LionTech Rocket Labs

USLI Flight Readiness Review Report 2016-2017

Project Odyssey

The Pennsylvania State University
46 Hammond Building State College, PA 16802
March 6, 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

Nomenclature

C_d = Coefficient of Drag

D = Drag

V = Velocity

KE = Kinetic Energy

m = mass

$\dot{m}$ = mass flow rate

M_i = Initial propellant mass

M_f = Final propellant mass

M_t = total mass under parachute descent

M_m = mass of heaviest component descending under parachute

h_b = Height at burnout

g = acceleration due to gravity on the surface of the Earth

T = Thrust

t = Time

ρ = Air density (assumed 0.002378 slugs/ft^3)

P_a = Atmospheric pressure

P_e = Exhaust Pressure

A_e = Exit area

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

I_{sp} = Specific Impulse

U_e = Exhaust velocity

U_{eq} = Equivalent velocity

t_b = Burn time

t_{ba} = Time from burnout to apogee

V_f = Forward velocity

V_{fnd} = Non-dimensional forward velocity

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Section 1: General Information

1.1: Important Personnel

Adult Educator

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

Safety Officer

Laura Reese - ler5201@psu.edu

Team Leader

Luke Georges - lag5461@psu.edu

NAR Contact

Alex Balcher NAR L2 Certification - #96148SR - alex.balcher@gmail.com
NAR Sections: Pittsburgh Space Command (PSC) #473

1.2: Team Roster and Structure

Lion Tech Rocket Labs has approximately 40 active members, ranging from freshman to senior undergraduates and graduate students. 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 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 NASA representatives and department heads. Guides team in the overall design and construction of the systems.
Evan	Vice President	Assists President in managerial tasks as well as 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
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. The officer positions and subsystem duties within the technical branch are shown in Table 2. Due to the size of each subsystem, a description of the duties of each are is given in place of a description of individual member's duties. The officers take a leadership role in the subsystems while working with the general members in their subsystem to complete their duties.

Table 2: Technical Infrastructure

	Position	Duties
Evan	A&R Leadership	Creates the avionics bay for the flight vehicle, tests altimeters, ejection charges, and parachutes Ensures proper parachute packing and successful vehicle recovery
Gretha		
Torre	Payload Leadership	Designs and creates science packages Ensures these packages are functioning properly for launch.
Dan		
Alex P.	Propulsion Leadership	Selects motors for the vehicle, performs flight analysis and drag estimates In charge of motor preparation for launch
Kurt	Structures Leadership	Designs and creates the flight vehicle, tests materials and ensures all necessary components of the vehicle are compatible and flight ready Completes final assembly of the rocket for launch
Anthony		
Kartik		

Section 2: Summary of FRR Report

2.1: Team Summary

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

2.2: Vehicle Summary

Size and mass

The current launch vehicle design is 147-in. long, and has total mass of 30.5-lbm. Without the motor and 41.5 lbm with the motor at launch. The outer diameter of the airframe is 6.079 in and is constructed of Blue Tube 2.0.

Final motor choice

The AeroTech L1170 composite motor was selected as the full-scale motor. The fuel is an ammonium perchlorate composite variant known as Black Max. The predicted apogee is 4876-ft and thrust to weight ratio of 6.39.

Recovery system

Aeolus uses a dual deployment event recovery system in which the drogue parachute is deployed at apogee while the main parachute is deployed at 700ft AGL. The parachutes selected are an 18-in. Classic Elliptical and a 72-in. Iris Ultra parachute from FruityChutes for the drogue and the main respectively. The avionics system is comprised of two completely redundant independent systems that will ensure the safe descent and landing of the rocket.

Rail Size

The launch vehicle will use a 1515 rail. It is capable of launching on an 8-ft launch rail; however, for safety and increased rail exit velocity, the rail length chosen is 12-ft. in length. Launching off of a 12-ft. rail yields a velocity of 71.6-ft/s and a stability of 2.94-calibers off of the rail from OpenRocket simulations.

2.3: Payload Summary

FOPS (Fragile Object Protection System)

The objective of FOPS is to evaluate the use of shear thickening liquid as a method for protecting a fragile specimen of unknown dimensions and mass. A shear thickening liquid composed of a solution of cornstarch in water at a ratio of 6:5 by mass will be used. The unknown objects will be placed inside a plastic, flexible materials bag to protect the objects from the non-Newtonian Fluid.

Kiwi

Kiwi is an autonomous gyrocopter which will exit the rocket at apogee and autonomously navigate towards a predetermined landing location by use of GPS. By default, Kiwi will deploy a parachute at 500 feet to complete the landing process. If flight conditions permit, Kiwi will guide itself to ground and land without the use of a parachute.

Milestone Review Flysheet

Institution	Pennsylvania State University		**Milestone**	FRR

Vehicle Properties

Total Length (in)	147
Diameter (in)	6.079
Gross Lift Off Weight (lbm)	41.5
Airframe Material	Blue Tube 2.0
Fin Material	G10 FR4 Fiberglass
Drag	0.6119

Motor Properties

Motor Manufacturer	AeroTech
Motor Designation	L1170
Max/Average Thrust (lbf)	Avg: 256.51
Total Impulse (lbf-s)	951.39
Mass Before/After Burn	4990g/2190g
Liftoff Thrust (lbf)	276.78

Stability Analysis

Center of Pressure (in from nose)	115
Center of Gravity (in from nose)	91.75
Static Stability Margin	3.8
Static Stability Margin (off launch rail)	2.65
Thrust-to-Weight Ratio	6.39
Rail Size and Length (in)	1.5/144
Rail Exit Velocity (ft/s)	75.8

Ascent Analysis

Maximum Velocity (ft/s)	620
Maximum Mach Number	0.56
Maximum Acceleration (ft/s^2)	225
Target Apogee (From Simulations) (ft)	4876
Stable Velocity (ft/s)	36
Distance to Stable Velocity (ft)	3

Recovery System Properties

Dogue Parachute

Manufacturer/Model	Fruity Chutes Elliptical			
Size	18-in. Diameter			
Altitude at Deployment (ft)	5280			
Velocity at Deployment (ft/s)	-			
Terminal Velocity (ft/s)	95.7			
Recovery Harness Material	Kevlar			
Harness Size/Thickness (in)	0.5			
Recovery Harness Length (ft)	30			
Harness/Airframe Interfaces	1/2-in. Steel Eye Bolt			
	Forward Body	Aft Body	Section 3	Section 4
Kinetic Energy of Each Section (Ft-lbs)	1390	2695		

Recovery System Properties

Main Parachute

Manufacturer/Model	Fruity Chute Iris Ulra			
Size	72-in. Diameter			
Altitude at Deployment (ft)	700			
Velocity at Deployment (ft/s)	95.7			
Terminal Velocity (ft/s)	19.48			
Recovery Harness Material	Kevlar			
Harness Size/Thickness (in)	0.5			
Recovery Harness Length (ft)	40			
Harness/Airframe Interfaces	1/2-in. Steel Eye Bolt			
	Nose/Body Tube	Avionics Bay	Booster	KIWI
Kinetic Energy of Each Section (Ft-lbs)	51.68	48.65	51.58	15.52

Recovery Electonics

Altimeter(s)/Timer(s) (Make/Model)	Stratologger CF
Redundancy Plan	Two independently wired altimeter and charge systems. A single point failure anywhere in one system can be tolerated by the redundant system.
Pad Stay Time (Launch Configuration)	2 hours

Recovery Electonics

Rocket Locators (Make/Model)	Garmin Astro 320
Transmitting Frequencies	MURS (151.820 MHz - 154.600 MHz)
Pyrodex Mass Drogue Chute (grams)	3
Pyrodex Mass Main Chute (grams)	3.5

Section 3: Changes Made Since CDR

3.1: Vehicle Design

Structure

Minor changes were made to the design of the larger 3D printed transition coupler. In addition, the 3D printed fin brackets were made 1 in. shorter than CDR specifications due to a manufacturing error. Because of this error, the fin shape was altered in order to fit the fins exactly to the fin brackets. Lastly, the tail cone was removed from the launch vehicle since the previous design. These changes are highlighted and explained in Section 4.

Recovery System

The recovery system design specified in CDR has been checked with updated mass estimates and there were no design changes necessary to meet NASA requirements for kinetic energy and drift distance. Ground deployment testing performed at on-campus combustion research facility showed that the previous black powder charge size estimates were too large and the charge sizes were subsequently reduced. Difficulties in the manufacturing of the Faraday cage retention system, located in the tubular insert, has resulted in a change from cross-hatching to a solid wall.

Motor Selection

The motor selection was switched from a Cesaroni L1350 composite motor to an AeroTech L1170 composite motor. This change was necessitated due to the unavailability of Cesaroni's 75mm motors, while they restore full production capability following the fire of last year.

3.2: Payloads

FOPS

The mass of the FOPS design in the Critical Design Review was found to be higher than expected during the construction of the module. These errors occurred during the transition from subscale dimensions to full-scale dimensions. A review of the design found that the specimen holding bag was smaller than expected and required more shear thickening liquid to envelop the bag enough to protect the fragile specimen. To correct the mass, the specimen containment bag was rebuilt with correctly scaled dimensions: 7-inches tall by 5.5-inches across (the width of the FOPS bay). The mass of the rebuilt FOPS confirmed the design matched the original full-scale mass estimates.

Kiwi

The diameter of Kiwi's parachute bay was increased by 0.25 in because the parachute bay was too small for the allotted parachute. The increase in bay size is necessary to permit the parachute to be packed without risk of accidental deployment during flight. The length of Kiwi was increased by 0.5 in to accommodate the larger parachute bay. The rotor has been changed from a purely 3D printed design to a 3D printed bracket with basswood blades for decreased density and greater control of angle of attack. The propeller will be folded while Kiwi is stored in the rocket and the propeller will fold out upon spin-up to increase the thrust produced while still fitting within the body of the rocket. Additionally, Kiwi will deploy parachutes by default at 500 ft instead of the original 100 ft. A system keeping Kiwi in the rocket has been added per NASA request. The system will connect the sabot to the rocket body using shear pins and to the shock cord using a tender descender. If Kiwi is permitted to fly, Kiwi will get pulled out of the rocket via tender descender and shock cord, and break the shear pins. If Kiwi needs to say in the rocket, the tender descender will be blown and the shear pins will keep the sabot and Kiwi in the rocket.

3.3: Project Plan

The original full scale test launch was planned for February 12th at MDRA; however, the launch was cancelled due to weather. The test launch was then pushed to February 19th at PSC; however, during ground tests a 3D printed coupler broke and the vehicle was unable to launch. Finally, a third attempt was scheduled for February 26th at MDRA's make-up launch. Wind tunnel tests were moved to a week earlier than originally planned, occurring February 20th instead of the week of February 27th. The launch was successful; however, the rocket landed in trees during its descent preventing a proper landing from being tested. The possibility of launching once more to test a successful landing will be including in the plan.

Section 4: Vehicle Criteria

4.1: Design and Construction of Vehicle

Changes from CDR

Structure

After the initial full scale ground test, the larger 3D printed transition coupler sheared laterally due to low infill and layer continuity. To accommodate for this failure, wall thickness of the transition piece was increased and four sections of the interior wall were flattened so that self-tapping screws could be replaced with bolts and washers; thus, reducing the stress produced by those screws. See Figure 1 for a comparison of the previous and current 3D printed transition coupler.

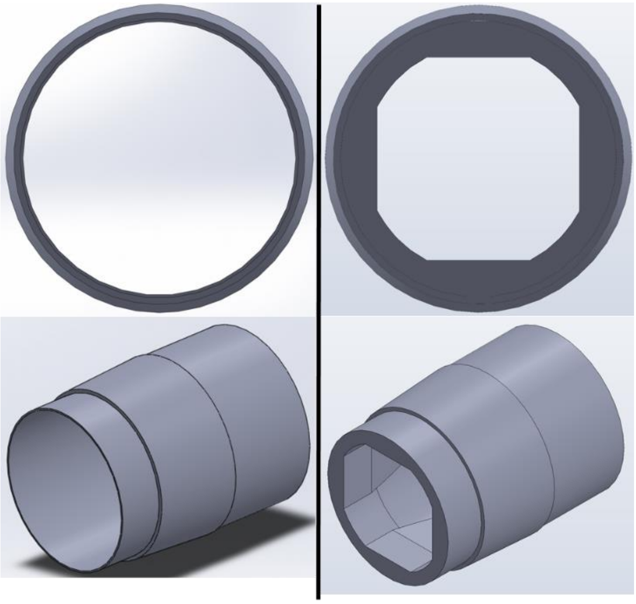


Figure 1: Transition comparison

During production of the 3D printed fin brackets, a manufacturing mistake led to the overall length of the fin brackets being 1-in. shorter than intended. To eliminate the possibility of aerodynamic instabilities, the length of the bottom of the fin was shortened by 1-in. to match the length of the fin brackets. This removed area of the fins is illustrated in Figure 2. Before altering the fin's profile, OpenRocket simulations were performed using the new fin profile. The simulation with the new fins calculated a velocity of 71.6 ft/s and a stability of 2.94 calibers off of a 12-ft. rail, compared to a velocity of 70.2 ft/s and a stability of 3.25 calibers off of a 12-ft. rail using the previous design.

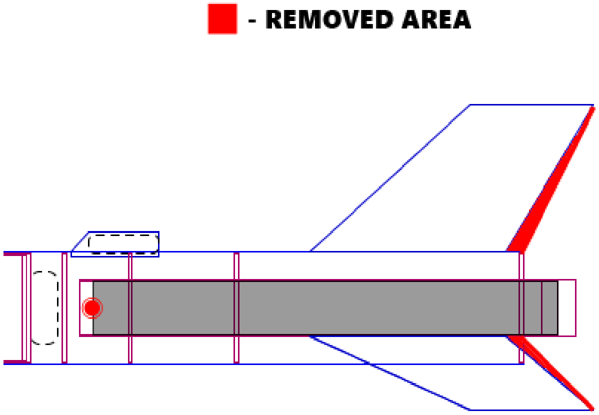


Figure 2: Fin profile area removal

Finally, the tail cone of the launch vehicle was removed since the previous design. In preparation for the full-scale test launch, a prefabricated tail cone was researched with the intention to purchase one for use on the launch vehicle. Unfortunately, a tail cone could not be acquired that fit both the motor tube diameter of 75mm as well as the airframe diameter of 6.079” in the distance located between the ends of the airframe and motor tube. Manufacturing a completely custom tail cone was investigated; however, was deemed unrealistic and impractical. OpenRocket simulations were calculated without the use of a tail cone and yielded a rail exit velocity of 71.6-ft/s and a stability of 2.94-calibers off of a 12-ft. rail. Therefore, the tail cone was removed from the current launch vehicle design.

After parts were assembled to full scale, a discrepancy was noticed between the actual mass of the rocket and mass calculated by OpenRocket. Upon analysis, the weight of Blue Tube 2.0 listed on the manufacturer’s website was not accurate to the parts in hand. We calculated for every 1.5 feet of Blue Tube 2.0, OpenRocket estimated 4-oz less than that of the actual value. All of the components were weighed individually prior to assembly, and the component masses in OpenRocket were replaced with their actual values. This was done to produce a more accurate altitude prediction.

Recovery System

There have been three changes to the full scale recovery system since CDR; one being the ejection charge sizes, the next being slight changes to the Faraday Cage retention system, and the last being the addition of "Fireball" devices to prevent zippering. The charge size changes were made as a result of ground deployment testing of the ejection charges, during which high separation velocity with the CDR charge sizes were observed. High separation velocities of the body tube during parachute deployment may lead to premature main deployment or zippering. To address these concerns, the main ejection charge size was reduced from 5.0g to 3.5g of black powder and the main ejection charge was reduced from 4.0g to 3.0g of black powder. The change to the Faraday cage retention system was a result of manufacturing difficulties. The retention system is a thin (non-structural) retaining wall attached to the structural additively manufactured coupler. Originally, the retention wall incorporated a hatched design to reduce the mass of the coupler. However, this angled hatch design was troublesome for the printer to manufacture and, instead, the retaining wall was redesigned to be solid. This change resulted in marginal mass increase to the avionics bay. The decision to add "Fireball" devices was to prevent zippering experienced during the full-scale test flight.

Motor

At CDR, the chosen motor had been the Cesaroni L1350; however, due to a fire last year production of 75mm Cesaroni motors has been extremely limited and no L1350's were available for purchase. Because of this, another motor of similar impulse was needed. The replacement motor selected was the AeroTech L1170. This motor has a slightly lower yet similar thrust curve and impulse to the L1350. The motor characteristics of the Cesaroni L1350 and the AeroTech L1170 are compared in Table 3. The AeroTech L1170 was selected as a replacement due to comparable motor characteristics with the Cesaroni L1350.

Table 3: Motor comparison

	CDR Motor	**FRR Motor**
Manufacturer:	Cesaroni Technology	AeroTech
Common Name:	L1350	L1170
Total Weight:	7.87 lbs	11.00 lbs
Prop. Weight:	4.20 lbs	6.17 lbs
Average Thrust:	303.40 lbs	256.51 lbs
Maximum Thrust:	375.99 lbs	334.74 lbs
Total impulse:	958.38 lbs/s	951.39 lbs/s
Burn Time:	3.2 s	3.7 s
Isp:	228 s	153.75 s
Propellant Info:	C-Star (SLOW)	Fast Blackjack

Vehicle Features

Figure 3: Three view model of assembled launch vehicle

A model of the assembled full scale launch vehicle is shown in Figure 3. The following sections break down the parts and components that make up the full assembly.

Nosecone:

The overall specifications for the launch vehicle nosecone are as follows:

- 5.5:1 length to diameter ratio
- 5.5-in. outer diameter
- 30.25-in. length
- 3-in. shoulder (5.4-inch diameter)
- 50.26-oz. (including all the components housed within nosecone)

Refer to **Error! Reference source not found.** for a dimensioned drawing of the nosecone.

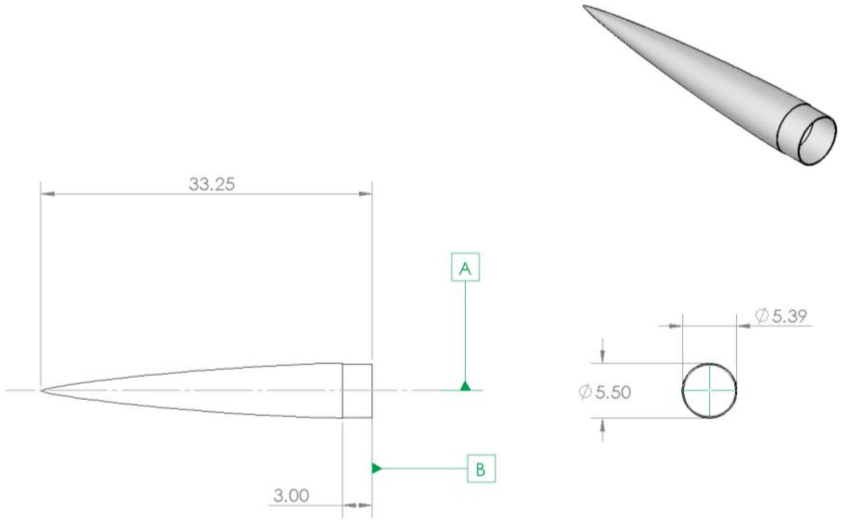


Figure 4: Von Kármán nosecone

Nosecone to Acrylic Transition Coupler:

The transition coupler is made of PLA thermoplastic using additive manufacturing. PLA was chosen as a material over ABS thermoplastic due to PLA having a lower and more consistent coefficient of linear thermal expansion (CLTA). According to experiments carried out by SpecialChem on various plastics, ABS exhibited a CLTA of between 7E-5 and 15E-5/℃ while PLA exhibited a consistent CLTA of 8.5E-5/℃. A lower CLTA contributes to less shrinking during cooling, making the PLA less susceptible to warping during 3D printing. Given the need for tight geometric tolerance in parts such as the nosecone to acrylic transition coupler, PLA was chosen as a material to ensure a more consistent fit when assembling the launch vehicle. Specifications for the transition are as follows:

- 1.5-in. length
- 5.5-in. forward diameter and 5.75 in aft diameter
- 1.49-oz.

Refer to Figure 5 for a dimensioned drawing of the forward transition.

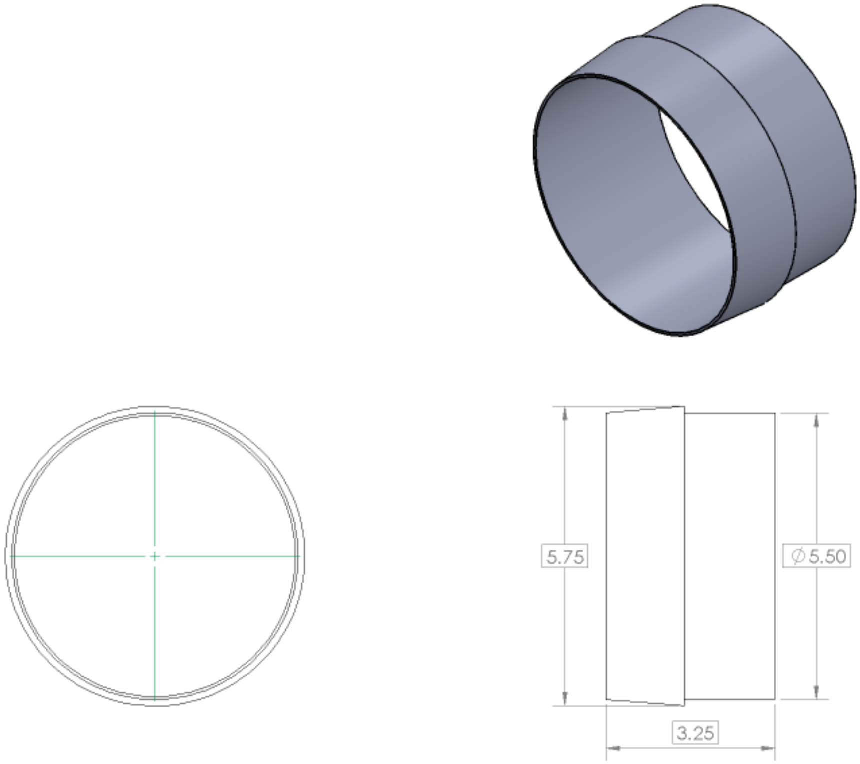


Figure 5: Nosecone to acrylic transition coupler

Acrylic Section:

This airframe section contains the FOPS payload assembly. It also contains the transition stabilizing coupler made from blue tube 2.0. Refer to Figure 6 for dimensions and a rendering of the acrylic section. The specification for the acrylic section is as follows:

- 12-in. length
- 5.75-in. outer diameter
- 5.5-in. inner diameter
- 37-oz.

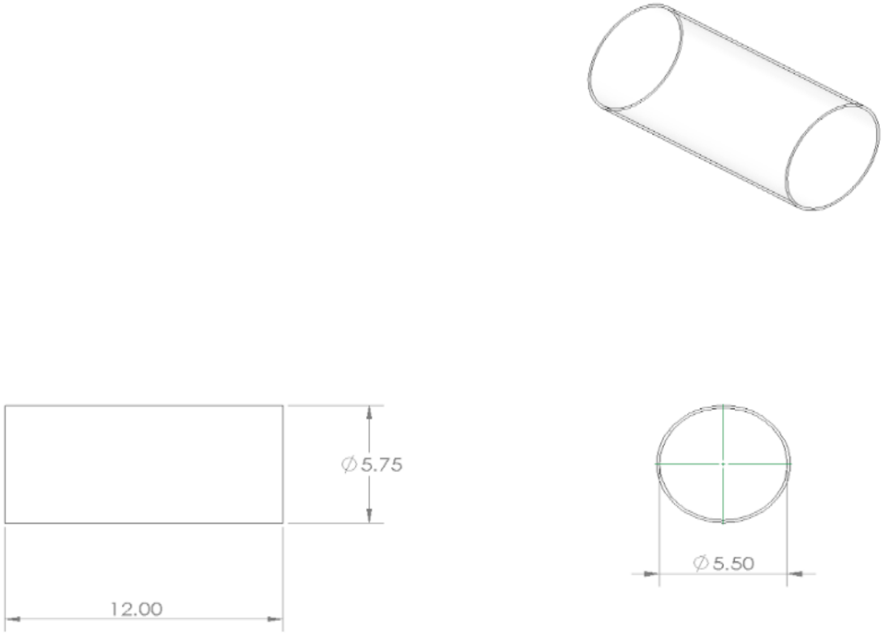


Figure 6: Acrylic section

Acrylic to Main Body Tube Transition:

This section will again comprise of a 3D-printed PLA thermoplastic section. Refer to Figure 7 for a dimensioned drawing of the forward transition. The specifications are as follows:

- 3-in. length
- 5.75-in. forward diameter
- 6.079-in. aft diameter
- 3.13-oz.

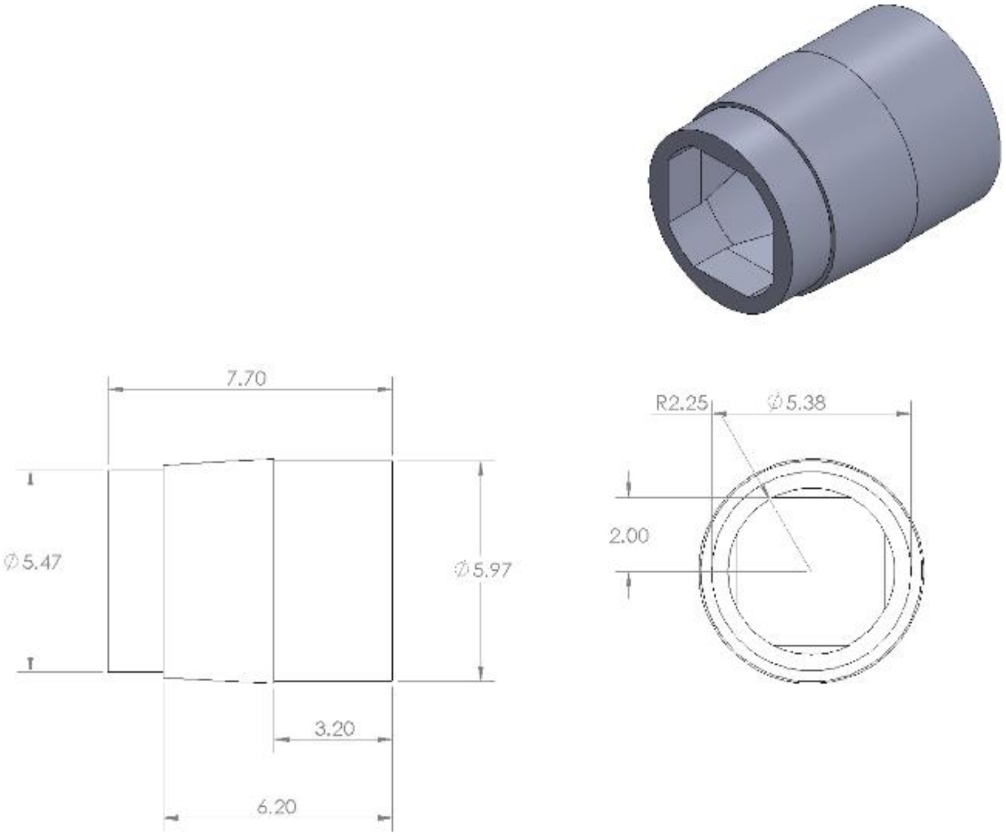


Figure 7: Acrylic to main body tube transition

Airframe (Main):

The total specifications for the Blue Tube 2.0 Airframe containing the main parachute is as follows:

- 26-in. length
- 6.079-in. outer diameter
- 58-oz.

Avionics Bay:

The avionics bay aboard the launch vehicle will be constructed using Blue Tube 2.0. The specifications of the avionics bay are as following:

- 4-in. length
- 6.079-in. outer diameter
- 58.9-oz. (mass includes all internal components)

Airframe (Drogue):

The total specifications for the Blue Tube 2.0 Airframe are as follows:

- 32-in. length
- 6.079-in. outer diameter
- 89.3-oz.

Coupler (Drogue to Booster):

The total specifications for the Blue Tube 2.0 coupler are as follows:

- 12-in. length
- 5.973-in. outer diameter
- 12.2-oz.

Airframe (Booster):

The total specifications for the Blue Tube 2.0 Airframe are as follows:

- 34-in. length
- 6.079-in. outer diameter
- 140-oz.

Bulkheads and Centering Rings:

The bulkheads are made up of 0.25 in. plywood and assist in reinforcing the airframe as well as provide mounting points for parachutes. We chose the width of the bulkheads and centering rings to be 0.25 to provide ample surface area to epoxy to the interior of the airframe. A rendering that displays the centering ring locations relative to the bottom of the booster section is shown Figure 8.

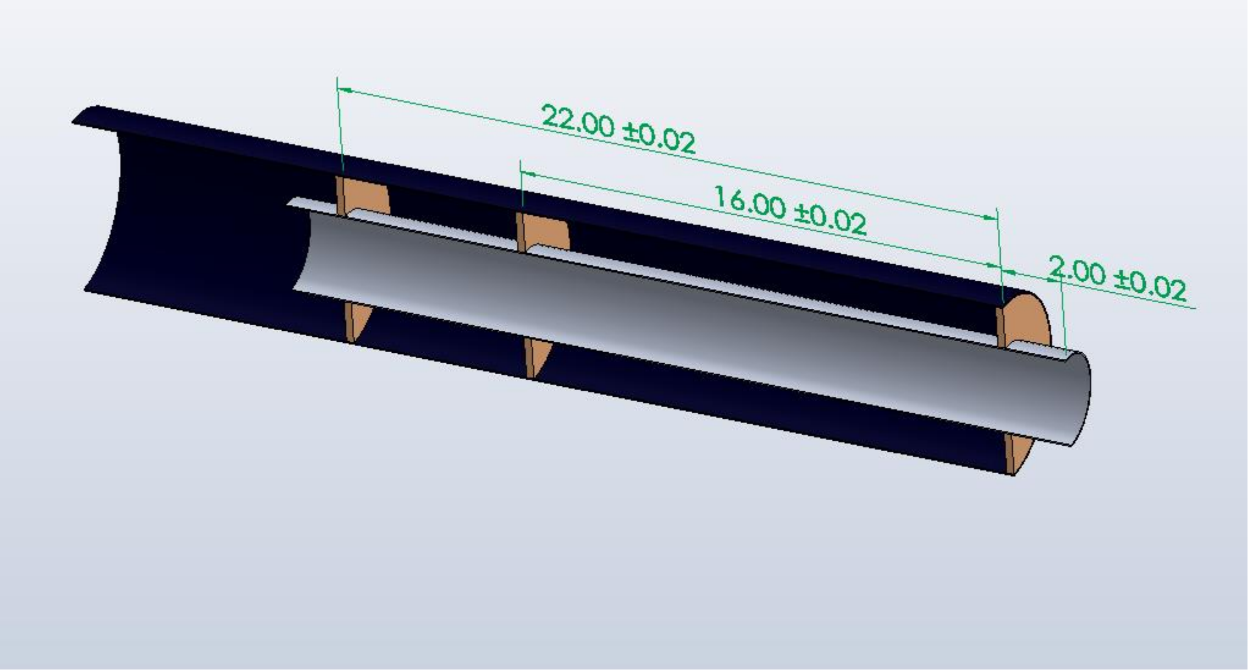


Figure 8: Section view of booster section and motor tube

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 passage between the interior and exterior of the booster section. Figure 9 shows a dimensional drawing of the camera cover.

