NASA Student Launch
2016-2017

Critical Design Review

1000 W. Foothill Blvd.
Glendora, CA 91741

Project Aegis

Fragile Material Protection

January 13, 2016

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Commonly Used Acronyms

AED ....Automated External Defibrillator
APCP...Ammonium Perchlorate Composite Propellant
ATF...Bureau of Alcohol, Tobacco, Firearms and Explosives
BLS ....Basic Life Support
BMP .... Barometric Pressure
CAD .... Computer-Aided Design
CATO...Catastrophic Takeoff
Cd ....Coefficient of Drag
CPR .... Cardiopulmonary Resuscitation
CNC ....Computer Numerically Controlled
EMF .... Electromotive Force
FAA..Federal Aviation Administration
FAR..The Friends of Amateur Rocketry
GUSD...Glendora Unified School District
HTC... Honors Transfer Council of California
IMU .... Inertial Measurement Unit
MDARS .... Mojave Desert Advanced Rocketry Society
MSDS...Material Safety Data Sheet
NAR .... National Association of Rocketry
PPE... Personal Protective Equipment
PS ....Physical Science
NFPA .... National Fire Protection Association
RAC ....Risk Assessment Code
ROC ....Rocketry Organization of California
RSO...Range Safety Officer
STEM .... Science, Technology, Engineering, and Mathematics
TRA... Tripoli Rocketry Association
UV ....Ultraviolet

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General Information

1. School Information

Citrus College
1000 W. Foothill Blvd
Glendora, CA 91741

More information about Citrus College can be found in Appendix A.

2. Adult Educators

Dr. Lucia Riderer
- Team Advisor
- Physics Faculty

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(626) 914-8763

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- Team Mentor
- Director, Sugar Shot to Space

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3. Safety Officer

Janet
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(626) 608-8584

4. Team Leader

Yvonne
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(909) 244-2662

5. Team Members and Proposed Duties

Table 1 gives the title and proposed duties of five team members on the Rocket Owls team.

Table 1: Team Member Proposed Duties		
Team Member	**Title**	**Proposed Duties**
Isabella	Outreach Officer	• Educational engagement • Rocket design and construction
Janet	Safety Officer	• Implementation of safety plan • CNC programmer
Jimmy	Payload Specialist	• Website maintenance • Payload analysis
Lillian	Payload Specialist	• Rocket design and construction • Payload analysis
Yvonne	Team Leader	• Communication and coordination • Rocket design and construction

Figure 1 below shows the hierarchy based on which the Citrus College Rocket Owls team is structured.
Figure 1: Team Organization Chart

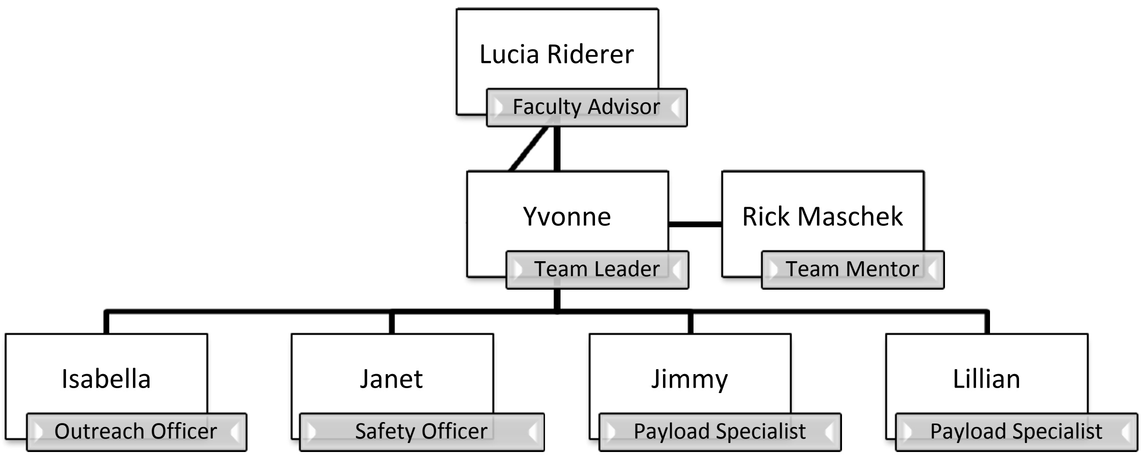

Figure 1 outlines the Rocket Owls team organization chart

5. NAR/TRA Sections

For launch assistance, mentoring, and review, the Rocket Owls will associate with the Rocketry Organization of California (ROC) (NAR Section #538, Tripoli Prefecture #48) and the Mojave Desert Advanced Rocket Society (MDARS) (Tripoli Prefecture #37).

