspection

1. Read the maximum altitude and velocity from the altimeters at landing
2. Confirm that the altimeters have consistent data
3. Make sure parachutes are not damaged from the ejection charges
4. Make sure all ejection charges have detonated
5. Connect altimeters to a computer and ensure that the flight when as predicted
6. Understand and explain any variations from the modeled flight path

2: Safety and Environment

Personal 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.

Safety procedures were developed by consulting the Material Safety Data sheets (MSDS) attached to the end of this report. 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.

Table 12 shows the hazards that may be encountered during this project, their respective mitigations and the verifications for the mitigation. 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 12: Personnel Hazard Analysis

Hazard	Cause	Effect	Likelihood	Severity	Mitigation	Verification
Blue tube and sheet machining and sanding	Inhalation of small particulates	Dust particles can cause respiratory irritation and damage	3	2	Use face mask and shop vacuum, maintain adequate ventilation	Visual verification prior to machining or sanding

Power Tool Use	Flying debris	Cuts, possible eye injury	2	3	Wear safety glasses, follow tool safety instructions	Visual Verification and education of team members about possible precautions
Solder iron use	Tip of solder iron becomes very hot	Personnel are burned, Potential fire hazard if left on near flammable	1	3	Personnel will be instructed in safe use before soldering. Solder iron should not be left on unattended	Verify that personnel have been trained in solder iron use. Verify whether solder iron is hot before leaving room.
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.	Secure Black powder so that only the qualified personnel have access.
Pyrodex	Material is a fire hazard and explosive	Fire, personal injury, equipment damage	1	4	Only qualified people are permitted to handle these materials.	Secure Pyrodex so that only qualified personnel have access.

					Use only in small quantities and away from sparks and statics.	
Spray paint use	Inhalation of aerosol and solvent vapors	Skin and or respiratory irritation	2	2	Use PPE and adequate ventilation	Visual PPE inspection, use of specialized painting booth on campus
Use of adhesives (e.g. JB Weld)	Inhalation of solvent vapors	Respiratory irritation	2	2	Use PPE and adequate ventilation	Visual PPE inspection
Motor misfire	Possible unexpected explosions	Personal injury, equipment damage	1	5	Wait for a safe period of time, disarm ignition sources.	Ensure that the motor is inserted properly.
Unfired ejection charges after launch	Possible unexpected explosions	Personal injury, equipment damage	1	5	Ensure that ignition charge is inserted properly and connected securely. Ensure altimeters are working correctly	Verify that ignition charge is inserted properly and connected securely. Verify altimeters are working correctly
Pre-firing of ejection	Possible unexpecte	Personal injury,	1	5	Ensure no one is	Verify no one is

charges prior to launch	d explosion	equipment damage			standing behind or in front of rocket once charges have been placed in the rocket. Ensure that ignition charge is inserted properly and connected securely. Ensure altimeters are working correctly	standing behind or in front of rocket once charges have been placed in the rocket. Verify that ignition charge is inserted properly and connected securely. Verify altimeters are working correctly
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	Use the preflight and launch safety checklists.
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	Use the packing check list.
Rockets may fall without	Rockets have high kinetic	Damage to equipment,	1	4	Instruct all personnel on launch	Verify all personnel understand

parachute deployment at launches	energy due to lack of parachute deployment	injury to personnel			day safety, keep equipment and vehicles a safe distance from the launch pad	launch day safety before taking them to a launch. Verify all equipment and vehicles are stored a safe distance from the launch pad.

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 13 shows the preliminary set of failure modes. The likelihood and impact of each failure mode is ranked on a scale of 1-5.

Table 13: Failure Modes and Effects Analysis

Failure Mode	Cause	Effect	Likelihood	Impact	Mitigation	Verification
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	Computer modelling and full scale test
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	Compare the simulations to the Tensile test results
Crack along outer	Body tube cracks due to torsional stress and	Functional / structural inadequacy	2	3	Reducing the stress concentration	Simulation of expected stresses,

seam of body tube	bending moment					materials testing
Unwanted separation of coupler from body tube	Premature shear pin failure	Undeployed parachutes, uncontrolled descent	3	2	Screw adequate number of screws	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	Visual inspection , pre-flight check
Nosecone tip removal	Extreme impact	Aerodynamic instability, instability, sky debris	1	4	Simulation of expected stresses, material testing	Pre Flight check
Fin fracture crack	Extreme or repeated impact, bending moment	Aerodynamic instability, structural failure	2	2	Simulation of expected stresses, material testing	Visual inspection , pre-flight check
Fins separate from the fin brackets	Insufficient epoxy strength, loosening of bolts	Sky debris	1	5	Epoxied well with the fin brackets	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	Screwed and epoxied adequately	Visual inspection, pre-flight check
Fin brackets separate from body tube	Insufficient epoxy strength	Sky debris	1	5	Removing the dust from the body tube before epoxying	Simulation of expected stresses, materials testing, pre-flight check
Fracture crack in bulkheads	Material Defect, stress on eyebolt	Structural Failure,	2	5	Simulation of expected stresses,	Visual Inspection,

	threads, insufficient epoxy strength	pressure leakage			material testing	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	Computer modelling and motor testing to confirm the motor thrust characteristics
Fin flutter	Width of fins is too small	Aerodynamic instability, structural failure	2	3	Increase in width of the fins	Simulation of expected stresses
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.	FOPS will be flown in test rocket launches to ensure it does not affect the center of gravity.
Kiwi loses balance and is no longer able to sustain flight	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 during free fall. The design of Kiwi will use ballast	Kiwi will undergo multiple test flights with different starting orientations to ensure that the vehicle can

					to prevent sudden attitude change	reach and maintain stability.
Drive Shaft failure occurs while Kiwi is in flight	Drive shaft failure	Kiwi guided section falls under parachute to the ground	2	4	Kiwi will be equipped with a parachute that will ensure the vehicle meets kinetic energy requirements	Parachute testing will be performed to ensure the vehicle will meet Kinetic energy requirements.
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 and be equipped with a tracking GPS	Test the range of the tracking GPS and test the GPS failure mode of the Kiwi flight computer.
Kiwi loses contact with Ground Station	Communication Failure	Kiwi cannot be shut down in case of emergency	2	3	If Kiwi loses contact with the Ground Station, it will deploy its parachutes and shutdown.	Kiwi’s communication systems will be tested at extreme ranges
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	Test launches as well as independent tests will verify the ability of the parachute to open correctly

					ensure paracord operation	
Payload Integration						
Integration Failure	Lack of communication between subsystems	One or more subsystems do not function properly when integrated	2	4	Hold weekly subsystem leads meetings to promote cross subsystem communications	Routine testing will ensure rocket systems will work together
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.	Motor testing using the igniters that will be used at the competition
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.	Motor testing using the competition casing
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	There will be prior testing and the launch checklist will have at least 2 members of A&R verify that there are the correct number of

						shear pins and grams of black powder in the blast caps
Drogue chute fails to deploy	Drogue chute either does not leave the tube or doesn’t unravel	Kinetic energy at main chute deployment is higher than expected	2	3	Ground test recovery system for optimal ejection strength	The launch checklist will have two members of A&R ensure that the parachute is packed correctly and there is sufficient black powder in the blast caps for the parachute to deploy.
Main chute fails to deploy	Main chute either does not leave tube or doesn’t unravel	Kinetic energy of rocket at ground impact is too high	2	4	Maintain sufficient airflow to deploy main chute from deployment bag	The launch checklist will have two members of A&R ensure that the parachute is packed correctly and there is sufficient black powder in the blast caps for the parachute to deploy.
Main chute	Main chute deploys at apogee	Kinetic energy during	3	3	Proper labeling of wires, ground	Two members of A&R will

deploys first		main chute deployment is too high			test, use correct number of shear pins	verify that the parachutes are in the correct segment of the rocket and that all of the wires are going to the correct charges and altimeters.
Main and drogue get tangled together	Main chute gets deployed below drogue and tangles	Rocket descent is unstable, kinetic energy at ground impact is too high	2	4	Use adequate lengths of recovery harness	There will be prior test launches where the length of the shock cord will be confirmed to work. The shock cords will be at least 10 ft different in length.
Ejection charges do not ignite	No parachute deployment	Ballistic descent, ground impact kinetic energy is too high	2	5	Use fresh batteries for each launch, check altimeter continuity	Two members of A&R will confirm that the charges are loaded correctly, the batteries are new, and the altimeter has continuity beeps

Ejection charges ignite early/late	Ejection occurs before/after apogee	Parachute deployment not as expected, possible uncontrolled descent	2	3	Properly sized vent holes	Two members of A&R will verify that the e-matches are connected to the correct ports on the altimeters and there will be redundancy to ensure that it deploys.
Parachute gets burned	Ejection charges damage parachute	Parachute does reduce kinetic energy as much as expected	1	3	Use Nomex/Kevlar chute protector	Two members of A&R will verify that the parachute is completely protected by the chute protector.
Recovery harness burns	Ejection partially or fully burns through harness	Ballistic descent of rocket	1	4	Use heat resistant recovery harness material	The only shock cords that are purchased are made out of Kevlar and these will be verified to be strong enough during the ejection of the parachutes.

Recovery harness attachment breaks	Bulkhead, U-bolt or harness breaks	Uncontrolled rocket descent	2	3	Adequately size recovery harness, flight test	There will be modeling done before any launches and there will be test launches that will confirm that the bulkheads and U-bolts are strong enough
High kinetic energy at landing	Parachutes undersized, or intentionally deployed at incorrect altitude	Rocket lands at an excessive velocity	2	4	Accurate estimate, OpenRocket	There will be modelling to confirm that the parachutes will be the correct size and A&R will receive confirmation from NASA about the parachutes chosen
Altimeter doesn't detect pressure change	Altimeter is unable to detect pressure change during ascent	No data is recorded and ejection charges are not fired, ballistic descent of rocket	1	5	Properly sized vent holes away from airflow obstructions	The vent hole size will be checked several times in practice launches and the hole will be of adequate size compared to previous similar

						rockets that we have successfully launched.
Loss of power	Battery dies or wires become unattached	Altimeter does not record data, ejection charges are not fires, rocket descends ballistically	2	4	Use fresh batteries that can withstand rocket accelerations, redundant altimeters	New batteries will be used on launch day and two A&R members will confirm that the batteries are connected and wired securely.
Parachute gets tangled	Parachute is not packed correctly	Lowered coefficient of drag, kinetic energy of the rocket would be above target levels	2	3	Pack parachute correctly and have it confirmed by at least two other A&R members	Two members of A&R will confirm that the parachutes are packed correctly.
Ejection charges are not sufficient	Rocket fails to deploy one or both of the parachutes	Higher kinetic energy when landing, potentially ballistic descent	1	4	Do ground testing to ensure that the ejection charges will separate the rocket	The ground tests and previous launches will confirm the proper amount of black powder to use and two members of A&R will confirm that the charges

						are packed correctly

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 14 below summarizes this risks, ranking the likelihood and impact on a scale of 1-5.

Table 14: Environmental Hazards

Environmental Hazard	Cause	Effect	Likelihood	Impact	Mitigation	Verification
Solvent, paint or other toxic substance released to environment	Improper disposal of used chemicals	Potential contamination of environment	2	3	Contact relevant personnel in building	Penn State EHS is contacted and notified
Motor gases	Hot, toxic gases released during takeoff	Contamination of environment, air pollution hazard	4	2	Follow all launch safety regulations	Checklist for safety regulation to be completed prior to launch
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	Visual verification, wind speed monitor
Motor burning into ground	Titanium sponges, motor burning out without	Cause fire at launch pad or surrounding area	1	4	Not using motors with titanium sponges, securely retaining	Ensure that “Skidmark” and similar motors are not used, test motor

	launching the vehicle				the motor into the booster	retention system
Ejection charge fails to go off during launch	Altimeter failure	Charge could go off on ground and cause a fire	1	5	Redundant altimeters	Follow standard launch procedure checklist
Parachutes exposed to ejection charges	Nomex Chute Protector doesn't fully cover the parachutes	Parachutes catch on fire which could spread if still lit when vehicle lands	1	5	Properly cover parachutes with Nomex cover	Follow launch procedure checklist
FOPS leaks fluid outside the rocket body	Physical damage to FOPS fluid containment or transfer section	Chemical damage occurs to local area/watershed	3	2	Organic materials (cornstarch) will be used for dilatant	Test flights will ensure the ability of external FOPS components to survive landing
Kiwi rotor or propeller spins after landing	Programming error	Damage to local flora	2	1	Test Kiwi before initial launch	Examine robustness of programming

Overall Project Risk Management

There are several concerns with the overall project, mostly related to budget and personnel management. These are presented in Table 15 below.

Table 15: 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 13	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 gets 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

Section 6: Payload Criteria

1: Selection, Design and Rationale of payload

FOPS:

Due to the inadequate performance of the prototype system in the subscale launch, a new method of inserting the specimen before the liquid was developed. The shear thickening liquid remains the main method of protection; however, the open-cell foam which was featured in the original design was removed, eliminating much of the gross acceleration isolation. A spring system is used to fulfill the purpose of the open-cell foam. This design retains the force-distribution abilities of the dilatant while employing the spring system's acceleration isolation abilities. The drawing for FOPS is contained in Figure 25 below.

Figure 25: FOPS Drawing

The exterior of FOPS is integrated into the body of the rocket, and is attached to the materials bag (shown in black) by elastic bands or springs. These bands allow the bag to be isolated from the shocks and forces of launch and recovery, while still restraining the motion of the bag. The dilatant will fill the space between the materials bag and the exterior of the bay. It will be held in a reservoir (shown in black above the FOPS bay) until after the fragile object is placed into the materials bag. Once the object is secure, the FOPS bay valve will be opened manually from the exterior, and the non-Newtonian fluid will flow into the bay. FOPS dimensions are shown in Figure 26.

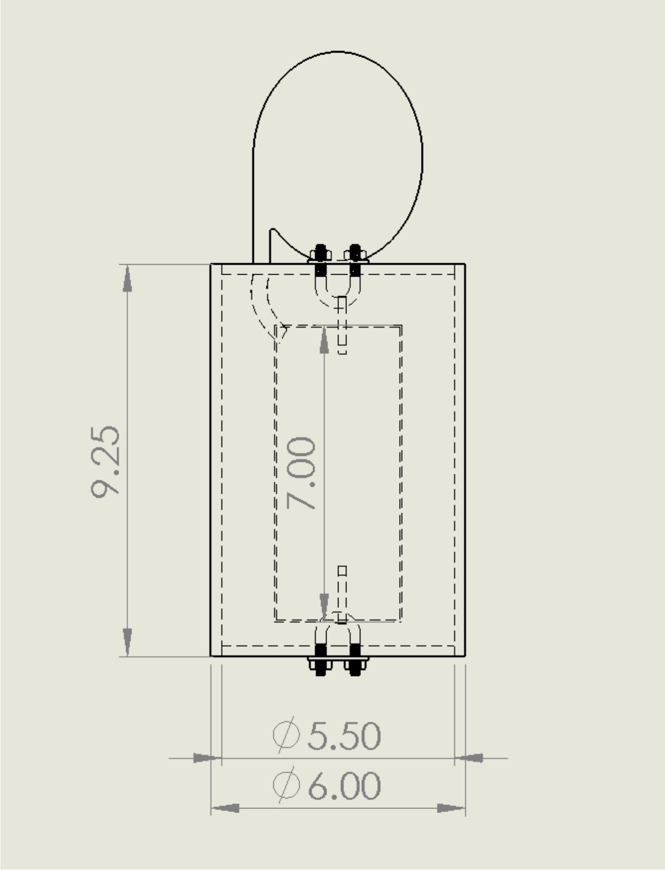


Figure 26: FOPS Dimensions

As evident by the drawing dimensions, the materials bag is large enough to contain the unknown fragile object(s) of dimensions 3.5 x 6 inches. FOPS will act as a section of rocket body, and be independent of other systems, as it does not require power or actuation and is completely contained within the FOPS bay. The max acceleration for the rocket is 8 G's, and this system is designed to handle this acceleration.

Kiwi:

Originally, Kiwi was designed as a coaxial helicopter. After further research into the nature of coaxial rotor mechanisms, the design was changed to an autogiro, or gyrocopter, which uses a large, unpowered rotor on the top of the craft to provide lift. The drag of forward motion on the rotor is greater on the leading edge than the trailing edge, which exerts a moment that turns the rotor and generates downward thrust. A small powered propeller on the rear of the craft provides forward thrust. Simpler mechanical systems and increased stability make the autogiro preferable to the coaxial helicopter as a small-scale autonomous vehicle for use in this competition. Figure 27 shows the full body view of Kiwi.

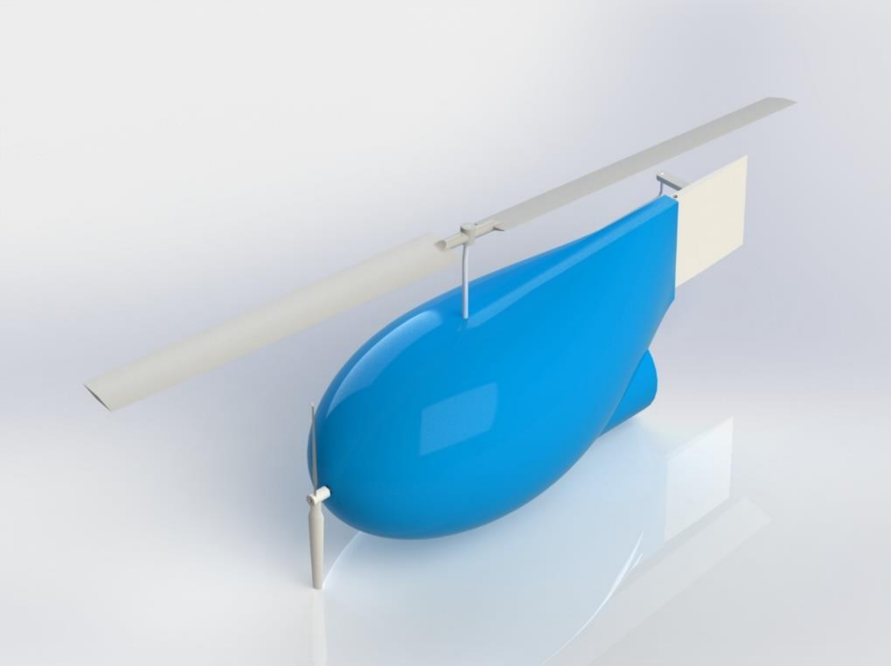


Figure 27: Exterior View of Kiwi Vehicle

Kiwi will be powered by a front propeller and steered by a rear rudder, both shown in the above figure. The top rotor will provide lift to slow the descent of the vehicle. Kiwi weighs 17 oz, and its terminal velocity will cause Kiwi to be below the kinetic energy requirements even if it falls without parachutes. The Kiwi dimensions are shown in Figure 28 below.