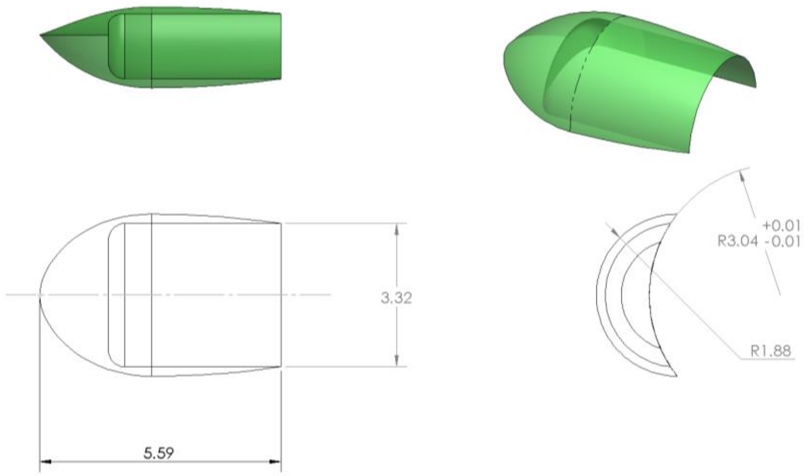


Figure 9: Camera cover

Fin brackets:

The fin brackets will be 3D printed using PLA thermoplastic for the same reasons outlined. Refer to Figure 10 for a dimensioned drawing of the fin brackets.

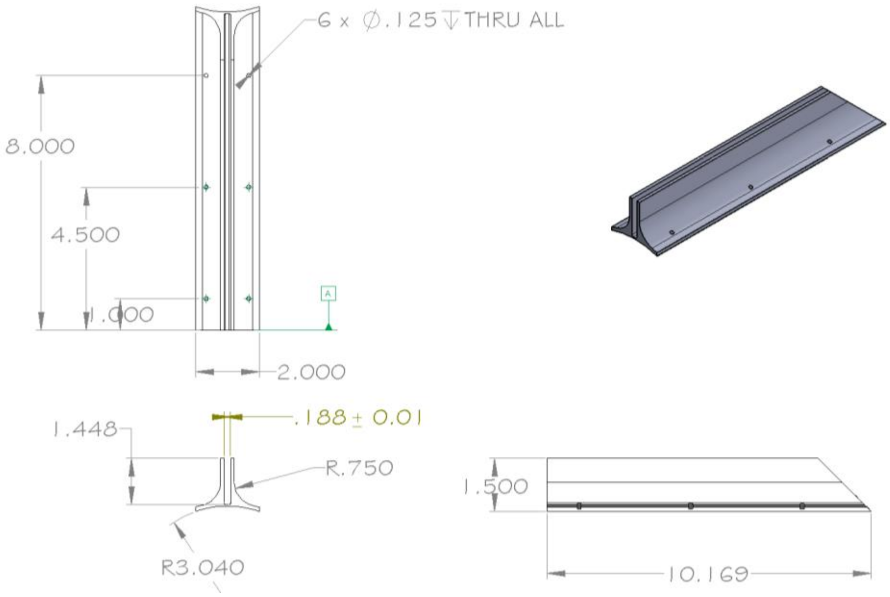


Figure 10: Fin brackets

Fins:

Refer to Figure 11 for a dimensioned drawing of the fins. The specifications are as following:

- 3/16-in. thick
- Fiberglass Construction
- 3 fins

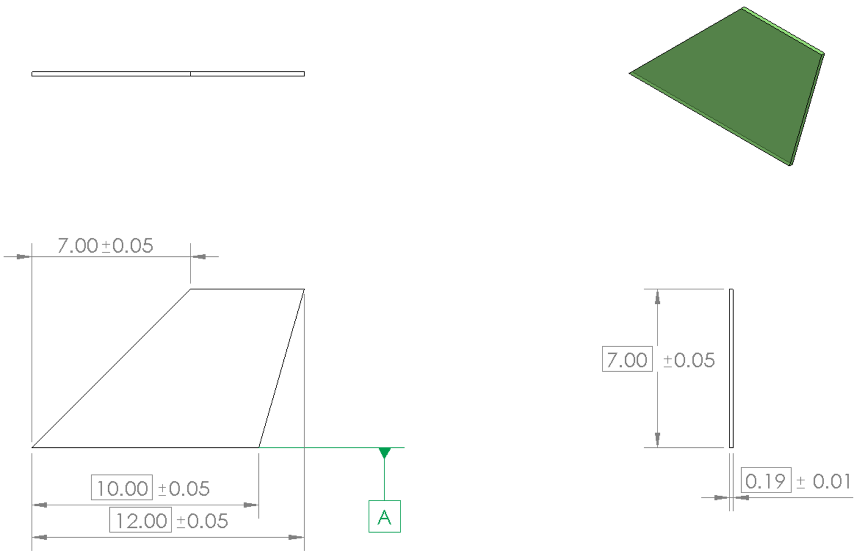


Figure 11: Fin dimensions

Flight Reliability

The flight reliability of the launch vehicle is determined to be suitable for mission criteria and will be reusable and reliable into the future. The full-scale test launch and its applied loads did no visual damage to any of the structural components upon inspection.

The larger 3D printed coupler proved to withstand the shock of main parachute deployment over the previous design iteration that failed due to shear during an initial ground test. This was due to better layer cohesion within the piece as well as the use of bolts, washers and nuts to secure the coupler to the acrylic airframe section. The use of #6-32 bolts over self-tapping #4 screws meant more evenly distributed stresses across the printed coupler due to the bolts going completely through the coupler instead of only through one wall. In addition, an infill was increased from 20 to 60% from the previous design to further increase the structural integrity.

From the multiple successful ground tests as well as a successful full-scale test flight, it has been determined that the launch vehicle will be reliable for repeated flights and will meet mission criteria.

Assembly Process

Definitions:

- The Nosecone to acrylic transition coupler as seen in Figure 5 will be referred to as 3D printed coupler A in the following section
- The Acrylic to main body tube transition as seen in Figure 7 will be referred to as 3D printed coupler B in the following section
- The Airframe (main) will be referred to as 26-in. body tube in the following section
- The Airframe (drogue) will be referred to as 32-in. body tube in the following section
- The Coupler (drogue to booster) will be referred to as Kiwi Coupler in the following section

Procedure:

Assure that the tip of the nosecone is secure and if not, tighten it using a Phillips head screwdriver while holding the nosecone tip. Insert the shoulder of the nosecone into 3D printed coupler A, lining up the alignment marks on both pieces.

Consult with A&R that the AV-Bay is properly packed with necessary components and sealed. Feed the main shock cord through the 26-in. body tube from top-to-bottom and attach the quick link to the U-bolt at the bulkhead at the top of the AV-Bay. Place the top of the AV-Bay coupler inside of 26-in. body tube lining up alignment marks on both pieces. Insert six shortened #4 screws using a Philips head screwdriver into the AV-Bay coupler attaching the 26-in. body tube to the top of the AV-Bay coupler. Feed the drogue shock cord through the 32-in. body tube from bottom-to-top and connect to the U-Bolt attached to the bulkhead at the bottom of the AV-Bay. Make sure that the shock cord is connected properly to the U-bolt attached to the bulkhead at the bottom of the AV-Bay. Attach the bottom of the AV-Bay coupler with the top of the 32-in. Body tube, placing the AV-Bay coupler inside the body tube. Screw six shortened #4 screws using a Philips head screwdriver through the 32-in. Body tube to attach the bottom of the AV-Bay coupler.

Consult with Payload to assure that Kiwi is properly packed in the Kiwi sabot. Attach the camera recording module to the Velcro patch located on the bulkhead on top of booster section. Secure the down-body camera to the camera mount located underneath the camera cover on the exterior of the booster section. Feed the HDMI cable attached to the camera through the hole in airframe under the camera cover. Connect the down body camera HDMI cable to the camera recording module. Place excess HDMI cord along the perimeter of airframe and secure it in place. Carefully and cautiously slide the Kiwi coupler down into the top of the booster section assuring that the alignment marks on both pieces are aligned. Take the longer unhooked end of the drogue shock cord and feed it through the Kiwi coupler from top to bottom, finally feeding the shock cord through opening of the bulkhead at the bottom of the Kiwi coupler. Attach the longer unhooked shock cord to the U-bolt on the bulkhead at the top of the booster section. Insert the bottom of the Kiwi Coupler into the top of the booster section.

Assure that the Kiwi coupler is at the proper height such that the holes in the booster section and Kiwi coupler are aligned, and that alignment marks on the coupler and airframe are aligned. Secure the Kiwi coupler into the booster section using six shortened #4 screws and a Philips head screwdriver.

Orient the Kiwi sabot so that the section marked 'top' is facing away from the fins of the rocket. Unscrew the quick link on the Kiwi sabot and place the longer drogue shock cord inside the Kiwi sabot quick link such that the quick link surrounds the longer drogue shock cord. Attach the quick link on Kiwi sabot to the shorter unhooked end of the drogue shock cord and secure the quick link. Place the Kiwi sabot into the Kiwi coupler until the Kiwi sabot contacts the bulkhead at the bottom of the Kiwi coupler. Consult with A&R to assure that the Drogue parachute has been properly pack into the 32-in. body tube. Insert the top of the Kiwi coupler into the bottom of the 32-in. body tube, aligning them using alignment marks located on both pieces.

Assure that the shock cord is properly stored inside of the Kiwi coupler without any obstructions. Place four M2 shear pins through the 32-in. body tube into the top of the Kiwi coupler.

Consult with Payload to assure that FOPS is ready be assembled into the rocket. Assure that the GPS tracker is on, and attach the Velcro portion of the GPS tracker to the Velcro located on the bulkhead at top of the FOPS payload. Assure that bulkhead holding the FOPS reservoir and the GPS tracker at the top of FOPS payload is pushed down and touching the retaining shelves located inside of the acrylic section. Insert the nosecone and 3D printed coupler A into the top of the acrylic section, assuring that the GPS tracker and the FOPS are inside the nose cone. Line up alignment marks between the acrylic section and the nose cone. Screw through the acrylic section to attach the nose cone and 3D printed coupler A using four #4 screws and a Philips head screwdriver. Insert the top portion of the 3D printer coupler B into the bottom of the acrylic section assuring that the alignment mark lines up between the two pieces. Insert four #6-32 bolts through the acrylic section and through the 3D Printed Coupler B. Place washer over exposed bolt end inside 3D printed coupler B and secure bolt and washer using a #6-32 nut. Repeat three more times for other three holes at the bottom of the acrylic section.

Feed the end of the Main shock cord through the 26-in. body tube from bottom to top. Connect quick-release properly to the U-bolt attached to the bulkhead at the bottom of the FOPS Payload. Place the bottom of 3D printed coupler B into the top of the 26-in. body tube lining up alignment marks. Consult with A&R that the main parachute is properly packed into the 26-in. body tube. Insert four M2 shear pins through the 26-in. body tube into the 3D printed coupler B.

Consult with Propulsion that the motor is properly placed into the motor tube. Screw the motor retainer onto the end of the motor tube to secure the motor in place. Assure that the rail buttons are properly aligned and fastened securely using 1/4-20 bolts. Assure that fins are attached to fin brackets using three #1 bolts for each fin and tighten any that exhibit any movement during inspection. Assure that each of the three fin brackets are secured to the booster section using six #4 screws per fin bracket. Locate the Center of Gravity of the rocket using a mass balancing method and record the distance from the tip of the nose cone. Consult with Propulsion to assure that the Center of Pressure is within specifications. Locate Range Safety Officer and perform final safety inspection of the assembled launch vehicle. After obtaining clearance, slide the launch vehicle onto a 12-ft. 1515 extruded aluminum launch rail while the rail is in a horizontal position. Lift the launch rail up to a vertical position and lock the rail in place.

4.2: Recovery Subsystem

Structural

A major focus of the recovery subsystem design was to cut down on mass and volume used by the recovery subsystem. The avionics bay designs in previous competitions were often expansive, taking up an entire 12-in. or longer length of coupler, and massive. By finding a way to shorten the avionics bay, the additional volume created can shorten the rocket as a whole and reduce mass. Another major focus was designing the avionics bay to be highly integrated and easily prepackaged.

The avionics bay is located within a 6-in. Blue Tube coupler that lies between the main and drogue body tube sections. Structurally, the core of the avionics bay is an additively manufactured tube insert. This insert was designed such that the OD of the insert matches the ID of the 6-in. Blue Tube coupler. The insert has two holes for key switches as well as a shell to house the Faraday cage. During avionics bay construction, the Faraday cage was placed in the insert and secured in place. Next, the OD of this insert was covered in epoxy (J.B. Weld) and placed into the center of the Blue Tube coupler. Once the epoxy dried, holes were drilled into the Blue Tube coupler for key switch placement. In addition to the epoxy and the key switches holding the insert in the coupler, three 1/8-in. countersunk screws were also inserted. The technical specifications of the additively manufactured insert are shown in Figure 12.

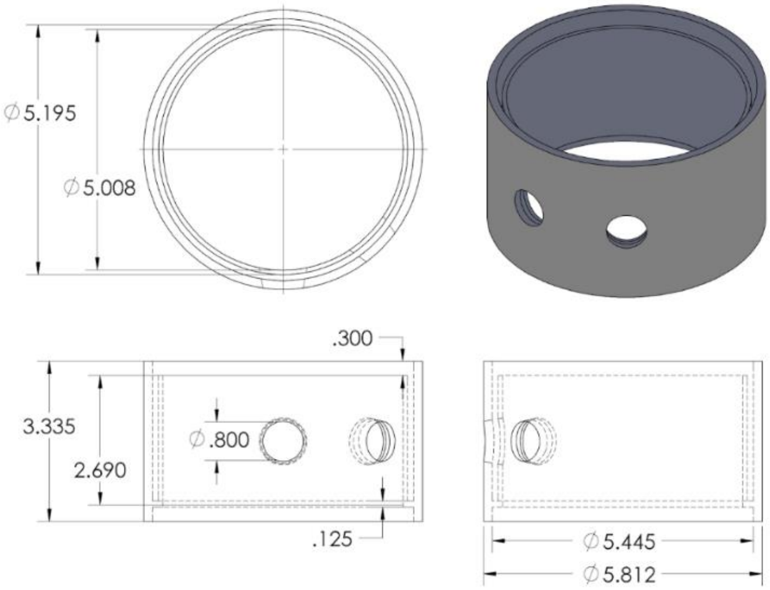


Figure 12: Schematic of additively manufactured tubular insert

The other major structural components of the avionics bay are the wooden bulkheads. Each bulkhead is made from two 1/4-in. plywood bulkheads mated with a small amount of epoxy and screwed together. The upper portion of this bulkhead matches the ID of the Blue Tube coupler with an OD of 5.82-in. and rests on the structural tubular insert. The OD of the inner bulkhead is 5.38-in. and is just under the ID of the tubular insert. The combination of these two different bulkhead sizes allow the bulkheads to rest on the tubular insert in a shoulder joint configuration. The bulkheads each have three 3/8-in. diameter holes designed for the 3/8-in. aluminum threaded rods used to hold the avionics bay together. The holes for these threaded rods are in a roughly equilateral triangle. However, due to low manufacturing tolerances, there is a single orientation of the bulkheads relative to one another that has the best fit between all of the components. This configuration has been noted and steps are included in the avionics bay assembly to ensure that the optimal configuration is attained by an inexperienced user. The technical specifications of the bulkheads are shown in Figure 13.

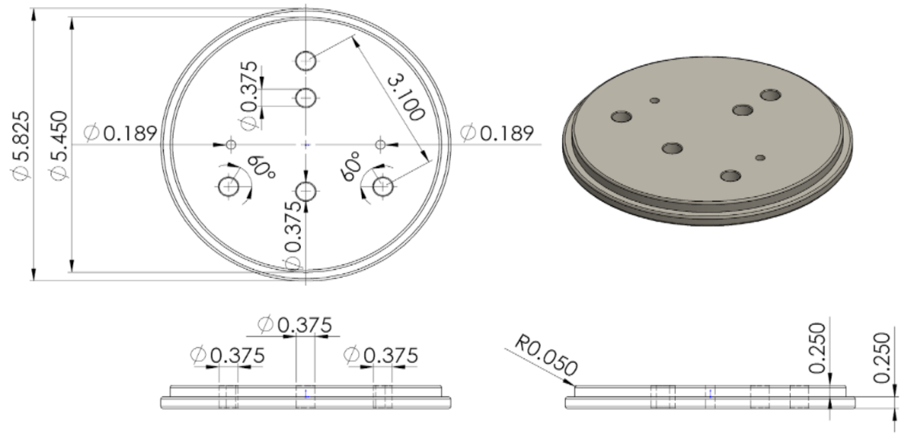


Figure 13: Schematic of bulkhead layout and dimensions

On each bulkhead, there is a 3/8-in. U-bolt connected to the bulkhead with nuts and washers. This U-bolt acts as the main connection point for the shock cord and therefore distributes the force from the U-bolt to the bulkhead. The loads transferred to the bulkhead will then be transferred through the tubular insert to the Blue Tube coupler. This coupler is screwed into both body tube sections with six 1/8-in. screws each to ensure structural integrity during deployment. Also on each bulkhead are two blast caps for holding the ejection charges.

To connect the multiple section of the rocket, 1/4-in. quick-links are used. These link the U-bolt on each bulkhead to the 1/2-in. tubular Kevlar shock cord. This shock cord is attached to the respective parachutes by identical 1/4-in. quick-links. This process repeats on the opposite side of the parachute, connecting the parachute to the remaining body components via 1/2-in. tubular Kevlar shock cord. This shock cord is attached with another quick link attached to an identical 3/8-in. bulkhead.

The final structural component of the avionics bay is the additively manufactured avionics board. As mentioned, in previous competitions the A&R subsystem team wasted large amounts of volume due to poorly optimized features. Notably, previous avionics boards consisted of fiberglass boards with components screwed or epoxied to a single side of the board. This year, the goal was to utilize more of the outer perimeter space available in the rocket and subsequently reduce the necessary length to fit all avionics equipment. Oftentimes, it was impossible to accurately secure all four holes of the altimeter into the fiberglass board and one corner of each altimeter would be left unscrewed. The fiberglass board design also placed the altimeters and batteries in orientations that made them susceptible to large accelerations, which may result in loss of connection and subsequent catastrophic failure.

With the advent of commercially available additive manufacturing and prototyping, many new avenues of design and production became available. The accuracy issue of manual construction was eliminated by printing holes into the design. The orientation of the components was changed from vertical to horizontal and supporting structures were added to retain the components during high acceleration periods in flight. Integrated battery holders printed into the design meant that the batteries could be clipped in and secured throughout flight without additional measures. All of these design components were realized in an additively manufactured avionics board that occupies less than 3.5-in. of rocket length. As a consequence of its compact size, the avionics bay is tedious to assemble. In addition to easy to understand assembly procedures, the avionics bay is designed such that it can be assembled almost completely the day before the launch such that during launch day the remaining set up is minimal. The specifications and layout of the additively manufactured avionics board can be seen in Figure 14.

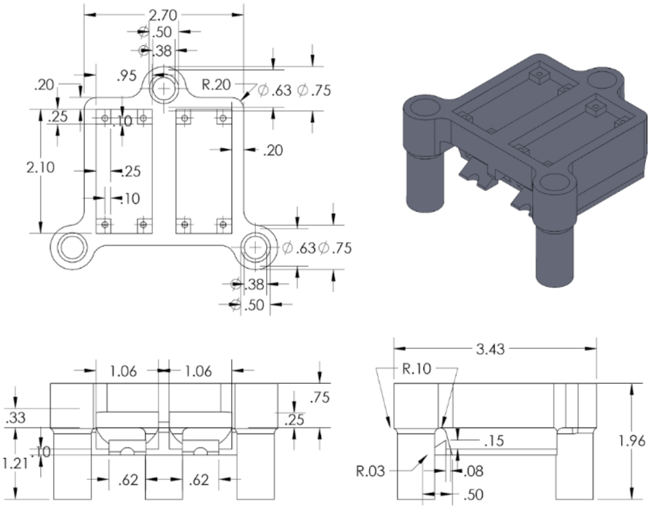


Figure 14: Schematic and layout of additively manufactured Avionics board

Electrical Elements

The electronics used in the recovery system were chosen with a focus on durability and simplicity. The altimeter model chosen to operate the recovery system is the Stratologger CF. Although the CF is a relatively new model from PerfectFlite, it is the direct successor to the reliable Stratologger 100 altimeter which the recovery team has over three years of legacy experience with. Furthermore, three LTRL club flights over the past year have used the CF with a 100% rate of success. There are two recessed rectangles on the avionics board that are measured to the dimensions of the altimeter. In each corner of the recessed areas are standoffs that are additively manufactured in the board which incorporate 0.1-in. diameter screw holes. The altimeters rest on these standoffs and are secured with four 1/8-in. wood screws that go through the altimeter anchor points and into the screw holes on the standoffs. The recessed altimeter areas are deep enough that the sides of the boards are flush with the walls of the recessed areas but the wiring ports on the altimeters are still accessible. This configuration supports the avionics board during lateral motion while still ensuring easy access and assembly.

On the opposite side of the board are the two battery holders. Each battery holder surrounds the battery on the four largest sides with a minimum wall thickness of 1/8-in. The terminal side of the battery is left open so that the battery can be taken in and out. Opposite the insertion opening, a partial wall secures the back of the battery but allows for a small object to be inserted into the compartment to assist in battery removal. These battery holders are recessed into the board and incorporate a slanted entrance ramp that allow for battery insertion but make it difficult for the battery to slip out of the holder without resistance. The retention system used to secure the battery during flight, consists of a plastic clip printed as part of the avionics board. Multiple iterations of this clip design have been printed and tested to find the maximum height that still allows for the battery to be inserted and removed without breaking the clip. The current clip design has a height of .15 inches as seen in Figure 14. This design has been tested in four club flights within the past year and no issues have been found regarding battery retention.

Key switches will be used to control the recovery electronics. As described previously, two key switches are fed from the outside of the rocket through the coupler to provide a method of activating and deactivating the rocket without disassembly. Both switches are secured using nuts on the inside of the coupler. To ensure proper electrical connection, the wires are soldered to each switch terminal before being fed into the screw terminals provided on the Stratologger CF altimeters. Other electrical connections within the avionics bay include screw terminals, placed on the bulkheads, used to connect e-matches to the altimeter. These screw connectors allow for the avionics bay to be assembled prior to connecting the e-matches to the altimeter.

The wiring of the recovery electronics is done to ensure dual redundancy during launch. This means that one single point failure will not cause a catastrophic failure of the system. This is accomplished through the use of two altimeters, two batteries, and two deployment charges per stage. Each altimeter consists of eight pins, two for the battery, two for the switch, and two for each the main, and drogue charges. Each altimeter is wired to an independent battery, to ensure a single battery failure is not critical. Likewise, each altimeter is wired to an independent switch for redundancy. The two altimeters are then connected to separate main and drogue charges. This configuration allows for a single point failure in one of the altimeters as this failure would have no effect on the redundant altimeter. Alternatively, if the system works as designed, one of the altimeters will be programmed with a one second delay to avoid over- pressurizing the rocket. A detailed wiring schematic of the recovery electronics can be seen in Figure 15.

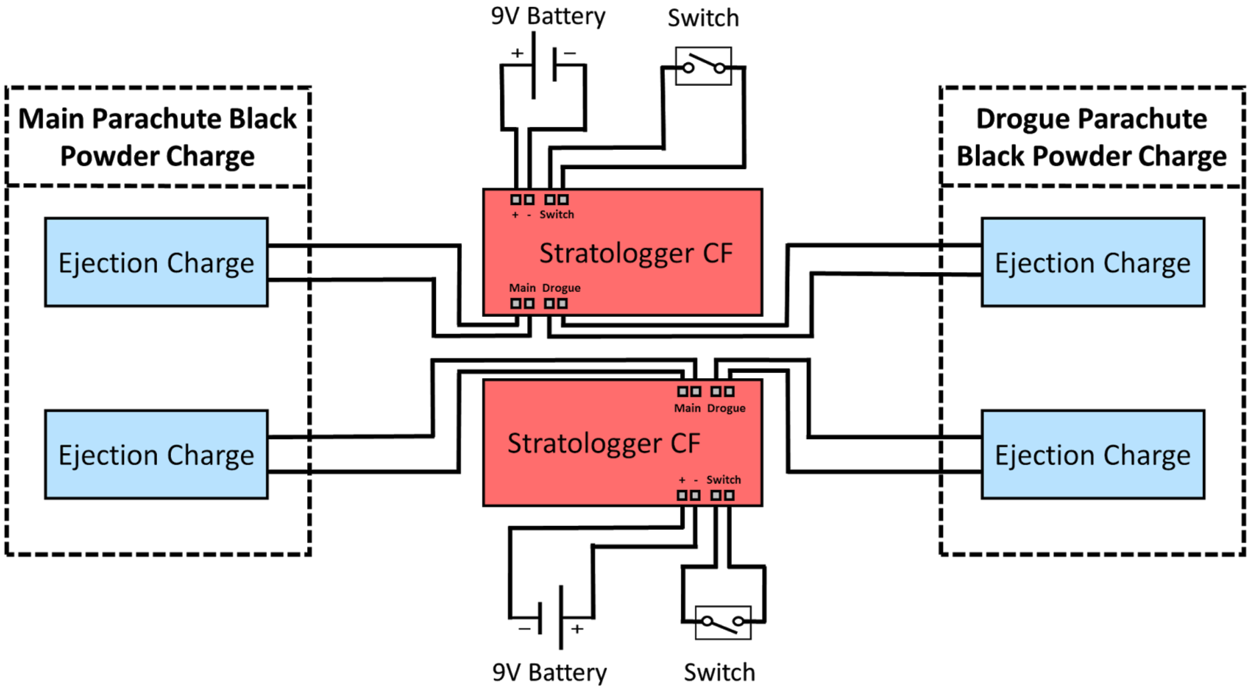


Figure 15: Wiring schematic of recovery electronics

The recovery subsystem will use FruityChutes parachutes for the full-scale rocket. Club experience with these parachutes has proven that they are reliable in performance when used correctly. Previous recovery failures can be attributed to errors in deployment methods such as incorrect parachute packing and inadequate deployment charges. Full scale will use a 72-in. Iris Ultra main parachute and an 18-in. classic elliptical drogue parachute. Recovery calculations predict a descent rate of 95.7 ft/s under drogue and 19.68 ft/s under main parachute. Further recovery calculations will be discussed in 4.3: Mission Performance Predictions.

To ensure location and recovery of the rocket, a GPS unit is included in the nose cone. A Garmin Astro 320 is used with a T-5 receiver placed inside the rocket. This device operates on a MURS frequency between 151.82MHz and 154.6MHz and has a line of sight range of nine miles.

The recovery electronics are crucial to successful flight and therefore are protected from outside electromagnetic interference through use of a Faraday cage. As described previously, the Faraday cage is located in the tubular insert within the avionics bay. In addition, the cage was extended to cover both bulkheads to provide full coverage of electromagnetic fields from any direction. The Faraday cage works by lining the chamber with metal so that any entering electric field will be absorbed and distributed throughout the metal lining. This limits what signals pass through, effectively protecting the recovery electronics from rogue electromagnetic fields. The tubular insert and inner bulkheads are lined with aluminum foil to create this metal lining. Heavy duty aluminum foil was chosen due to its high functionality, high workability, small size. These factors were essential in making the avionics bay smaller and more integrated, all without sacrificing any protection for the electronics.

This design is intended to reduce the volume used by the avionics bay. Compared to previous years, the effective body length consumed by the avionics bay has been reduced by approximately two-thirds (from 12-in. to 4-in.). The concept behind this reduction is to provide more usable volume in the coupler. Now that this concept has been proven, the newly available volume can be used to reduce the overall length and weight of the rocket. The completed avionics bay, when placed inside the Blue Tube coupler, weighs 58.9 ounces. The avionics bay can also be fully assembled the day before launch, greatly reducing the workload required on launch day to accelerate the assembly of the full-scale rocket. Renderings of the exploded assembly are shown in Figure 16.

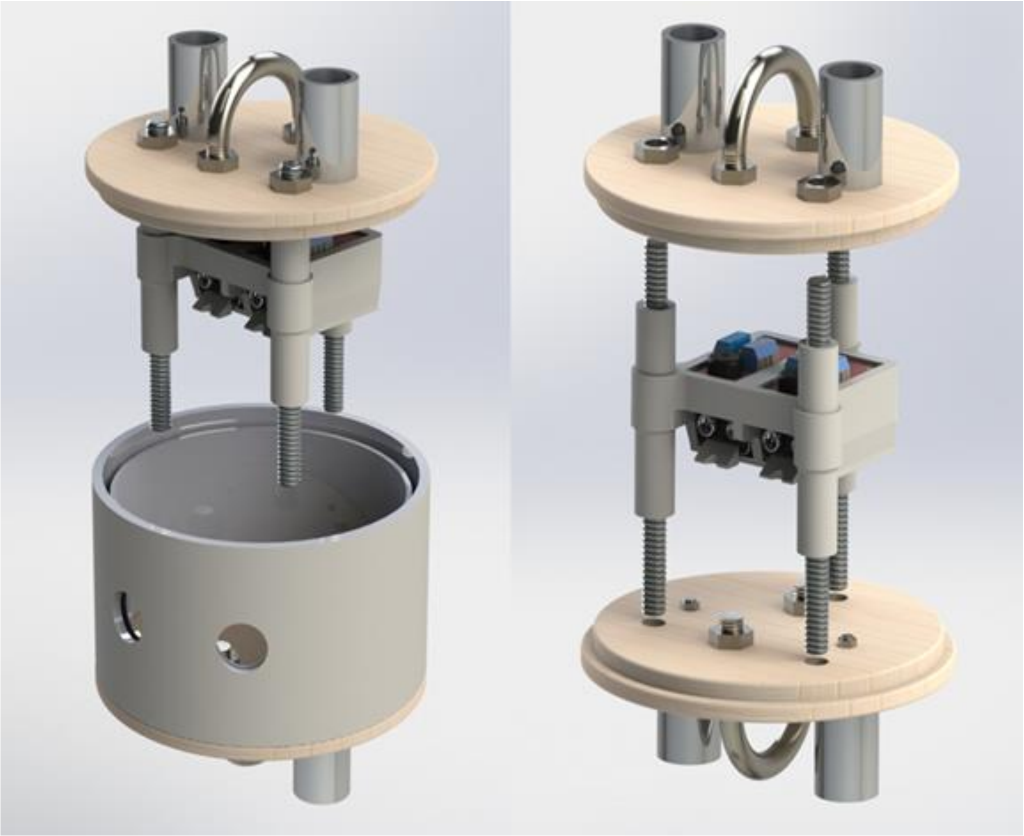


Figure 16: (Left) Assembly view of completed avionics bay with tubular insert (Right) Exploded view of avionics bay without tubular insert

Flight Reliability

There are two main criteria that the recovery system must meet during the competition to be considered a success. The landing kinetic energy of each component landing independently must be less than 75 ft-lbs and the drift distance of each component must be less than 2500 ft in 20 mph winds. The recovery subsystem is very confident that the landing kinetic energy for each component can be maintained under the required kinetic energy limit. The current projection for the maximum landing kinetic energy of the rocket is 51.68 ft-lbs if the Kiwi payload is deployed at apogee. If Kiwi is not deployed at apogee and remains in the booster section, the maximum landing kinetic energy is 60.96 ft-lbs. Ground deploy tests have shown that the current charge amounts easily have the capability of separating the rocket at a given altitude and ensuring parachute ejection. The avionics bay was also designed to be composed of two completely redundant deployment systems, so should one fail the other would still perform all recovery tasks nominally. These factors all lead to the conclusion that the probability of meeting kinetic energy requirements at landing is very high.