I. Summary of CDR Report

1.1 Team Summary

Team Name: Citrus College Rocket Owls
Mailing Address:
Dr. Lucia Riderer
Physics Department Citrus College
1000 W. Foothill Blvd.
Glendora, CA 91741

Team Mentor Information:
Rick Maschek
TRA # 11388
Certification Level 2

1.2 Launch Vehicle Summary

Vehicle Dimensions

Length: 119 in
Diameter: 6.08 in
Mass (without motor): 30.03 lbs
Mass (with motor): 40.09 lbs

Rail Size

12 ft in length and fits size 1515 launch rail buttons

Motor Choice

Aerotech L1420R

Recovery System

All flight events will be initiated by the Missile Works RRC2+ altimeters. A black powder charge will separate the rocket and deploy a 24 in drogue parachute at apogee. The rocket will fall as two tethered sections with a descent rate of 78.18 fps. A second black powder charge will eject the 120 in main parachute at 800 ft AGL. The rocket will descend as three tethered sections at a rate of 12.92 fps. Both parachute deployments will utilize redundant black powder charges with a 1 sec delay.

Milestone Review Flysheet

• The milestone review flysheet will be available as a separate document

1.3 Payload Summary

Payload Title

"Fragile Materials Protection"

Payload materials

- Polycarbonate
- Silicone/silicone rubber
- Metal
- Aerogel

Payload Experiment Overview

The team will be designing and constructing a container to protect a fragile sample(s) before, during, and after flight. The finalized container is designed to safely hold a maximum of eight separate samples. The main components of the team's container are: radiation shield, insulation shield, outer shell, inner chamber, and inner rack. These components focus on protecting the sample(s) from impact, shock, contamination, temperature change, pressure change, and radiation. The design of the container was made with the main objective being sample retrieval from the surface of Mars.

II. Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

1. The mass of the launch vehicle has increased from 369.831 oz to 425.641 oz. This increase in mass is a result of adding expoy, fiberglass, and hardware to the RockSim simulation.
2. The motor has been replaced with the Aerotech L1420R due to the increase mass of the launch vehicle.
3. The motor mount length has been decreased to 20 in to better fit the Aerotech L1420R motor.
4. The thickness of the forward and the aft centering rings was increased from 0.25 in to 0.5 in to provide additional support to the motor mount.
5. Two bulkheads in the forward section of the launch vehicle were removed after being deemed uneccessary.
6. All airframes and fins will be fiberglassed to prevent damage.
7. A LSM9DS1 altimeter will be used to calculate the acceleration, mag, and gyro of the launch vehicle during flight.
8. An Arduino Uno will be used to program the LSM9DS1 altimeter.
9. A SD shield will be used to attach the LSM9DS1 altimeter to the Arduino Uno and record the flight data to a SD card.

2.2. Changes Made to Payload Criteria

1. The layer of Line-X on the outer chamber of the payload will no longer be used because of the increase in total diameter.
2. The length of the payload has changed from 13.25 in to 16 in and the diameter has changed from 5.25 in to 5.8 in. This was done to increase the area that can be used to house the samples.
3. A new lid and lid adapter have been chosen for the container.
4. Silicone rubber will be used instead of the borated flexi panel to reduce cost.
5. A polycarbonate cover with rubber sealants will be used for the liquid compartment because of the changes made to the container's lid.
6. The substitute radiation shielding and the Aerogel sheilding will be placed inside the outer shell to prevent damage to the insulated materials.
7. The liquid compartment's width has decreased from 0.50 in to 0.25 in to increase the volume of the inner chamber.
8. The steel rods in the inner chamber have been replaced with 0.125 in diameter and 12.25 in long steel rods.
9. The diameter of the silicon disks within the inner chamber has been increased from 4.0 in to 4.25 in to provide a larger area to hold the sample(s).
10. The outer diameter of the inner chamber has been increased from 4.25 in to 4.5 in and the inner diameter has been increased from 4.0 in to 4.25 in to provide a larger area to hold the solid sample(s).

11. The length of the inner rack has increased from 12.53 in to 12.62 in providng more space for larger sample(s).
12. The outer diameter of the outer shell has been increased from 5.0 in to 5.5 in and the inner diameter has been increased from 4.75 in to 5.25 in allowing the container to secure larger sample(s).

2.3 Changes Made to Project Plan

Timeline and Activity Lists

There have been no changes to the project plan since the PDR.

Budget

The table below lists the new items added to the budget and their prices.

Table 2: New Budget Items

Item	Price
Engine Casing	$248.27
Forward Closure	$110.80
Aft Closure	$87.47
Forward Seal Disk	$49.88
L1420R Motor	$221.43
Motor Retainer	$63.79

2.4 PDR Feedback

1. "*What is the length of the launch rail used in your simulations because the rail exit velocity listed is low? You may be using too short of a launch rail.*"

There was a mistype in the PDR flysheet. A 12 ft long launch rail that fits size 1515 launch rail buttons was utilized in the recent simulations. The rail exit velocity is estimated to be 78.05 fps.