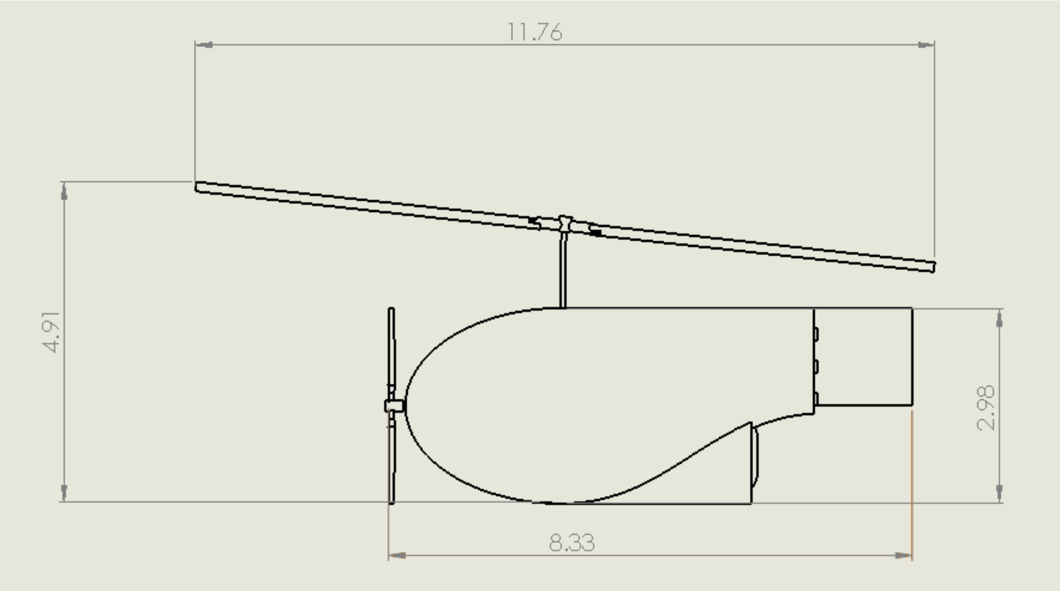


Figure 28: Kiwi vehicle dimensions

The size of the front propeller is 3 inches due to space constraints. Using equations 4-6 below, the forward velocity was determined:

$$V_{tip} = \omega r \tag{4}$$

$$T = \frac{1}{2}\rho A {V_{tip}}^{2} C_{l_{avg}} \tag{5}$$

$$V_f = V_{fnd}\sqrt{\frac{T}{2\rho A}} \tag{6}$$

The ideal forward velocity was found to be 94 ft/s, however, this number does not account for drag or the downwash of the top rotor. The top rotor will provide lift, and be 1-foot-long due to size constraints set by the Kiwi Bay. A view of Kiwi's interior is shown in Figure 29 below.

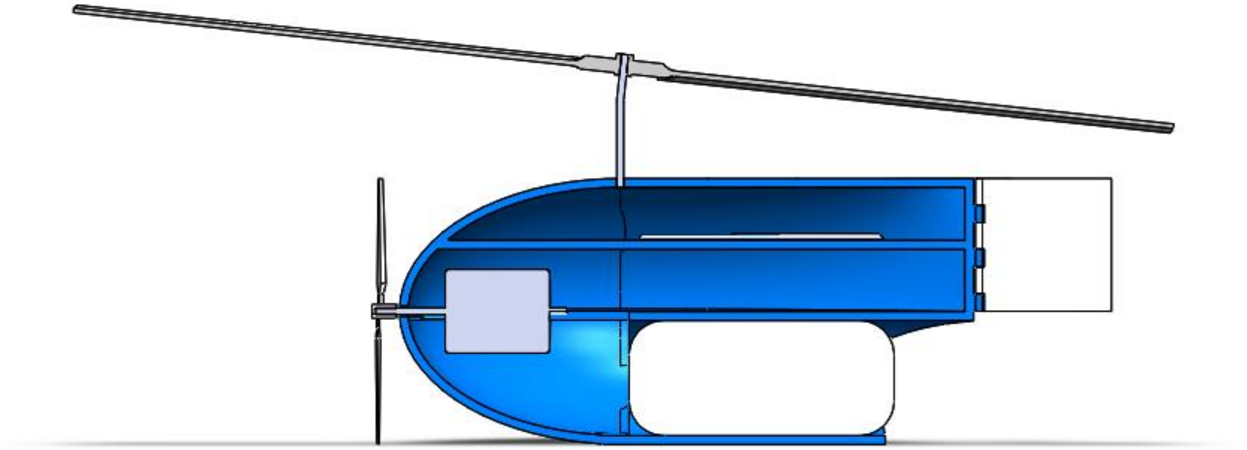


Figure 29: Cross Section view of Kiwi Vehicle

The white cylinder at the bottom front of the vehicle contains the parachute, which will be used for landing and in case of emergencies. The shelves shown in the interior of the vehicle will be used to hold the electrical components in place. The electrical schematic is shown later in the report. The fasteners used to hold the electronics are shown in Figure 30 below.

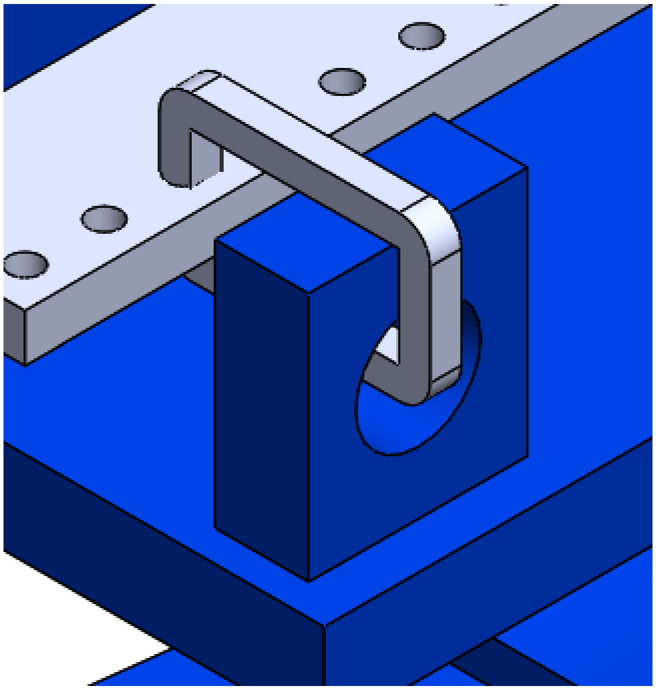


Figure 30: Fastening mechanism for the electronic components

The shelves will be equipped with loops (shown in blue) so that the electrical components can be secured to the shelves via zip ties (shown in gray). Securing the components in this way will allow for easy adjustment of the components and a reduction of weight.

Kiwi will be encased in a shell within the rocket body. This shell acts to restrain Kiwi during the ascent of the rocket, protecting it from impact against the walls of the rocket. When the rocket reaches apogee and the body opens, the shell's two sections separate, and allow Kiwi to exit the rocket body and begin descending. After its exit, Kiwi acts independently from the rocket.

Below are the electrical schematics used in the Kiwi system. The schematic for the ground station for the Kiwi system is shown in Figure 31.

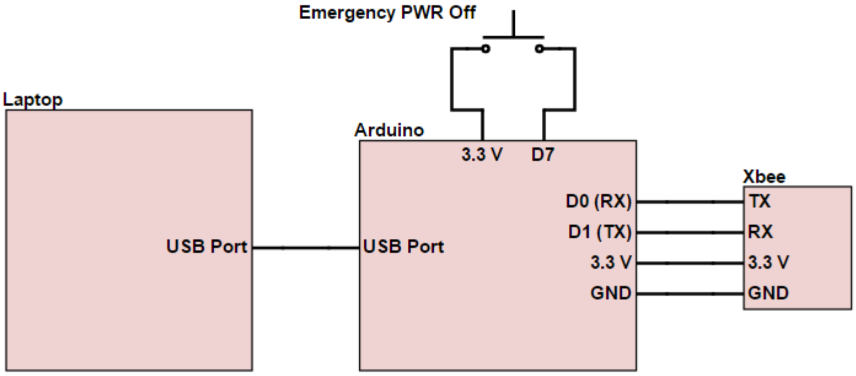


Figure 31: Ground station wiring schematic

The ground station contains a laptop, a Leonardo Arduino, and an Xbee radio. The Laptop is used for interfacing with and powering an Arduino. The Arduino is equipped with an Xbee which allows the team and Kiwi to communicate. The team will use the Xbee to send messages to Kiwi to ensure that the communication link has not been lost. If the link is lost, the Kiwi flight computer will deploy the parachute and power off all systems. Additionally, the Ground Station Arduino is equipped with an Emergency PWR off button. Pressing this button will transmit a message to the Kiwi flight computer that will deploy the parachute and shut down all systems. The schematic for the electrical systems on board the Kiwi vehicle are is shown in Figure 32.

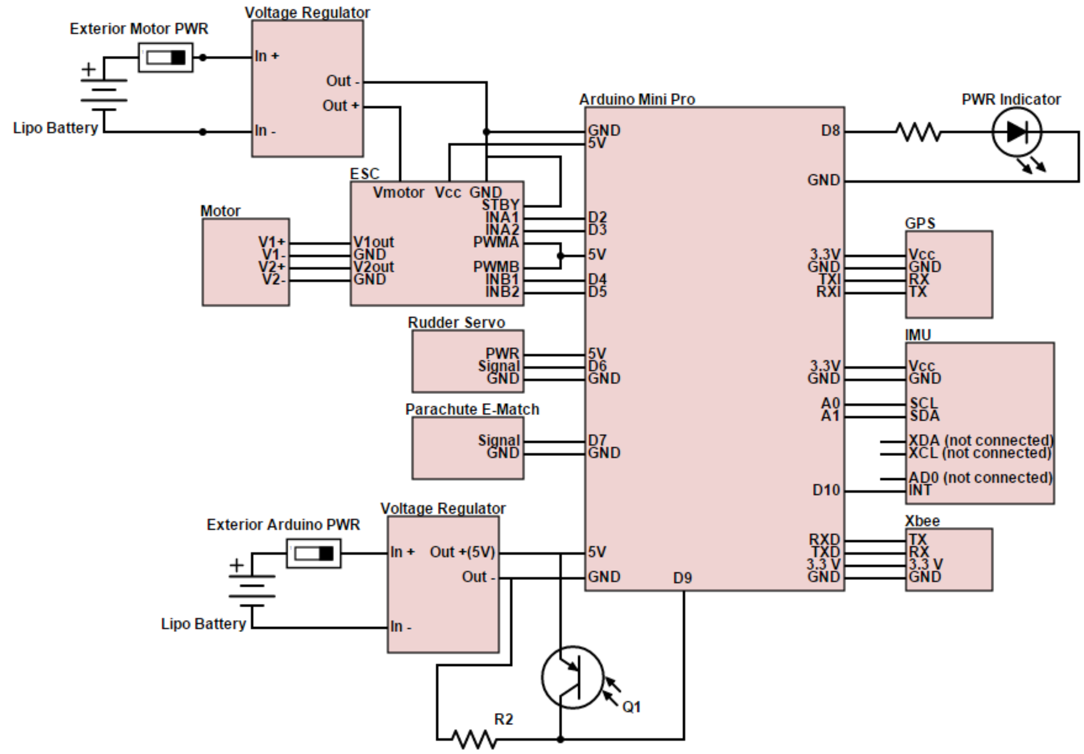


Figure 32: Schematic for the electrical systems onboard the gyrocopter

A Mini Pro Arduino will act as the flight computer on board Kiwi. It will receive data from the GPS and IMU to determine Kiwi's location, speed, and direction of movement. The Mini Pro will have an indicator LED which will be visible from the outside of the vehicle to show that the system is receiving power. The flight computer will be powered by a Lipo Battery through a voltage regulator. The system will be activated by flipping an exterior switch which will connect the battery to the voltage regulator. An additional Lipo battery will power the motor that drives the propeller. The battery will also have an external switch to connect it to the voltage regulator. The motor will be connected to an electronic speed controller, which will receive signals from the Arduino. A servo will control the rudder, as directed by the Arduino to adjust the direction of the vehicle's flight. The Arduino will use an Xbee radio to communicate with the ground station. The phototransistor will be used to determine when Kiwi has exited the rocket.

The flight computer will also be equipped with an e-match to eject the parachute. There will also be a completely separate altimeter system, including batteries, an altimeter, and an e-match, on board Kiwi, for redundancy. This altimeter will automatically trigger an e-match at 150 feet to ensure the safe recovery of the Kiwi. Figure 33 shows the software flow diagram of the Ground Station.

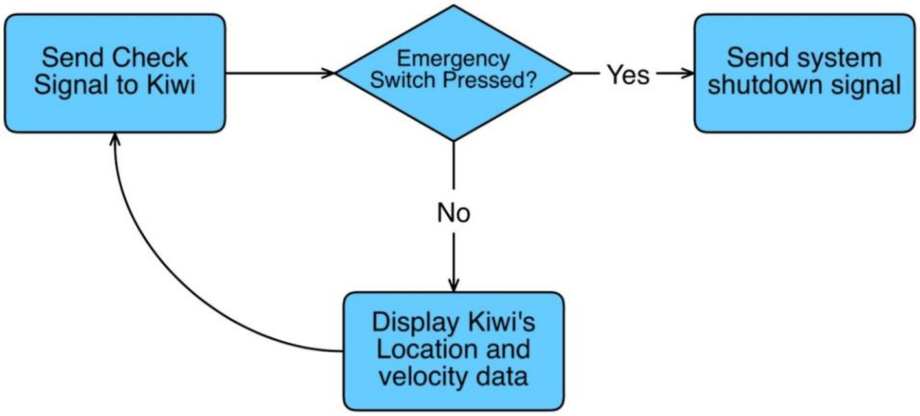


Figure 33: Kiwi Ground Station (GS) Software Diagram

The ground station is mainly used for monitoring Kiwi's stability and flight path and to provide a way to remotely shutdown the vehicle and deploy the parachutes. The system begins by sending the communication check signal to the vehicle. It then checks if the emergency button has been pressed. If it has, the ground station will send a shutdown message to Kiwi, which will initiate a shutdown sequence on the vehicle. If the emergency button has not been pressed, the laptop will display the received location and velocity data from Kiwi so the team can monitor the flight of the vehicle. The Kiwi on board software flow diagram is shown in Figure 34.

As shown in the diagram, the flight computer will not power the propellers unless the ground station signal has been received, the altitude is over 100 feet, the target coordinates have been received, and a photoelectric sensor reports that Kiwi is outside the rocket. Once all of these criteria have been met, the autogiro will wait thirty seconds and then activate the propellers. After verifying that Kiwi is still in communication with the ground station, a shutdown signal has not been received, and that the altitude is greater than 150 feet, the flight computer will check that the vehicle is on the correct trajectory. If the trajectory is correct, the Xbee will send the GPS coordinates and the velocity of the vehicle so the team can ensure the flight is stable. If the trajectory is not correct, the proper adjustments will be made and then the Location and velocity data will be sent to the team. If the communication check signal has not been received in a specific number of iterations, a shutdown signal has been received, or the altitude of Kiwi is less than 150 ft, the flight computer will deploy the parachute by activating the e-match, and turn off all systems.

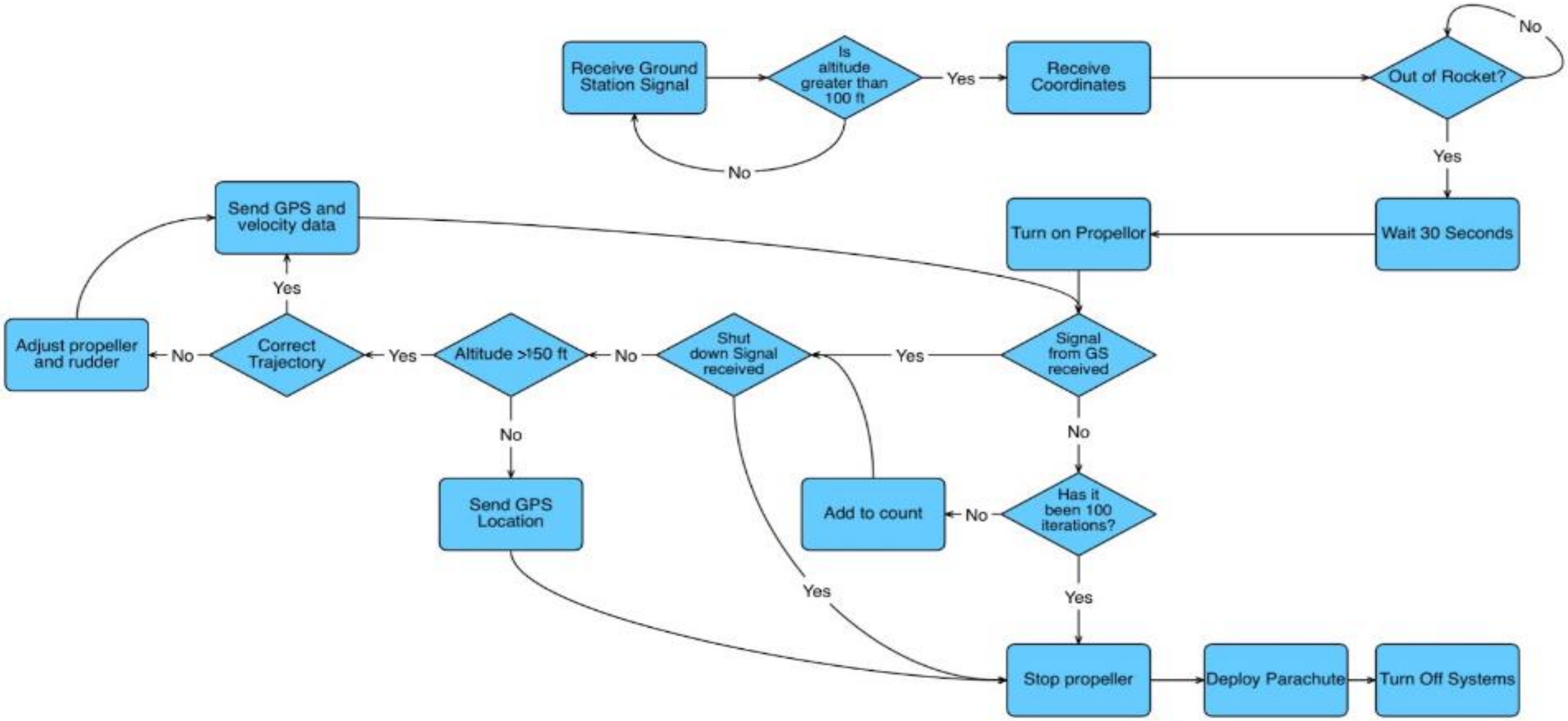


Figure 34: Kiwi's onboard software flow diagram

Section 7: Project Plan

1: Testing

Airframe Material Testing:

Material testing is to be completed alongside full-scale construction which will help verify that the launch vehicle is capable of withstanding the expected loads from launch through to touchdown. Lab facilities at Research Building West at Penn State will be used for the testing to create an apparatus which requires the machining of aluminum bulk plates in order to hold the test specimen to the tensile test machine. Previously, a similar tensile test had been conducted on a G12 fiberglass airframe specimen as seen in Figure 35 and Figure 36.