The confidence in meeting the drift distance requirement is not as high as the kinetic energy requirement. With the correct parachute configuration, with the drogue parachute deployment at apogee and the main parachute deployment at 700 ft AGL, the drift distance of the vehicle in 20 mph winds is predicted to be 2319 ft, meeting drift requirements. However, during the one full scale test flight, the main parachute deployed at apogee and the rocket drifted one mile during its descent. The current belief is that this apogee main deploy was a direct result of substituting the M2 nylon shear pins specified in the design with #2 nylon shear pins due to supply issues. These smaller shear pins require much less force to separate and are too short to go all of the way through the inner coupler. The team has ordered more M2 shear pins and will have a sufficient supply for the competition. However, there is no way to know for sure if the use of #2 shear pins was the apogee deployment cause. Therefore, the recovery team will perform more ground tests to increase the confidence in the current shear pin configuration and, subsequently, the vehicles ability to stay within required drift distances. The testing is discussed further in 8.1: Testing. The robustness of the recovery system is described further in 3.1: Vehicle Design.

4.3: Mission Performance Predictions

Flight Profile

Flight simulations performed using OpenRocket, Figure 17, predict a maximum velocity of Mach 0.56 and an apogee of 4876 ft. The apogee prediction was simulated with an average wind speed of 4.47 mph and no ballast weight. With zero ballast weight in the rocket, any mass or wind speed increase will lower the apogee, without any means of decreasing mass to compensate.

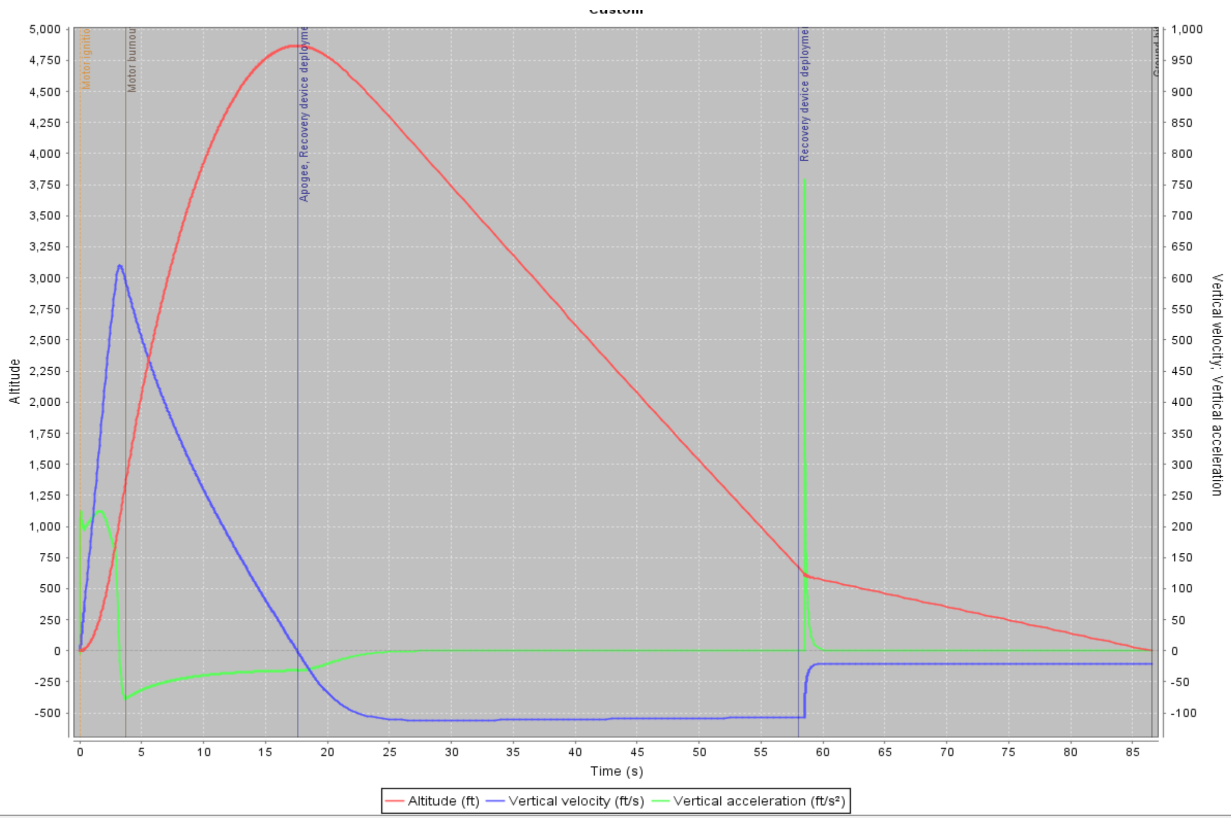


Figure 17: Flight simulation of altitude and drag coefficient

The AeroTech L1170 motor has an average thrust of 256.51-lbf. and peak thrust of 334.74-lbf, with a 3.7 second burn time, Figure 18.

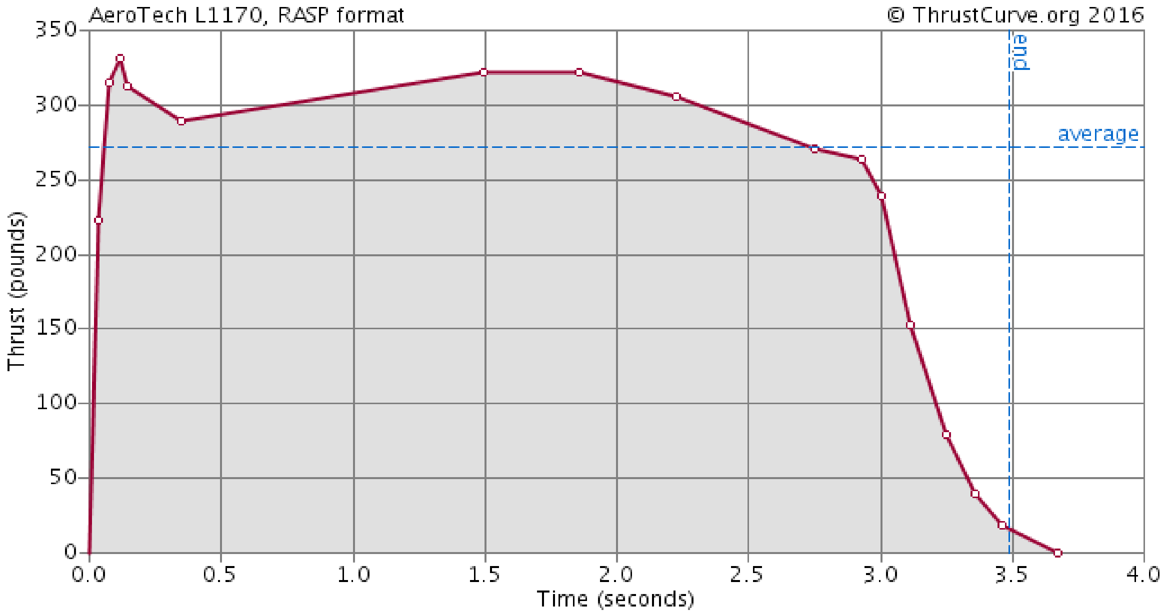


Figure 18: AeroTech L1170 motor thrust curve.

To ensure that the flight simulations do not lose accuracy due to thrust predictions, the simulated thrust curve, Figure 19, was compared to the manufacturer's thrust curve. The simulated characteristics are: average thrust of 265.15-lbf, maximum thrust of 329.54-lbf, and a 3.7 second burn time. The percent errors are 3.31%, 1.57%, and 0%; respectively. The percent error rates lead to a conclusion that the flight predictions don't have significant error due to incorrect thrust predictions. Furthermore, to verify the motor characteristics from Figure 18, static motor testing will be performed at Penn State's High Pressure Combustion Laboratory (HPCL). Due to supply shortages, motor testing has not yet occurred; however, it will be performed before the USLI launch if supplies allow. Details of the planned motor testing are in Section 8.

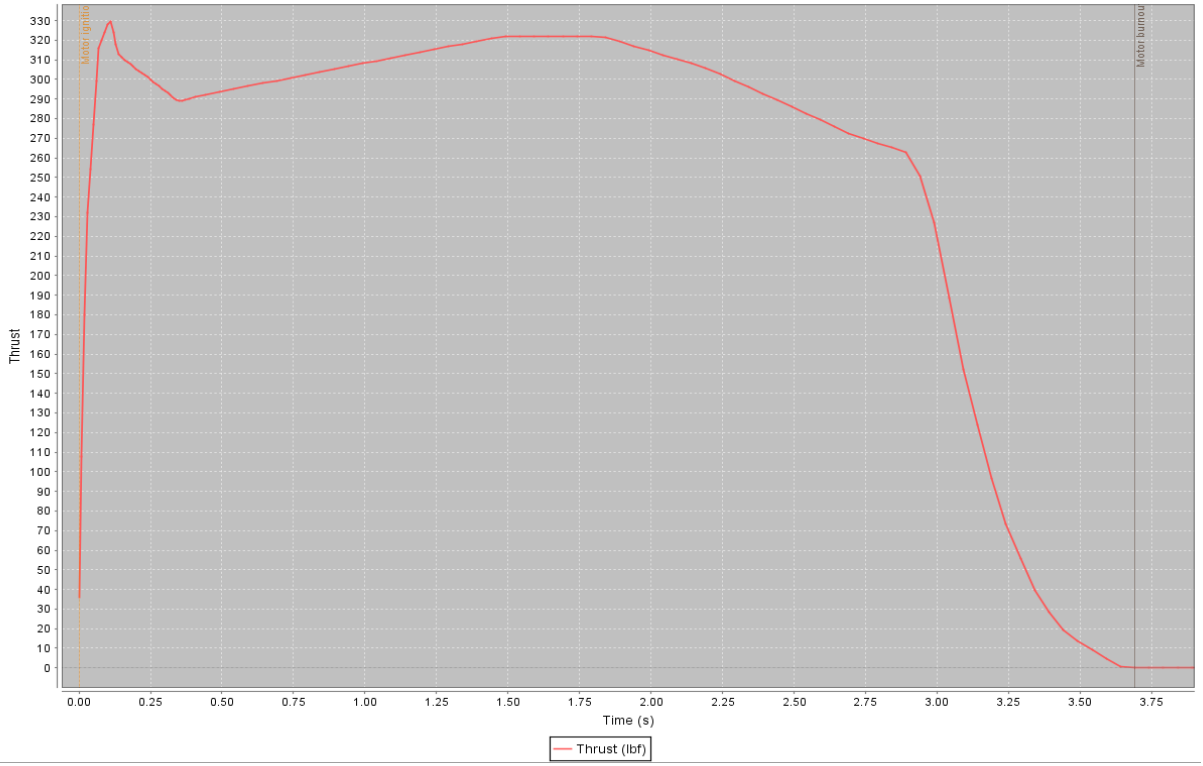


Figure 19: OpenRocket simulated thrust curve

The simulated C_d from OpenRocket is 0.6119, to verify the accuracy of said simulation the C_d is experimentally determined in sub-scale wind tunnel tests. The wind tunnel test results were invalid; the testing, results, and analysis are detailed in Section 8. Wind tunnel testing will be repeated if access to the wind tunnel can be scheduled before the USLI launch.

Stability Margin

The current OpenRocket model has a calculated center of gravity location about 92.856 in. from the tip of the nosecone and a center of pressure of 118 in. from the nose cone, as seen in Figure 20.

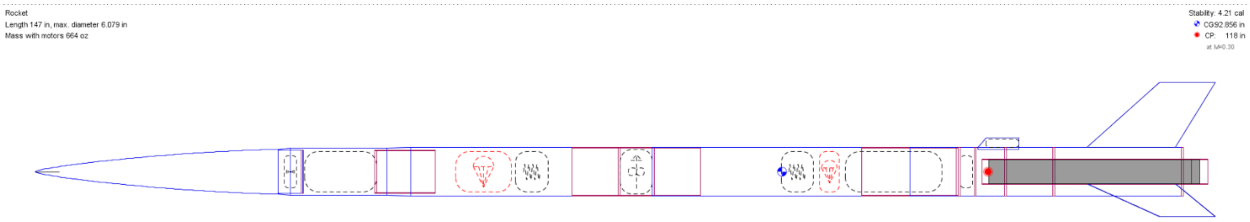


Figure 20: Full-scale OpenRocket Model

The center of gravity is 25.14 in. forward of the center of pressure, which corresponds to a static stability margin of 4.21 calibers, 3.1 calibers off of a 12 ft launch rail, and 3.05 calibers off of an 8-ft rail. Figure 21 and Figure 22 describe the center of gravity, center of pressure, and the stability margin from lift off until the stability becomes relatively constant when launched from a 12-ft or an 8-ft launch rails respectively.

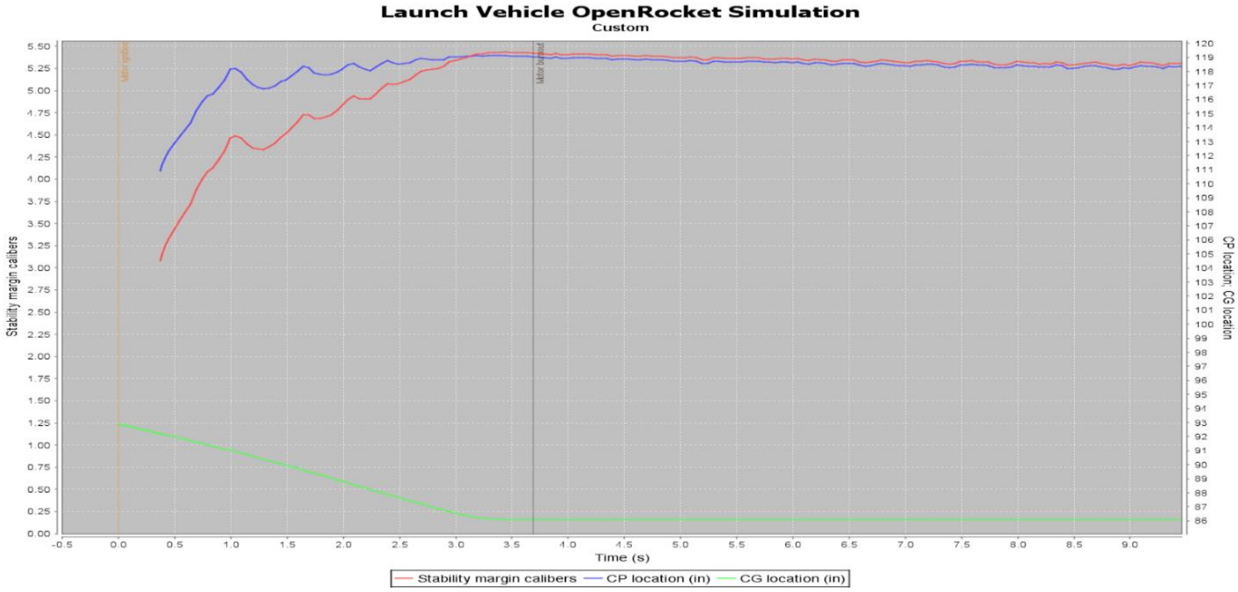


Figure 21: Full-scale OpenRocket stability simulation for 12-ft. launch rail

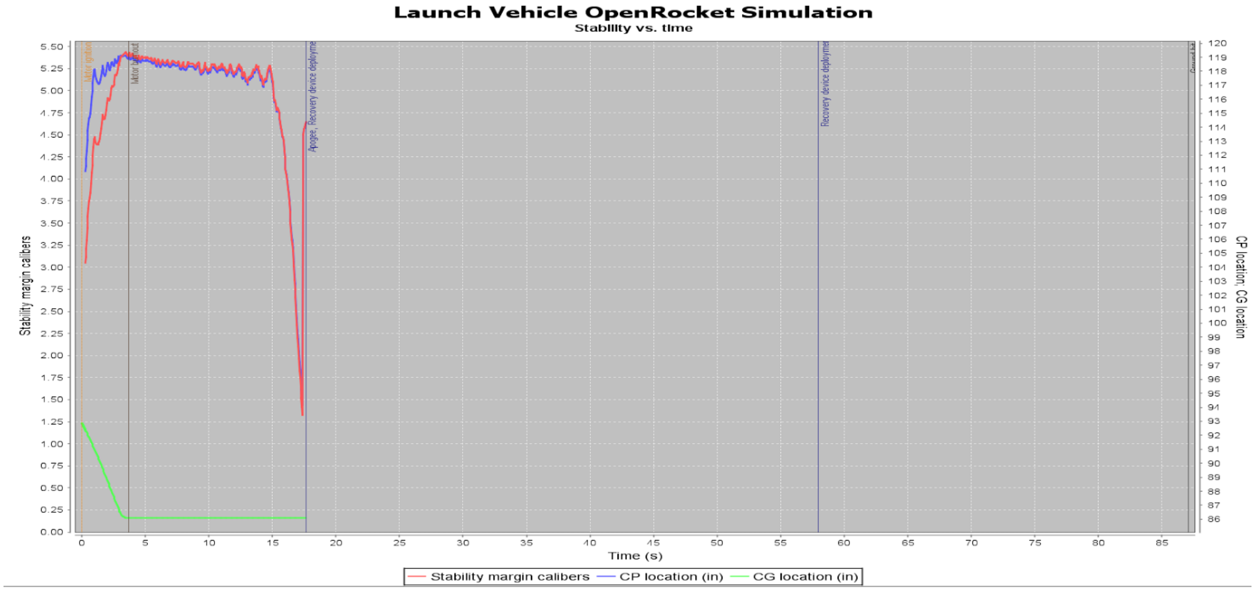


Figure 22: Full-scale OpenRocket Stability Simulation for 8-ft rod

Kinetic Energy Management and Drift Calculations

The success criteria for the recovery system are that the kinetic energy of the largest component must be less than 75 ft-lbs and the drift distance in 20 mph winds must be less than 2500 ft. The parachutes chosen for the rocket were selected to meet the aforementioned criteria. These parachute sizes were selected using the Recovery Descent Profile Calculator (RDPC), a MATLAB code generated by the recovery to make decent predictions and select parachute sizes. RDPC 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. The full code for RDPC can be found in Appendix A: RECOVERY DESCENT PROFILE CALCULATOR.

After rocket characteristics like component mass and the coefficient of drag of the parachutes are input by the user, RDPC estimates a required main parachute size necessary to meet the kinetic energy requirements. This plot for parachute size estimation used for Aeolus is shown in Figure 23. This plot was made under the assumption that the main parachute has a coefficient of drag (C_d) of 2.2. This is the C_d specified by FruityChutes for their Iris Ultra parachutes which the recovery team commonly uses and has a variety of. From this plot, it can be seen that any parachute above roughly 64-in. in diameter is sufficient to meet the kinetic energy requirements. However, the 72-in. Iris Ultra parachute was selected instead because it allowed for some margin of error in the parachute characteristics.

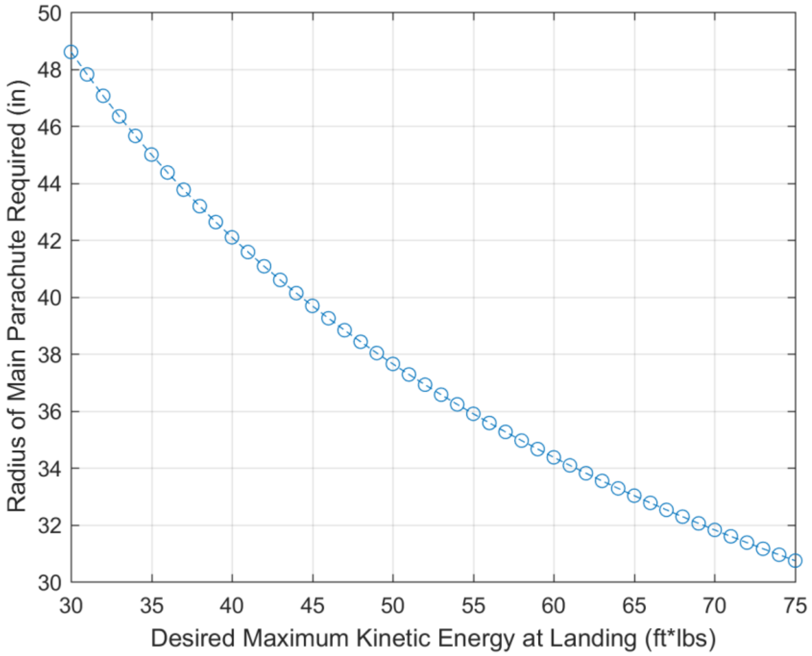


Figure 23: Parachute size plotted vs desired kinetic energy at landing

After the main parachute was selected, RDPC was run with varying sized drogue parachutes in order to find a drogue that would adequately stabilize the descent while still allowing the rocket to fall relatively quickly to reduce descent time. The coefficient of drag used for the drogue predictions was 1.5, which is consistent with Iris Classic Elliptical parachutes. The final drogue size settled upon was an 18-in. Iris Classic Elliptical parachute. Once these parachute parameters were known a recovery prediction for the full-scale rocket was calculated in RDPC. Shown in Figure 24 is the descent profile prediction. Both the altitude and the velocity vs time are shown. The terminal descent velocity under drogue is estimated to be 95.7 ft/s while the terminal descent velocity under main is predicted to be 19.48 ft/s.

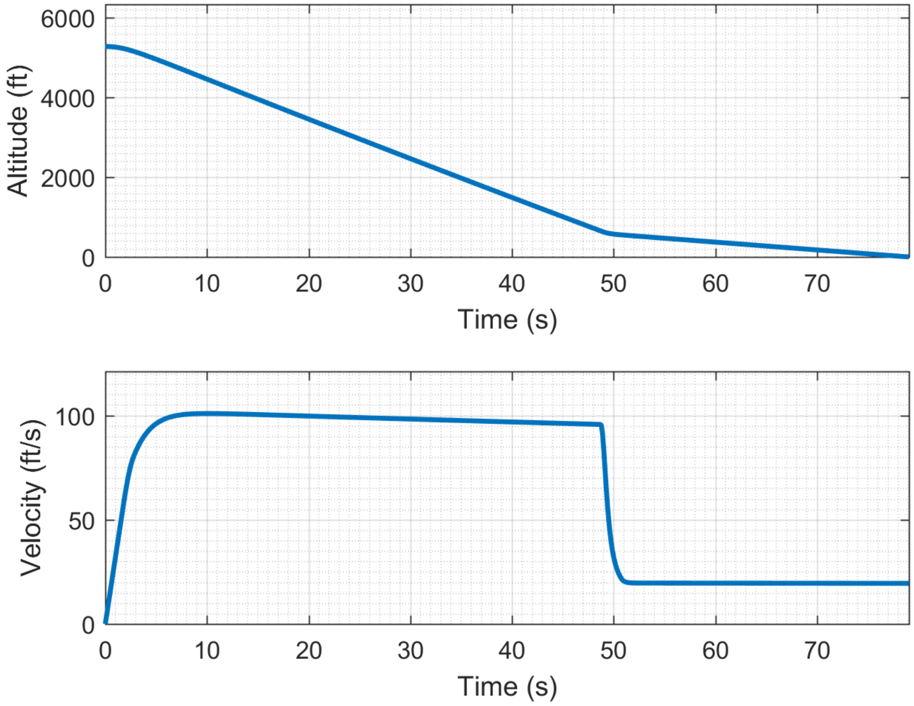


Figure 24: Flight Descent Profile from RDPC with altitude and velocity history

With the predicted velocity history during the descent known, the predicted kinetic energy history can be plotted for each portion of the rocket. Shown in Figure 25 is the predicted time history of the kinetic energy of each component during descent. Note that the forward and middle sections of the rocket remain attached until the main parachute deployment, so the kinetic energy of those two components can be summed before the main parachute deployment to find the combined kinetic energy. Shown in Table 4 are the kinetic energy values of each component of the rocket at key points during descent. The maximum energy at landing is 51.68 ft-lbs of energy achieved by the forward section. Therefore, the kinetic energy requirement is easily met.

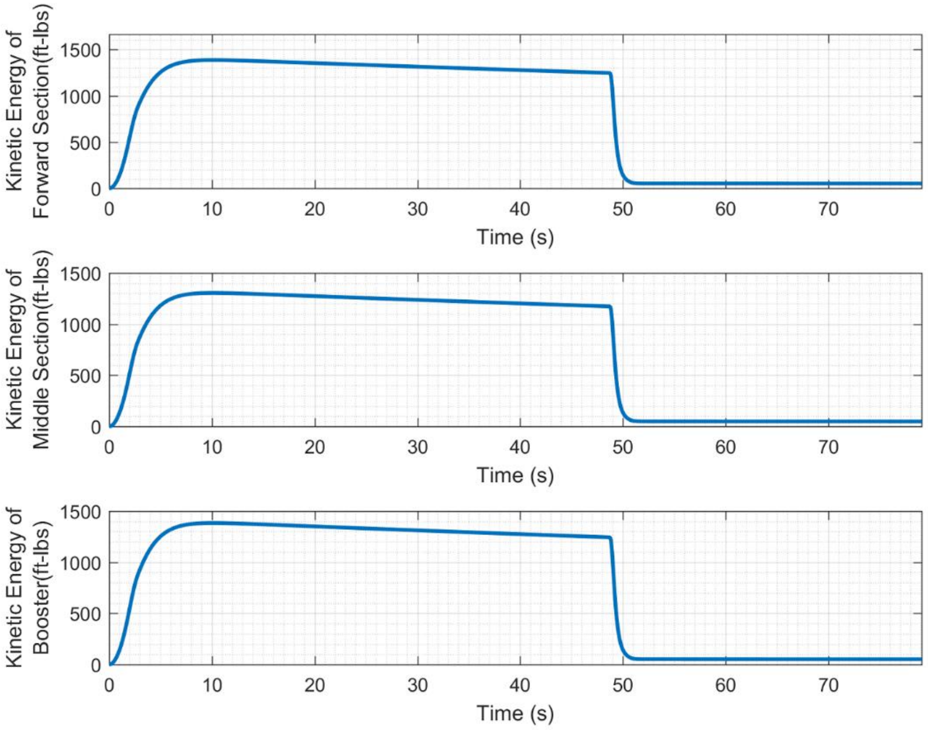


Figure 25: Predicted kinetic energy profile of each rocket component during descent

Table 4: Predicted kinetic energy values at key times during descent

Descent Event	Time Since Apogee	Forward Section		Middle Section		Booster Section	
		Mass (lbm)	KE (ft-lbs)	Mass (lbm)	KE (ft-lbs)	Mass (lbm)	KE (ft-lbs)
Main Deploy	48 seconds	8.768	1249	8.254	1176	8.750	1247
Landing	79 seconds	8.768	51.68	8.254	48.65	8.750	51.58

In recovery system design, kinetic energy/descent velocity and the drift distance are often a trade-off. If the descent velocity is reduced for safety, the drift distance will increase because the system will be subject to atmospheric winds for a longer period of time. RDPC predicted a total descent time of 79 seconds and used this value to predict drift distance by multiplying this time by the wind speed. Predicted drift distances in different wind conditions are shown in Table 5. The drift distance of Aeolus in 20-mph winds is 2319-ft. Aeolus is able to stay under drift requirements while maintaining conservative kinetic energy due to the systems even mass distribution between the three significant landing components. The difference in mass between the most and least massive component is only 0.514-lbm.

Table 5: Drift distances of rocket in certain wind conditions

Wind Speed (mph)	0	5	10	15	20
Drift Distance (ft)	0	580	1160	1740	2319

4.4: Full Scale Flight

Recovery System

The full-scale test flight was performed on February 26th at the MDRA launch site in Church Hill, MD at 3:45 pm. Wind speeds from the closest reliable weather station, Dover AFB, indicated winds around 15 mph W at that time. During assembly, #2 nylon shear pins were used instead of the specified M2 shear pins because of supply issues. These shear pins are smaller diameter and shorter than the M2 shear pins. The rocket was launched and reached an apogee of around 4518 ft. At apogee, there was an anomaly during drogue deployment during which the main parachute also deployed. It is believed that this anomaly was a direct result of the use of the #2 shear pins, which require much less force to break. The rocket proceeded to descend under the main parachute in strong winds. Shown in Figure 26 is the actual and predicted descent profiles of the rocket. The total descent time was 169 seconds, in comparison to the expected 225 seconds expected under these conditions.