2. "*Both of descent velocities listed are slow, and will certainly lead to high drift. You can afford to speed these velocities up.*"

The team had made changes to the recovery subsystem by using a 24 in Elliptical drogue parachute and a 120 in Iris Ultra Toroidal Compact main parachute to increase the descent velocity of the launch vehicle. This reduces the drift and prevents the launch vehicle from landing with a kinetic energy above 75 ft-lbf. For detailed information on the terminal velocity of the drogue and main parachute and the kinetic energy of each tethered section, see section 3.3.1 Final Recovery Subsytem Design, *Terminal Velocity, Kinetic Energy, and Drifting Distance.*

III. Vehicle Criteria

3.1. Design and Verification of Launch Vehicle

3.1.1 Mission Statement

The Citrus College Rocket Owls are a science and engineering team dedicated to a successful participation in the NASA Student Launch (NSL) competition. The Rocket Owls are community college students committed to achieving a university level education, followed by a successful career in science, technology, engineering, and mathematics (STEM). In addition, one of the Rocket Owls' main goals is to inspire and educate students from the local community in STEM.

During Project Aegis, the Rocket Owls will design, construct, and launch a rocket capable of carrying a scientific and engineering payload to 5,280 ft above ground level (AGL). This payload consists of a container that will protect one or more unknown fragile samples throughout the duration of the entire flight to simulate successful sample retrieval from Mars.

3.1.2 Mission Success Criteria

Certain criteria must be met for the mission to be considered successful. These criteria are secondary to all NASA mission requirements as set forth in the Statement of Work (SOW). More information on the SOW requirements, the verification plan, and its status can be found in sections 7.2.3 and 7.2.6 of this document.

The launch vehicle is required to complete the following objectives:

- reach a target altitude of 5,280 ft
- have a stable flight
- deploy the drogue parachute at apogee ±10 ft
- deploy the main parachute at 800±15 ft AGL
- land safely (details are provided in section IV)
- be easily located with the GPS
- be reusable after flight

The fragile material protection payload will be considered successful if the following decisive factors are achieved:

- the unknown samples are fully accommodated in the container
- the unknown samples remain in their designated container compartments throughout the duration of the entire flight
- the unknown samples return in their original state after flight

Further details on payload success criteria are provided in section 7.2.3 of this document

3.1.3 Major Milestone Schedule

Table 3 displays the schedule for major launch vehicle milestones including its design, construction, testing, operations, and reviews.

Table 3: Major Milestone Schedule		
Operation	**Date(s)**	**Status**
Proposal submission	9/30/16	Complete
Notification of selection	10/19/16	Complete
Web presence established	10/28/16	Complete
PDR report, presentation, and flysheet submitted	11/04/16	Complete
PDR presentation	11/16/16	Complete
Order materials	11/27/16	Complete
Sub-Scale ground ejection tests	12/10/16	Complete
Sub-Scale test flight	12/18/16	Complete
Order motors	1/10/17	Planned
CDR report, presentation, flysheet submitted	1/13/17	Planned
Cut, sand, and fiberglass fins	1/16/17	Planned
Construct booster section of launch vehicle	1/16/17 - 1/18/17	Planned
Attach fins	1/18/17	Planned
Test motor mount/centering ring strength	1/19/17	Planned
Avionics bay construction and assembly	1/20/17 - 1/21/17	Planned
CDR presentation	1/23/17	Planned
RRC2+ vacuum test	1/23/17	Planned
TeleGPS ground test	1/23/17	Planned
Test forward bulkhead (where shock cord is attached)	1/24/17 - 1/26/17	Planned
Integration of subsections, add static ports	1/26/17	Planned
Ground ejection tests	1/27/17	Planned
Launch	2/05/17	Planned
Reconstruct(if necessary)	2/05/17 – 2/10/17	
Backup launch	2/11/17	Planned
Reconstruct(if necessary)	2/11/17 – 2/17/17	
Backup launch	2/18/17	Planned
FRR report, presentation, and flysheet due	3/06/17	Planned
FRR presentation	TBD	Planned
LRR	4/05/17	Planned
Launch day	4/08/17	Planned
PLAR due	4/24/17	Planned

A description of completed tests can be found in Section 7.1.

3.1.4 System Level Design Review

3.1.4.1 *Launch Vehicle Specifications*

The Citrus College Rocket Owls have chosen to go with the first design presented in the team's Preliminary Design Review report. The launch vehicle is designed to satisfy the requirements of the project and is further described in this section. Figure 3 displays the fully assembled launch vehicle.

Table 4 below provides the general vehicle dimensions and illustrates the way the specifications of the launch vehicle are altered based on the motor utilized.