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 35.

Figure 35: Tensile Test Setup for G12 Fiberglass Specimen

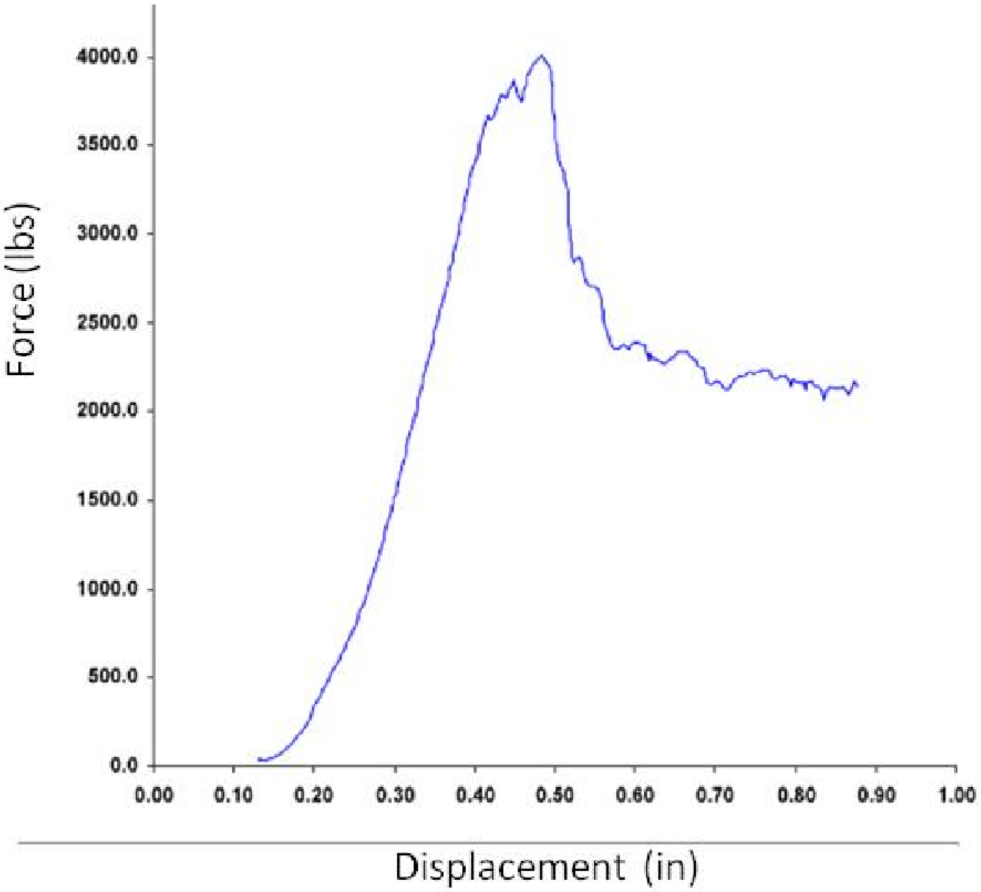


Figure 36: Force vs. Displacement of 3-inch diameter G12 Fiberglass Specimen

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 36.

This yield force resulted in a corresponding yield stress of approximately 42.7 ksi, as calculated in Figure 37. 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 37: Calculation of Yield Stress from Tensile Test Data

This test methodology is slotted to be performed on a specimen of Blue Tube 2.0 airframe by February 11th, 2017. Preparations have been made for reserving lab space and the equipment necessary for carrying out the test. The necessary bulk plates will be constructed during the coming days and will consist of machined 6061 Aluminum bar stock. After the creation of the bulk plates, testing will be able to commence in relatively short order, and data will be analyzed for comparison of Blue Tube 2.0 Against The existing data from the G12 Fiberglass specimen mentioned above.

Payload Testing

Table 16: Payload Test Overview

Test (7.1.1)	Objective (7.1.2)	Success Criteria (7.1.2)	Variable (7.1.2)	Methodology (7.1.2)	Completed? (Y/N)
FOPS: Impact test.	To determine if the dilatant will be able to protect the object	The fragile object does not break.	The height at which the system is dropped	FOPS is dropped from increasing height.	Y
FOPS: Optimal Concentration Determination	Determine which concentration is the most effective at reducing forces on the fragile object	The least amount of stress compared to the other concentrations is measured by the force sensor	The concentration of the fluid	Force sensors are placed in different concentrations of the non-Newtonian Fluid and dropped from	N

				the same height.	
Kiwi: Stability Test	Determine if the orientation of Kiwi will affect its ability to stabilize itself	Kiwi is able to correctly orient itself at all different starting attitudes	The beginning orientation of Kiwi	Kiwi is dropped from a set height at different orientations	N
Kiwi: Parachute Test	To determine if the parachute can safely slow the descent of Kiwi regardless of orientation	The parachute fully opens during descent regardless of orientation	The beginning orientation of Kiwi	Kiwi's parachute is activated at different orientations	N
Kiwi: Remote Turn off Distance Test	To determine the height at which Kiwi's parachute can be activated and the vehicle can be powered off in case of emergencies	Kiwi is powered off and the parachute is successfully deployed	The height at which the team attempts to power off Kiwi	The emergency power off button is activated midway through Kiwi's descent off of a parking deck	N

At this point in time, the team has only completed the first test in Table 16 for FOPS. The test procedure was to drop a cylindrical container filled with the dilatant and the fragile object (an egg) off of increasing levels of a parking deck. This test was a success, as the system protected the fragile object from any damage during each test run. This test served as proof of concept, and allowed LTRL to move forward with designing a system which would use the dilatant as its main source of protection.

Drag coefficient testing

Two experimental methods will be used to compensate for the high drag estimation in OpenRocket. One, through multiple full scale test launches it will be experimentally determined how much the actual apogee differs from simulations. If enough launches are performed than compensation for factors such a wind should be possible. If not, then this method will not be as effective but it will still prove useful in predicting apogee in the specific winds pertaining to each launch.

Two, by implementing wind tunnel testing on the subscale rocket. By taking drag force readings at varying wind speeds in the controlled tunnel environment, a drag coefficient profile can be developed as a function of rocket velocity. Due to limitations of the tunnel, the velocity will range from zero to approximately 120 ft/s. Now, although this velocity range is much lower than the maximum predicted rocket velocity, because the prediction does not exceed Mach 0.61, incompressibility will be assumed. Due to said assumption extrapolation is possible between the low speed tests and the much higher flight speeds. This testing has not yet occurred but will be performed in the Penn State Aerospace Department's Boundary Layer Tunnel in the coming months. Figure 38 is a schematic (not to scale) of the test setup.

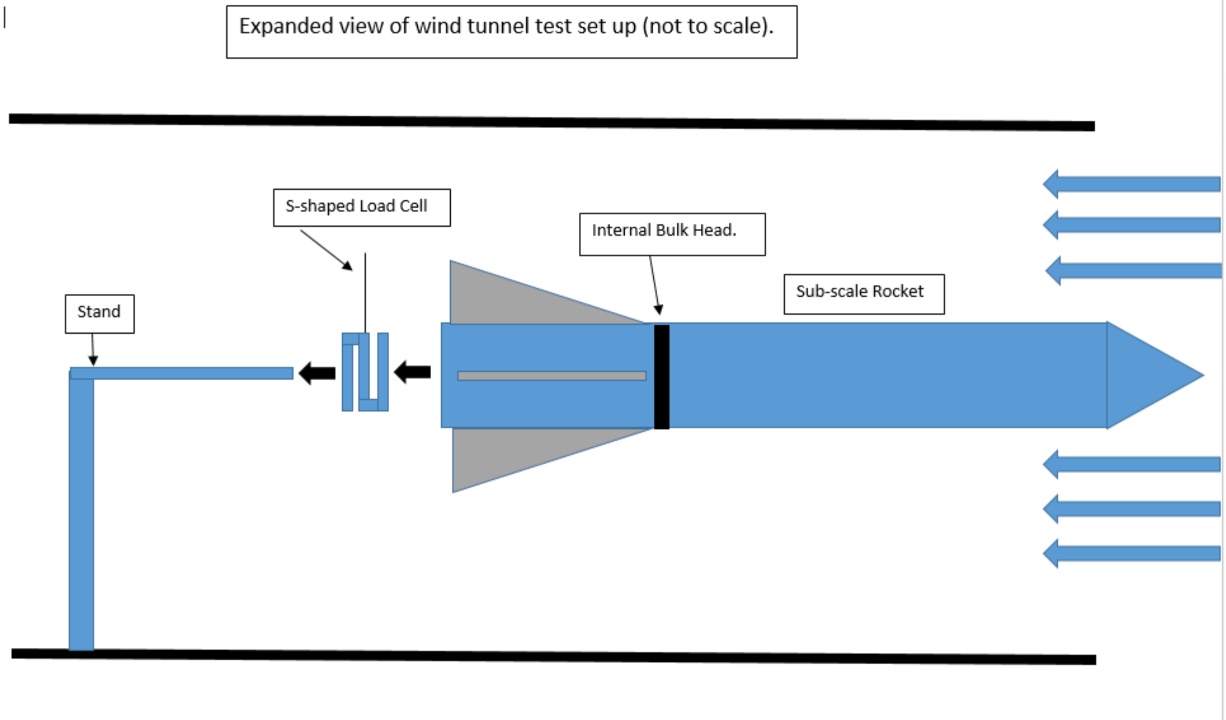


Figure 38: Diagram of Wind Tunnel Test Setup

Static Motor testing:

To further validate the flight predictions, section 3.4.1, the motor characteristics mentioned in section 3.1.2 are experimentally validated. This will be done under the supervision of trained and experienced researchers. During the testing characteristics such as burn time, peak thrust, average thrust, impulse, and the overall shape of the thrust curve will be determined for each tested motor and then compared to the specifications given by the manufacturer. This will ensure that the predictions based on the manufacturer specifications will not have error resulting from incorrect motor characteristics. The testing will use three L1350 motors in order for a standard deviation to be calculated for the various motor characteristics mentioned above. The standard deviation will also be used to verify consistency between motors and the given specifications. Figure 39 shows the motor testing setup. The I-Beam not shown in the figure is used to secure the entire assembly to ground during the static test firings. During which time all data will be collected via the 500 lb. load cell from within a concrete bunker. Static motor testing has not yet occurred, but is planned for the coming weeks.

Figure 39: Static Motor Test Setup

2: Requirements Compliance

Requirement Verification

Table 17: 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 two StratoLogger CF barometric altimeters, which are commercially available, 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. Our 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. Our 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 our 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.

Table 18: 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 test launch.
2.2	Demonstration	LTRL will ground test ejection charges before any subscale or full scale 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 dual 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 in order to arm each altimeter independently.
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 sections of the rocket will be tethered together, but if any are not, they will have independent GPS units. Specifically KIWI will fall independent with a second GPS unit.
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, and not be interfered with by 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.

Table 19: 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 autogyro payload will be flown in the rocket, but will not be submitted for scoring.
3.1.3	Inspection	The autogyro payload will be included in reports so that the safety of the project can be reviewed by overseeing engineers.
3.1.3	Inspection	The autogyro payload will be equipped with its own GPS.
3.1.3	Analysis	The autogyro 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.

Table 20: 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 manage 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 Alex Balcher
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.

Table 21: 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.

Team 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.

Table 22: 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.
1.5 Kiwi lands within 5 feet of the landing point.	Testing	Measure the distance between Kiwi's actual landing site and Kiwi's attempted landing site.
1.6 All parts of the fragile object protection system and Kiwi remain intact and fully functional during the duration of the rocket flight.	Testing	Include the protection system in subscale and full-scale test launches to test how the parts of the system withstand forces placed on them by the vehicle's flight.
1.7 All FOPS and Kiwi systems can be used in another flight.	Inspection/Analysis	Determine if the systems are structurally sound enough to be flown again
2 Avionics and Recovery		
2.1 The redundant altimeter will be at a delay	Demonstration	The redundant altimeter will be at a slight delay.

as to not overwhelm the body tube.		
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.
2.4.1 Avionics board will remain structurally sound throughout launch, descent, and landing.	Testing	The PLA avionics board will be tested prior to launch in high stress and high heat conditions.
2.4.2 3D printed AV Bay cover will be secured to the body tube coupler in such that the avionics bay as a whole will remain secured.	Testing/Demonstration	The avionics bay cover/coupler will be secured with a high factor of safety through the use of both epoxy and steel screws.
2.5 All electrical connections will be tightly secured throughout launch.	Inspection	On launch day all electrical connections between the altimeters, batteries, and e-matches will be double checked.
2.5.1 Battery terminal connections will remain tight throughout the launch.	Inspection	Design iterations of avionics bay moved batteries to a horizontal position within the rocket to account for inertial forces. Batteries are tightly secured eliminating any connection dislocations during flight.
2.6 Faraday cage will completely enclose the avionics bay.	Demonstration	Our faraday cage will extend completely around the perimeter of the avionics bay as

		well as above and below in order to provide complete coverage.
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
4.3 Proper lab safety equipment will be worn at all times.	Demonstration	It is a club and University requirement for all members to wear safety equipment in the lab.
4.4 Explosives will be stored in a safe environment.	Demonstration	All motors and black powder charges are stored at Penn State’s High Pressure Combustion Lab in a

		commercial grade explosive safe.
4.4.1 All handling of explosive material will be supervised by a level 2 NAR certified member.	Demonstration	LTRL will ensure that a level 2 certified member will monitor all procedures on launch day.
5 Structures		
5.1 Improve aerodynamics of launch vehicle	Testing	Components will be selected to maximize aerodynamic efficiency.
5.1.1 Camera cover aerodynamically efficient	Testing	Streamlines the protruding camera. Confirmed through wind tunnel testing.
5.1.2 Transition couplers aerodynamically efficient	Testing	3D printed transition pieces designed in order to streamline aerodynamics between different diameter sizes.
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.
5.3.1 Fin brackets used for removable fins, will survive flight and landing impacts.	Demonstration/Testing	Fin brackets have been tested for durability and demonstrated through use during the subscale flight.
5.4 Visually confirm payload status	Inspection	Launch vehicle will contain transparent section of airframe to obtain visual status of FOPS.
5.5 Recording of launch	Demonstration	On-board camera will record the entirety of the launch of the rocket.
5.6 Fins will not flutter during flight	Analysis	Fin thickness was increased to 3/16” to eliminate fin flutter.

5.7 Fins strength testing	Testing	Fins will be tested on shear strength.

3: Budget and Timeline

Line Item Expenses

Table 23: Projected Line Item Expenses

Full Scale			
Structures			
J-B Weld Adhesive 8270, Fast Hardening, 10 Ounce Tube	2	$20.12	$40.24
6” Blue Tube	2	$66.95	$133.90
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	$27.10
75mm Blue Tube	1	$29.95	$29.95
Bulkheads Inner	6	$7.61	$45.66
Bulkheads Outer	6	$8.93	$53.58
3/16” G10 Structural Fiberglass Sheet, 24" x 24"	2	$76.32	$152.64
5.5” 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
Freight Charges(Predicted)	1	$100.00	$100.00
Payload			
Arduino Nano	1	$25.00	$25.00
GPS	1	$80.00	$80.00
IMU	1	$20.00	$20.00
Rudder	1	$5.00	$5.00
Propeller	1	$5.00	$5.00

Top rotor	1	$5.00	$5.00
Miscellaneous (motors, servos, electrical connectors, etc.)	1	$150.00	$150.00
A&R			
StratoLogger CF Altimeter	3	$54.95	$164.85
Iris Ultra 72" Compact Parachute	1	$265.00	$265.00
18” Classical Elliptical Parachute	1	$53.00	$53.00
Shock Cord 100’	1	$133.22	$133.22
21” Nomex Blanket	1	$21.00	$21.00
13” Nomex Blanket	1	$16.00	$16.00
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.)	4	$209.00	$836.00
Cesaroni J290	2	$80.00	$160.00
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
Miscellaneous Expenses		$500.00	$500.00

Budget:

The projected expenditures for the 2016-2017 school year are included in Table 24. This table lists all expected costs for the club.

The full scale and subscale sections include the cost of building materials for the rocket plus additional supplies for material testing. The given subscale and full scale costs are final as all parts have been purchased. These exact prices can be seen in the line item expense table.

Propulsion encompasses all motors needed for subscale and full scale flights as well as additional motors of multiple sizes for motor testing. The specific motors are listed as line items and the total cost given reflects the summation of 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 taken into account 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 24: Updated Annual Expenses

Expected Costs 2016-2017	
Full Scale	$1,776.35
Subscale	$277.65
Propulsion	$1,183.00
Travel	$7,000.00
Outreach	$300.00
Miscellaneous Equipment	$750.82
Total	$11,287.82

Funding:

Funding for the USLI competition will be mainly provided through various academic sponsors who provide our club with financial aid. Table 25 shows the funding received from these various sources.