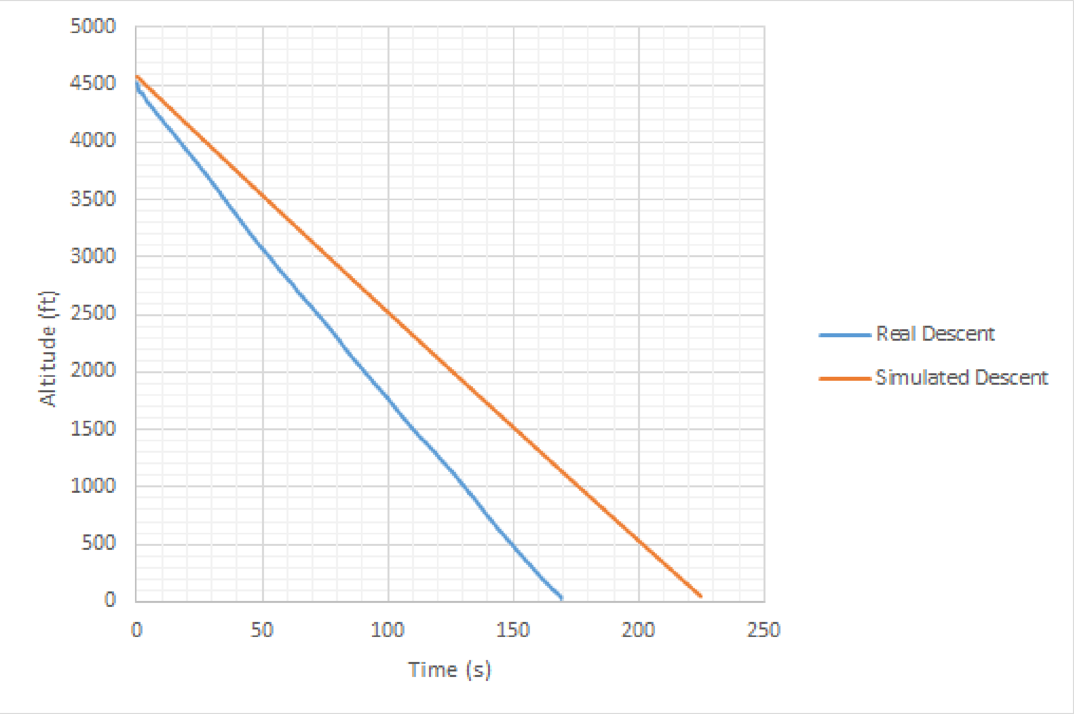


Figure 26: Real and Simulated descent profiles of the rocket

The rocket drifted 1.03 miles while descending and landed in a group of trees about 40 ft high. Using the drift distance and the descent time it was calculated that the minimum average wind speed during launch was 21 mph. However, upon leaving the rail the rocket tilted into the wind and traveled into the wind for an unknown ground distance. This means that the real drift distance was higher than 1.03 mile and that the average wind was higher than 21 mph to blow the rocket that far during descent.

The real descent rate was much higher than the model at almost 27 ft/s. This is compared to the predicted descent rate of around 20 fps. The real and predicted velocity profiles are shown in Figure 27. It appeared as though the main parachute was partially restricted during descent, leading to a faster descent than expected. This is likely to have been a result of tangled shroud lines. Another factor that may have sped the descent is a tear in the parachute. The parachute used had two holes burned from a previous ejection test in which the parachute was not well protected enough. These holes were covered on both sides generously with duct tape, which had held through at least one previous launch. However, during this launch, a large tear opened from one of the holes to the edge of the parachute. This tear is about 20-in. long. It is believed that the tear was caused during deployment but it is possible the tree branches damaged it during landing. Another factor that may have hampered the parachute is the extreme winds. High winds may deform the parachute and reduce its effective area. These three factors are combinations that may have contributed to the faster than expected rate of descent.

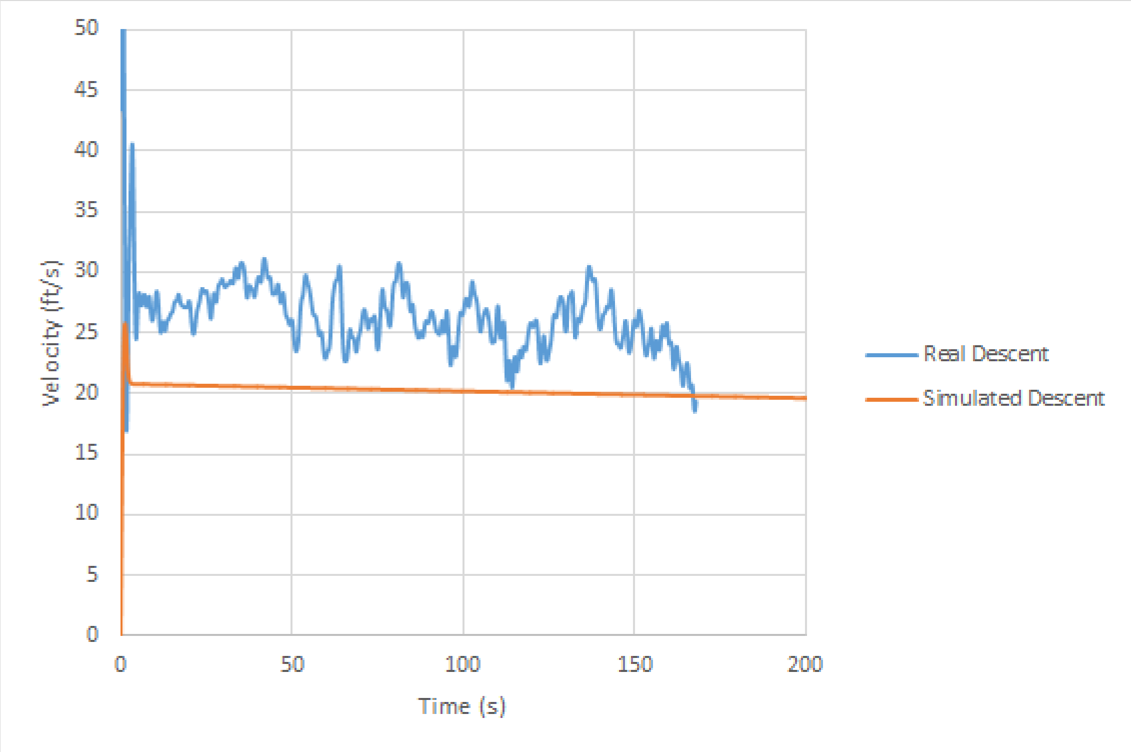


Figure 27: Real and predicted velocity descent profile

Another issue noticed was that there were two undetonated ejection charges, one on either side of the avionics bay. Both of these charges were linked to the same altimeter. This altimeter, while it failed to detonate the charges, did collect data for the entire duration of the flight. It is possible that the altimeter has malfunctioning charge pins but the more likely explanation is that there were intermittent power supply issues such that access to full battery power was not available at the deployment times but there was still enough connection time to keep the altimeter running. Upon removal of the avionics equipment from the rocket, one of the battery wires was observed to have fallen out of the power pin on the altimeter. It is likely that the screw terminal on the altimeter was loose and connection was not constant. This will be fixed by ensuring that the screw terminals are tight and that the wires cannot be removed during the construction phase of the avionics preparation.

Apogee and Drag Coefficient

The predicted full scale apogee based on a nearby weather report of 15-mph wind and a 5-degree launch angle was 4615-ft. The actual apogee recorded by the altimeters onboard the vehicle was 4518-ft resulting in a percent error of 5%. Updating the model for a wind speed of 21-mph resulted in a predicted apogee of 4514-ft. From this and recovery descent time calculations it was determined that the wind at the launch site was closer to 20-mph than the 15-mph given by the weather report from Dover AFB.

From the flight to apogee time, C_d was calculated to be 0.6978. The MATLAB script used to calculate C_d is in Appendix D. The code takes known rocket characteristics and the time to apogee to calculate C_d. An assumption made is that the equivalent velocity equals the exhaust velocity. The rocket characteristics used are: burn time, average thrust, initial mass, final mass, and I_{sp}. From these mass flow rate, height of burnout, equivalent velocity, drag force, and then C_d is calculated. First, as flowrate is calculated using Eq. 1:

$$\dot{m} = \left(M_i - M_f\right)t \tag{1}$$

Then, mass flow rate is divided from the average thrust using Eq. 2 to obtain the exhaust velocity. Then applying the assumption in Eq. 3 that exhaust pressure equals atmospheric pressure; Eq. 4 results. Then, the equivalent velocity is set equal to the exhaust velocity, Eq. 5.

$$U_e = \tau\dot{m} \tag{2}$$

$$T = \dot{m}U_e + (P_a - P_e)A_e \tag{3}$$

$$T = \dot{m}U_e \tag{4}$$

$$U_{eq} = U_e \tag{5}$$

Then, the first stage velocity is found using the equivalent velocity, the mass ratio, and burn time in Eq. 6:

$$U_1 = U_e \log\left(\frac{M_i}{M_f}\right) + gt_b \tag{6}$$

Now, height at burnout can be found using burn time, specific impulse, and mass ratio in Eq. 7:

$$h_b = g[\frac{-t_b I_{sp} \log\left(\frac{M_i}{M_f}\right)}{\frac{M_i}{M_{f-1}}} + t_b I_{sp} - \frac{1}{2} t_b^2 \tag{7}$$

Using height at burnout and first stage velocity with the time from burnout to apogee, found from flight test, the drag force was found using Eq. 8:

$$D = h_b - U_1 t_{ba} - \frac{1}{2} g t_{ba}^2 \tag{8}$$

Finally, the coefficient of drag was found using the drag force, first stage velocity, and standard atmospheric conditions in Eq. D:

$$C_d = -\frac{2D}{\rho A U_1^2} \tag{9}$$

Structure

During the full- scale test flight, multiple parts were damaged that must be repaired prior to competition. Zippering occurred in both the main section body tube and booster coupler during main parachute deployment. These sections will be replaced with new pieces of Blue tube 2.0. To mitigate this failure during future launches, large "Fireballs" will be placed along the shock cord to evenly distribute the force during deployment. Images of the failure points can be seen in Figure 28.

Figure 28: Zippering of main body tube (LEFT) and booster coupler (RIGHT)

Additional damage was found in the fin brackets. As shown in Figure 29, one of the fin brackets cracked in the center and began to peel away from the body tube. There are several possible causes for this severe fin bracket damage. During descent, the fin may have hit a branch or tree upon landing. Such an impact may have transferred much of the momentum from the rocket through one fin into a hard surface, breaking the fin. However, a more likely scenario is that the fin was damaged when the booster section was cut free from the tree it landed in. The booster was hanging approximately 30ft above the ground and landed at about 44 ft/s. A fall at this speed would explain the structural failure on the fin bracket. It is believed that, in normal flight conditions and at a reasonable landing velocity, the fin brackets would all have survived intact. In addition to the critical failure in one fin bracket, another fin bracket showed some minor cracking and separation from the body, most likely from the same series of causes.

Figure 29: Damaged fin bracket

To repair the damage caused from this descent, new fin brackets will be printed to replace those damaged from this test flight. The design of the fin brackets allows for the fins to be removed through use of three small bolts. Since no structural damage occurred to the fins, they will be removed and reused for future launches.

Section 5: Payload Criteria

5.1: Payload Design

Design, Construction and Verification

FOPS

FOPS consists of a specimen containment bag held within an acrylic body section. The assembled protective components of FOPS are depicted in Figure 30.

Figure 30: Assembled model of FOPS

The bottom of the body is sealed with a wooden bulkhead bonded to the acrylic with epoxy. The top section has two restraining tabs bonded to the acrylic with epoxy, which serve to hold the top bulkhead against the nose cone. Both bulkheads were treated so that they are waterproof. The top bulkhead contains two valves, which serve as a dilatant inlet and air outlet. Dilatant is held in a balloon in the nose cone and is mounted on the dilatant valve (not shown in figure). The containment bag is a gallon-sized sealable bag lined with open-cell foam and cotton which can compress to accommodate different sized payloads. The specimen containment bag is submerged in dilatant, which provides the necessary support to prevent specimen damage due to acceleration. The bag protects the objects from damage from the dilatant as well. Major dimensions of FOPS are contained in Figure 31 below.

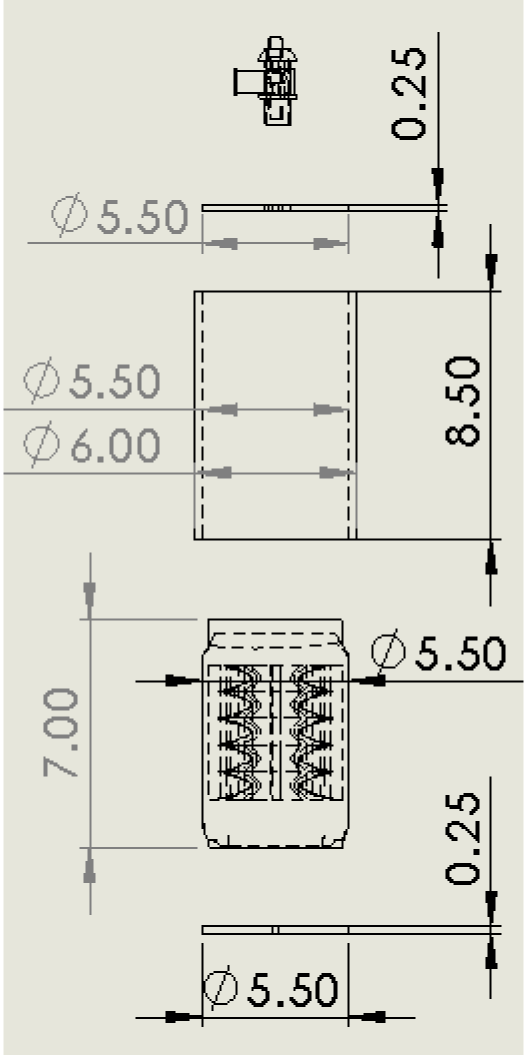


Figure 31: Major dimensions of FOPS

As shown in the diagram, the materials bag will comfortably fit objects that are within the 3-in. radius by 6-in. length cylinder.

Kiwi

An assembled model of Kiwi is shown in Figure 32. The physical components of Kiwi include a top rotor, a propeller, a rudder, and a fuselage, divided into two sections for assembly. The rudder is controlled by a wire connected to a servo. Kiwi is 8.9-in. long and 3.5-in. wide. The parachute bay is on the bottom right of Kiwi as it is shown in Figure 32. The bay is 1.3-in. wide, 1.75-in. tall, and 3-in. long.

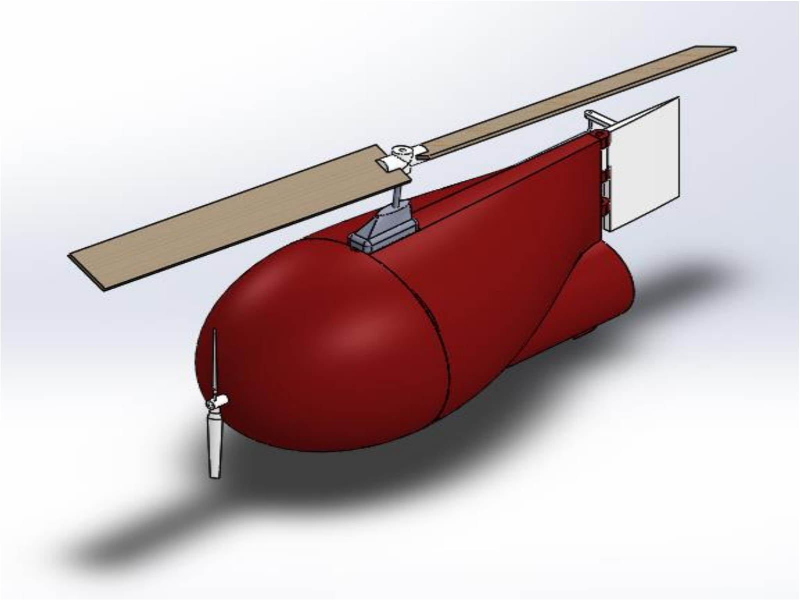


Figure 32: Assembled model of Kiwi

In order to protect Kiwi during launch, a sabot will be used that will encase Kiwi inside of the rocket body. An isometric image of the sabot is shown in Figure 33.

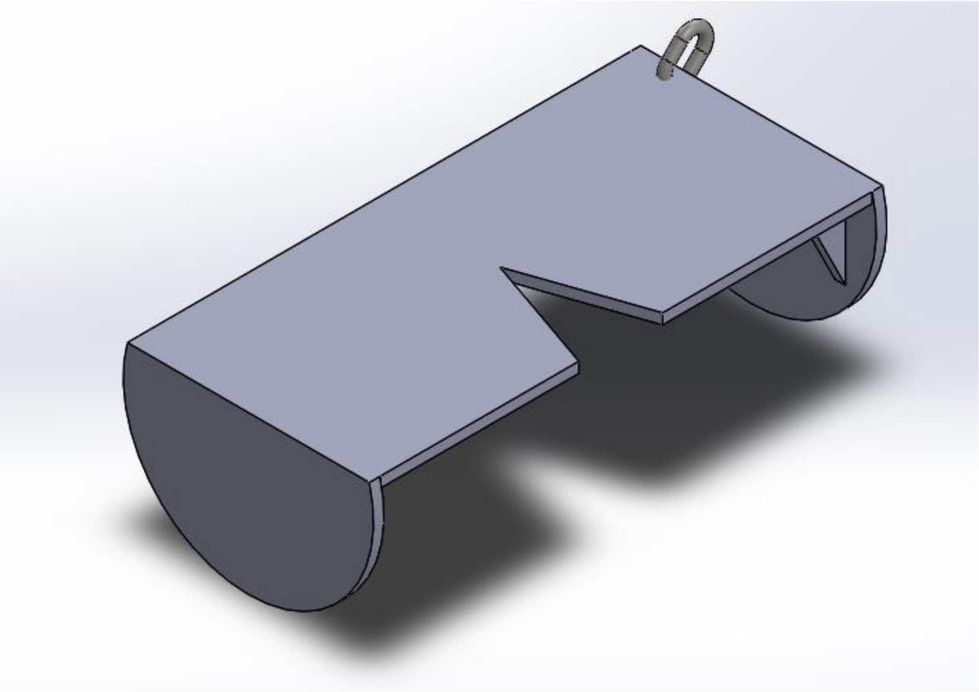


Figure 33: An isometric view of Kiwi's sabot

The quick-link connects the sabot to the shock cord by providing a connection point for an interim cord. In the motor retainer side of the sabot, shear pins connect the sabot to the bulkhead. The nose cone side of the sabot has the ability to open so the shear pins can be placed in the bottom of the sabot. The quick link shown in the figure connects to a Tender Descender. The Tender Descender attaches the sabot to the shock cord, so that the sabot can be pulled out and Kiwi will be released. The force of the shock cord will be enough to break the shear pins. In the event that Kiwi is not allowed to launch, Kiwi will blow the Tender Descender via e-match and shear pins will hold the sabot in place. The rotor axis of Kiwi rests in the notch cut into the sabot. Resting the axle will prevent the rotor or body from being damaged during exit.

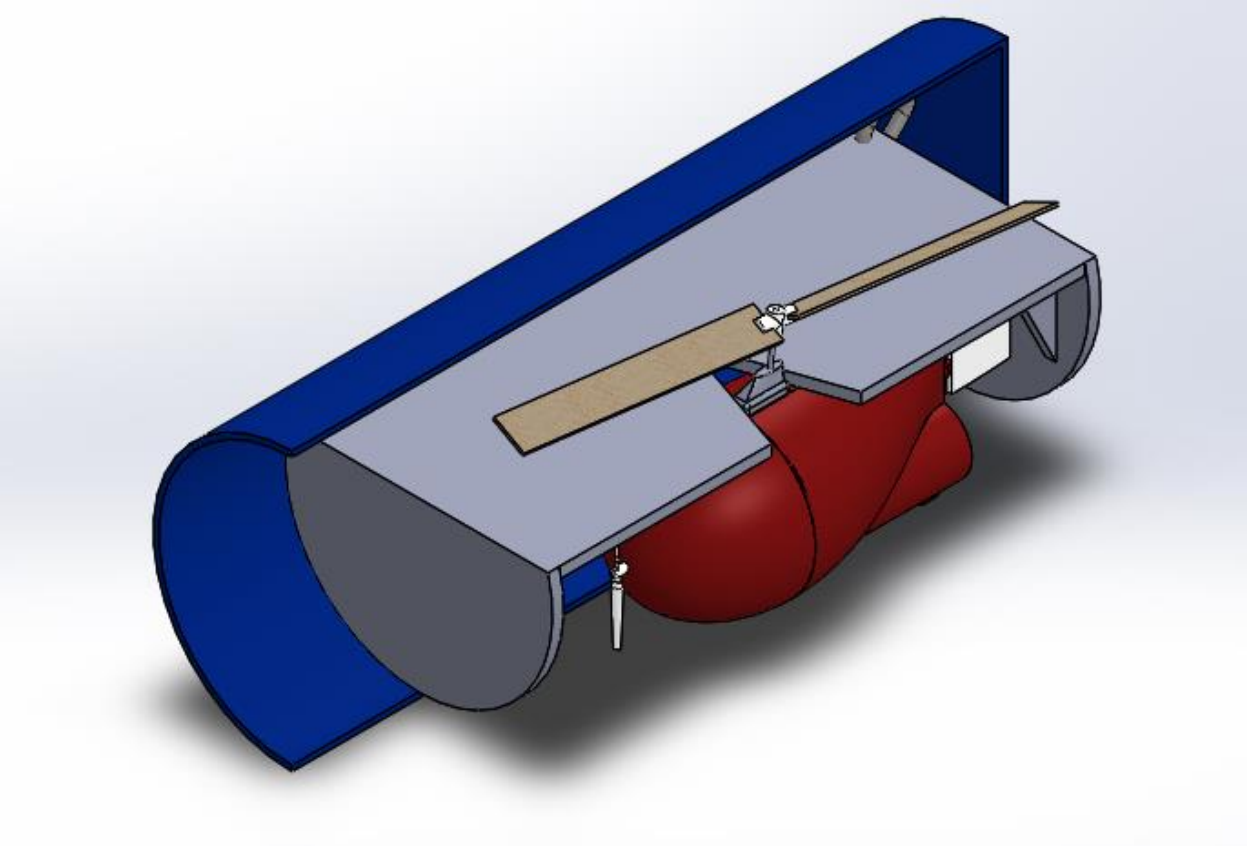


Figure 34: Kiwi resting in its sabot.

An assembly of the sabot and Kiwi inside the rocket body is depicted in Figure 34. A sample of the rocket body is shown in blue. The body of the rocket will prevent Kiwi from exerting force on the propeller by moving. The shear pins and Tender Descender are not shown in this image.

Precision and Repeatability

The GPS and IMU are precise to within 3 feet. The GPS takes an average of 20 minutes to reliably lock onto the satellite. The percentage of packets that the XBees drop is negligible. The rudder angle is precise within 1 degree. During e-match testing, Kiwi deployed its parachute five out of five times. The photo-resistor correctly differentiated between complete darkness, low light (shade), and bright light (sunlight) levels during all testing. The RPM of the propeller motor is consistent.

Electronics

Below are the electrical schematics used in the Kiwi system. The schematic for the ground station for the Kiwi system is shown in Figure 35.

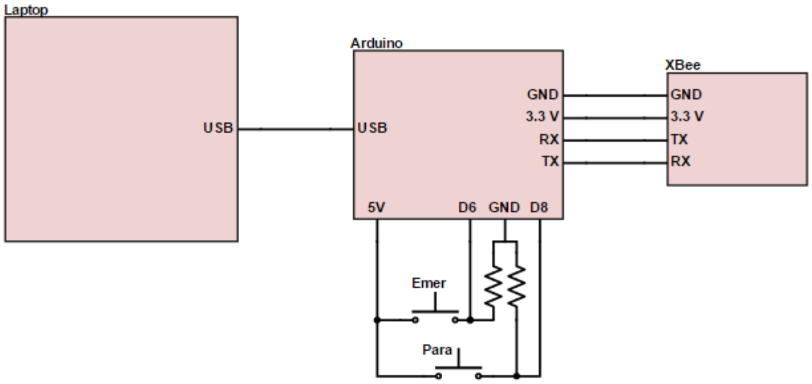


Figure 35: Ground station

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. If the RSO gives permission for the team to land Kiwi without deploying the parachute, the team will press the No Parachute switch, which will send a signal to Kiwi to turn off the altimeter and not deploy the parachute at 500 ft.

The schematic for the electrical systems on board the Kiwi vehicle is shown in Figure 36. A Nano 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 Nano 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 9V battery will power the motor that drives the propeller. That battery will also have an external switch to connect it to the voltage regulator. The motor will be connected to a transistor, 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 photo-resistor 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. For redundancy, there will also be a separate altimeter system, including a 9 V battery, an altimeter, and an e-match on board Kiwi. Kiwi will have the ability to turn off the altimeter system via transistor.

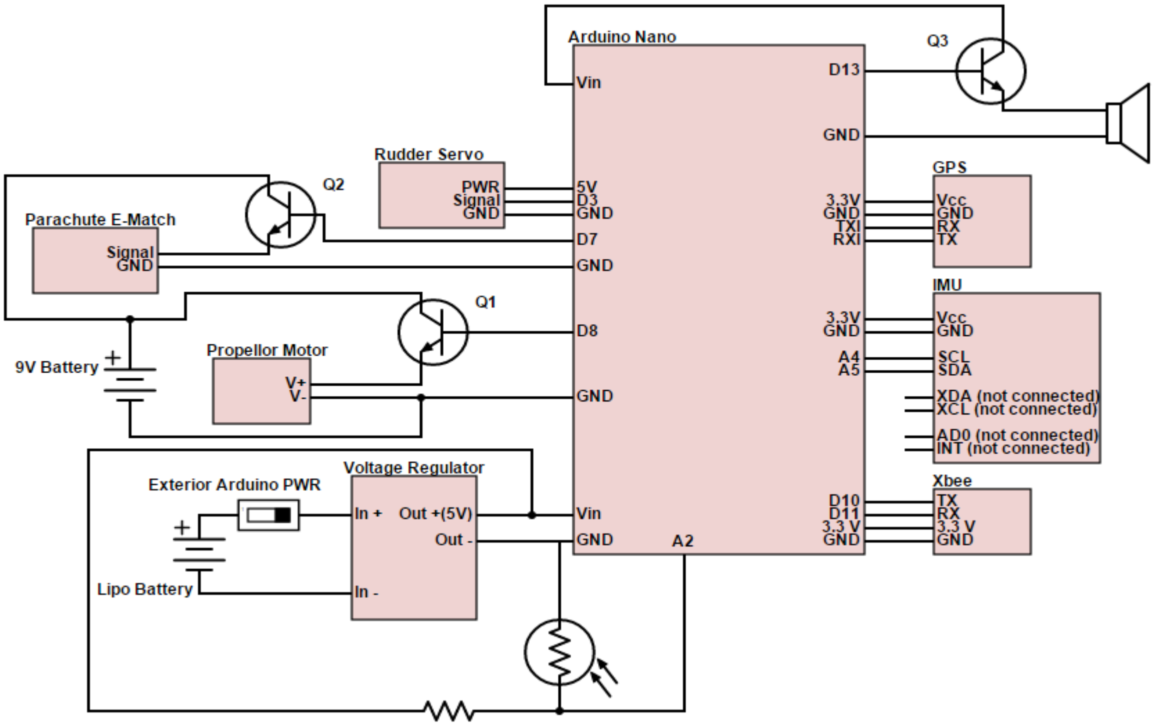


Figure 36: Schematic for the electrical systems onboard Kiwi

The software flow diagram of the Ground Station is shown in Figure 37. The ground station is used for monitoring Kiwi's stability and flight path, to provide a way to remotely shutdown the vehicle and deploy the parachutes, and to instruct the vehicle to land without a parachute with the permission of the RSO. The ground 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 system will check if the button that gives Kiwi permission to land without a chute has been pressed. If the button has been pressed, the Ground Station will send a message to Kiwi permitting the vehicle to land without a chute. Then, the laptop will display the received location and velocity data from Kiwi so the team can monitor the flight of the vehicle.

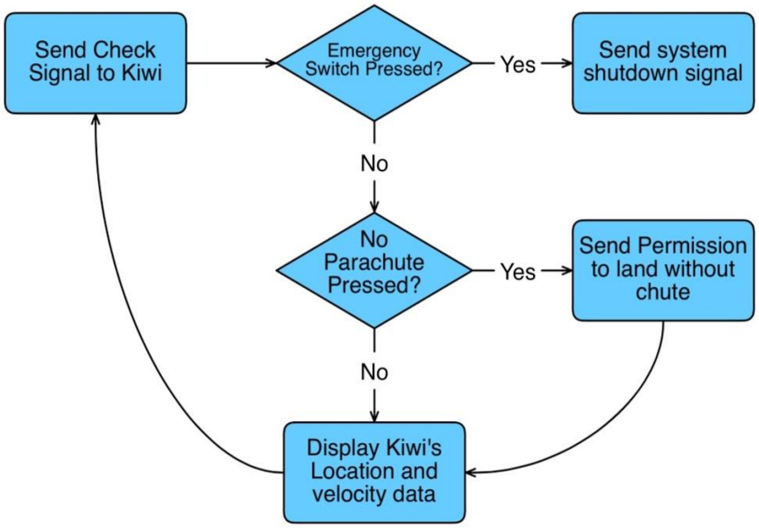


Figure 37: Kiwi Ground Station Software Diagram

The Kiwi on board software flow diagram is shown in Figure 38. The flight computer will not power the propellers unless the ground station signal has been received, the altitude is over 500 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 autogyro 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 50 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 Kiwi receives permission to land without a parachute, the system will turn off the altimeter and not deploy the parachute. 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 500 ft and Kiwi has not received permission to land without a parachute, the flight computer will deploy the parachute by opening the transistor, and turn off all systems.