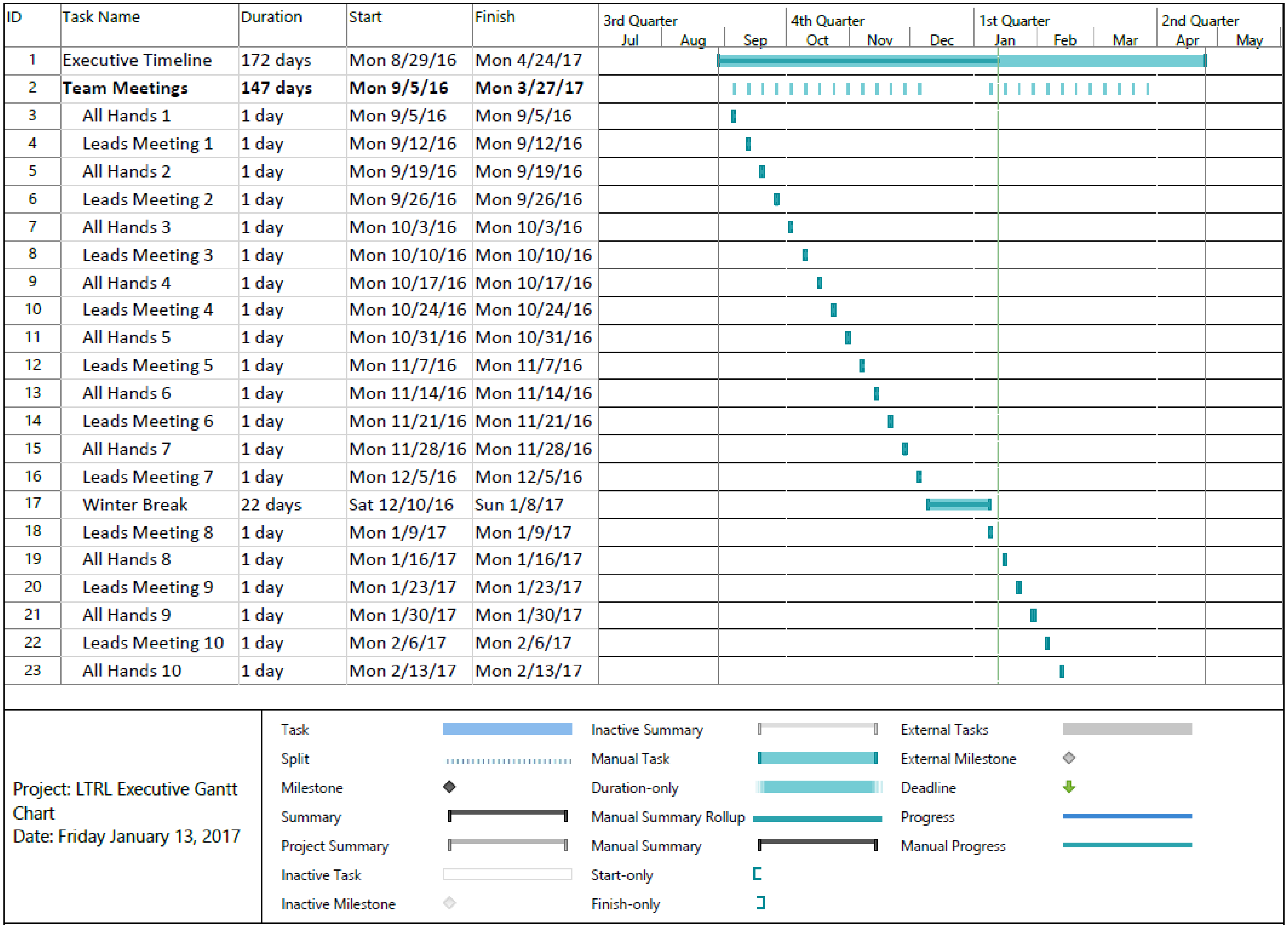
The Aerospace Department of Penn State has been the main sponsor of LTRL and they will continue to support our club this year. They have agreed to provide a donation of $5,000.00.
The Mechanical Department of Penn State has also agreed to support our club due to the large number of mechanical students involved. They have provided a donation of $1,000.00 to the club.
This year our club is proud to have received the Samuel A. Shuman Endowment in Engineering. This endowment is given to groups who work to advance education in engineering as well as improve the students experience. The money from this endowment will go directly towards the USLI Competition and travel to Alabama in order to provide our members with the best experience possible. This endowment was given to LTRL in the amount of $8,700.00.
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 our club in the past and has agreed to give a donation of $500.00 for this school year.

Since the club has received the Samuel A. Shuman Endowment in Engineering, there is no longer a need to continue to pursue additional sources of income. The income received this year has been very substantial and will easily cover our expected costs for this year's competition. The club also hopes to save some funding to jumpstart our preparation for next year's competition. Even though the club have been very successful in receiving funding this year, LTRL still wishes to continue developing new and existing relationships with academic departments. The Mechanical Engineering Department at Penn State supported our club this year and they are one department that LTRL wishes to solidify a relationship with in order to 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 in future years. Again the club plans to develop relationships with these groups in order to diversify our funding pool for the future.
Due to LTRL's success in acquiring additional funding, our goals for the year have been expanded in order to further student participation, learning, and development. LTRL is currently looking into ways to do this that may include more club launches of the current and past subscale rockets, as well as club driven research or activities aimed towards expanding students' knowledge of rocketry. NAR certifications are another example of how the club will continue to encourage students to diversify their experience within the club beyond one specific subsystem.

Table 25: Expected Income

2016-2017 Income	
Aerospace Engineering Department	$5,000.00
Mechanical Engineering Department	$1,000.00
Samuel A. Shuman Endowment in Engineering	$8,700.00
Club Fundraising	$1,500.00
The Boeing Company	$500.00
Total	$16,700.00

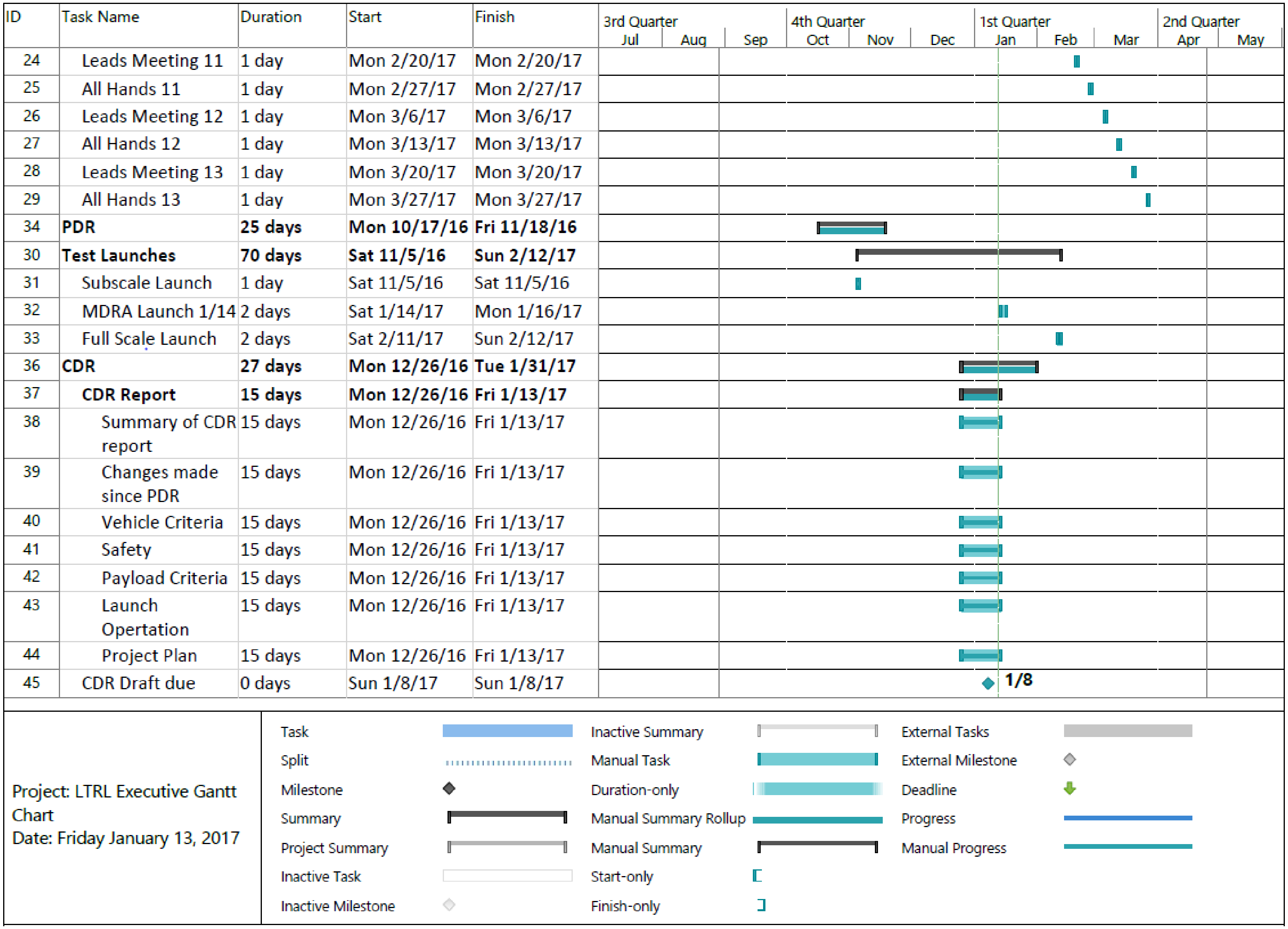
Project Timelines



ID	Task Name	Duration	Start	Finish
1	Executive Timeline	172 days	Mon 8/29/16	Mon 4/24/17
2	**Team Meetings**	**147 days**	**Mon 9/5/16**	**Mon 3/27/17**
3	All Hands 1	1 day	Mon 9/5/16	Mon 9/5/16
4	Leads Meeting 1	1 day	Mon 9/12/16	Mon 9/12/16
5	All Hands 2	1 day	Mon 9/19/16	Mon 9/19/16
6	Leads Meeting 2	1 day	Mon 9/26/16	Mon 9/26/16
7	All Hands 3	1 day	Mon 10/3/16	Mon 10/3/16
8	Leads Meeting 3	1 day	Mon 10/10/16	Mon 10/10/16
9	All Hands 4	1 day	Mon 10/17/16	Mon 10/17/16
10	Leads Meeting 4	1 day	Mon 10/24/16	Mon 10/24/16
11	All Hands 5	1 day	Mon 10/31/16	Mon 10/31/16
12	Leads Meeting 5	1 day	Mon 11/7/16	Mon 11/7/16
13	All Hands 6	1 day	Mon 11/14/16	Mon 11/14/16
14	Leads Meeting 6	1 day	Mon 11/21/16	Mon 11/21/16
15	All Hands 7	1 day	Mon 11/28/16	Mon 11/28/16
16	Leads Meeting 7	1 day	Mon 12/5/16	Mon 12/5/16
17	Winter Break	22 days	Sat 12/10/16	Sun 1/8/17
18	Leads Meeting 8	1 day	Mon 1/9/17	Mon 1/9/17
19	All Hands 8	1 day	Mon 1/16/17	Mon 1/16/17
20	Leads Meeting 9	1 day	Mon 1/23/17	Mon 1/23/17
21	All Hands 9	1 day	Mon 1/30/17	Mon 1/30/17
22	Leads Meeting 10	1 day	Mon 2/6/17	Mon 2/6/17
23	All Hands 10	1 day	Mon 2/13/17	Mon 2/13/17

Project: LTRL Executive Gantt Chart
Date: Friday January 13, 2017

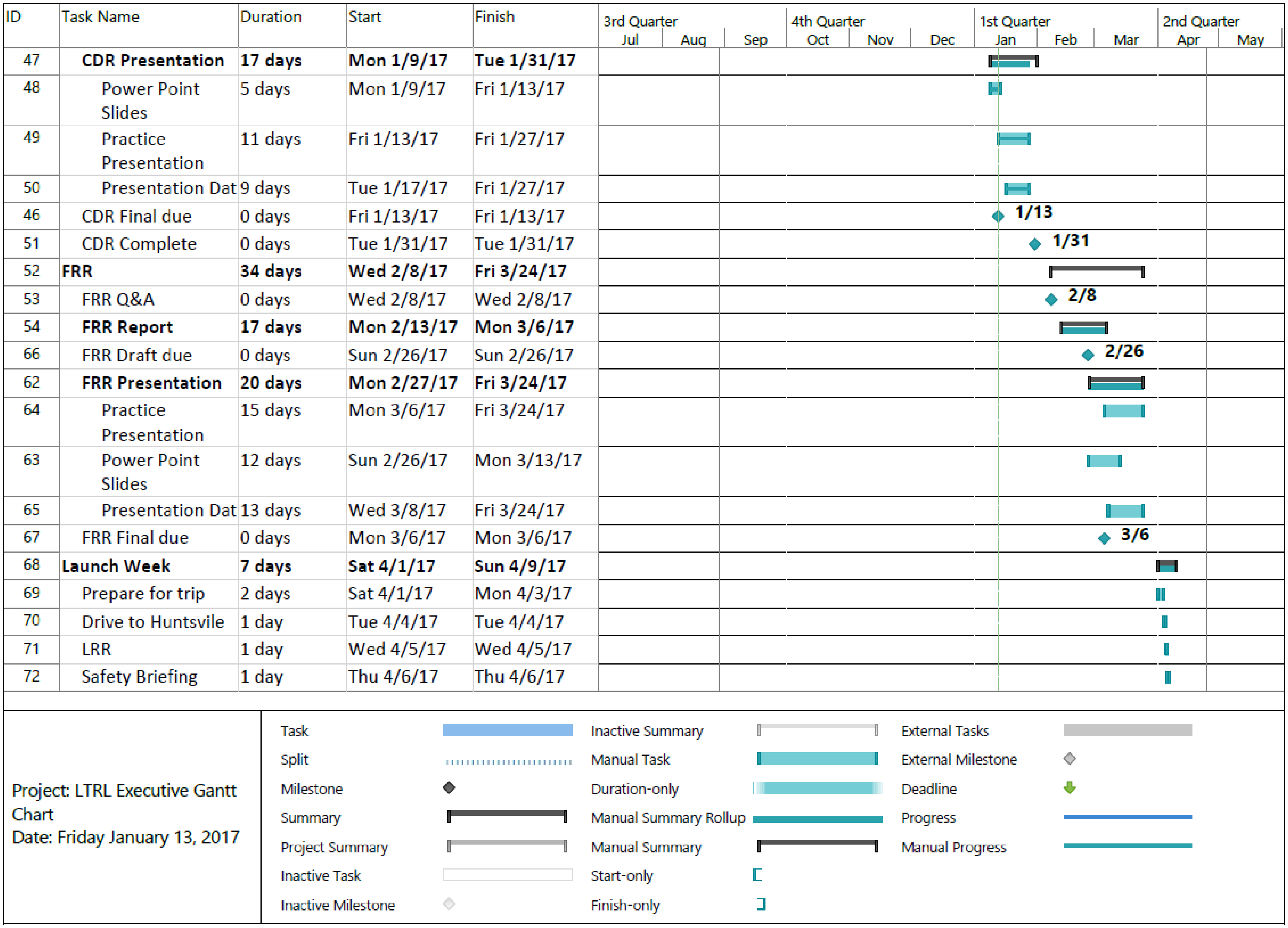
Figure 40: Executive Timeline Page 1 of 4



ID	Task Name	Duration	Start	Finish
24	Leads Meeting 11	1 day	Mon 2/20/17	Mon 2/20/17
25	All Hands 11	1 day	Mon 2/27/17	Mon 2/27/17
26	Leads Meeting 12	1 day	Mon 3/6/17	Mon 3/6/17
27	All Hands 12	1 day	Mon 3/13/17	Mon 3/13/17
28	Leads Meeting 13	1 day	Mon 3/20/17	Mon 3/20/17
29	All Hands 13	1 day	Mon 3/27/17	Mon 3/27/17
34	**PDR**	**25 days**	**Mon 10/17/16**	**Fri 11/18/16**
30	**Test Launches**	**70 days**	**Sat 11/5/16**	**Sun 2/12/17**
31	Subscale Launch	1 day	Sat 11/5/16	Sat 11/5/16
32	MDRA Launch 1/14	2 days	Sat 1/14/17	Mon 1/16/17
33	Full Scale Launch	2 days	Sat 2/11/17	Sun 2/12/17
36	**CDR**	**27 days**	**Mon 12/26/16**	**Tue 1/31/17**
37	**CDR Report**	**15 days**	**Mon 12/26/16**	**Fri 1/13/17**
38	Summary of CDR report	15 days	Mon 12/26/16	Fri 1/13/17
39	Changes made since PDR	15 days	Mon 12/26/16	Fri 1/13/17
40	Vehicle Criteria	15 days	Mon 12/26/16	Fri 1/13/17
41	Safety	15 days	Mon 12/26/16	Fri 1/13/17
42	Payload Criteria	15 days	Mon 12/26/16	Fri 1/13/17
43	Launch Operation	15 days	Mon 12/26/16	Fri 1/13/17
44	Project Plan	15 days	Mon 12/26/16	Fri 1/13/17
45	CDR Draft due	0 days	Sun 1/8/17	Sun 1/8/17

Project: LTRL Executive Gantt Chart
Date: Friday January 13, 2017

Figure 41: Executive Timeline Page 2 of 4

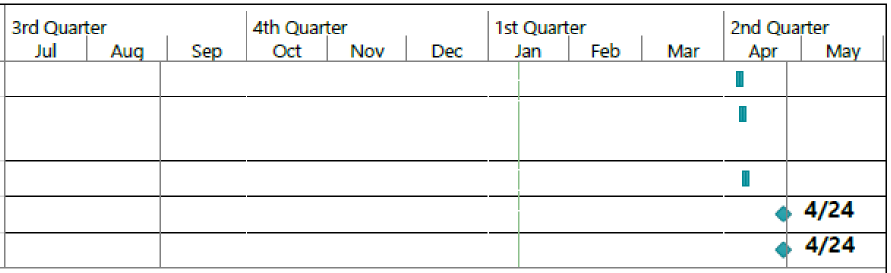


ID	Task Name	Duration	Start	Finish
47	**CDR Presentation**	**17 days**	**Mon 1/9/17**	**Tue 1/31/17**
48	Power Point Slides	5 days	Mon 1/9/17	Fri 1/13/17
49	Practice Presentation	11 days	Fri 1/13/17	Fri 1/27/17
50	Presentation Dat	9 days	Tue 1/17/17	Fri 1/27/17
46	CDR Final due	0 days	Fri 1/13/17	Fri 1/13/17
51	CDR Complete	0 days	Tue 1/31/17	Tue 1/31/17
52	**FRR**	**34 days**	**Wed 2/8/17**	**Fri 3/24/17**
53	FRR Q&A	0 days	Wed 2/8/17	Wed 2/8/17
54	**FRR Report**	**17 days**	**Mon 2/13/17**	**Mon 3/6/17**
66	FRR Draft due	0 days	Sun 2/26/17	Sun 2/26/17
62	**FRR Presentation**	**20 days**	**Mon 2/27/17**	**Fri 3/24/17**
64	Practice Presentation	15 days	Mon 3/6/17	Fri 3/24/17
63	Power Point Slides	12 days	Sun 2/26/17	Mon 3/13/17
65	Presentation Dat	13 days	Wed 3/8/17	Fri 3/24/17
67	FRR Final due	0 days	Mon 3/6/17	Mon 3/6/17
68	**Launch Week**	**7 days**	**Sat 4/1/17**	**Sun 4/9/17**
69	Prepare for trip	2 days	Sat 4/1/17	Mon 4/3/17
70	Drive to Huntsvile	1 day	Tue 4/4/17	Tue 4/4/17
71	LRR	1 day	Wed 4/5/17	Wed 4/5/17
72	Safety Briefing	1 day	Thu 4/6/17	Thu 4/6/17