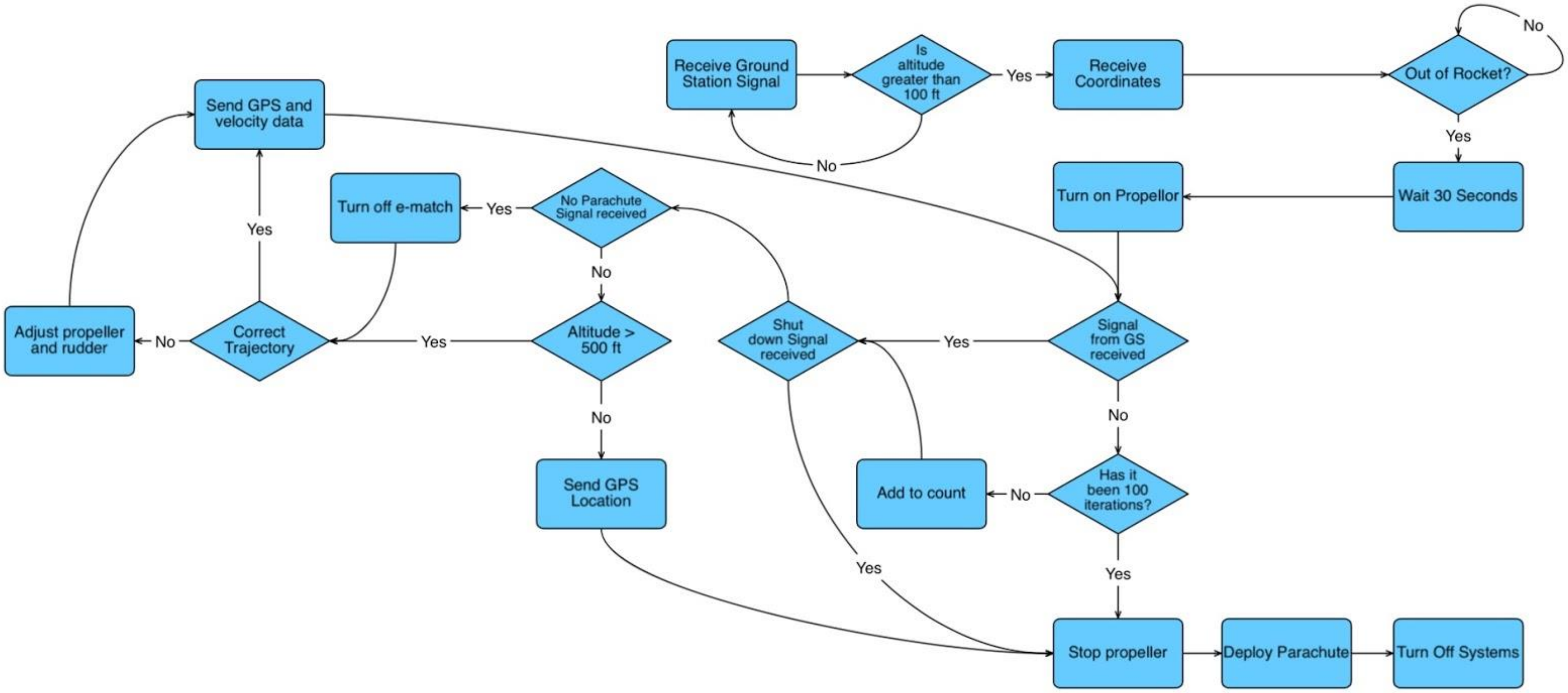


Figure 38: Kiwi’s onboard software flow diagram

Section 6: Safety

6.1: Safety and Environment

Personnel Hazard analysis

All team members have taken Penn State's lab safety course containing information safety regulations for working with hazardous materials. Safe working habits will be enforced when working on any project. The team safety officer is responsible for ensuring all team members are informed of any hazards and abide by the guidelines for accident avoidance.

Safety procedures were developed by consulting the Material Safety Data sheets (MSDS) in Appendix 2. All NAR regulations pertaining to high powered rocketry safety are followed. Operator's manuals are also available to members to consult prior to using any unfamiliar equipment. More experienced individuals will be present in the lab during construction, as only leads have access to the lab. Leads will supervise team members so that no one is unsupervised while using a tool with which they are not experienced.

Table 6 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 6: Personnel Hazard Analysis

Hazard	Cause	Effect	Mitigation	Verification
Blue tube and sheet machining and sanding	Inhalation of small particulates	Dust particles can cause respiratory irritation and damage	Use face mask and shop vacuum, maintain adequate ventilation	Visual verification by the lead present in the lab that proper PPE is in place prior to machining or sanding
Power Tool Use	Flying debris	Cuts, possible eye injuries	Wear safety glasses, follow tool safety instructions	Visual verification by the lead present in the lab that safety glasses are being worn, and that all precautions are being followed

Soldering iron use	Tip of soldering iron becomes very hot	Personnel are burned, Potential fire hazard if the solder iron is left on near a flammable object	Personnel will be instructed in safe use of the solder iron before soldering. Solder iron will not be left on unattended	Lead present will verify that personnel have been trained in solder iron use. The lead will ensure that the solder iron is unplugged before leaving room for an extended time.
Black Powder	Black powder is a fire hazard and explosive	Fire, personal injury, equipment damage	Only subsystem leads are permitted to handle these materials. Use only in small quantities and away from sparks and statics.	Black powder is secured so that only the qualified personnel have access.
Pyrodex	Pyrodex is a fire hazard and explosive	Fire, personal injury, equipment damage	Only subsystem leads are permitted to handle these materials. Use only in small quantities and away from sparks and statics.	Pyrodex is secured so that only qualified personnel have access.
Spray paint use	Inhalation of aerosol vapors	Skin and or respiratory irritation	Make sure adequate ventilation is in place when working with aerosols	Subsystem leads will ensure that all use of aerosols occurs in properly ventilated areas, specialized painting booth on campus will be used
Use of adhesives (e.g. JB Weld)	Inhalation of solvent vapors	Respiratory irritation	Make sure adequate ventilation is in place when working with solvents	Subsystem leads will ensure that all use of solvents occurs in properly ventilated areas
Motor misfire	Possible unexpected explosions	Personal injury, equipment damage	Ensure that the motor ignition charge is inserted properly, wait for the proper length of time before going to check the rocket if the motor does not fire	The propulsion subsystem leads will ensure that the ignition charge is inserted properly.

Unfired ejection charges after launch	Possible unexpected explosions	Personal injury, equipment damage	Ensure altimeters are working correctly	The avionics and recovery subsystem leads will verify that the altimeters are working correctly
Pre-firing of ejection charges prior to launch	Possible unexpected explosion	Personal injury, equipment damage	Ensure no one is 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. Use a key switch to isolate the charges from the altimeters before moving the rocket to the launch pad. Ensure altimeters are working correctly	The safety officer will verify no one is standing behind or in front of rocket once charges have been placed in the rocket. The avionics and recovery leads will verify that ignition charge is inserted properly and connected securely and that the altimeters are working correctly. The avionics and recovery leads will be responsible for turning the key switch to the on position once the rocket is on the launch pad.
Unstable or dangerous rocket flights at launches	Rocket hitting personnel or equipment	Injury to personnel or equipment	Obey launch officials, pay attention during launch, pre-launch safety briefings	The preflight and launch safety checklists will be used.
Improperly loaded equipment during transport	Equipment moves during transport	Damage to equipment, possible injury to personnel	Proper packaging and securing of all transport equipment	Leads will ensure that the parts and tools needed for their subsystem are secured and will not move during transport.
Rockets may fall without parachute deployment at launches	Rockets have high kinetic energy due to lack of parachute deployment	Damage to equipment, injury to personnel	Instruct all personnel on launch day safety, keep equipment and vehicles a safe distance from the launch pad	Verify all personnel understand 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. The failure modes and effects analysis for the rocket structure are shown in Table 7.

Table 7: Failure Modes and Effects Analysis: Rocket Structure

Failure Mode	Cause	Effect	Mitigation	Verification
Motor does not stay retained	Ejection charges push motor out of rear of rocket	Motor does not remain in rocket	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	Simulation of expected stresses, materials testing	Compare the simulations to the tensile test results
Crack along outer seam of body tube	Body tube cracks due to torsional stress and bending moment	Functional/structural inadequacy	Reducing the stress concentration	Simulation of expected stresses, materials testing
Unwanted separation of coupler from body tube	Premature shear pin failure	Undeployed parachutes, uncontrolled descent	Screw adequate number of screws	Visual inspection during pre-flight check
Fracture crack in coupler	Torsional stress and/or bending moment	Aerodynamic inconsistency and/or structural failure	Simulation of stresses, materials testing	Visual inspection during pre-flight check
Nosecone tip removal	Extreme impact	Aerodynamic instability, instability, sky debris	Simulation of expected stresses, material testing	Pre-flight check
Fin fracture crack	Extreme or repeated impact, bending moment	Aerodynamic instability, structural failure	Simulation of expected stresses, material testing	Visual inspection during pre-flight check

Fins separate from the fin brackets	Insufficient epoxy strength, loosening of bolts	Sky debris	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	Screwed and epoxied adequately	Visual inspection, pre-flight check
Fin brackets separate from body tube	Insufficient epoxy strength	Sky debris	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 threads, insufficient epoxy strength	Structural Failure, pressure leakage	Simulation of expected stresses, material testing	Visual Inspection, Pre-flight check
All-threads shear	Insufficient all thread strength	Unwanted separation of rocket	Simulation of expected stresses, visual Inspection	Pre-flight check
Airframe zippers	During ejection shock cord cuts into body tube	Rocket body is damaged	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	Increase in width of the fins	Simulation of expected stresses

Failure modes and effect analysis was conducted for the launch operations, such as motor firing, and rocket recovery. These are presented in Table 8 below.

Table 8: Failure Modes and Effects Analysis: Launch Operations

Hazard	Cause	Effect	Mitigation	Verification
Motor does not ignite	Motor does not ignite on launch day	Rocket does not lift off pad	Use recommended igniters. Store motors properly to avoid oxidation.	Motor testing using the igniters that will be used at the competition
Motor CATOs	Motor casing or components rupture	Damage to rocket	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	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	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	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 deploys first	Main chute deploys at apogee	Kinetic energy during main chute deployment is too high	Proper labeling of wires, ground test, use correct number of shear pins	Two members of A&R will 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	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	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	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	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	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	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	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	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	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	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	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

A separate failure modes and effects analysis was also conducted for the payloads, as these were unique operations which presented different risks. They are presented below in Table 9.

Table 9: Failure Modes and Effects Analysis: Payloads

Hazard	Cause	Effect	Mitigation	Verification
FOPS 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 ballistic in populated areas	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 flight control and is no longer able to sustain flight	Hazardous wind conditions exert more forces on Kiwi than control surfaces can withstand	Kiwi becomes ballistic in populated areas	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 to prevent sudden attitude change	Kiwi will undergo multiple test flights with different starting orientations to ensure that the vehicle can reach and maintain stability.
Drive Shaft failure occurs while Kiwi is in flight	Kiwi's propeller axle separates from the propeller and eliminates power to Kiwi	Kiwi becomes ballistic in a populated area	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	The GPS receiver within Kiwi is damaged or separates from the microcontroller	Kiwi guided section does not reach proper location	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	Xbee radios disconnect from their microcontrollers or move out of contact range	Kiwi cannot be shut down in case of emergency	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 and soldered into place

Kiwi gets tangled in parachute cords	Upon opening, the parachute cords come into contact with the moving rotor or propeller	Kiwi becomes ballistic in a populated area	Care will be taken in the packing of Kiwi in the rocket body to ensure ease of exit without interference. In case of entanglement, Kiwi will be designed to be light enough to ensure paracord operation	Test launches as well as independent tests will verify the ability of the parachute to open correctly
Kiwi's electronic package stops working during descent	The electronic components within Kiwi lose connection to one another	Kiwi fails to control its descent, parachute fails to deploy	An independent altimeter will be used to deploy Kiwi independently of control systems using a direct battery connection	Test launches and ground tests will confirm Kiwi's ability to independently deploy its parachute

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. A breakdown of these hazards is shown in Table 10.

Table 10: Environmental Hazards

Environmental Hazard	Cause	Effect	Mitigation	Verification
Solvent or paint released to environment	Improper disposal of used chemicals	Potential contamination of environment	Properly dispose of all used chemicals through the EHS	Penn State EHS is contacted and notified to pick up used chemicals
Motor gases	Hot, toxic gases released during takeoff	Contamination of environment, air pollution hazard	Follow all launch safety regulations	Checklist for safety regulation to be completed prior to launch
Motor burning into ground	Titanium sponges, motor burning out without launching the vehicle	Cause fire at launch pad or surrounding area	Use motors without titanium sponges, securely retain the motor into the booster	Ensure that “Skidmark” and similar motors are not used, test motor retention system
Ejection charge fails to go off during launch	Altimeter failure	Charge could go off on ground and cause a fire	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, burning parachute would also release airborne toxins	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 would occur to local area/watershed if toxic chemicals were used in the FOPS fluid	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	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 11, below.

Table 11: Overall Project Risks

Risk	Cause	Effect	Mitigation	Verification
Labor leaves/graduates	Seniors graduate or students stop attending meetings	There are no longer enough students available to perform the necessary work	Recruitment at beginning of each semester. Team building activities.	Social chair presents activities planned at all-hands and officer meetings.
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	Dedicated member to track expenses and make funding contracts possible.	Treasurer presents pertinent financial information at officer meetings.
Project falls behind schedule	Team fails to build critical components in a timely manner	Major milestones are not met in time	Weekly status meetings, follow project plan	The president oversees bi-weekly all-hands meetings and bi-weekly officer meetings.
Failure to acquire transportation	Team doesn't reserve vans early enough, lacks funding to rent them, or cannot find enough qualified drivers.	Team is unable to travel to the competition	Have plan to carpool if necessary, treasurer will ensure that there are enough funds to rent vans, and that reservations are made in advance.	The treasurer presents updates on Alabama trip planning to the officers on a bi-weekly basis.

Injury of team personnel	Hazards outlined in Table (4.3)	Team member is injured	Inform and enforce team safety	The safety officer is responsible for informing and enforcing team safety.
Project over budget	Testing/fabrication/ travel costs exceed expectations	Project cost exceeds amount of money projected.	Compare prices from different vendors, avoid excess shipping costs, make all hotel and car rentals in a timely manner.	The treasurer has been assigned the responsibility of ensuring that all purchases made are cost effective and within budget.
Damage during testing	Accident/malfunction during testing	Catastrophic damage to rocket	Ground testing, maintain stock of spare parts	All sub-system leads maintain stocks of spare parts for their subsystem. Ground testing is conducted during design and development, and before each launch.
Club loses facilities	University revokes club access to lab	Club loses access to 46 Hammond	Maintain clean environment and proper storage of materials	The safety officer oversees the proper storage of materials and help maintain a clean environment in the lab.

Parts are unavailable	Parts needed for rocket are not available commercially	Rocket cannot be completed using planned parts	Use non-exotic materials and check for availability during the design process. Order parts far in advance.	All sub-system leads check for availability of parts during the design process.
Theft of equipment	Parts or testing equipment get stolen	Rocket construction becomes more difficult, excess cost to the club	Only subsystem leaders and officers will have card access to the LTRL lab	The president oversees card access rights to the lab.

Section 7: Launch Operation Procedures

7.1 Recovery Preparation

In order to assemble the avionics bay in preparation for flight, all necessary materials and tools relevant to the assembly of the avionics bay and the recovery system are gathered and inspected for defects. Any faulty materials are removed and replaced with backup supplies. Install the altimeters in the avionics board with screws. Place fresh batteries into the avionics board and wire them to the altimeters with 9V battery clips. Tape must be placed over the batteries to ensure that they will stay connected throughout the flight. Wire the key switches into the altimeters and install in the body tube. Wire the blue connector wires to the main ports of altimeter 1, the green connector wires to the main ports of altimeter 2, the yellow connector wires to the drogue ports of altimeter 1, and the white connector wires to the drogue ports of altimeter 2. Then thread the white connector wires through the central feed hole on the drogue side bulkhead and wire them into a connector terminal. Do the same with the yellow connector wires on the drogue side bulkhead with the remaining connector terminal. It is crucial that these colored wires are done correctly in order to ensure that the appropriate charges are ignited.

Now, with the avionics board held to the drogue bulkhead and with the batteries facing the bulkhead, align the three numbered holes on the board with the three numbered holes on the bulkhead. Take a threaded rod with a single nut on the end and insert it through hole 1 in the main bulkhead and then through the corresponding hole on the avionics board until the nut is flush with the bulkhead. Insert a small nut on the opposite side of the threaded rod and screw it onto the threaded rod until it is flush and tight against the avionics board. Repeat these steps for the remaining two threaded rods and holes in the bulkhead. Insert the partially constructed avionics bay into the structural coupler until the bulkhead is flush with the internal bay coupler, such that the altimeters are facing the up arrow on the structural coupler. Ensure that the numbered holes are aligned with their corresponding labels on the structural coupler. The threads must be secure so that the avionics coupler is structurally sound. Then thread green connector wires through the central feed hole on the main side bulkhead and wire them into the connector terminal. Do the same with the blue connector wires and the main side bulkhead with the remaining connector terminal. Now, install the main side bulkhead into the structural coupler with the holes, numbered 1-3, aligned with correspondingly numbered threads. Finally, add the bolts to all three threaded rods and screw each bolt down until it is tightly flush on the main bulkhead. The bolts must be fastened correctly so that the avionics coupler can withstand the forces applied by the shock cords during parachute ejection.

Assembling the recovery harness begins by first ensuring that the key switches are in the OFF position. This is important, because it prevents premature lighting of the e-matches that can be potentially dangerous to those installing them. Then the e-matches are wired to the other side of the connector terminals. Then place the other ends of each of the four e-matches into blast caps and secure each to the exterior of blast cap with tape. If this is not done, then there is a risk that the e-match are displaced and do not ignite the ejection charge. Before setting up the charges, safety glasses and latex or nitrile gloves are required when handling black powder. For the main charges, measure 3.5g of black powder for each of the two main blast caps and pour them each into their respective caps. The proper amount of black powder must be measured to ensure deployment of parachutes. Pack the remaining space in blast cap tightly with wadding and tape over blast cap opening with painter's tape. If this is not done, then the ejection charges will fall out of the blast caps and will not ignite. Repeat these for the drogue charges, but with only 3g of black powder.

Now, use a ¼-in. quick-link to connect the shock cord designated for use between main parachute and main bulkhead to the U-bolt on the main bulkhead. Use another quick-link to connect the shock cord designated for use between drogue bulkhead and drogue parachute to the U-bolt on the drogue bulkhead. Pull main side shock cord through main body tube section and secure the main body tube section to the avionics bay with shortened screws. Do the same for drogue side shock cord and the drogue body tube. All quick-links must be installed properly to ensure that every part of the rocket stays connected to each other and that parachutes during descent and lands under the kinetic energy limit.

Now to pack the main parachute, begin by folding the parachute in the approved pattern and ensuring the cords aren't tangled for proper and full opening of chute. Tangled cords may cause the parachute to not fully open and improper folding may cause tangling of the cords. Attach the parachute and protective blanket to the shock cord from the avionics bay via quick-link, this placement of the blanket prevents it from sliding up the parachute cords in a way that prevents the parachute from opening. The nomex blanket prevents damage from the ejection charges and attaching it to the quick-link ensures that it does not cause partial opening of the parachute. Wrap the parachute in its protective blanket. Take the slack of the shock cord between the parachute and the avionics body tube and fold it, accordion style, back and forth over itself in approximately 8 inch increments. Place it loosely into the avionics body tube. Now, place the folded, wrapped parachute in the avionics body tube on top of the shock cord with the blanket facing the charge to optimally shield parachute from the potentially damaging ignition.

Connect the designated shock cord between the U-bolt on the booster section and the quick-link of the main parachute. Fold the shock cord between the parachute and the booster section in the same manner that the other shock cord was and again place loosely on top of the parachute. Repeat these parachute-packing steps on drogue parachute on the nose cone side on the avionics bay. Finish remaining assembly of rocket and set it up on the launch rail. At the launch rail, turn on each key switch and listen for each of the two altimeter's triple beeps that signify that they are ready for launch. Altimeters must have continuity beeps to ensure that they will function properly during flight.

7.2 Payload Preparation

Kiwi

The team programmed Kiwi with the coordinates of the landing location determined prior to launch. The GPS, 9V battery, propeller, and e-match were connected to the main circuit board. The LiPo battery was attached to the voltage regulator and the team connected the voltage regulator to the circuit board. All circuit board connections are labelled with what should be connected at that junction. All electronic components, including the extra altimeter system, were packed into Kiwi. The e-match, but not the black powder, was inserted into the blasting chamber. The halves of Kiwi were attached via screws using the side nut and bolt holes in the middle of the body. After confirming that the altimeter was off, the avionics team filled the blasting cap with correct amount of black powder and loaded the parachute into the parachute bay on Kiwi, pushing any excess shock cord into the shock cord access hole. The sabot's tender descender was attached to the shock cord, and the shear pins were placed into the bottom flap of the sabot. The tender descender e-match was placed in the tender descender. Kiwi was placed facing the nose cone into the sabot and the rotor shaft was placed in the sabot cut out. The top flap of the sabot was closed and secured. The team checked that Kiwi was operating by listening for its buzzer.

FOPS

The team mixed 15.7-oz cornstarch and 12.9-oz water together, and put half of the mixture in the bottom of the FOPS bay and half of the mixture in a balloon. The materials bag was put into the chamber. The team attached the balloon to the closed dilatant valve, and opened the air flow valve. The fragile object or objects were placed into the materials bag, and the bag was sealed. The team placed the top bulkhead on the FOPS bay opened the dilatant valve, and attached the nose cone to the bulkhead. The nose cone and FOPS bay were screwed together.

7.3 Motor Preparation

The smoked train grain assembly is first loaded into the forward closure. The O-ring is then inserted into the groove of the forward closure. The nozzle is inserted into the casing liner. Four motor grains are inserted into the casing liner and spaced with three O-rings between each grain. An O-ring is inserted into the forward insulating disk which is then inserted into the casing liner opposite of the nozzle. This assembly is then inserted into the motor casing. The lower retaining ring is sealed on the bottom of the casing, followed by the forward closure which contains the smoke trail grain assembly. The O-ring is inserted into the forward seal ring which is then inserted into the casing above the forward closure. Forward retaining ring is inserted above. Then use the closure wrench to firmly tighten both retaining rings. Install the motor casing into the motor retainer. The exterior closure is sealed on the base of the casing. Finally, place the red nozzle cap over the nozzle exit.

7.4 Setup on Launcher

Consult with Propulsion that the motor is properly placed into the motor tube. Screw the motor retainer onto the end of the motor tube to secure the motor in place. Assure that the rail buttons are properly aligned and fastened securely using 1/4-20 bolts. Assure that fins are attached to fin brackets using nine #1 bolts and tighten any that exhibit any movement during inspection. Assure that each of the three fin brackets are secured to the booster section using six #4 screws per fin bracket. Locate the Center of Gravity of the rocket using a mass balancing method and record the distance from the tip of the nose cone. Consult with Propulsion to assure that the Center of Pressure is within specifications. Locate Range Safety Officer and perform final safety inspection of the assembled launch vehicle. After obtaining clearance, slide the launch vehicle onto a 12 ft. 1515 extruded aluminum launch rail while the rail is in a horizontal position. Lift the launch rail up to a vertical position and lock the rail in place.

7.5 Igniter Installation

Twist the e-match leads together if this has not been done. Check to make sure the ignition circuit is deactivated. Remove the red nozzle cap from the nozzle exit, and then feed the e-match through the nozzle up to the top of motor. Separate the two e-match leads to at least one foot in distance. Connect each e-match lead to the ignition circuit. Ensure the e-match leads will not contact each other.

7.6 Troubleshooting

Payload

Table 12: Payload Troubleshooting

Problem	Solution
Dilatant for FOPS is too thick/not thick enough	Add corn starch or water in 0.5-oz. increments and mix thoroughly until desired consistency is achieved
Fragile specimens interact with each other after insertion	Remove specimens from containment bag, re-insert with greater distance between objects
Specimen containment bag fails to close	Remove fragile specimens and clean locking threads in bag, replace specimens
Kiwi fails to initialize its systems properly	Replace battery and ensure all electronic components are connected. Check that the GPS is not connected during boot-up
XBees are not communicating	Check their input voltage and circuitry connections
GPS or XBee information contains too much noise	Check the connection on the capacitor between Vin and GND
Kiwi's propeller fails to turn during systems check	Replace battery

Kiwi's altimeter is on before launch pad	Check resistor connections

7.8 Post-flight Inspection

Recovery

After landing, approach the rocket with caution because there might be parts scattered and possibly hot from the ejection charges. Listen to the altimeters to determine apogee. Turn the avionics switches to the OFF position. This is to ensure that any undetonated charges do not go off unexpectedly from handling. Firstly, disconnect the shock cords attached to the booster and the nose cone to ease transportation back the launch preparation area. Once at a safe area, remove the body tube sections and check to see if there are any undetonated charges. If there are, carefully cut one wire to the e-match going to each undetonated charge and remove the material in the blast cap. The stuffing inside the blast cap should be disposed of while the black powder should be poured back into the black powder bag. Then, disassemble the recovery harness. This involves detaching all of the quick-links from the bulkheads, parachutes, and shock cords. Then, wrap the shock cords to be stored. Then, lay out the parachutes and inspect them for any damage. Damaged parachutes do not work as well and need to be replaced. After inspection, fold and wrap the parachutes for storage. Place every recovery harness component in their respective place to be stored or transferred to the lab and then stored.

For the avionics bay and coupler, start by detaching the blue, green, yellow, and white wires from the bulkhead. Then, remove one of the bulkheads from the coupler. Detach the key switch wires from the altimeters. Now, the avionic bay should be free to slide out of the couplers. Remove the avionics bay and the other bulkhead from the coupler. The altimeter should then be taken to the RSO to inform them of the altitude of apogee. Since the switch is no longer attached, bring a wire to serve as a switch for the official altimeter. Then, continue disassembling the avionics coupler. Unscrew the key switches from the coupler and carefully remove them. Being too forceful with the switch may break it. Next, detach the blue, green, yellow, and white wires from the altimeters. Detach the power supply wires from the altimeter as well. The altimeters should now not have any wires connected so they can be unscrewed from the avionics bay. Lastly for the avionics bay, remove the batteries. Place every avionics bay and coupler component in their respective place to be stored or transferred to the lab and then stored.

Once at a computer, plug the altimeters in and extract the data. Compare the actual flight data to the estimated data from computer simulations. If there are any discrepancies, the data must be looked over and the discrepancy accounted for. The flight data should be stored on the computer for future reference.

Kiwi

One member of the team will check that the parachute was deployed and that the e-matches and black powder pose no threats to personnel.

FOPS

The nose cone will be unscrewed from the FOPS bay and the nose cone and top bulkhead will be removed. The non-Newtonian fluid will be carefully taken out of the chamber. Once all of the fluid is removed, the containment bag will be opened, the fragile objects will be removed and inspected for damage.

Section 8: Project Plan

8.1: Testing

Payload

The tests performed to verify payload functionality are shown in Table 13

Table 13: Payload Tests

Test	Variables	Results	Success	Methodology
Protective abilities of different fluids	Solution concentration, type of dilatant	15.7-oz. cornstarch in 12.9-oz. water provides the best protection.	Yes	Identical containers were filled with different test substances, including various concentrations of Cornstarch in water, marshmallow fluff, hair conditioner, and peanut butter. A corn chip wrapped in a bag was suspended in each. Each was dropped from a height of 30 ft. Once each had landed, it was disassembled and the condition of the corn chip was noted.
GPS, IMU	Location, Altitude	The GPS and IMU are accurate.	Yes	The team took the GPS and IMU to different locations on campus and different heights in buildings to ensure that they gave accurate location and altitude readings.
E-match	N/A	Kiwi's circuit can ignite the e-match.	Yes	Try to ignite an e-match by putting a 9V on the drain of a transistor, the e-match on the source, and opening the gate via Arduino digital pin.
Maneuvering Code	Location, velocity	The rudder rotated to direct movement of Kiwi correctly.	Yes	A pre-programmed point was entered into Kiwi's software. While in a moving car, Kiwi was turned on. The movement of the rudder was observed to see if Kiwi would respond properly.
XBee communication range	Distance between XBees	The XBees have a 1.2-mile range	Yes	Two teams had an XBee and a laptop. One team remained at one end of a straight road,

		with a clear line of sight.		and the other moved with their XBee down the road until the connection was unreliable or lost.
Photo-resistor turning on the propeller	Amount of light hitting the photo-resistor	The propeller correctly responds to the photo-resistor	Yes	The photo-resistor was placed in darkness to simulate Kiwi being inside the rocket body, shade to simulate Kiwi being under the rocket or outside on a cloudy day, and in direct sunlight to see if the propeller was turned on at the correct times. The propeller should only turn on during the latter two scenarios.

Wind Tunnel Testing

Wind tunnel testing was performed in the Penn State Laminar Flow Wind Tunnel on the sub-scale rocket to determine the coefficient of drag. The sub-scale and full scale coefficients are equal while the incompressible flow condition is assumed to still be in effect. This is a reasonable assumption with the maximum velocity equaling Mach 0.56.

Figure 39: Sub-scale rocket mounted in Laminar Flow wind tunnel

The rocket was inserted into the wind tunnel with the nose of the rocket facing upstream. A load cell was attached to an internal bulkhead which was measured to be ten inches from the base of the rocket's fins as shown in Figure 40. A picture of the rocket mounted in the wind tunnel is shown in Figure 39. Pressure transducers were placed in the venturi of the wind tunnel. Before each test, the ambient pressure was measured. The fan was slowly raised to ten percent of its maximum wind velocity. The pressure transducers were used to measure the pressure change over the venturi, which was then used to calculate air velocity. The force of the rocket on the load cell, drag, was measured. Both measured values were recorded. This procedure was repeated with increments of ten percent until the velocity was seventy percent of the total. Then increments of five percent were used until ninety percent of total velocity. Several measurements were taken at 90 and 92 percent. The cross-sectional area of the rocket was measured using calipers. These values were used to calculate the coefficient of drag using Eq. 10.

$$C_d = \frac{F_d}{\frac{1}{2}\rho A V^2} \tag{10}$$

The results of the testing are inconclusive, no reasonable drag coefficients were obtained. It is believed by the wind tunnel manager and propulsion lead, who lead the testing, that the force readings were inaccurate. As the load cell was calibrated prior to testing, it is believed that the mounting system for the rocket was the greatest source of error in the experiment. If the wind tunnel can be booked before the USLI launch, the testing will be repeated with an altered mounting system.

If usable results are found, a comparison between the wind tunnel derived coefficient, apogee derived coefficient, and the OpenRocket simulated coefficient will be performed. The comparison would have the aim of determining the most accurate coefficient for use in predicting apogee.

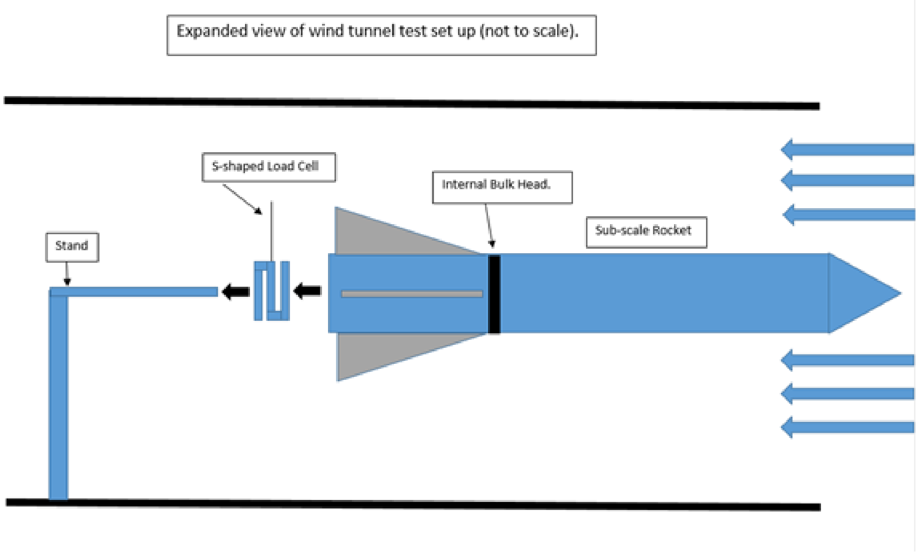


Figure 40: Diagram of wind tunnel setup.