Project: LTRL Executive Gantt Chart
Date: Friday January 13, 2017

Figure 42: Executive Timeline Page 3 of 4

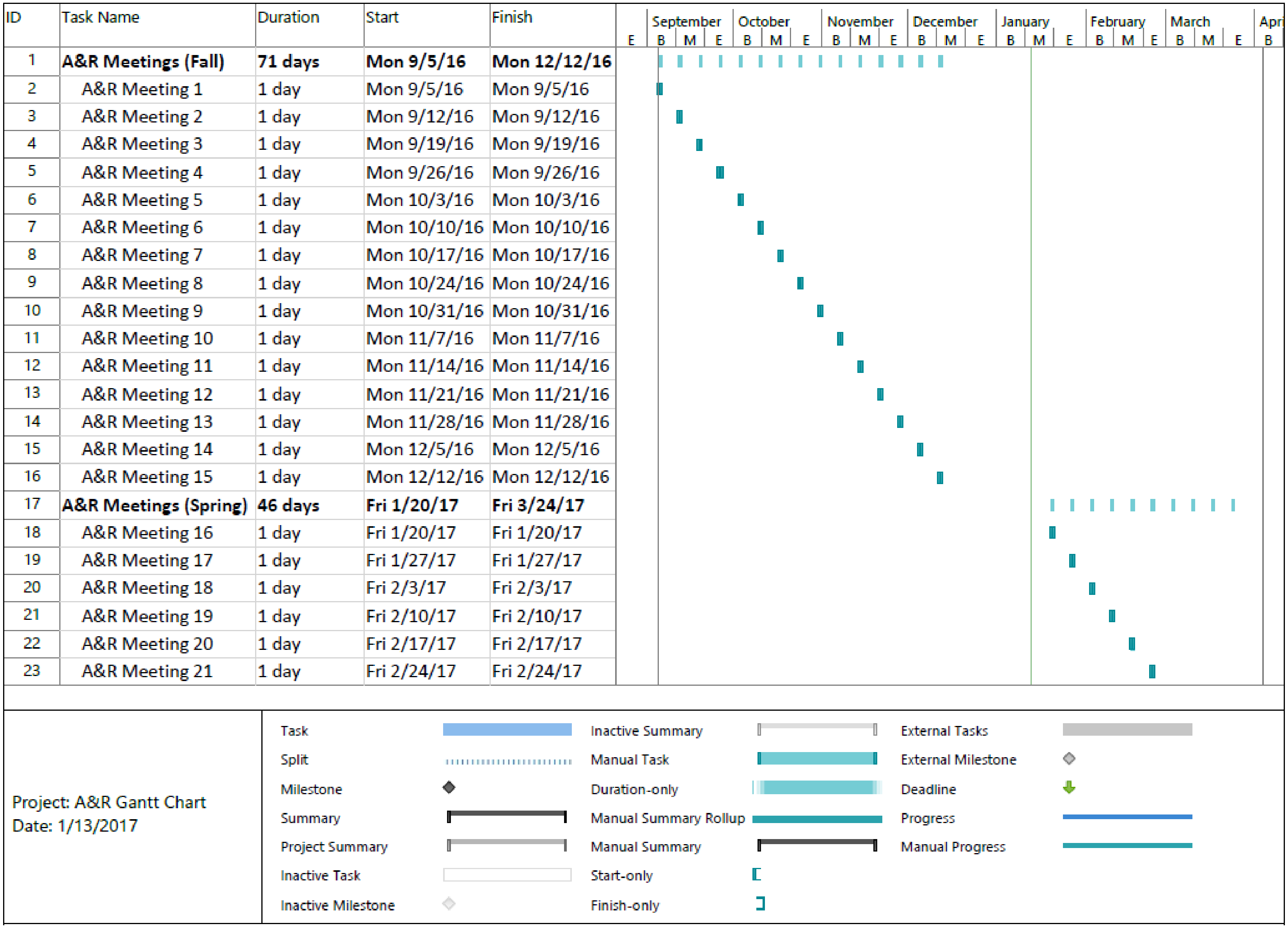
ID	Task Name	Duration	Start	Finish
73	Rocket Fair and Tou	1 day	Fri 4/7/17	Fri 4/7/17
74	Launch Day and Banquet	1 day	Sat 4/8/17	Sat 4/8/17
75	Backup Launch Day	1 day	Sun 4/9/17	Sun 4/9/17
76	PLAR Due	0 days	Mon 4/24/17	Mon 4/24/17
77	NASA USLI Complete	0 days	Mon 4/24/17	Mon 4/24/17



Project: LTRL Executive Gantt Chart
Date: Friday January 13, 2017

Task	▬	Inactive Summary	▭	External Tasks	▬
Split	┈	Manual Task	▬	External Milestone	◇
Milestone	◆	Duration-only	▬	Deadline	⬇
Summary	▬	Manual Summary Rollup	▬	Progress	▬
Project Summary	▬	Manual Summary	▬	Manual Progress	▬
Inactive Task	▭	Start-only	[		
Inactive Milestone	◇	Finish-only	]		

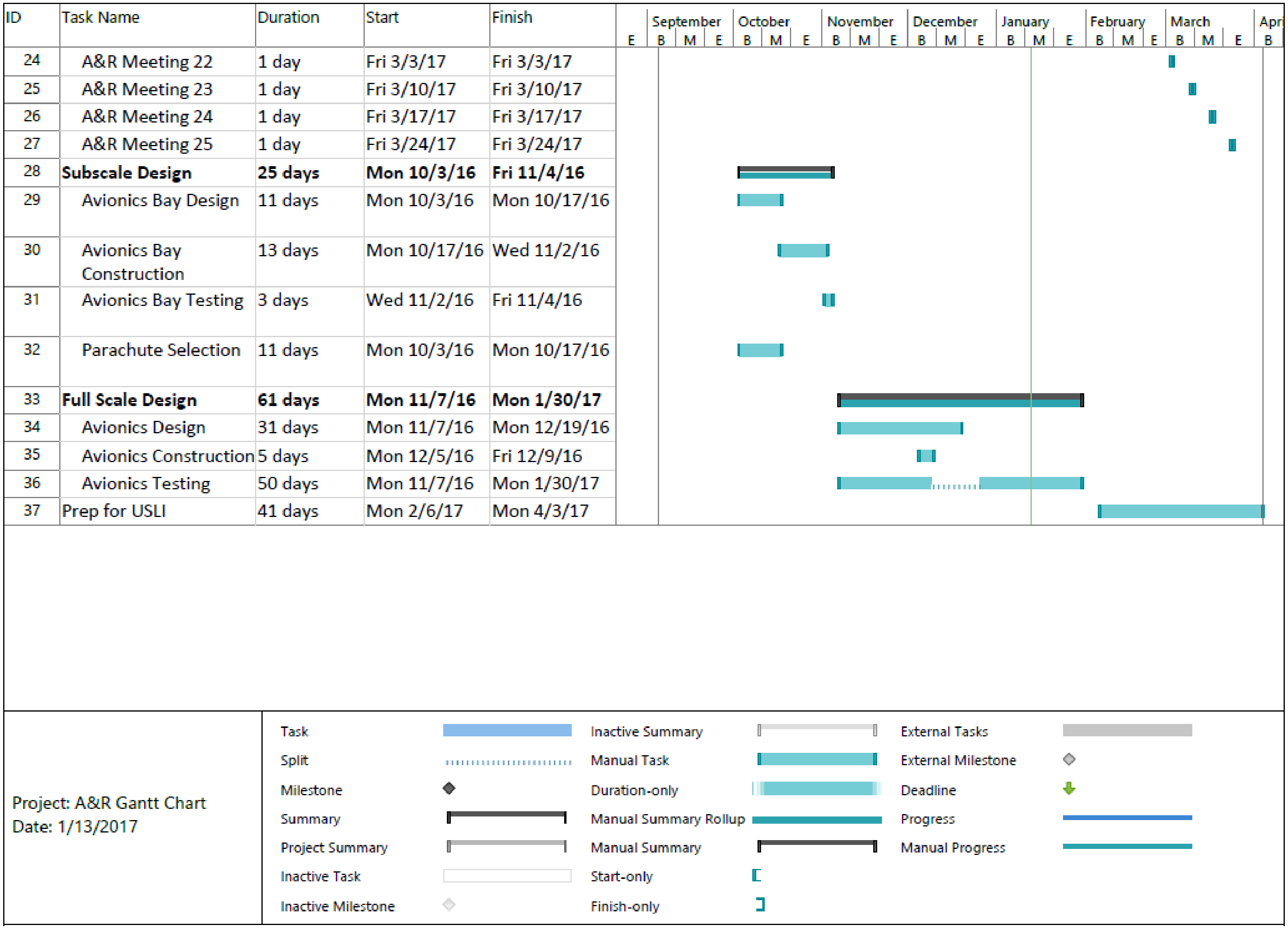
Figure 43: Executive Timeline Page 4 of 4



ID	Task Name	Duration	Start	Finish
1	**A&R Meetings (Fall)**	**71 days**	**Mon 9/5/16**	**Mon 12/12/16**
2	A&R Meeting 1	1 day	Mon 9/5/16	Mon 9/5/16
3	A&R Meeting 2	1 day	Mon 9/12/16	Mon 9/12/16
4	A&R Meeting 3	1 day	Mon 9/19/16	Mon 9/19/16
5	A&R Meeting 4	1 day	Mon 9/26/16	Mon 9/26/16
6	A&R Meeting 5	1 day	Mon 10/3/16	Mon 10/3/16
7	A&R Meeting 6	1 day	Mon 10/10/16	Mon 10/10/16
8	A&R Meeting 7	1 day	Mon 10/17/16	Mon 10/17/16
9	A&R Meeting 8	1 day	Mon 10/24/16	Mon 10/24/16
10	A&R Meeting 9	1 day	Mon 10/31/16	Mon 10/31/16
11	A&R Meeting 10	1 day	Mon 11/7/16	Mon 11/7/16
12	A&R Meeting 11	1 day	Mon 11/14/16	Mon 11/14/16
13	A&R Meeting 12	1 day	Mon 11/21/16	Mon 11/21/16
14	A&R Meeting 13	1 day	Mon 11/28/16	Mon 11/28/16
15	A&R Meeting 14	1 day	Mon 12/5/16	Mon 12/5/16
16	A&R Meeting 15	1 day	Mon 12/12/16	Mon 12/12/16
17	**A&R Meetings (Spring)**	**46 days**	**Fri 1/20/17**	**Fri 3/24/17**
18	A&R Meeting 16	1 day	Fri 1/20/17	Fri 1/20/17
19	A&R Meeting 17	1 day	Fri 1/27/17	Fri 1/27/17
20	A&R Meeting 18	1 day	Fri 2/3/17	Fri 2/3/17
21	A&R Meeting 19	1 day	Fri 2/10/17	Fri 2/10/17
22	A&R Meeting 20	1 day	Fri 2/17/17	Fri 2/17/17
23	A&R Meeting 21	1 day	Fri 2/24/17	Fri 2/24/17

Project: A&R Gantt Chart
Date: 1/13/2017

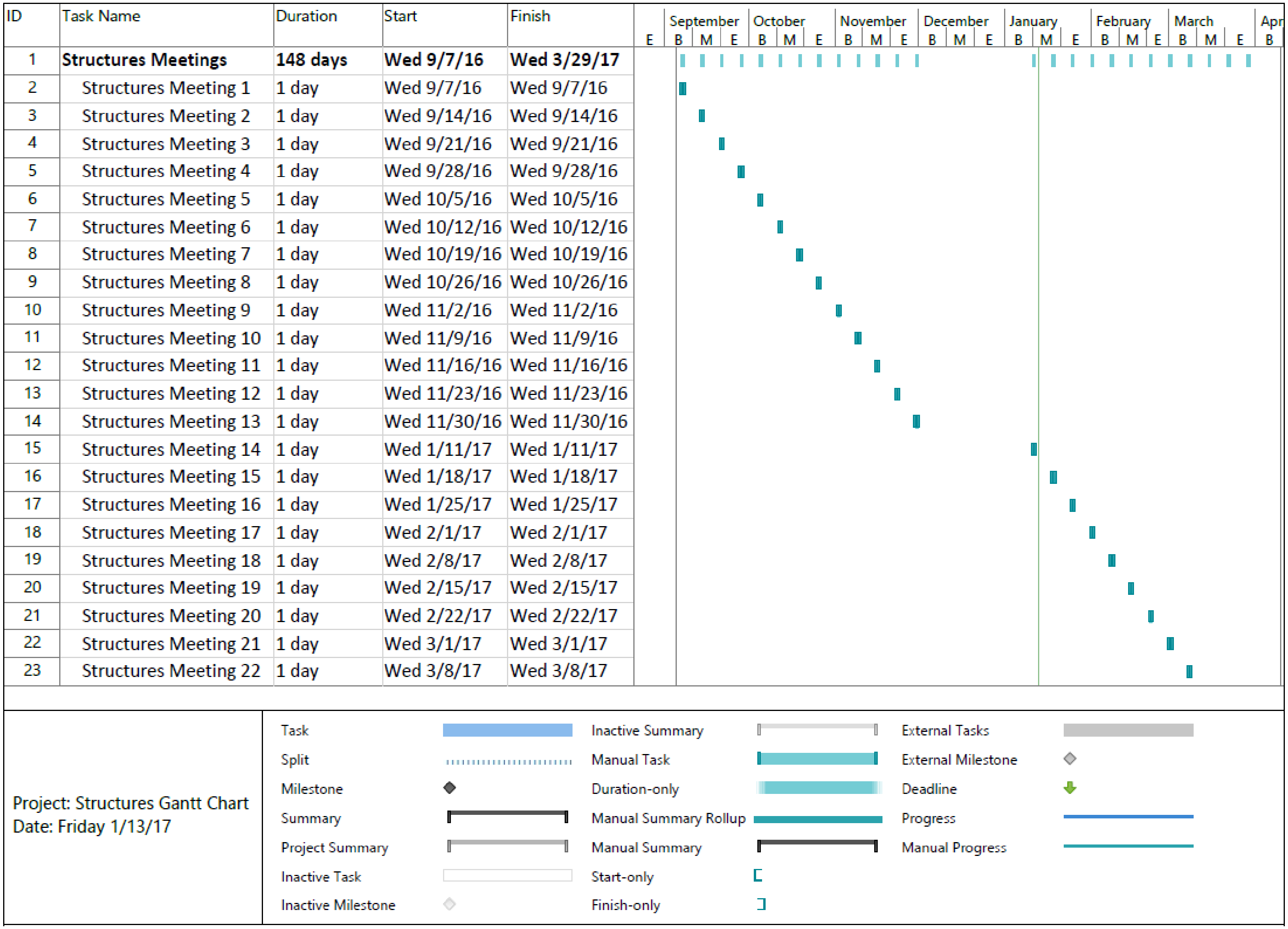
Figure 44: A&R Timeline Page 1 of 2



ID	Task Name	Duration	Start	Finish
24	A&R Meeting 22	1 day	Fri 3/3/17	Fri 3/3/17
25	A&R Meeting 23	1 day	Fri 3/10/17	Fri 3/10/17
26	A&R Meeting 24	1 day	Fri 3/17/17	Fri 3/17/17
27	A&R Meeting 25	1 day	Fri 3/24/17	Fri 3/24/17
28	**Subscale Design**	**25 days**	**Mon 10/3/16**	**Fri 11/4/16**
29	Avionics Bay Design	11 days	Mon 10/3/16	Mon 10/17/16
30	Avionics Bay Construction	13 days	Mon 10/17/16	Wed 11/2/16
31	Avionics Bay Testing	3 days	Wed 11/2/16	Fri 11/4/16
32	Parachute Selection	11 days	Mon 10/3/16	Mon 10/17/16
33	**Full Scale Design**	**61 days**	**Mon 11/7/16**	**Mon 1/30/17**
34	Avionics Design	31 days	Mon 11/7/16	Mon 12/19/16
35	Avionics Construction	5 days	Mon 12/5/16	Fri 12/9/16
36	Avionics Testing	50 days	Mon 11/7/16	Mon 1/30/17
37	Prep for USLI	41 days	Mon 2/6/17	Mon 4/3/17

Project: A&R Gantt Chart
Date: 1/13/2017

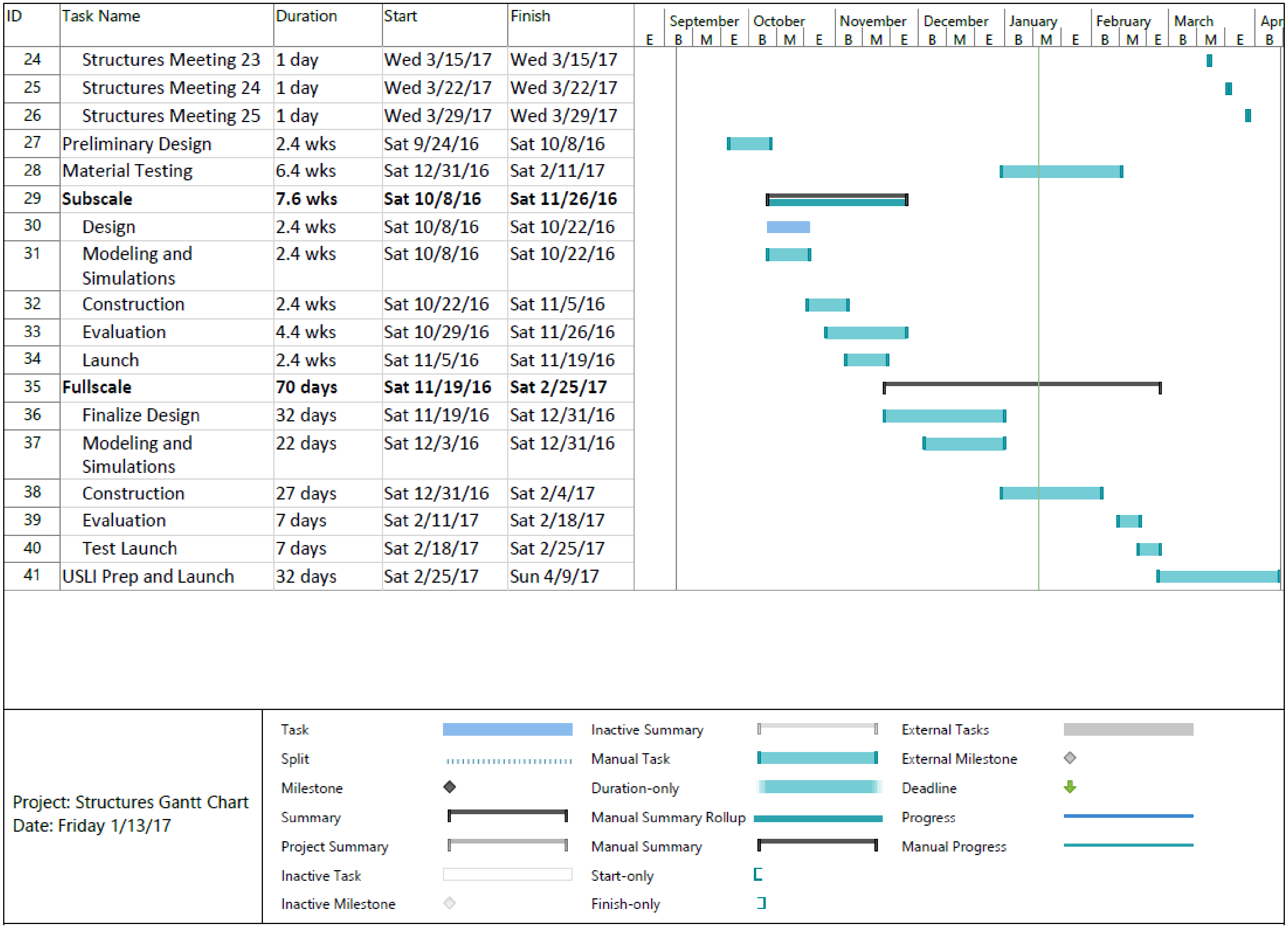
Figure 45: A&R Timeline Page 2 of 2



ID	Task Name	Duration	Start	Finish
1	**Structures Meetings**	**148 days**	**Wed 9/7/16**	**Wed 3/29/17**
2	Structures Meeting 1	1 day	Wed 9/7/16	Wed 9/7/16
3	Structures Meeting 2	1 day	Wed 9/14/16	Wed 9/14/16
4	Structures Meeting 3	1 day	Wed 9/21/16	Wed 9/21/16
5	Structures Meeting 4	1 day	Wed 9/28/16	Wed 9/28/16
6	Structures Meeting 5	1 day	Wed 10/5/16	Wed 10/5/16
7	Structures Meeting 6	1 day	Wed 10/12/16	Wed 10/12/16
8	Structures Meeting 7	1 day	Wed 10/19/16	Wed 10/19/16
9	Structures Meeting 8	1 day	Wed 10/26/16	Wed 10/26/16
10	Structures Meeting 9	1 day	Wed 11/2/16	Wed 11/2/16
11	Structures Meeting 10	1 day	Wed 11/9/16	Wed 11/9/16
12	Structures Meeting 11	1 day	Wed 11/16/16	Wed 11/16/16
13	Structures Meeting 12	1 day	Wed 11/23/16	Wed 11/23/16
14	Structures Meeting 13	1 day	Wed 11/30/16	Wed 11/30/16
15	Structures Meeting 14	1 day	Wed 1/11/17	Wed 1/11/17
16	Structures Meeting 15	1 day	Wed 1/18/17	Wed 1/18/17
17	Structures Meeting 16	1 day	Wed 1/25/17	Wed 1/25/17
18	Structures Meeting 17	1 day	Wed 2/1/17	Wed 2/1/17
19	Structures Meeting 18	1 day	Wed 2/8/17	Wed 2/8/17
20	Structures Meeting 19	1 day	Wed 2/15/17	Wed 2/15/17
21	Structures Meeting 20	1 day	Wed 2/22/17	Wed 2/22/17
22	Structures Meeting 21	1 day	Wed 3/1/17	Wed 3/1/17
23	Structures Meeting 22	1 day	Wed 3/8/17	Wed 3/8/17

Project: Structures Gantt Chart
Date: Friday 1/13/17

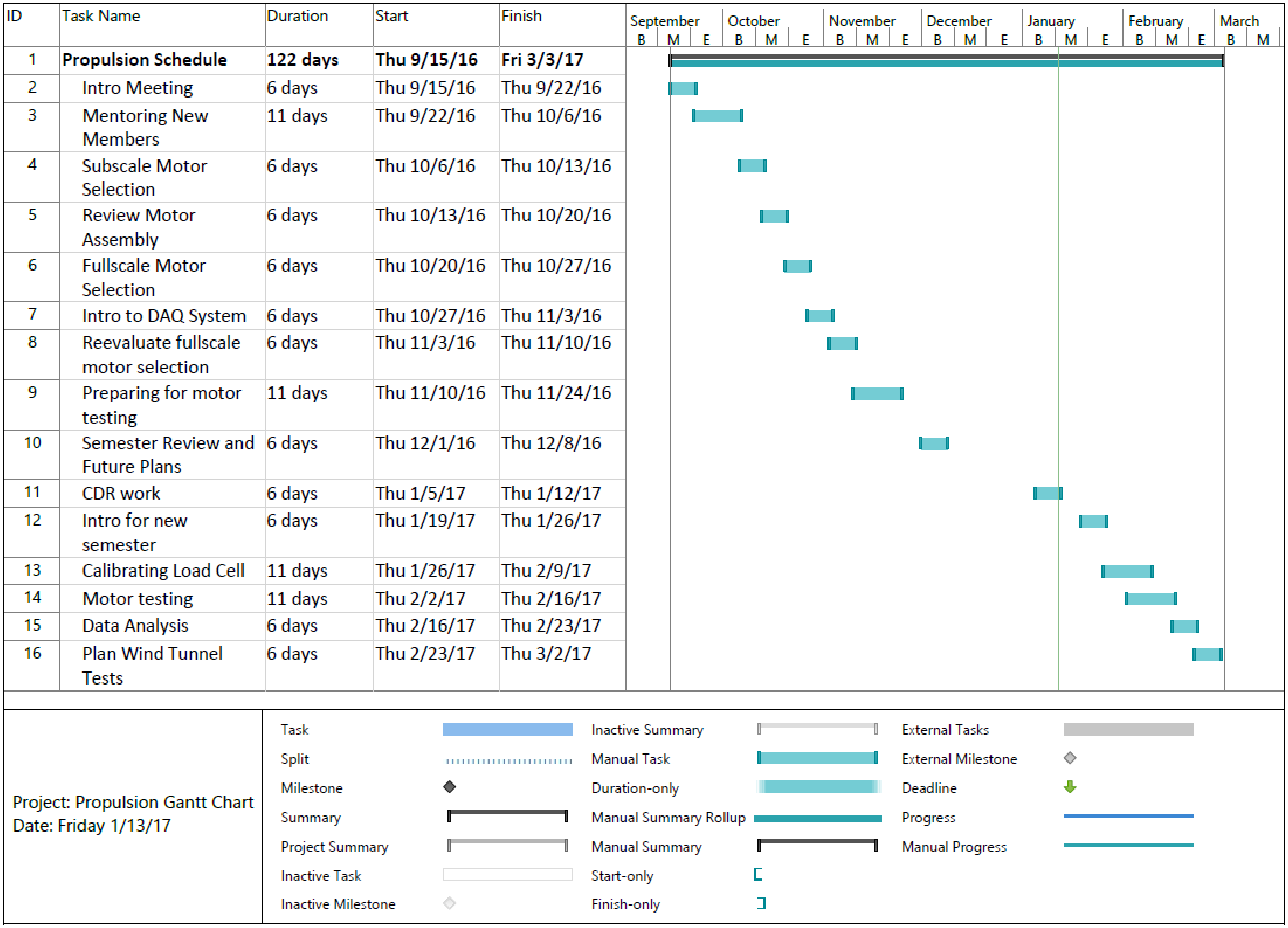
Figure 46: Structures Timeline Page 1 of 2



ID	Task Name	Duration	Start	Finish
24	Structures Meeting 23	1 day	Wed 3/15/17	Wed 3/15/17
25	Structures Meeting 24	1 day	Wed 3/22/17	Wed 3/22/17
26	Structures Meeting 25	1 day	Wed 3/29/17	Wed 3/29/17
27	Preliminary Design	2.4 wks	Sat 9/24/16	Sat 10/8/16
28	Material Testing	6.4 wks	Sat 12/31/16	Sat 2/11/17
29	**Subscale**	**7.6 wks**	**Sat 10/8/16**	**Sat 11/26/16**
30	Design	2.4 wks	Sat 10/8/16	Sat 10/22/16
31	Modeling and Simulations	2.4 wks	Sat 10/8/16	Sat 10/22/16
32	Construction	2.4 wks	Sat 10/22/16	Sat 11/5/16
33	Evaluation	4.4 wks	Sat 10/29/16	Sat 11/26/16
34	Launch	2.4 wks	Sat 11/5/16	Sat 11/19/16
35	**Fullscale**	**70 days**	**Sat 11/19/16**	**Sat 2/25/17**
36	Finalize Design	32 days	Sat 11/19/16	Sat 12/31/16
37	Modeling and Simulations	22 days	Sat 12/3/16	Sat 12/31/16
38	Construction	27 days	Sat 12/31/16	Sat 2/4/17
39	Evaluation	7 days	Sat 2/11/17	Sat 2/18/17
40	Test Launch	7 days	Sat 2/18/17	Sat 2/25/17
41	USLI Prep and Launch	32 days	Sat 2/25/17	Sun 4/9/17

Project: Structures Gantt Chart
Date: Friday 1/13/17

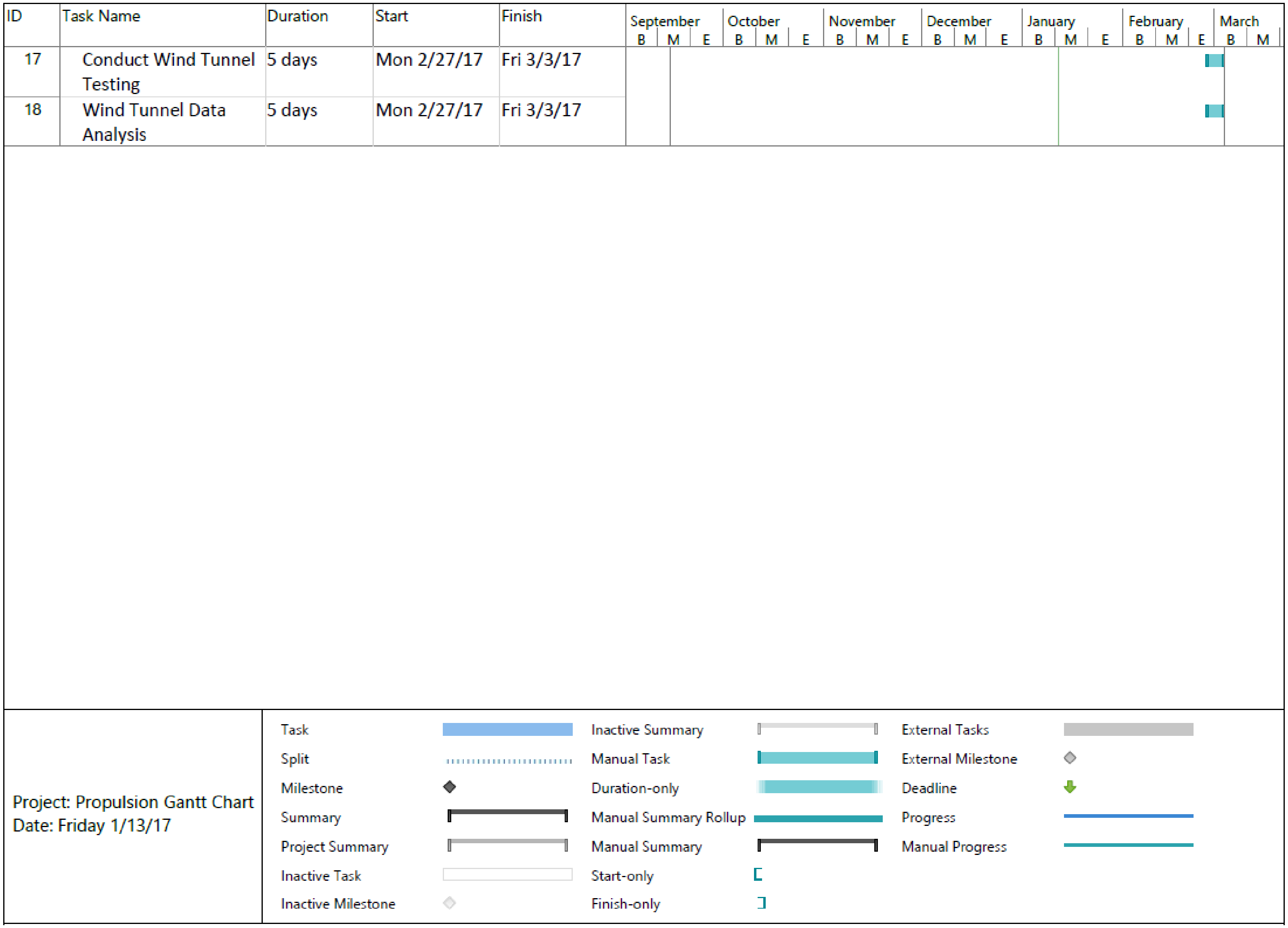
Figure 47: Structures Timeline Page 2 of 2



ID	Task Name	Duration	Start	Finish
1	**Propulsion Schedule**	**122 days**	**Thu 9/15/16**	**Fri 3/3/17**
2	Intro Meeting	6 days	Thu 9/15/16	Thu 9/22/16
3	Mentoring New Members	11 days	Thu 9/22/16	Thu 10/6/16
4	Subscale Motor Selection	6 days	Thu 10/6/16	Thu 10/13/16
5	Review Motor Assembly	6 days	Thu 10/13/16	Thu 10/20/16
6	Fullscale Motor Selection	6 days	Thu 10/20/16	Thu 10/27/16
7	Intro to DAQ System	6 days	Thu 10/27/16	Thu 11/3/16
8	Reevaluate fullscale motor selection	6 days	Thu 11/3/16	Thu 11/10/16
9	Preparing for motor testing	11 days	Thu 11/10/16	Thu 11/24/16
10	Semester Review and Future Plans	6 days	Thu 12/1/16	Thu 12/8/16
11	CDR work	6 days	Thu 1/5/17	Thu 1/12/17
12	Intro for new semester	6 days	Thu 1/19/17	Thu 1/26/17
13	Calibrating Load Cell	11 days	Thu 1/26/17	Thu 2/9/17
14	Motor testing	11 days	Thu 2/2/17	Thu 2/16/17
15	Data Analysis	6 days	Thu 2/16/17	Thu 2/23/17
16	Plan Wind Tunnel Tests	6 days	Thu 2/23/17	Thu 3/2/17

Project: Propulsion Gantt Chart
Date: Friday 1/13/17

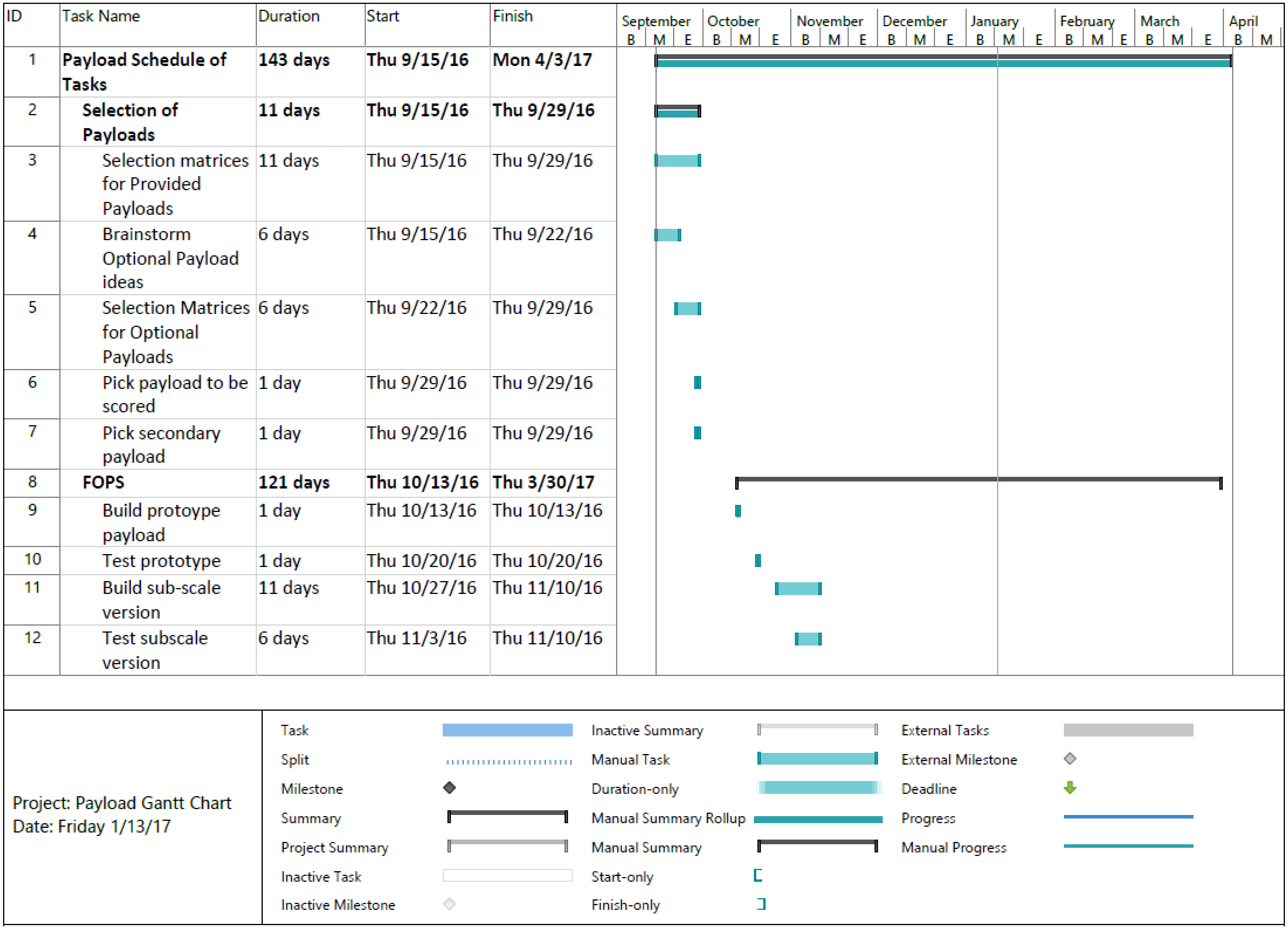
Figure 48: Propulsion Timeline Page 1 of 2