Motor Testing

To validate Figure 18, the motor characteristics will be experimentally validated. This will be done under the supervision of trained and experienced researchers at the HPCL. During 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. Due to budgetary constraints, the testing will use two L1170 motors. Figure 41 shows the motor testing setup. An I-Beam is used to secure the entire assembly to ground during the static test firings. During which time, all data will be collected via a 500-lbf. load cell from within a concrete bunker.

Static motor testing has not yet occurred, but is planned to occur before the USLI launch. The collected motor characteristics will be compared to the provided ones. Any significant deviations from the provided characteristics will be incorporated into flight simulations to improve accuracy.

Figure 41: Motor test stand setup.

Deployment Charge Testing

Ground deployment tests are set up by threading the leads of the e-matches through the bulkheads, into the avionics bay, and through one of the pressure ports. Once this has been done, the avionics bay is fully assembled without the avionics board and equipment and the charges loaded according to launch day procedures. Then the leads from the e-match to be tested are wired to the leads of a 30ft wire that runs from the test area to the operator at a safe distance. This 30ft wire has a 9V battery connector at the end for deployment tests. When ready, the operator can touch a 9V battery to the 9V connector to send full voltage through the wires to the e-match and detonate it.

Ground deployment testing was performed twice to test the adequacy of the charge sizes and to test the number of shear pins used. The original charge sizes specified in CDR were 5g of black powder for the main charge and 4g of black powder for the drogue charge. The first ground deployment testing of the 4g drogue charge was performed on February 19th at a launch site before a full-scale test launch was to be attempted. This test took place under the supervision of the RSO and a level 2 certified club member. The fully assembled rocket was resting approximately one foot above the ground on two stands. The deployment test shot both sides of the rocket away from the center in a violent fashion. During the test the nose cone hit the ground at an angle and the transition linking the FOPS payload to the rest of the body broke in half. This failure was attributed to manufacturing issues with the coupler and not the test. However, the separation of the two body components was still deemed to be too energetic and the recommended charge size was reduced from 4g to 3g of black powder for the drogue and from 5g to 4g of black powder for the main charge. The failure of the transition section resulted in the inability to test full scale on that day.

The next series of ground tests took place on February 23rd at the High-Pressure Combustion Lab (HPCL) research facility on campus. These tests took place under the supervision of a Level 3 certified NAR. The drogue deployment test with a 3g charge proceeded without issue with an acceptable apparent separation velocity. However, the separation velocity with the 4g main charge still looked to be too high and the decision was made to reduce the main charge size to 3.5g. The test setup can be seen in the frame from the moment of charge detonation in Figure 42. After these tests the charge sizes were set at 3g for the drogue section and 3.5g for the main section.

Figure 42: The moment of detonation during a main parachute deployment test

Avionics Bay Simulations

LTRL has built a vacuum based flight profile simulation chamber for avionics testing. This chamber, dubbed MARK II, consists of an airtight PVC pipe to which vacuum pumps are connected. The pumps can lower the pressure in the chamber to simulate an altitude of 10,000 ft. This chamber has been used multiple times by the club to test our fully designed and integrated avionics bays. MARK II provides data that is used to determine the necessary pressure port sizes of a fully designed avionics bay as well as to confirm the functionality of each altimeter. The goal of this chamber is to minimize failures during launch by testing all avionic bays and electronics prior to full-scale launch. However, the outer diameter of the chamber is 6-in. and, therefore, the full-scale avionics bay cannot fit into the chamber.

Testing with the MARK II has shown that all of the SL 100 and SL CF altimeters that the club possesses are in working condition and correctly reporting altitude and temperature. The two SL CF altimeters that will be in Aeolus during competition were both tested simultaneously in the MARK II to ensure that they had identical pressure readings.

8.2: Requirements Compliance

Requirement Verification

Vehicle Requirements

Requirement Number	Method of Verification	Verification
1.1	Demonstration	The onboard payload will be delivered to an apogee of 5,280 feet above ground level in a test launch.
1.2	Inspection	The vehicle has 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 has 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 are 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 are 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. There is a fourth section, KIWI, which is a payload for the vehicle.
1.6	Inspection	The vehicle contains a single stage four 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	Final motor choice is the AeroTech L1170.
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 4232 Ns (83% 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 tailcone for motor retention
1.19.7	Analysis	The launch vehicle will reach approximately Mach 0.6, below the Mach 1 maximum requirement. This value was simulated using OpenRocket. Value will also be verified after test launches.
1.19.8	Simulation	The vehicle ballast will not exceed 10% of vehicle weight. The current simulation includes a 10% ballast.

Recovery System Requirements

Requirement Number	Method of Verification	Verification
2.1	Demonstration	A drogue will deploy at apogee and a main will deploy at 700ft. Demonstrated through full scale test launch.

2.2	Demonstration	LTRL did ground tests ejection charges before any subscale or full scale launch. There have been successful ground tests of the rocket.
2.3	Analysis	The parachutes are correctly sized so that each component of the rocket lands within the kinetic energy constraint of 75 ft-lbs. The current parachute selection has the rocket well under the kinetic energy limit.
2.4	Inspection	The recovery system wiring is completely independent of any payload components.
2.5	Inspection	There are 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 controls the ejection charges.
2.7	Inspection	Each altimeter has 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 has an independent battery.
2.9	Demonstration	Each key switch is able to stay in the on position while on the launch pad.
2.10	Demonstration	Removable sheer pins are used to keep the rocket together for both parachute compartments until the ejection charges cause separation.
2.11	N/A	There is a GPS unit installed that will constantly send the position of the rocket.
2.11.1	Inspection	All sections of the rocket are tethered together, but if any are not, they will have independent GPS units. Specifically KIWI will fall independently with a second GPS unit.
2.11.2	Inspection	The GPS unit will be functional on launch day. There is a spare GPS unit in case of any electronic failures before the launch.
2.12	Inspection	The recovery system electronics are 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 is in a coupler without any other payloads or electronic components.
2.12.2	Testing	The faraday cage protects the recovery system from any interference. Testing before launch has confirmed this requirement.
2.12.3	Testing	The faraday cage protects the recovery system from any interference. Testing before launch has confirmed this requirement.
2.12.4	Testing	The faraday cage and being in its own coupler protects the recovery system from any interference. Testing before launch has confirmed this requirement.

Experimental Requirements

Requirement Number	Method of Verification	Verification
3.1.1	Inspection	The rocket carries 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 is included in reports so that the safety of the project can be reviewed by overseeing engineers.
3.1.3	Inspection	The autogyro payload is equipped with its own GPS.
3.1.3	Analysis	The autogryo payload is 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 houses a flexible bag, which contains and protects the fragile materials. The chamber is suspended by elastic bands in order to provide gross acceleration dissipation.
3.4.1.1	Demonstration	All specimens will be separated in the bag, which is inserted into the dilatan, cushioning each specimen individually.
3.4.1.2	Analysis	The cushioning provided by the dilatant ensures that any material placed inside the chamber will survive the accelerations and shocks of launch, landing, and recovery.
3.4.1.3	Inspection	A sealable materials bag inside the chamber allows for insertion of specimens, while the dilatant allows for objects to be of unknown size and shape.
3.4.1.4	Testing/Inspection	All dilatant for cushioning is 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-in. by 6-in. cylinder.
3.4.1.6	Analysis	The mass of the objects are accounted for in the estimations of flight, as well as the accelerative forces on the materials chamber.

Safety Requirements

Requirement Number	Method of Verification	Verification
4.1	Demonstration	The team will use launch and safety checklists. The team will demonstrate the use of launch and safety checklists during all launches.
4.2	N/A	Laura Reese is listed as safety officer

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

General Requirements

Requirement Number	Method of Verification	Verification
5.1	Demonstration	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches.
5.2	Demonstration	The team provided a project plan including project milestones, budget and community support, checklists, personnel assigned, educational engagement events, risks, and mitigations. The team will follow the project plan.

5.3	N/A	Foreign National Team members will be identified to NASA by Preliminary Design Review.
5.4	Demonstration	The team members attending the launch will be identified by Critical Design Review.
5.4.1	N/A	Only actively engaged team members will come to launch week activities.
5.4.2	N/A	One mentor will come to launch week activities.
5.4.3	N/A	At most two adult educators will come to launch week activities.
5.5	Demonstration	The team will engage at least 200 participants in educational, hands-on science and math related activities throughout the year and write reports on these events. The reports will be submitted at most two weeks after the activity.
5.6	Inspection	The team has developed a website for the competition. The website will be kept up to date throughout the competition.
5.7	Demonstration	Teams will post, and make available for download, the required deliverables to the team website by the due dates specified in the project timeline.
5.8	Demonstration	All reports shall be delivered in pdf format.
5.9	Demonstration	Every report shall include a table of contents outlining major sections and their respective sub-sections.
5.10	Demonstration	Every report shall include page numbers at the bottom of the page.
5.11	Demonstration	The team shall provide proper video conference equipment needed to perform a video teleconference with the review board.
5.12	Demonstration	The flight vehicle will be capable of launching using the launch pads provided by the launch service provider.
5.13	Demonstration	The team will meet the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards.

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.

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 as to not overwhelm the body tube.	Demonstration	The redundant altimeter is at a slight delay.
2.2 There will be backup electronics in case of failure on launch day.	Demonstration	The team has backup altimeters and GPS units in case of failure before launch.
2.3 Pressure port will be adequately sized.	Testing	The pressure port is of adequate size as determined during the full scale launch.

2.4 Structural materials will be strong enough to maintain integrity throughout descent and landing.	Testing	The rocket maintained integrity during descent and landing of the full scale launch.
2.4.1 Avionics board will remain structurally sound throughout launch, descent, and landing.	Demonstration	The PLA avionics board handled the full scale launch well and the heat rating for PLA is sufficient for any feasible temperature.
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 is 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 extends 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 are conducted to minimize point loss in the target altitude category.
3.1.1 Validation of manufacturer's data	Testing	Static motor testing is conducted to accurately model vehicle flight.
3.1.2 Vehicle Drag Assessment	Testing	Wind tunnel drag modeling is conducted on a subscale model of the final launch vehicle to calculate an accurate coefficient of drag.
3.2 Handling and risk mitigation	Testing	Motors and igniters are 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	A 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 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 Improved aerodynamics of launch vehicle	Testing/Demonstration	Selected components maximize aerodynamic efficiency, demonstrated through flight and wind tunnel testing.
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 and manufactured to streamline aerodynamics between different diameter sizes.
5.2 Materials testing for airframe selection	Testing	Under extraneous circumstances
5.3 Launch vehicle fins will be removable	Demonstration	Fins on launch vehicle are fully removable.
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 and full scale flight.
5.4 Visually confirm payload status	Inspection	Launch vehicle contains transparent section of airframe to obtain visual status of FOPS. Before fully constructed, Kiwi will be

		visually confirmed secured and operational.
5.5 Recording of launch	Demonstration	On-board camera records the entirety of the launch of the rocket.
5.6 Fins will not flutter during flight	Analysis	Fin thickness was increased to 3/16-in. to eliminate fin flutter. Results will be confirmed through flight video recording.
5.7 Fins strength testing	Testing	Fins will be tested on shear strength.

8.3: Budget and Timeline

Line Item Expenses

Table 14: Projected Line Item Expenses

Full Scale			
Structures			
J-B Weld Adhesive 8270, Fast Hardening, 10 Ounce Tube	2	$20.12	$40.24
6-in. Blue Tube	2	$66.95	$133.90
6-in. Blue Tube Full Length Coupler	1	$66.95	$66.95
5.5-in. Blue Tube Coupler	1	$18.95	$18.95
Centering Rings 75mm (fits Blue Tube) to 6.0-in. (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-in. G10 Structural Fiberglass Sheet, 24-in. x 24-in.	2	$76.32	$152.64
5.5-in. Von Karman nose cone	1	$116.33	$116.33
Optically Clear Cast Acrylic Tube, 6-in. OD x 5-3/4-in. ID, 1' Length	2	$47.98	$95.96
Freight Charges	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
XBEE900HP	3	$37.00	$117.00
Miscellaneous (motors, servos, electrical connectors)	1	$150.00	$150.00
A&R			
StratoLoggerCF Altimeter	3	$54.95	$164.85
Iris Ultra 72-in. Compact Parachute	1	$265.00	$265.00
18-in. Classical Elliptical Parachute	1	$53.00	$53.00
Shock Cord 100’	1	$133.22	$133.22
21-in. Nomex Blanket	1	$21.00	$21.00
13-in. 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-in. FLC	1	$31.95	$31.95
Mad Cow 2.6-in. 4:1 VK Fiberglass	1	$28.95	$28.95
Bulkhead - 75mm (1/pk.)	5	$3.83	$19.15
Bulkhead - 2.56-in. BT-80 (1/pk.)	2	$2.99	$5.98
Bulkhead - 2.6-in. (Thick/Thin) BT-80 (1/pk.) 1/4-in. Ply	1	$2.99	$2.99
ARR Blue Coupler AC- 2.56-in.	1	$9.25	$9.25
Structural Fiberglass (FRP) Sheet 1/8-in. Thick, 12-in. x 12-in.	2	$10.17	$20.34

Optically Clear Cast Acrylic Tube 2-3/4-in. OD x 2-1/2-in. ID, 1' Length	1	$40.04	$40.04
Freight charges	1	$48.81	$48.81
Propulsion			
Aerotech L1170FJ	3	$249.99	$749.97
Cesaroni J290	2	$80.00	$160.00
75mm Pro75-4G Casing w/ Hardware	1	$309.95	$309.95
75mm Forward Seal Disk	2	$32.00	$64.00
Travel			
Homewood Suites - 2 Queen Bed Suites	6	$812.95	$4,877.70
Minivan car rental	5	$408.57	$2,042.85
Fuel costs - subscale launch	1	$120.00	$120.00
Fuel costs - full-scale launch	1	$400.00	$400.00
Tools and Fabrication Supplies			
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
Hatchbox 3D Printing filament	3	$22.09	$66.27
Rosin Core Solder	1	$8.35	$8.35
Soldering Iron and holder	1	$34.99	$34.99
Heat Shrink Tubing	1	$10.19	$10.19
Folgertech FT-5	1	$500.00	$500.00
Outsourced Services			
3D Printing from Penn State 3D Printing Club	2	$100.00	$200.00
Tree service for rocket retrieval	1	$300.00	$300.00

Budget

The expenditures for the 2016-2017 school year are included in Table 15. This table is a summation of the line item costs by category as listed in Table 14. Full scale consists of the building materials and equipment purchased for this year’s full scale rocket. As seen in the line item expense table, full scale is subdivided by individual subsystems. Structures lists all building materials required in construction of the airframe, while Payload and A&R list internal equipment required for successful flight and recovery of the rocket. Subscale consists of building materials for the subscale rocket. This section was restricted to solely airframe costs because equipment from past years was adequate for successful flight and recovery. Propulsion encompasses all motors needed for subscale and full scale flight. This cost also includes an additional full scale motor to be used for testing to validate thrust properties. The specific motors are listed as line items.

Travel costs are divided between those planned for the Alabama trip and fuel costs from subscale and full scale test flights. The line item expense table lists the two main Alabama costs, hotels and car rentals. Homewood Suites in Huntsville was chosen this year due to the lack of space in the host hotel, Embassy Suites, as well as its location close to the host hotel. Rental cars have been found to be most cost effective for the club and therefore will be used again this year. Outreach costs consist of travel to outreach locations as well as any supplies needed for the event. Tools and fabrication supplies includes all tools, equipment, and supplies needed for the construction of the rocket. These supplies are used by club members to assist in the construction of all components of the rocket including both the airframe and multiple payloads. Outsourced services are included due to special needs of the club. Currently only two services have been used, Penn State 3D Printing Club and rocket recovery. Large 3D printers were required for full scale parts resulting in the need to go to the 3D Printing Club for multiple components. Additionally, at the most recent full scale test flight, the rocket landed in trees, resulting in the need for a professional tree climber to retrieve the rocket.

Table 15: Updated Annual Expenses

Expected Costs 2016-2017	
Full Scale	$1,926.33
Subscale	$277.65
Propulsion	$1,283.92
Travel	$7,440.55
Outreach	$300.00
Tools and Fabrication Supplies	$870.62
Outsourced Services	$500.00
Total	**$12,599.07**

Funding

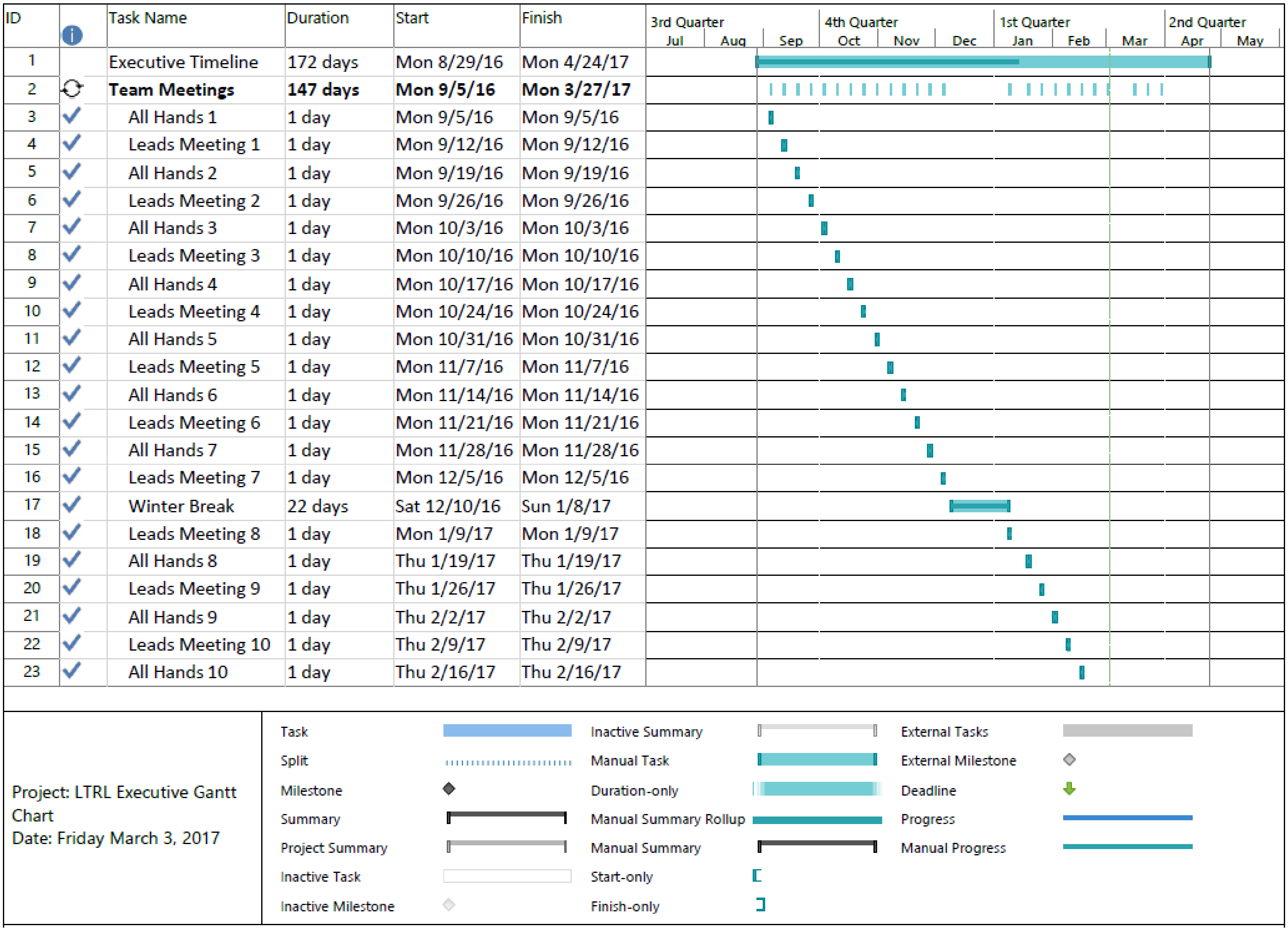
Funding for the USLI competition has been acquired through various academic sponsors. These sponsors are listed in Table 16. The Penn State Aerospace Engineering Department has been the main sponsor of LTRL and they will continue to support our club this year. They have agreed to provide a donation of $5,000.00. The Penn State Mechanical and Nuclear Engineering Department has agreed to support our club. They have provided a donation of $1,000.00. Lion Tech Rocket labs has received the Samuel A. Shuman Endowment in Engineering from the Penn State College of Engineering. This endowment is given to groups who work to advance education in engineering as well as improve the students' experience. This endowment is in the amount of $8,700.00. Yearly dues and fundraising opportunities gathered throughout the school year provide funding of $1,500.00. The Boeing Company has agreed to give a donation of $500.00 for this school year.

Table 16: Annual Funding

2016-2017 Funding	
Aerospace Engineering Department	$5,000.00
Mechanical and Nuclear 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**

The funding provided by these sponsors will be primarily used to compete in the University Student Launch Initiative. To ensure the construction and flight of the full-scale rocket, funding in the amount of $4,358.52 will be allocated. This allocation encompasses all airframe, payload, motor, and internal equipment costs required for successful flight. Travel costs are another major allocation of funds, expected to be $7,440.55. This total includes all club test flights required for competition as well as travel and housing costs for Huntsville, AL. An additional key allocation of funding lies in the purchase of the Folgertech FT-5 3D printer. This purchase was made to reduce the club's reliability on members' personal 3D printers. In addition, this printer will reduce the need to outsource large prints as described above in outsourced services.

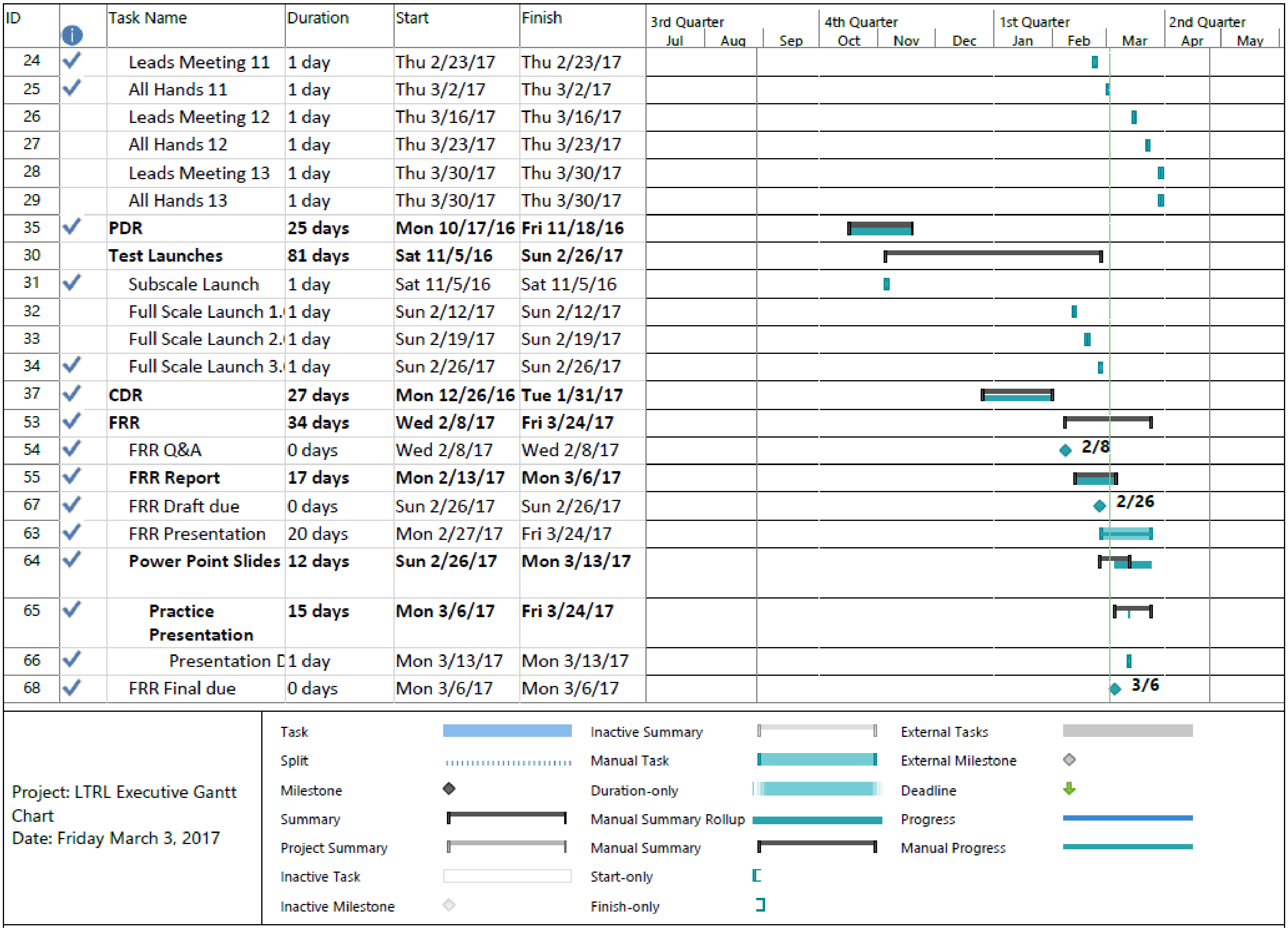
Project Timelines



ID	ℹ	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	Thu 1/19/17	Thu 1/19/17
20	✓	Leads Meeting 9	1 day	Thu 1/26/17	Thu 1/26/17
21	✓	All Hands 9	1 day	Thu 2/2/17	Thu 2/2/17
22	✓	Leads Meeting 10	1 day	Thu 2/9/17	Thu 2/9/17
23	✓	All Hands 10	1 day	Thu 2/16/17	Thu 2/16/17

Project: LTRL Executive Gantt Chart
Date: Friday March 3, 2017

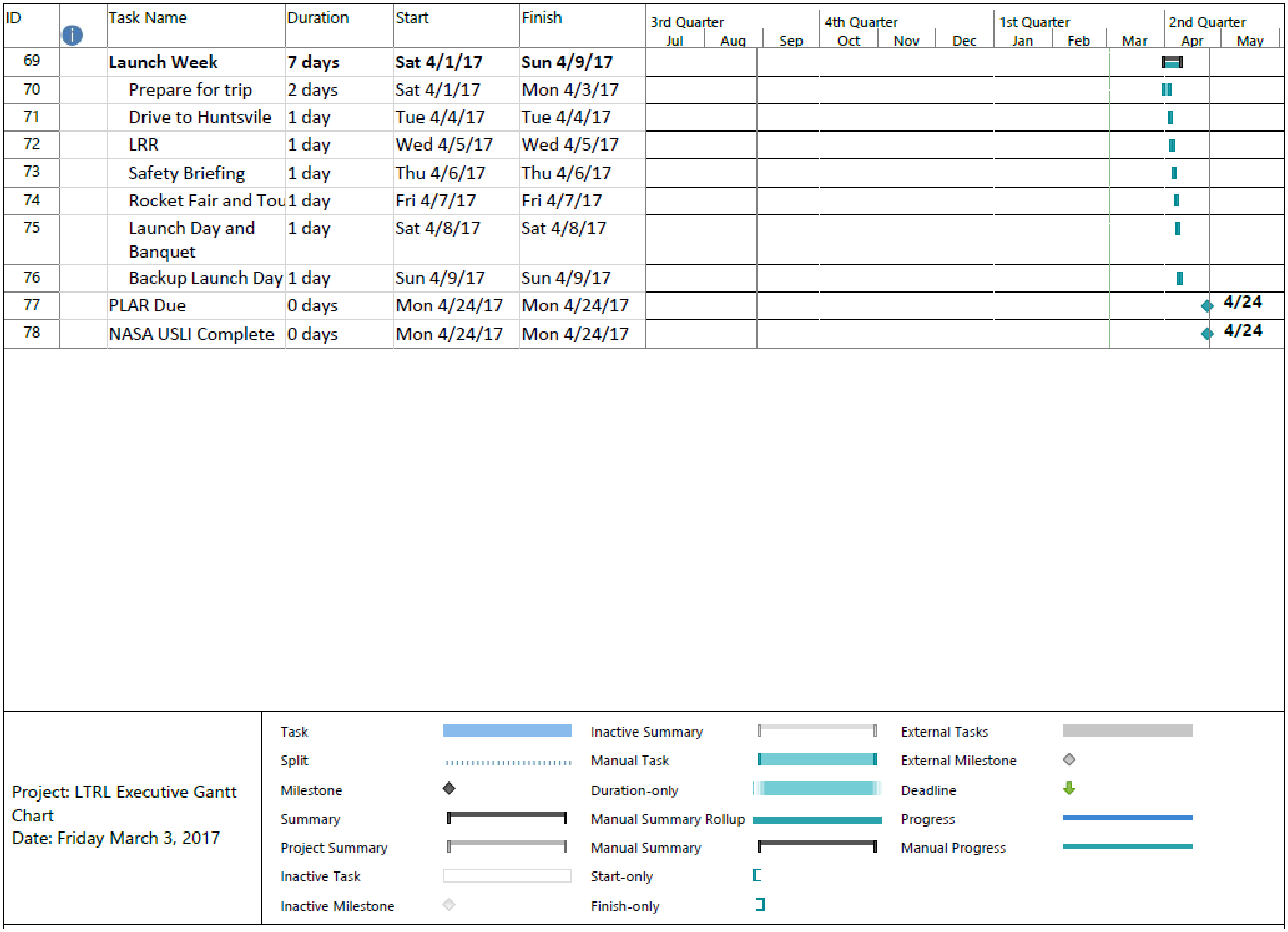
Figure 43: Executive Timeline Page 1 of 3