ID	Task Name	Duration	Start	Finish
17	Conduct Wind Tunnel Testing	5 days	Mon 2/27/17	Fri 3/3/17
18	Wind Tunnel Data Analysis	5 days	Mon 2/27/17	Fri 3/3/17

Project: Propulsion Gantt Chart
Date: Friday 1/13/17

Figure 49: Propulsion Timeline Page 2 of 2

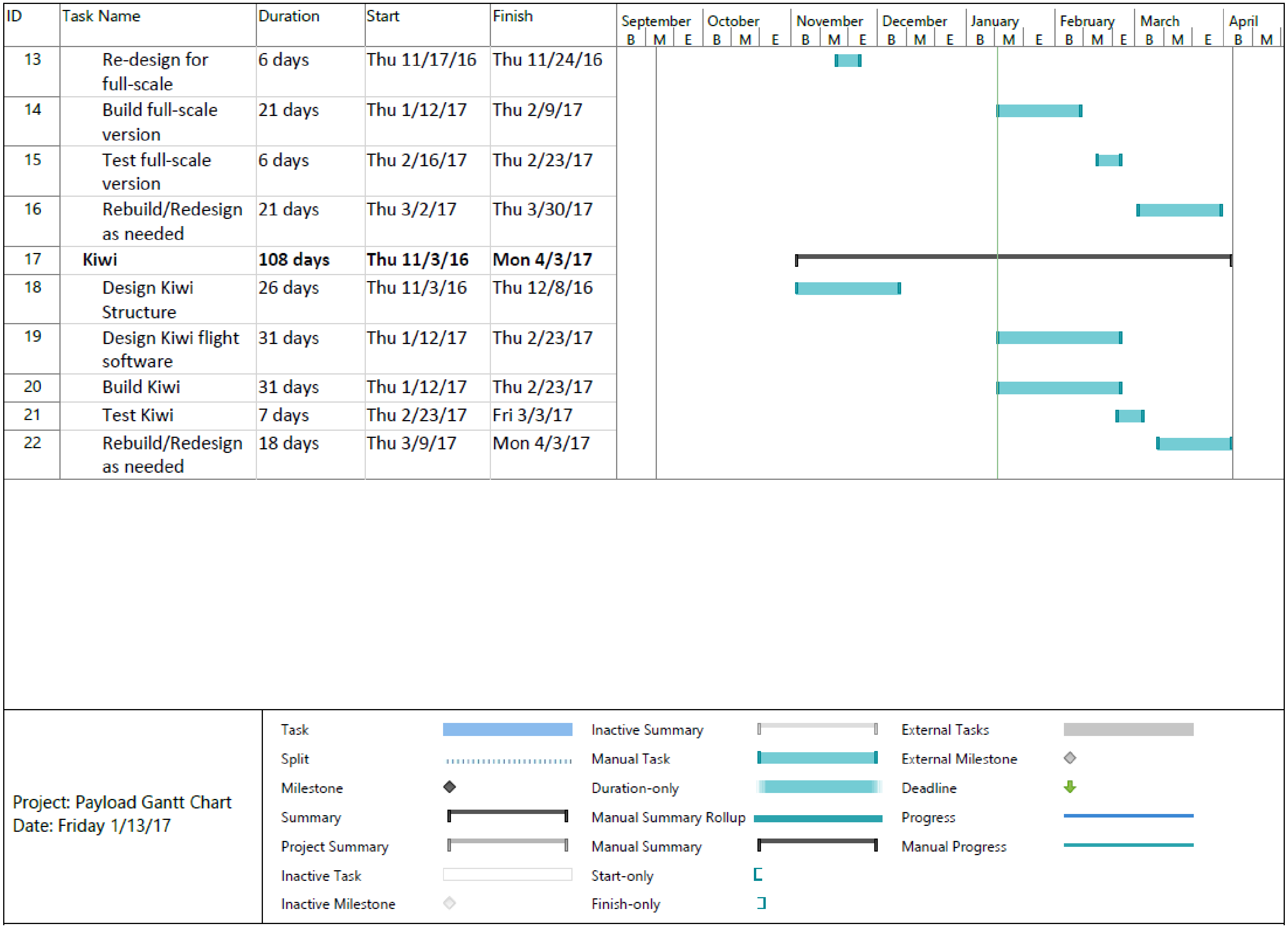


ID	Task Name	Duration	Start	Finish
1	**Payload Schedule of Tasks**	**143 days**	**Thu 9/15/16**	**Mon 4/3/17**
2	**Selection of Payloads**	**11 days**	**Thu 9/15/16**	**Thu 9/29/16**
3	Selection matrices for Provided Payloads	11 days	Thu 9/15/16	Thu 9/29/16
4	Brainstorm Optional Payload ideas	6 days	Thu 9/15/16	Thu 9/22/16
5	Selection Matrices for Optional Payloads	6 days	Thu 9/22/16	Thu 9/29/16
6	Pick payload to be scored	1 day	Thu 9/29/16	Thu 9/29/16
7	Pick secondary payload	1 day	Thu 9/29/16	Thu 9/29/16
8	**FOPS**	**121 days**	**Thu 10/13/16**	**Thu 3/30/17**
9	Build protoype payload	1 day	Thu 10/13/16	Thu 10/13/16
10	Test prototype	1 day	Thu 10/20/16	Thu 10/20/16
11	Build sub-scale version	11 days	Thu 10/27/16	Thu 11/10/16
12	Test subscale version	6 days	Thu 11/3/16	Thu 11/10/16

Project: Payload Gantt Chart
Date: Friday 1/13/17

Task	▬	Inactive Summary	▭	External Tasks	▬
Split	┈	Manual Task	▬	External Milestone	◇
Milestone	◆	Duration-only	▬	Deadline	⇩
Summary	▬	Manual Summary Rollup	▬	Progress	─
Project Summary	▬	Manual Summary	▬	Manual Progress	─
Inactive Task	▭	Start-only	[		
Inactive Milestone	◇	Finish-only	]		

Figure 50: Payload Timeline Page 1 of 2



ID	Task Name	Duration	Start	Finish
13	Re-design for full-scale	6 days	Thu 11/17/16	Thu 11/24/16
14	Build full-scale version	21 days	Thu 1/12/17	Thu 2/9/17
15	Test full-scale version	6 days	Thu 2/16/17	Thu 2/23/17
16	Rebuild/Redesign as needed	21 days	Thu 3/2/17	Thu 3/30/17
17	**Kiwi**	**108 days**	**Thu 11/3/16**	**Mon 4/3/17**
18	Design Kiwi Structure	26 days	Thu 11/3/16	Thu 12/8/16
19	Design Kiwi flight software	31 days	Thu 1/12/17	Thu 2/23/17
20	Build Kiwi	31 days	Thu 1/12/17	Thu 2/23/17
21	Test Kiwi	7 days	Thu 2/23/17	Fri 3/3/17
22	Rebuild/Redesign as needed	18 days	Thu 3/9/17	Mon 4/3/17

Project: Payload Gantt Chart
Date: Friday 1/13/17

Figure 51: Payload Timeline Page 2 of 2

Works Cited

[1] Polymaker, "Polymax PLA Technical Data Sheet," 2015. [Online]. Available: http://www.polymaker.com/wp-content/uploads/2015/06/PolyMax-PLA_TDS-v1.pdf. Accessed: Nov. 1, 2016.

[2] Glenn Research Center, "Velocity during recovery," in NASA Glenn Research Center, 2008. [Online]. Available: https://www.grc.nasa.gov/WWW/k-12/VirtualAero/BottleRocket/airplane/rktvrecv.html. Accessed: Oct. 29, 2016.

[3] Arconic Corporation, "5052 and 6061 Aluminum Sheet," 2010. [Online]. Available: http://www.arconic.com/mill_products/catalog/pdf/alcoa_insert_5052and6061_final.pdf. Accessed: Nov. 3, 2016.

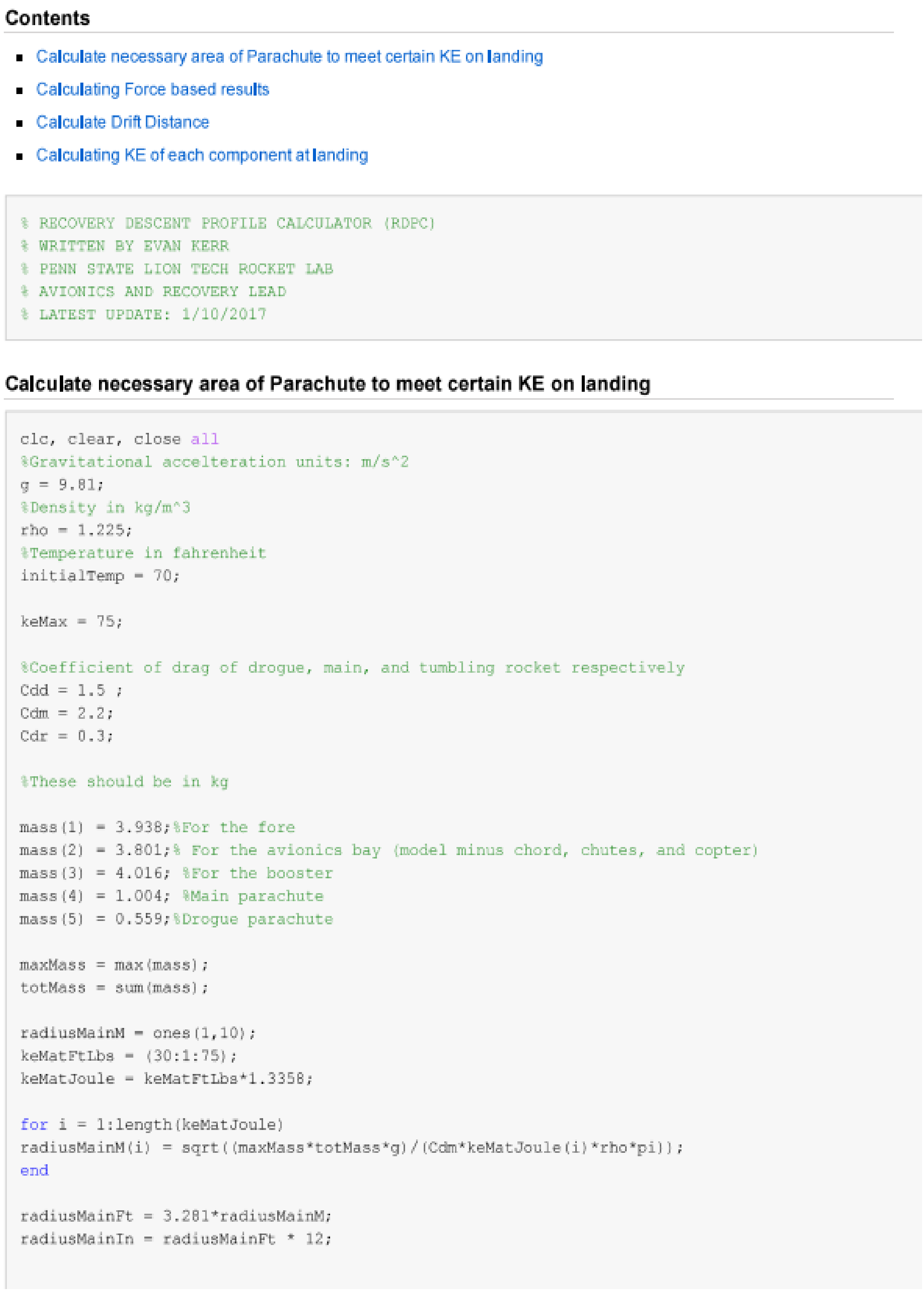
[4] PerfectFlite, "SL100 Altimeter," in PerfectFlite Altimeters, 2015. [Online]. Available: http://www.perfectflite.com/sl100.html. Accessed: Oct. 28, 2016.

[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.

[7] CÌ§engel, Yunus A., and John M. Cimbala. "Drag Coefficients of Common Geometries." Fluid Mechanics: Fundamentals and Applications. Boston: McGraw-Hill Higher Education, 2006. 573.

Appendix A: RECOVERY DESCENT PROFILE CALCULATOR

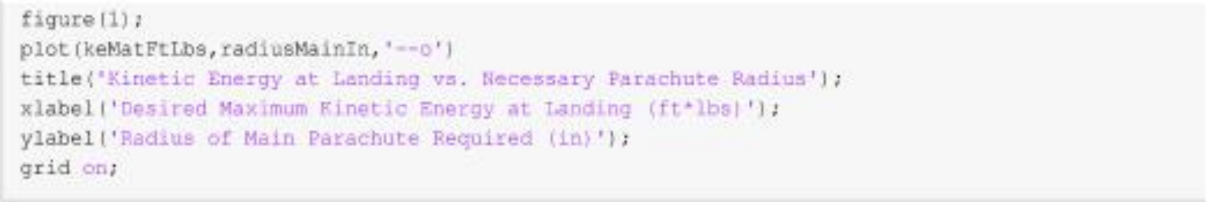


Contents

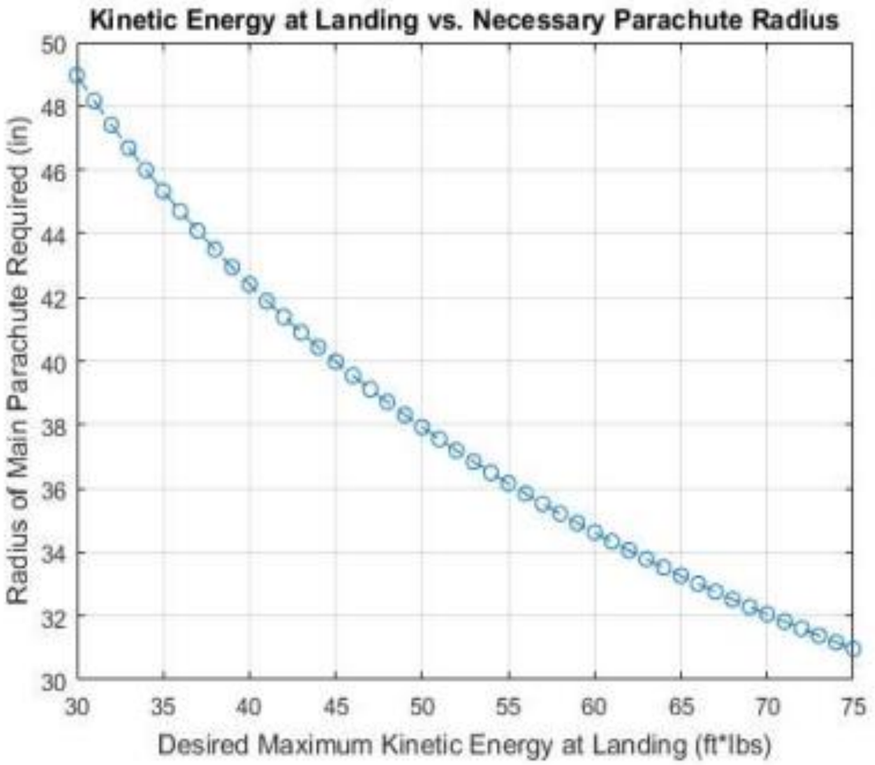
```
% RECOVERY DESCENT PROFILE CALCULATOR (RDPC)
% WRITTEN BY EVAN KERR
% PENN STATE LION TECH ROCKET LAB
% AVIONICS AND RECOVERY LEAD
% LATEST UPDATE: 1/10/2017
```

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 = 70;

keMax = 75;

%Coefficient of drag of drogue, main, and tumbling rocket respectively
Cdd = 1.5 ;
Cdm = 2.2;
Cdr = 0.3;