ID	ℹ	Task Name	Duration	Start	Finish
24	✓	Leads Meeting 11	1 day	Thu 2/23/17	Thu 2/23/17
25	✓	All Hands 11	1 day	Thu 3/2/17	Thu 3/2/17
26		Leads Meeting 12	1 day	Thu 3/16/17	Thu 3/16/17
27		All Hands 12	1 day	Thu 3/23/17	Thu 3/23/17
28		Leads Meeting 13	1 day	Thu 3/30/17	Thu 3/30/17
29		All Hands 13	1 day	Thu 3/30/17	Thu 3/30/17
35	✓	**PDR**	**25 days**	**Mon 10/17/16**	**Fri 11/18/16**
30		**Test Launches**	**81 days**	**Sat 11/5/16**	**Sun 2/26/17**
31	✓	Subscale Launch	1 day	Sat 11/5/16	Sat 11/5/16
32		Full Scale Launch 1.	1 day	Sun 2/12/17	Sun 2/12/17
33		Full Scale Launch 2.	1 day	Sun 2/19/17	Sun 2/19/17
34	✓	Full Scale Launch 3.	1 day	Sun 2/26/17	Sun 2/26/17
37	✓	**CDR**	**27 days**	**Mon 12/26/16**	**Tue 1/31/17**
53	✓	**FRR**	**34 days**	**Wed 2/8/17**	**Fri 3/24/17**
54	✓	FRR Q&A	0 days	Wed 2/8/17	Wed 2/8/17
55	✓	**FRR Report**	**17 days**	**Mon 2/13/17**	**Mon 3/6/17**
67	✓	FRR Draft due	0 days	Sun 2/26/17	Sun 2/26/17
63	✓	FRR Presentation	20 days	Mon 2/27/17	Fri 3/24/17
64	✓	**Power Point Slides**	**12 days**	**Sun 2/26/17**	**Mon 3/13/17**
65	✓	**Practice Presentation**	**15 days**	**Mon 3/6/17**	**Fri 3/24/17**
66	✓	Presentation D	1 day	Mon 3/13/17	Mon 3/13/17
68	✓	FRR Final due	0 days	Mon 3/6/17	Mon 3/6/17

Project: LTRL Executive Gantt Chart
Date: Friday March 3, 2017

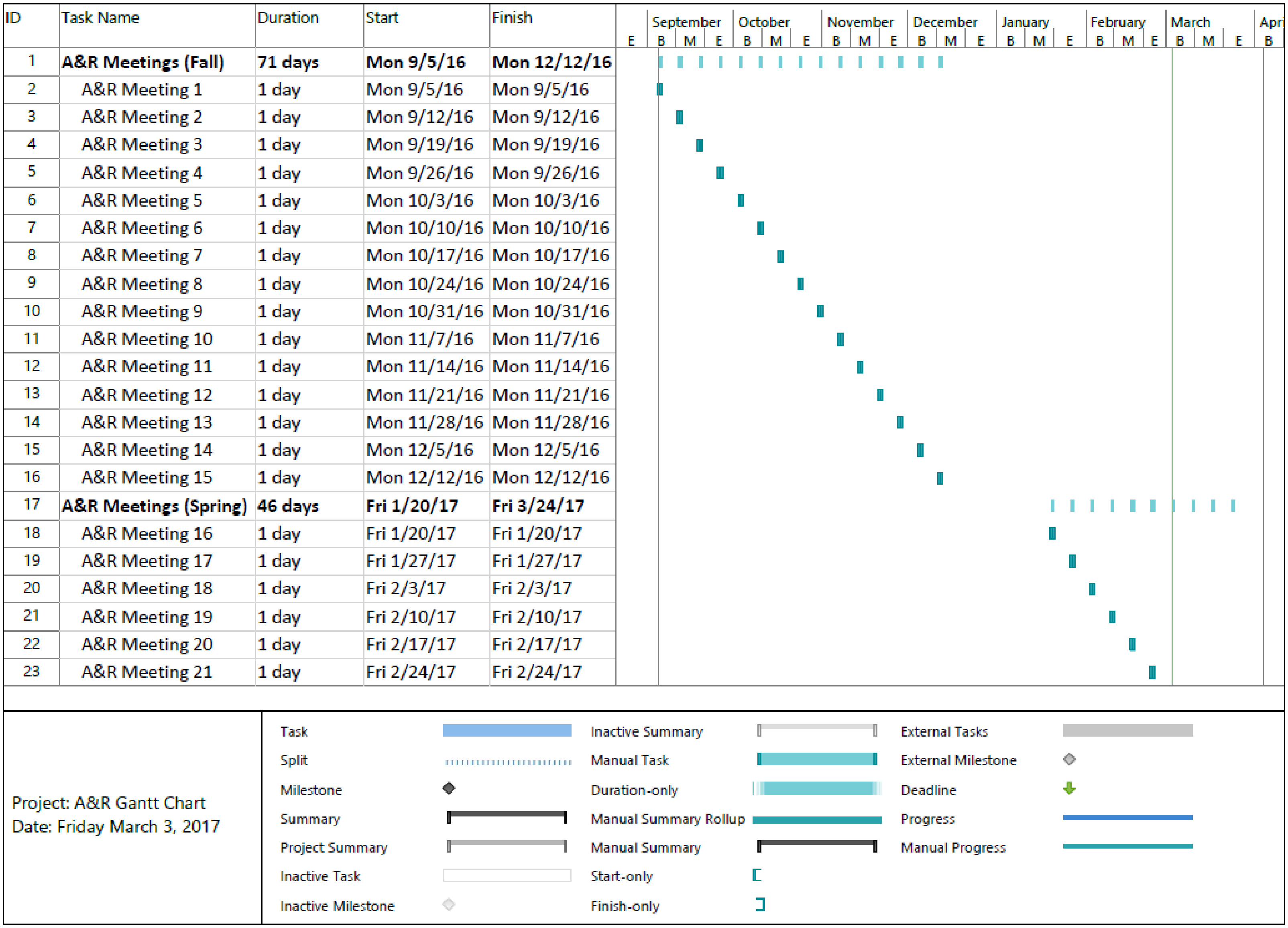
Figure 44: Executive Timeline Page 2 of 3



ID		Task Name	Duration	Start	Finish
69		**Launch Week**	**7 days**	**Sat 4/1/17**	**Sun 4/9/17**
70		Prepare for trip	2 days	Sat 4/1/17	Mon 4/3/17
71		Drive to Huntsvile	1 day	Tue 4/4/17	Tue 4/4/17
72		LRR	1 day	Wed 4/5/17	Wed 4/5/17
73		Safety Briefing	1 day	Thu 4/6/17	Thu 4/6/17
74		Rocket Fair and Tou	1 day	Fri 4/7/17	Fri 4/7/17
75		Launch Day and Banquet	1 day	Sat 4/8/17	Sat 4/8/17
76		Backup Launch Day	1 day	Sun 4/9/17	Sun 4/9/17
77		PLAR Due	0 days	Mon 4/24/17	Mon 4/24/17
78		NASA USLI Complete	0 days	Mon 4/24/17	Mon 4/24/17

Project: LTRL Executive Gantt Chart
Date: Friday March 3, 2017

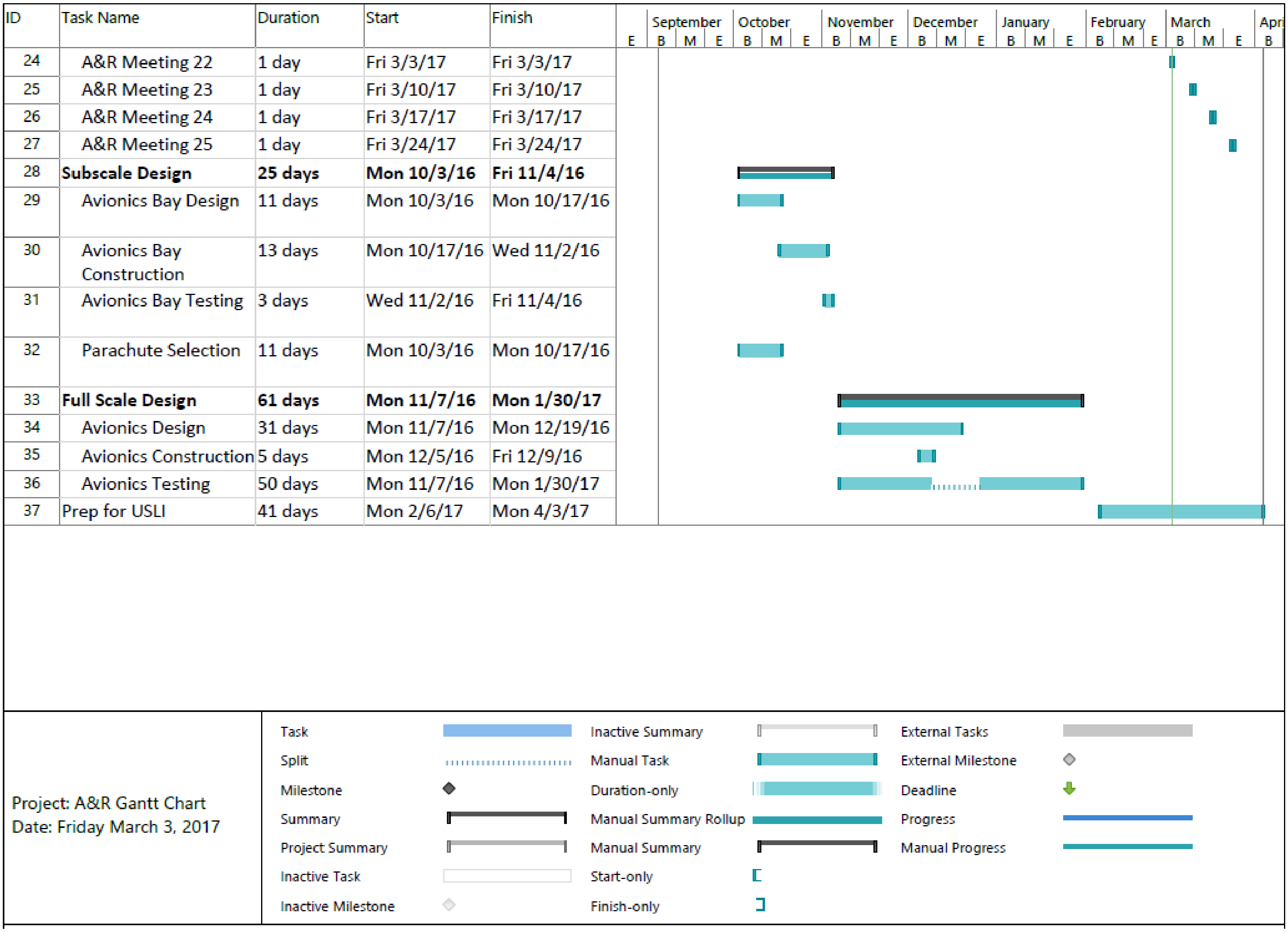
Figure 45: Executive Timeline Page 3 of 3



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: Friday March 3, 2017

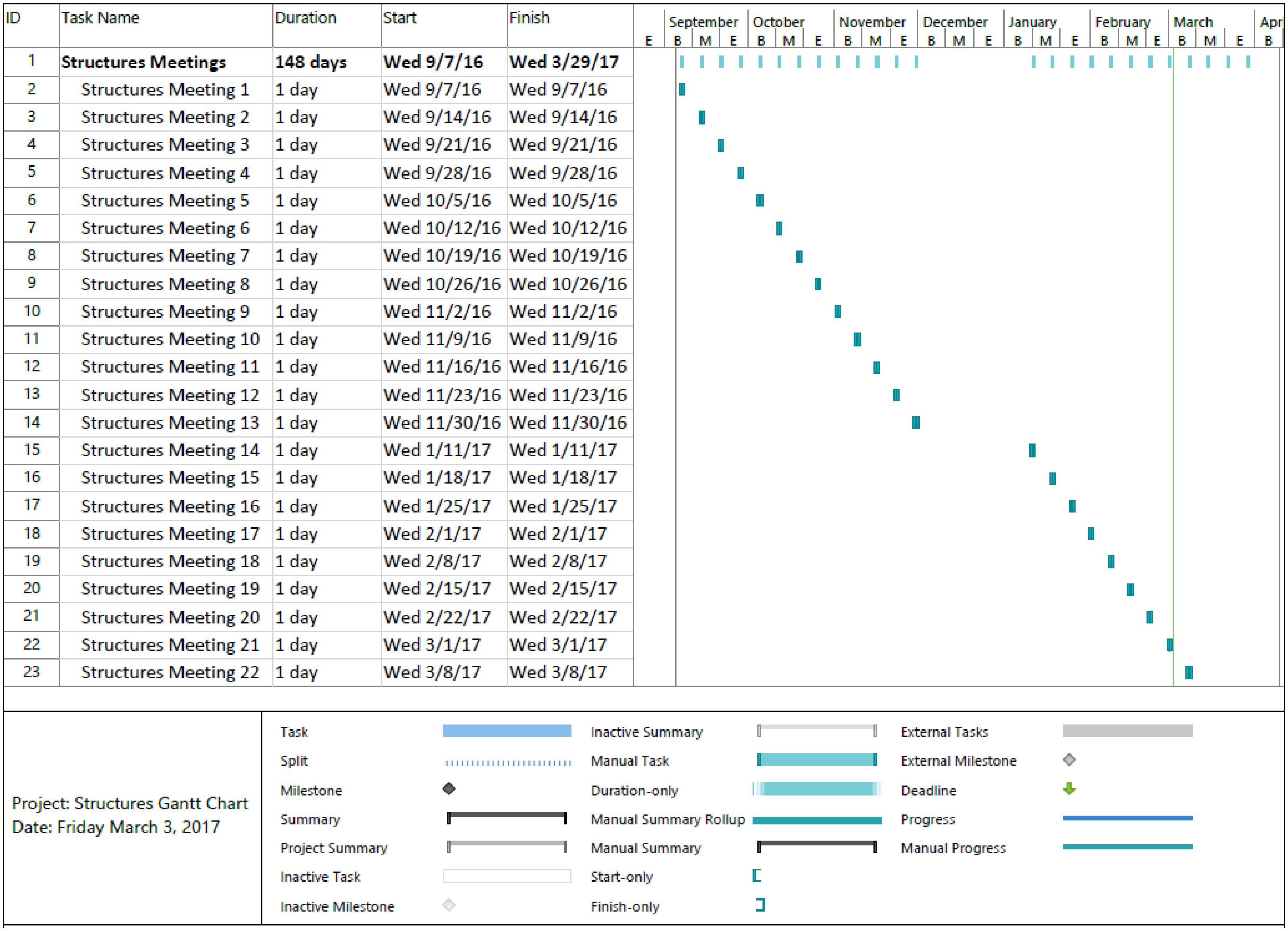
Figure 46: A&R Timeline Page 1 of 2



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: Friday March 3, 2017

Figure 47: A&R Timeline Page 2 of 2

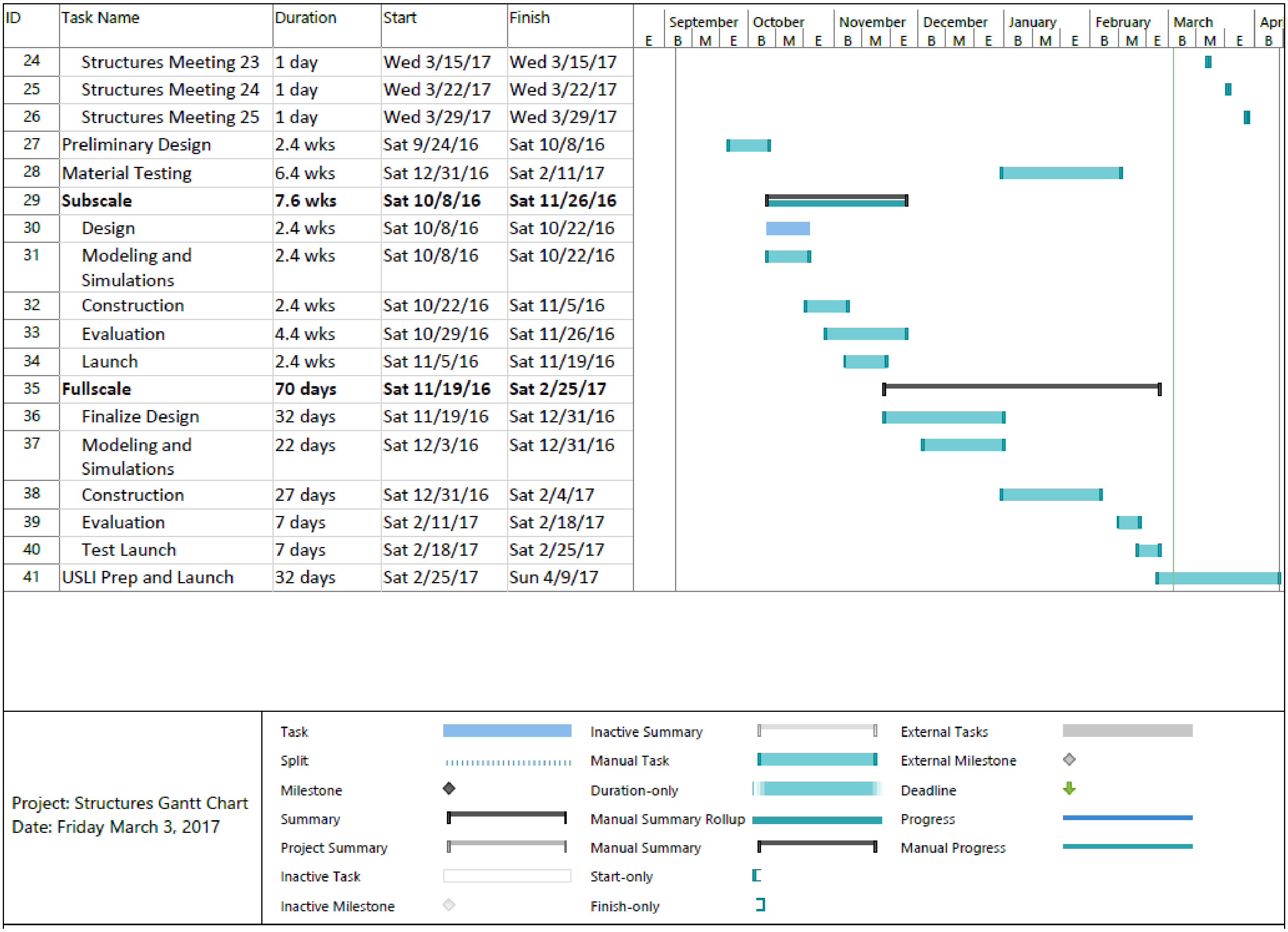


ID	Task Name	Duration	Start	Finish
1	**Structures Meetings**	**148 days**	**Wed 9/7/16**	**Wed 3/29/17**
2	Structures Meeting 1	1 day	Wed 9/7/16	Wed 9/7/16
3	Structures Meeting 2	1 day	Wed 9/14/16	Wed 9/14/16
4	Structures Meeting 3	1 day	Wed 9/21/16	Wed 9/21/16
5	Structures Meeting 4	1 day	Wed 9/28/16	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 March 3, 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 48: Structures Timeline Page 1 of 2

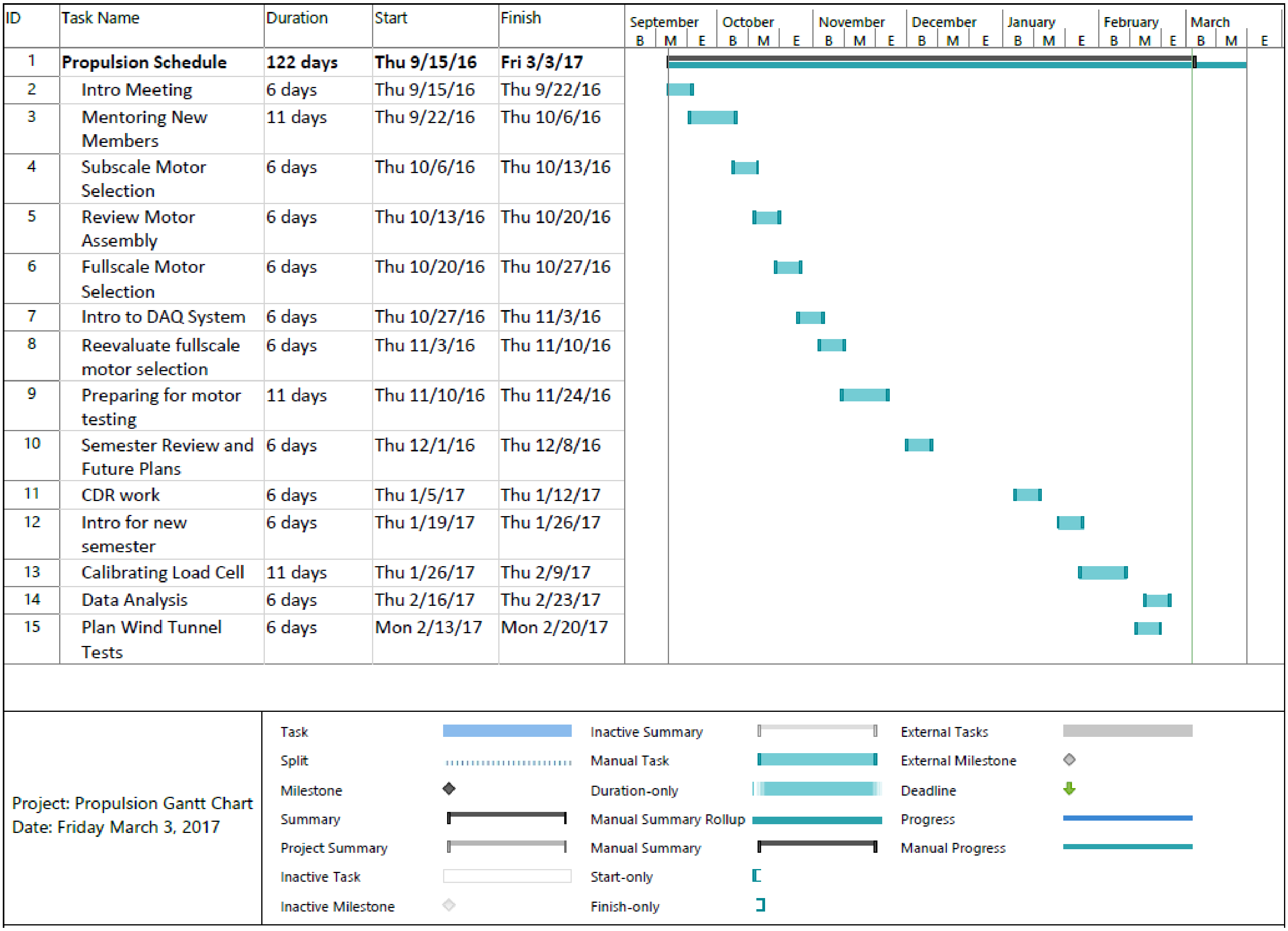


ID	Task Name	Duration	Start	Finish
24	Structures Meeting 23	1 day	Wed 3/15/17	Wed 3/15/17
25	Structures Meeting 24	1 day	Wed 3/22/17	Wed 3/22/17
26	Structures Meeting 25	1 day	Wed 3/29/17	Wed 3/29/17
27	Preliminary Design	2.4 wks	Sat 9/24/16	Sat 10/8/16
28	Material Testing	6.4 wks	Sat 12/31/16	Sat 2/11/17
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 March 3, 2017

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

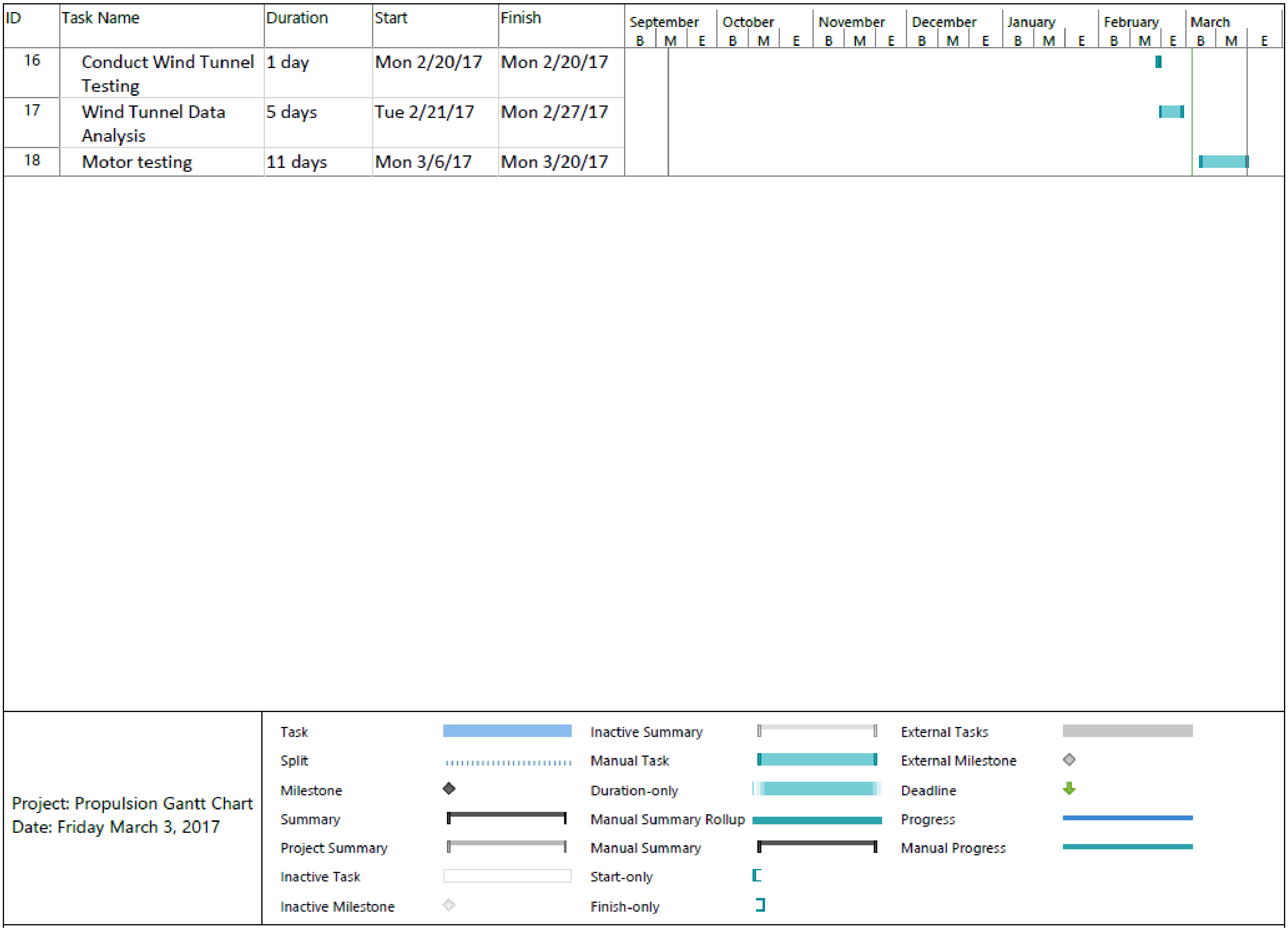
Figure 49: Structures Timeline Page 2 of 2



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	Data Analysis	6 days	Thu 2/16/17	Thu 2/23/17
15	Plan Wind Tunnel Tests	6 days	Mon 2/13/17	Mon 2/20/17

Project: Propulsion Gantt Chart
Date: Friday March 3, 2017

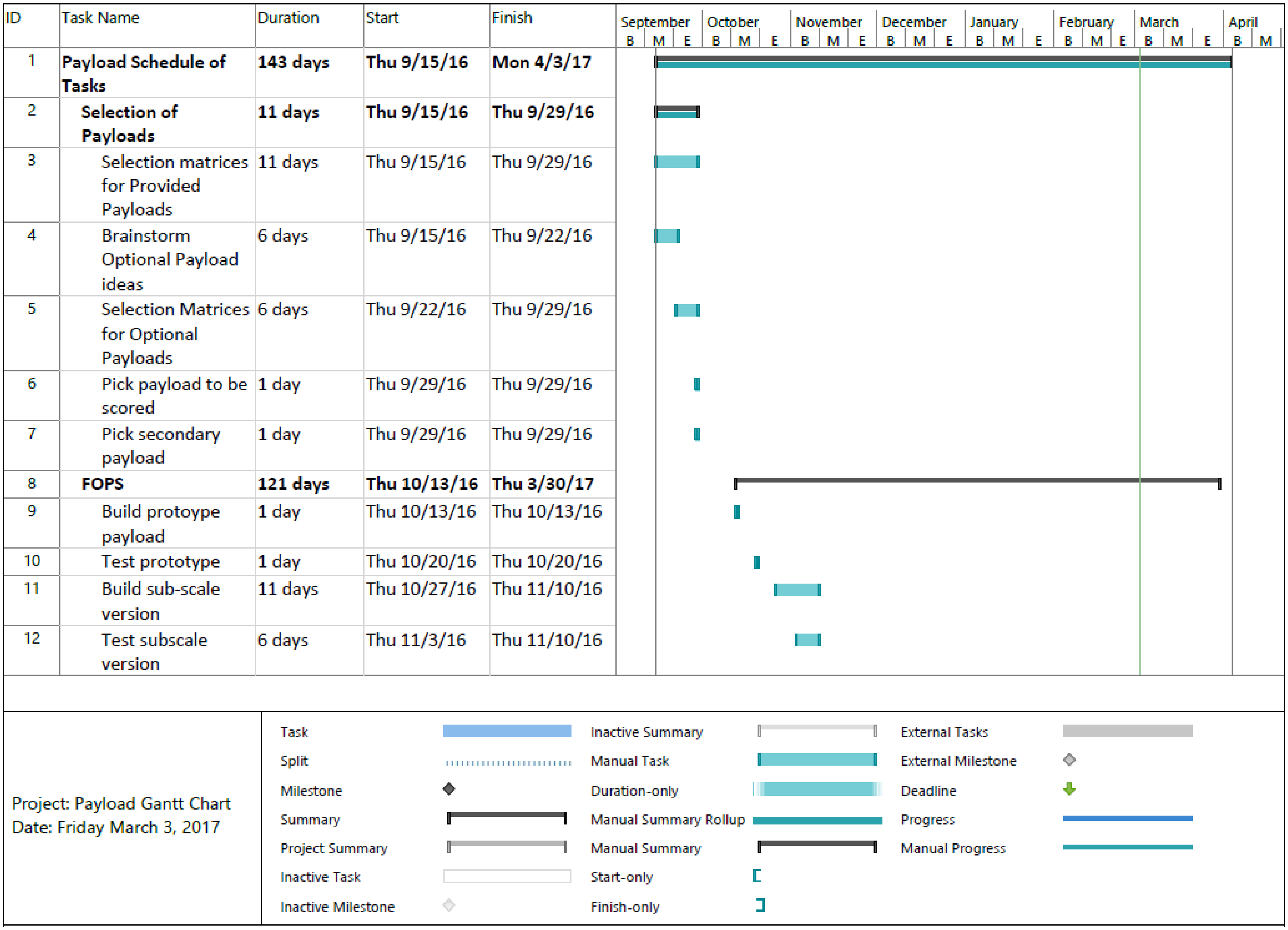
Figure 50: Propulsion Timeline Page 1 of 2



ID	Task Name	Duration	Start	Finish
16	Conduct Wind Tunnel Testing	1 day	Mon 2/20/17	Mon 2/20/17
17	Wind Tunnel Data Analysis	5 days	Tue 2/21/17	Mon 2/27/17
18	Motor testing	11 days	Mon 3/6/17	Mon 3/20/17

Project: Propulsion Gantt Chart
Date: Friday March 3, 2017

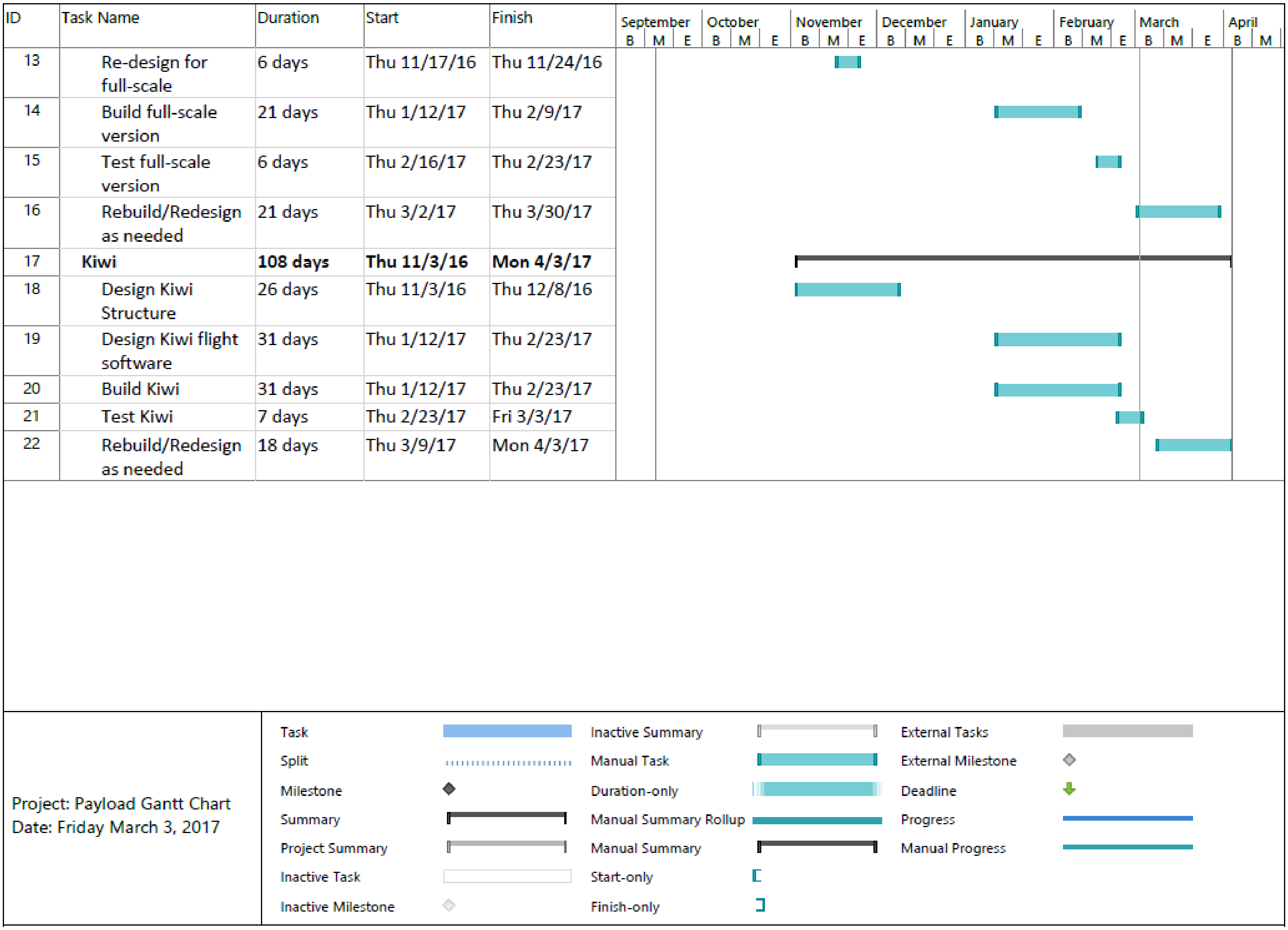
Figure 51: Propulsion Timeline Page 2 of 2



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 March 3, 2017

Figure 52: 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 March 3, 2017

Figure 53: 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.

[8] SpecialChem. "Coefficient of Linear Thermal Expansion." Coefficient of Linear Thermal Expansion – Plastic Properties. SpecialChem SA, n.d. Web. 28 Feb. 2017.

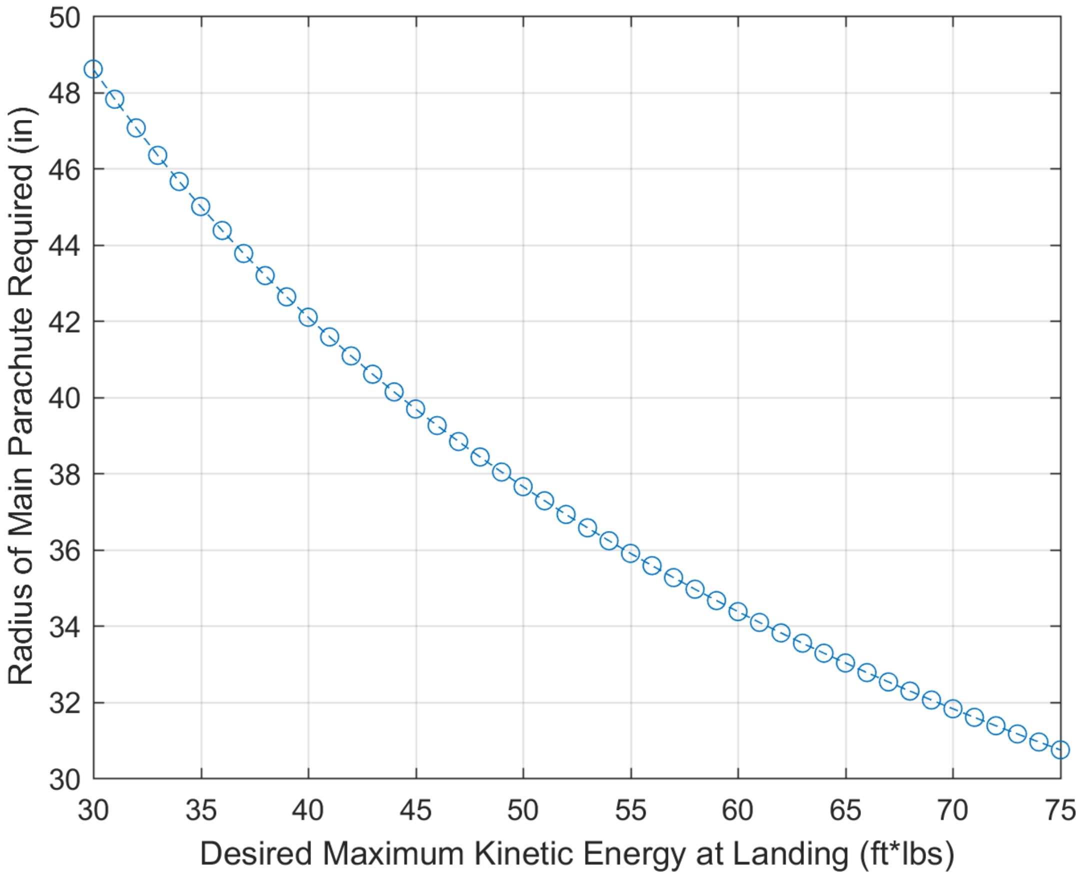
Appendix A: RECOVERY DESCENT PROFILE CALCULATOR

```
% RECOVERY DESCENT PROFILE CALCULATOR (RDPC)
% WRITTEN BY EVAN KERR
% PENN STATE LION TECH ROCKET LABS
% AVIONICS AND RECOVERY LEAD
% LATEST UPDATE: 2/28/2017
```

Calculate necessary area of Parachute to meet certain KE on landing

```
clc, clear, close all
%Gravitational acceleration, units: m/s^2
g = 9.81;
```

```
%Density in kg/m^3
rho = 1.225;
%Kinetic Energy Limit
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) = 3.977; %For the fore
mass(2) = 3.744; %For the avionics bay (model minus chord, chutes, and copter)
mass(3) = 3.969; % + (0.5386); %add if including Kiwi %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;
```

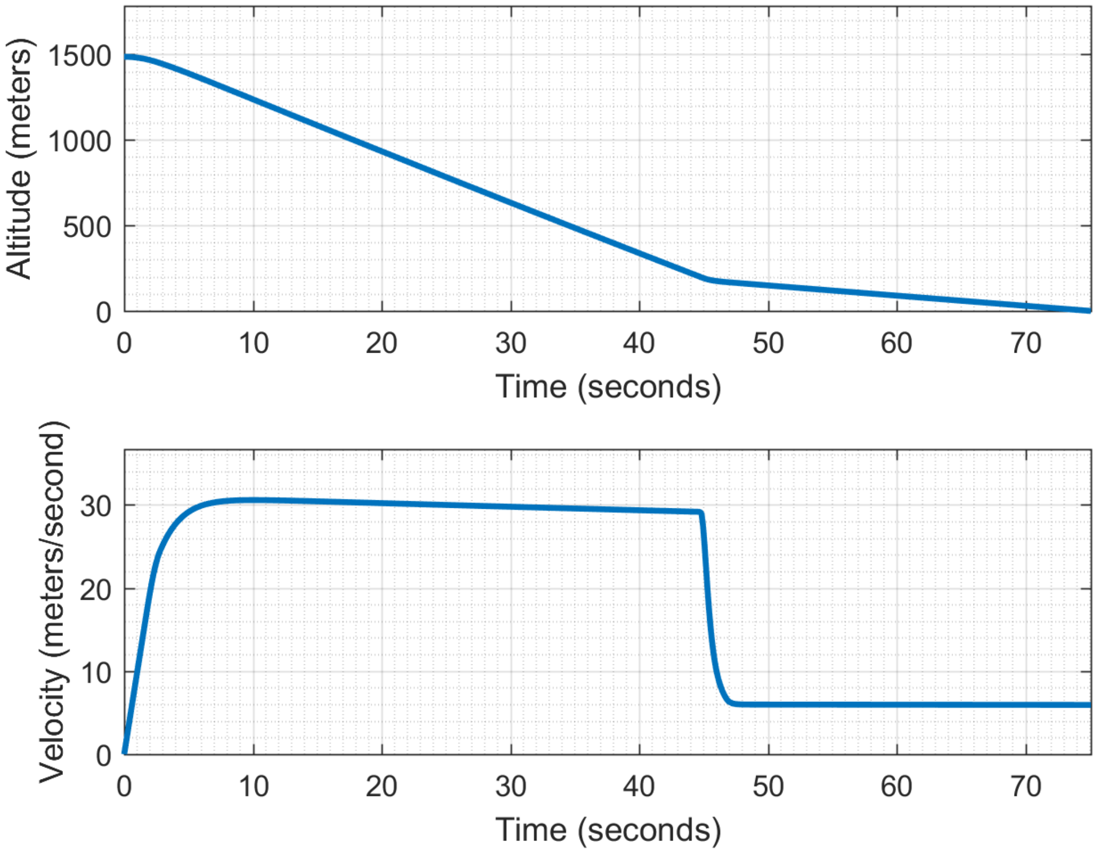


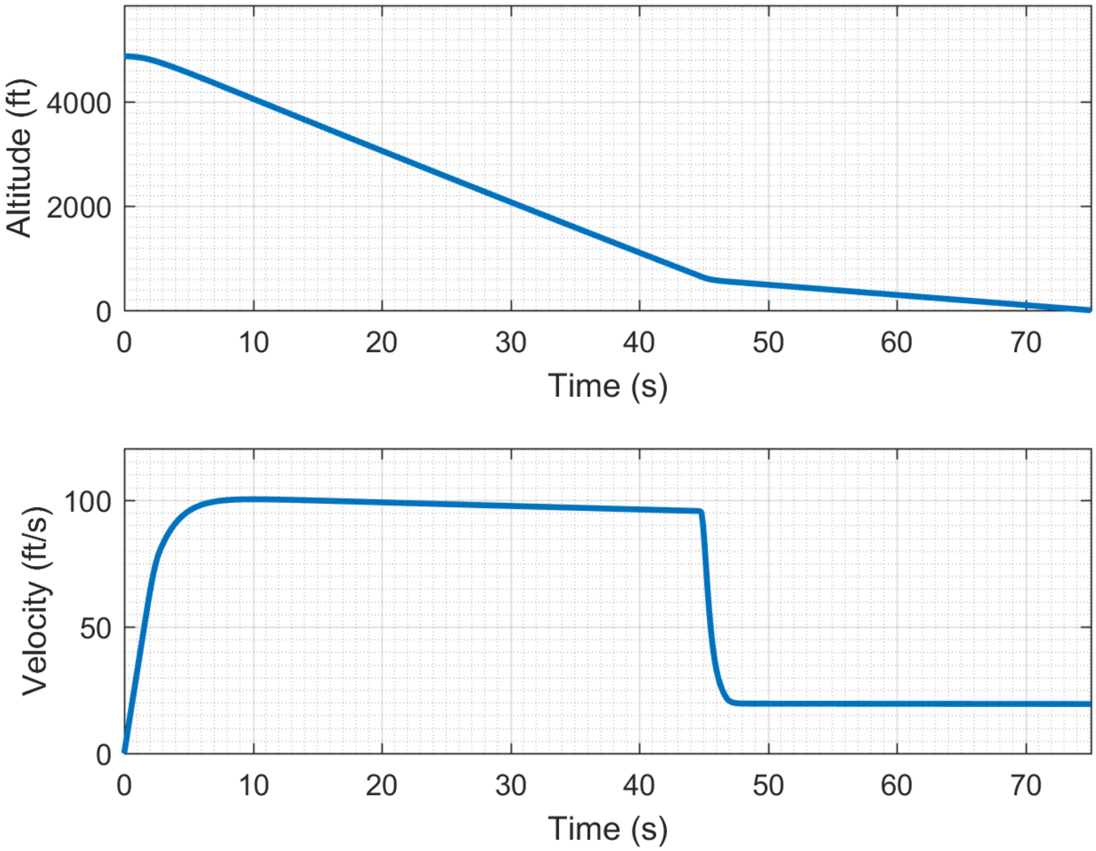
Calculating Force based results

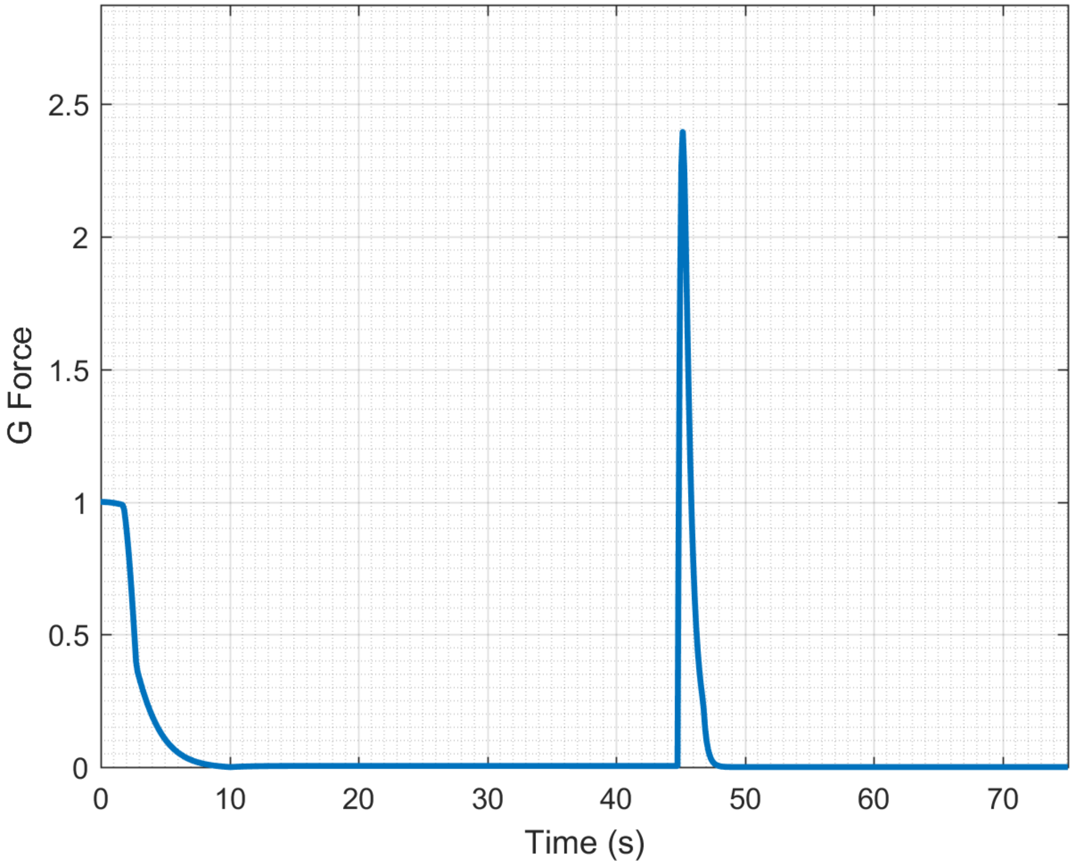
```
Rd_in = 9; %radius of drogue[in]
    Rd = 0.0254*Rd_in; %radius of drogue[m]
Rm_in = 36; %radius of main[in]
    Rm = 0.0254*Rm_in; %radius of main[m]
Rr_in = 4; %simulated radius of "tumbling" rocket parachute[in]
    Rr = 0.0254*Rr_in; %simulated radius of "tumbling" rocket parachute[m]

apogeeft = 4876; %apogee altitude above ground level [ft]
    apogee = 0.3048*apogeeft;
altDrogueft = apogeeft-1; %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 = 0.001;
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 = 1; % 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 deployed
Tm_dep = 2;
Tm_dep_elapsed = 0;

%Drag Calculation
while(h >= altLaunchSite) % Although we are integrating over time, the check is whether the
height is still above ground level.
    rho_new = rhocalcestSI(h,Temp); % Calculate the density at the given altitude and temperature
    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
accordingly by adding the drags
            Drag = Dragr(i); % If the drogue has yet to deploy, the drag of the rocket is the
only factor
        elseif h > altMain
            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 linear 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');

figure(4)
%title('G Forces vs Time');
plot(time,abs(a/g),'LineWidth',2);
ylabel('G Force');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(abs(a/g))*1.2]);
```


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)

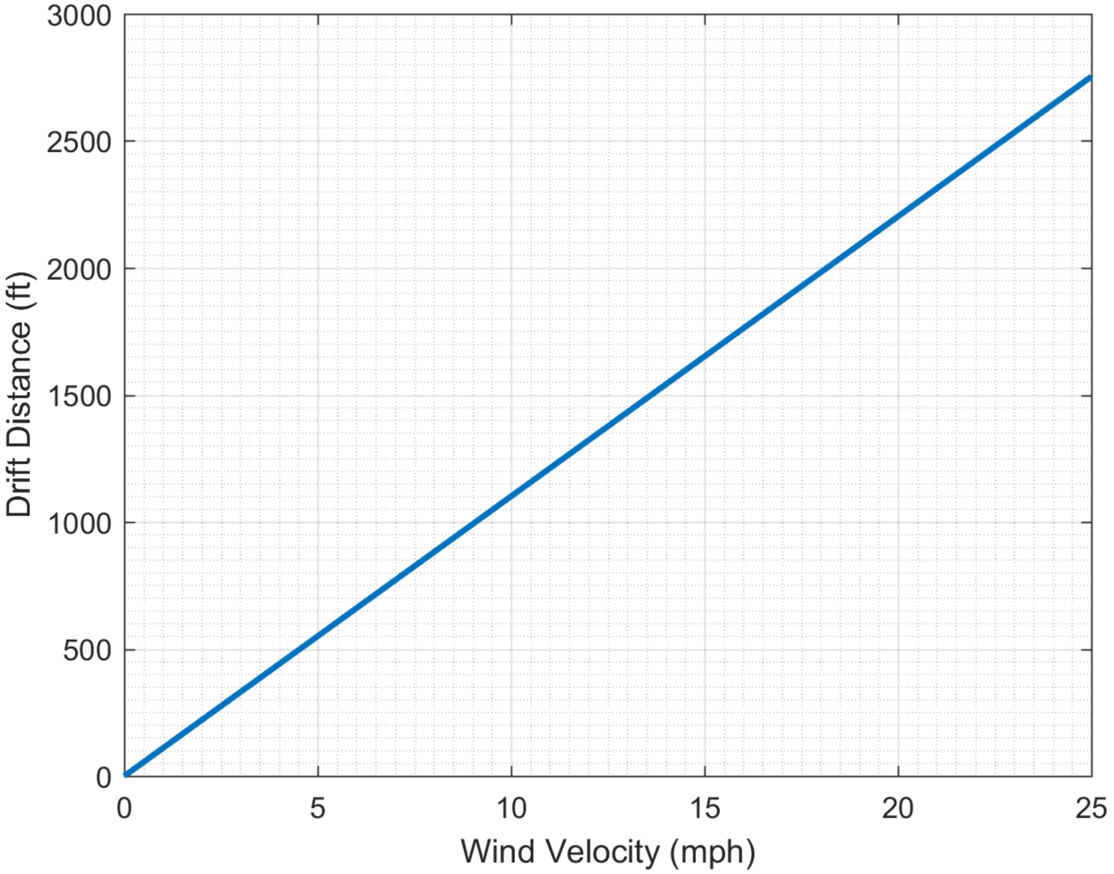

Altitude (ft)
4000
2000
0
0
10
20
30
40
50
60
70
Time (s)
Velocity (ft/s)
100
50
0
0
10
20
30
40
50
60
70
Time (s)



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(5)
plot(Windmph,driftDistFt,'LineWidth', 2);
ylabel('Drift Distance (ft)');
xlabel('Wind Velocity (mph)');
grid on;
grid minor;
%title('Drift During Descent');

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

```
The drift distance at a wind velocity of 25 mph is 2753.5 ft
```

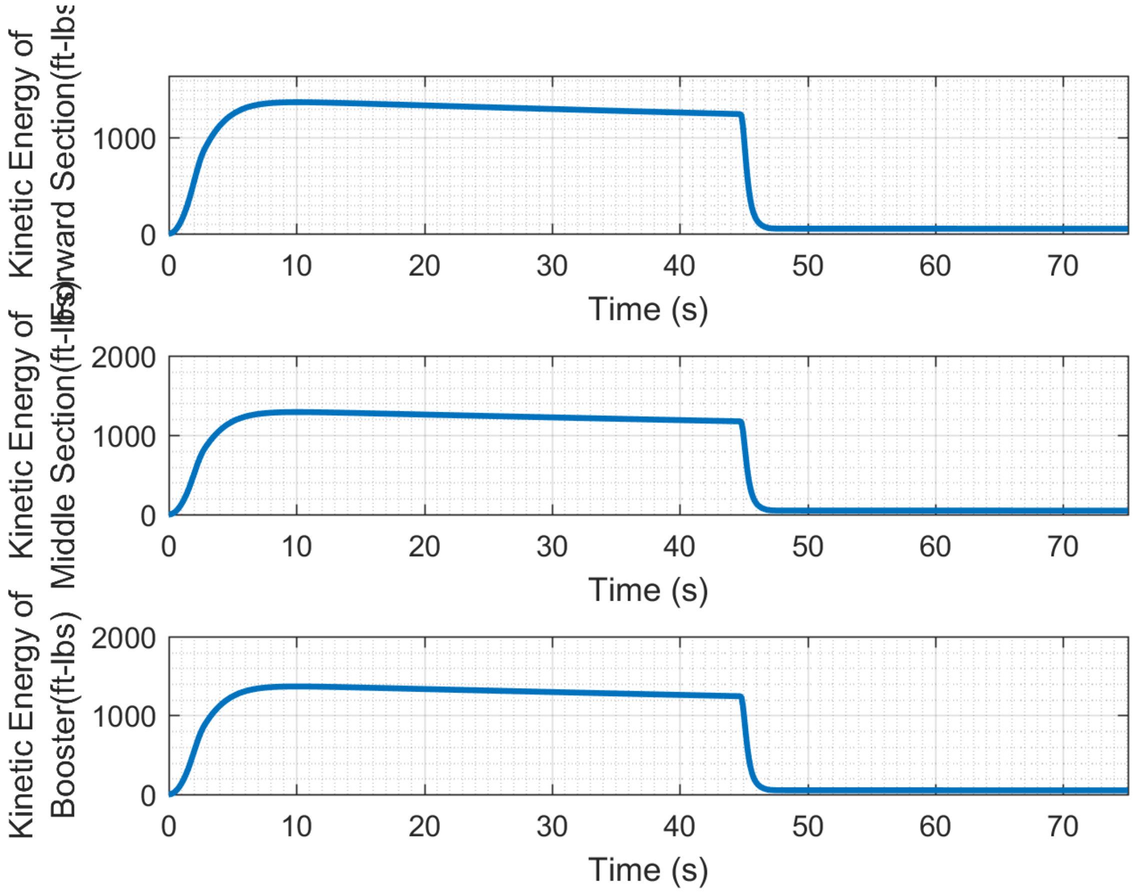


Calculate KE History of each component

```
KEforeSI_mat = (1/2)*v.^2*mass(1);
KEavSI_mat = (1/2)*v.^2*mass(2);
KEboostSI_mat = (1/2)*v.^2*mass(3);

maxKE_SI = max([max(KEforeSI_mat),max(KEavSI_mat),max(KEboostSI_mat)]);

KEforeST_mat = KEforeSI_mat*0.7376;
KEavST_mat = KEavSI_mat*0.7376;
KEboostST_mat = KEboostSI_mat*0.7376;

maxKE_ST = max([max(KEforeST_mat),max(KEavST_mat),max(KEboostST_mat)]);

% Calculate the KE of each component in Joules at landing
KEforeSI = KEforeSI_mat(end);
KEavSI = KEavSI_mat(end);
KEboostSI = KEboostSI_mat(end);

maxLandingKE_SI = max([KEforeSI,KEavSI,KEboostSI]);
```

```
% Calculate the KE of each component in Ft-lbs at landing
KEforeST = KEforeST_mat(end);
KEavST = KEavST_mat(end);
KEboostST = KEboostST_mat(end);

maxLandingKE_ST = max([KEforeST,KEavST,KEboostST]);

figure(6)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
ax13 = subplot(3,1,1);
title('Kinetic Energy of Each Component vs. Altitude');

plot(time,KEforeST_mat,'LineWidth',2);
ylabel({'Kinetic Energy of'; 'Forward Section(ft-lbs)'});
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 maxKE_ST*1.2]);

ax23 = subplot(3,1,2);
plot(time,KEavST_mat,'LineWidth',2);
ylabel({'Kinetic Energy of'; 'Middle Section(ft-lbs)'});
xlabel('Time (s)');
grid on;
grid minor;
linkaxes([ax13 ax23],'x');

ax33 = subplot(3,1,3);
plot(time,KEboostST_mat,'LineWidth',2);
ylabel({'Kinetic Energy of'; 'Booster(ft-lbs)'});
xlabel('Time (s)');
grid on;
grid minor;
linkaxes([ax23 ax33],'x');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Uncomment below and comment above to display all KE plots on one graph
% plot(time,KEforeST_mat, time, KEavST_mat, time, KEboostST_mat,'LineWidth',2);
% ylabel('Kinetic Energy (ft-lbs)');
% xlabel('Time (s)');
% grid on;
% grid minor;
% axis([0 max(time) 0 maxKE_ST*1.2]);
% legend('Forward Section', 'Middle Section', 'Booster Section');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
vf = v(end); %Find final landing velocity

% 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 51.68 ft*lbs
The kinetic energy of the avionics bay section is 48.65 ft*lbs
The kinetic energy of the booster section is 51.58 ft*lbs

The velocity at landing is 5.94 m/s or 19.48 ft/s
```



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Appendix B: MSDS for Black Powder

GOEX
BLACK
POWDER
–THE TRADITION CONTINUES–

Goex Powder, Inc.

Material Safety Data Sheet

MSDS-BP (Potassium Nitrate)

Revised 3/17/09

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

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

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

WARNING

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

HAZARDOUS COMPONENTS				
Material or Components	%	CAS NO.	TLV	PEL
Potassium nitrate	70-76	007757-79-1	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite[1]	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m^3
N/A = Not assigned NE = Not established				

---

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

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

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

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

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

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

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

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

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

SPECIAL PRECAUTIONS

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

STORAGE CONDITIONS

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

SHIPPING INFORMATION

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

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

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

SPECIAL PRECAUTIONS

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

STORAGE CONDITIONS

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

SHIPPING INFORMATION

Proper shipping name	Black Powder	
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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:
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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.

Appendix D: Drag Calculation MATLAB Script

```
%Calculates Cd from flight data: Apogee and Time to apogee
clc;
clear;
g = 9.81;%m/s^2
Tau = 1140.999978;% average thrust; newtons
rho = 1.225; %kg/m^3
A = 0.025109627; % m^2

tb = 3.7; %seconds  from manufacturer or thrustcurve
Mi = 18.8241; %kg   full mass of rocket from openrocket
Mf = 16.0241; %kg   mass of fuel grains; from manufacturer
m_dot = (Mi-Mf)/tb;  %mass flow rate
ISP = Tau/m_dot;
h_b = g*( (-tb*ISP)*((log(Mi/Mf))/(Mi/Mf-1))+tb*ISP-(1/2)*tb^2); %burnout hieght

% GET FROM FLIGHT DATA
% t_a = ; %flight time from ignition to apogee
% t_ba = t_a - t_b; %time from burnout to apogee
t_ba = 13.9; %seconds; time from burnout to apogee; found using OpenRocket
h_max = 4876*.3048;%ft-> meters

%Ue calculations from apogee
% epsilon = Mf/Mi;
% lambda = Mf/(Mi-Mf);
% R = (1+lambda)/(epsilon+lambda);
%
% syms x %exhaust velocity
% Ue = solve(h_max == (x^2*(log(R))^2)/(2*g) - x*tb*((R/(R-1))*log(R)-1))

Ueq = Tau/m_dot ;
Ue = Ueq;
U1=Ue*log(Mi/Mf) + g*tb;%tb is burnout time
D = h_b - U1*t_ba - 0.5*g*t_ba^2;%Solving for drag using distance from burnout to
apogee, with U1 as the speed at burnout
% and t is the time from burnout to apogee
Cd = -2*D/rho/A/(U1^2);
```

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