%These should be in kg

mass(1) = 3.938;%For the fore
mass(2) = 3.801;% For the avionics bay (model minus chord, chutes, and copter)
mass(3) = 4.016; %For the booster
mass(4) = 1.004; %Main parachute
mass(5) = 0.559;%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;
```

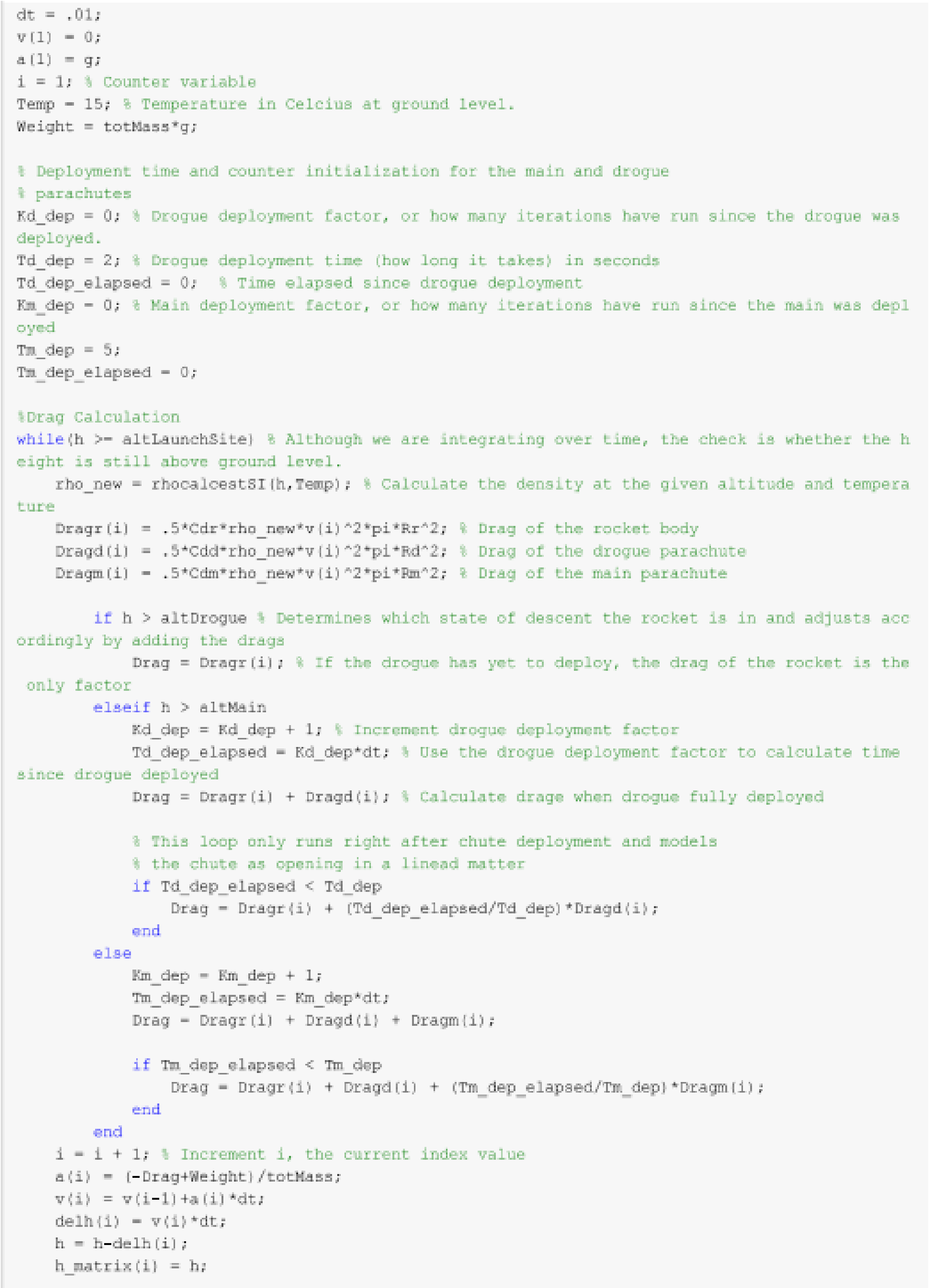


```
figure(1);
plot(keMatFtLbs,radiusMainIn,'--o')
title('Kinetic Energy at Landing vs. Necessary Parachute Radius');
xlabel('Desired Maximum Kinetic Energy at Landing (ft*lbs)');
ylabel('Radius of Main Parachute Required (in)');
grid on;
```



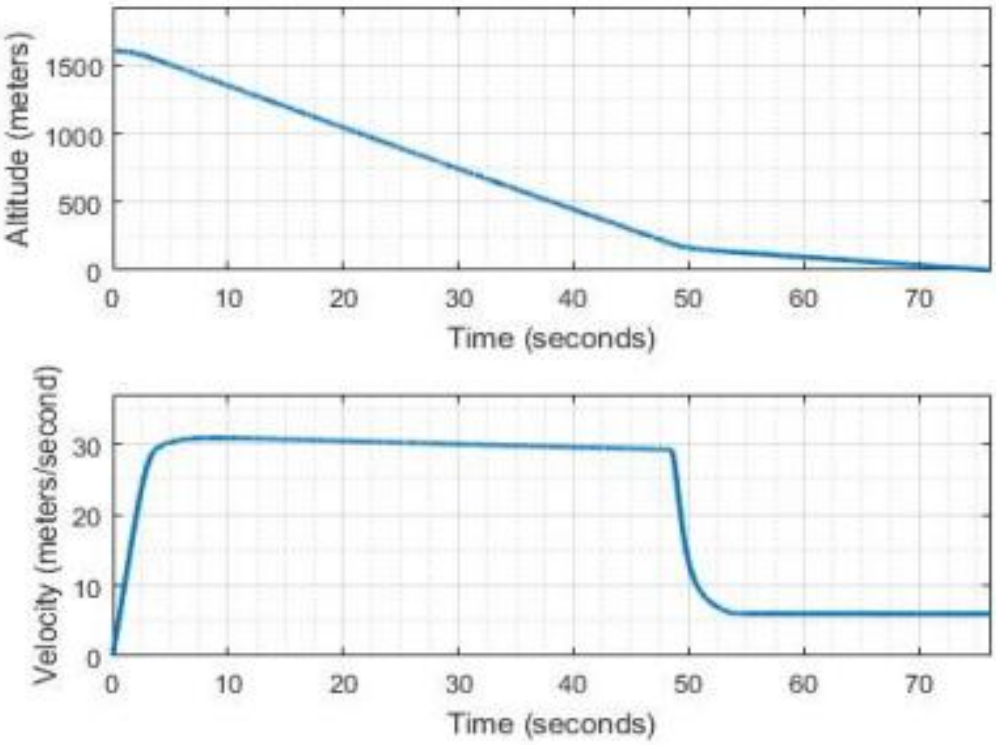
Calculating Force based results

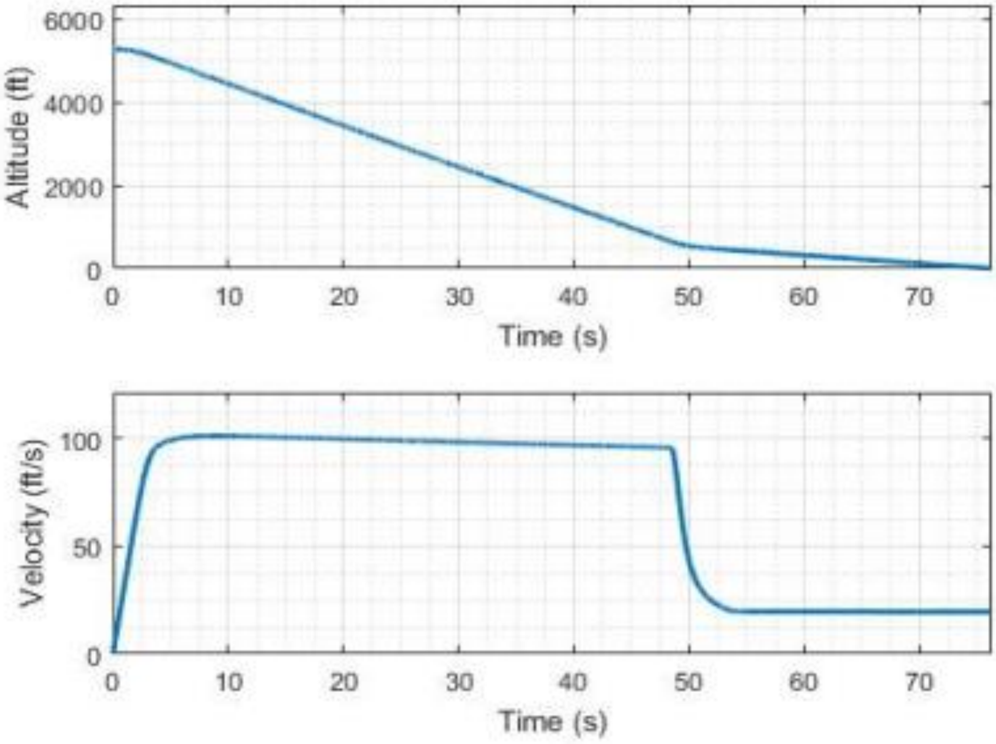
```
Rd_in = 9; %radius of drogue[in]
    Rd = 0.0254*Rd_in; %radius of drogue[m]
Rm_in = 36; %radius of main[in]
    Rm = 0.0254*Rm_in; %radius of main[m]
Rr_in = 4; %simulated radius of "tumbling" rocket parachute[in]
    Rr = 0.0254*Rr_in; %simulated radius of "tumbling" rocket parachute[m]

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 = 15; % 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;
```

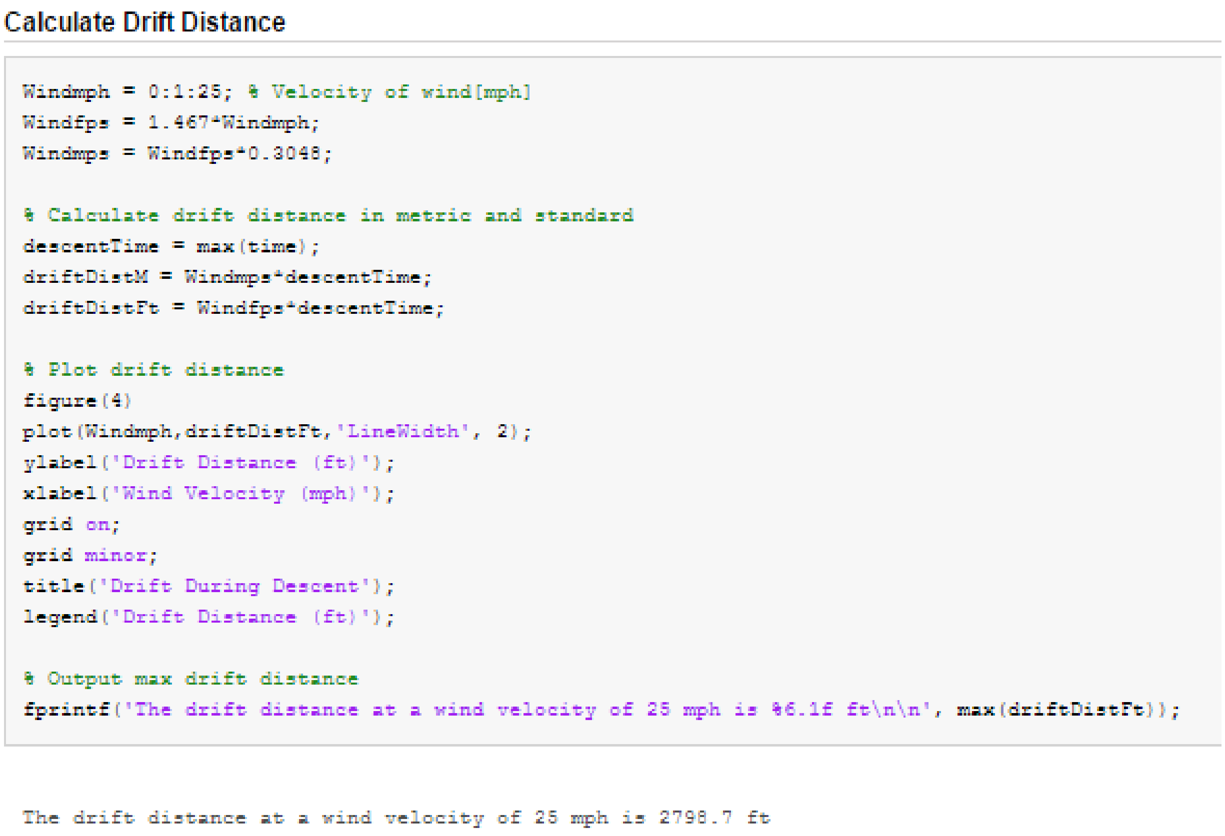


```
dt = .01;
v(1) = 0;
a(1) = g;
i = 1; % Counter variable
Temp = 15; % Temperature in Celcius at ground level.
Weight = totMass*g;

% 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 % Determines which state of descent the rocket is in and adjusts acc
ordingly 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
            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
Time (seconds)
Velocity (meters/second)
30
20
10
0
0
10
20
30
40
50
60
70
Time (seconds)

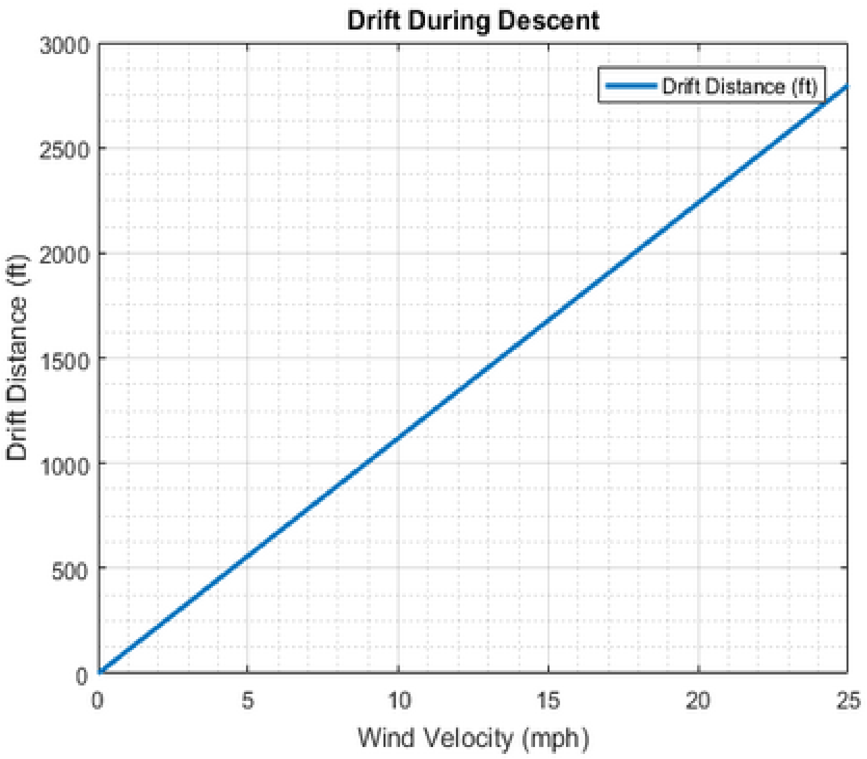

Altitude (ft)
6000
4000
2000
0
0
10
20
30
40
50
60
70
Time (s)
Velocity (ft/s)
100
50
0
0
10
20
30
40
50
60
70
Time (s)

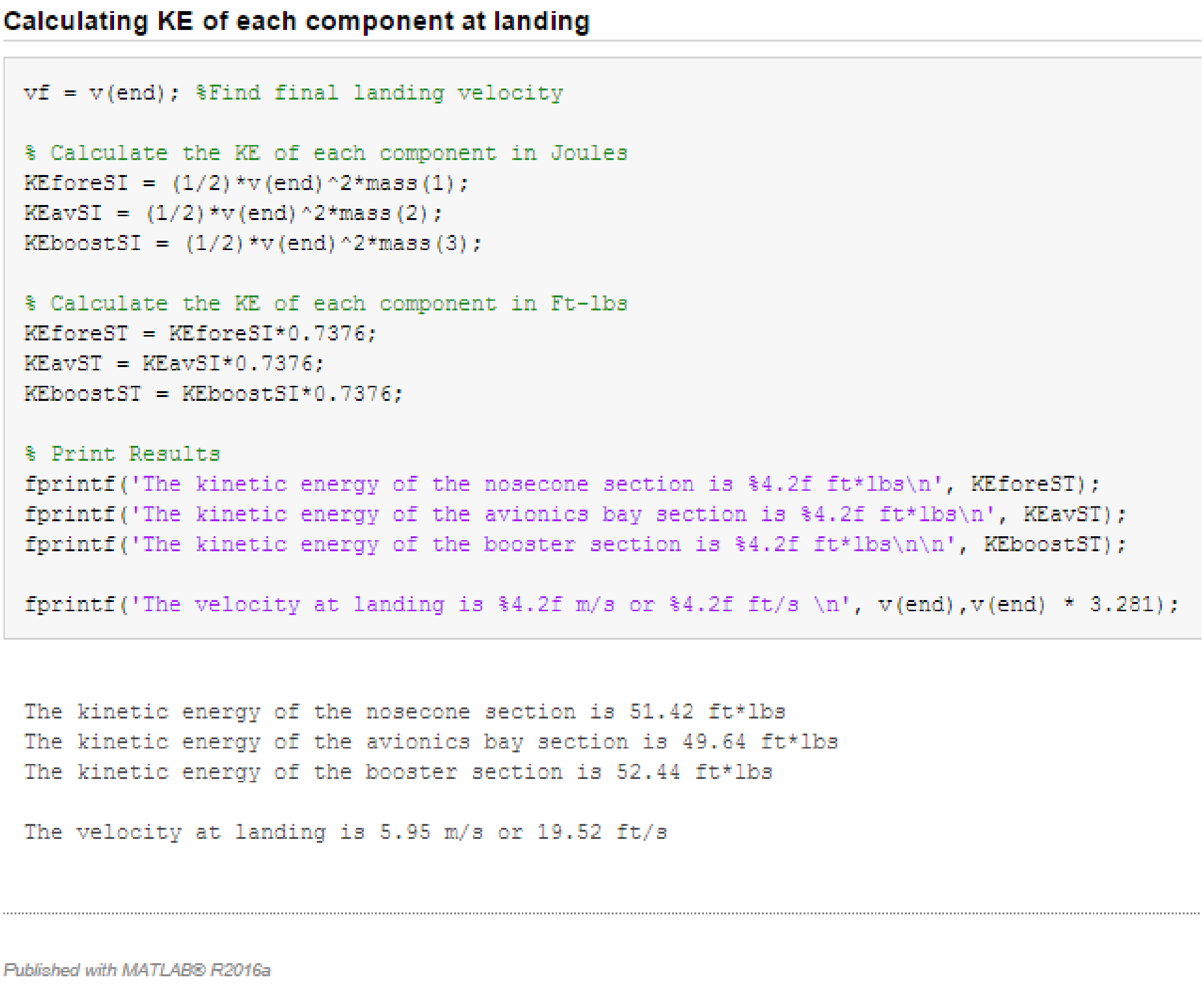


Calculate Drift Distance

```
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');
legend('Drift Distance (ft)');

% 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 2798.7 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(3);

% 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\n', KEboostST);

fprintf('The velocity at landing is %4.2f m/s or %4.2f ft/s \n', v(end),v(end) * 3.281);
```

```
The kinetic energy of the nosecone section is 51.42 ft*lbs
The kinetic energy of the avionics bay section is 49.64 ft*lbs
The kinetic energy of the booster section is 52.44 ft*lbs

The velocity at landing is 5.95 m/s or 19.52 ft/s
```

Published with MATLAB® R2016a

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

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.	

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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

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.