Table 4: General Launch Vehicle Dimensions

Aspect	Without Motor	With L1420R Motor
Length (in)	119.13	119.13
Diameter (in)	6.08	6.08
Length/diameter ratio	19.57	19.57
Mass (lbs)	30.03	40.09
C.P. from nose cone (in)	93.84	93.84
C.G. from nose cone (in)	61.66	79.89
Stability (caliber)	4.36	3.32
Average thrust (N)	-	1424

The launch vehicle consists of the following three independent sections:

1. Booster section
2. Recovery section
3. Payload section

The sections listed above will be tethered together with 1 in tubular webbing harnesses.

The most aft part of the launch vehicle is the booster section. The booster section is comprised of the motor mount and drogue parachute compartment. The booster section is connected to the avionics bay using 2-56.25 in nylon shear pins.

The middle section of the launch vehicle is comprised of the avionics bay and the main parachute compartment. Figure 4 shows the design for this section. The Blue Tube airframe for the main parachute compartment is held together by metal screws on the side of the coupler tube connected to the avionics bay and by 2-56.25 in nylon shear pins on the side connected to the forward section.

The fragile material protection payload is housed in the third and most forward section of the launch vehicle. This section includes the payload, Blue Tube airframe, and the coupler tube holding the airframe together with the middle airframe section.

3.1.4.2 *Subsystems*
The final launch vehicle design consists of the following three subsystems of significant importance to the safe completion of the vehicle's mission: propulsion, structural and aerodynamic stability, and recovery. These subsystems along with their components are described next.

3.1.4.3 *Propulsion Subsystem*
The propulsion subsystem is located in the booster section of the rocket.

The propulsion subsystem of the launch vehicle is comprised of the following:

- motor
- motor retainer
- motor mount

The functional requirements of the subsystem are listed below.

1. The total impulse must be sufficient to carry the launch vehicle to 5,280 ft AGL.
2. The rail exit velocity must be sufficient for the launch vehicle to have a stable flight (see section 3.4.1 Mission Performance Predictions for detailed information).
3. The subsystem must remain secured in the vehicle during the entirety of the flight.
4. The ratio of average thrust to weight of vehicle must be 5 or greater.

The launch vehicle's motor consists of the casing, forward and aft closures, forward seal disk, and the L1420R.

The motor mount and retention systems are further described in section 3.1.5 of this document.

3.1.4.4 *Structural and Aerodynamic Stability Subsystem*
The structural and aerodynamic stability subsystem of the launch vehicle is comprised of the following:

- Fins
- Nose cone
- Airframe

The functional requirements of the structural and aerodynamic stability subsystem are:

1. The subsystem must withstand the forces of thrust, weight, drag, and lift acting on the launch vehicle during the entirety of the flight.
2. The subsystem must withstand the stress placed on the vehicle during landing.
3. The subsystem must be aerodynamically stable.

The airframe of the launch vehicle consists of three sections (forward, middle, and aft) made out of fiberglass laminated Blue Tube (Figures 4). The airframe sections will be cut with a miter saw. The three sections are joined together with 12 in sections of Blue Tube coupler. For sections that must separate during parachute deployment, the coupler and airframe will be secured with 12-56.25 in nylon shear pins. For sections that do not need to separate, they will be secured together with metal screws.

The fiberglass nose cone shoulder will be sanded until it is aerodynamically suitable for integration with the launch vehicle.

3.1.4.5 *Recovery Subsystem*
The recovery subsystem consists of the following components:

- Drogue parachute
- Main parachute
- Avionics bay
- Recovery system electronics

The functional requirements of the recovery subsystem are:

1. The drogue parachute must be deployed at apogee and remain undamaged from ejection gases.
2. The main parachute must be deployed at 800 ft AGL and remain undamaged from ejection gases.
3. Each independent section of the launch vehicle must have less than 75 ft-lbf of kinetic energy at landing.
4. The TeleGPS must relay the coordinates of the landed rocket to the ground station.

The recovery subsystem is further described in section 3.3 of this document, Recovery Subsystem. The recovery system electronics are described in section 3.3.4 of the document, Recovery System Electrical Schematics.

3.1.4.6 Selection Rationale

The final launch vehicle design was selected because it was more efficient than the alternative launch vehicle design. The position of the payload bay in the forward section above the main parachute compartment was more desirable since this location allowed more mass to be present in the forward section of the launch vehicle, increasing the stability margin. Since neither the payload nor the launch vehicle incorporate additional electronics, a secondary avionics bay was not necessary in the design. Fiberglass laminating both the Blue Tube airframe and fins provides additional structural strength to the launch vehicle without increasing the project budget significantly.

3.1.5 *Launch Vehicle Design Drawings*

Figure 2: RockSim 9 Diagram of Launch Vehicle

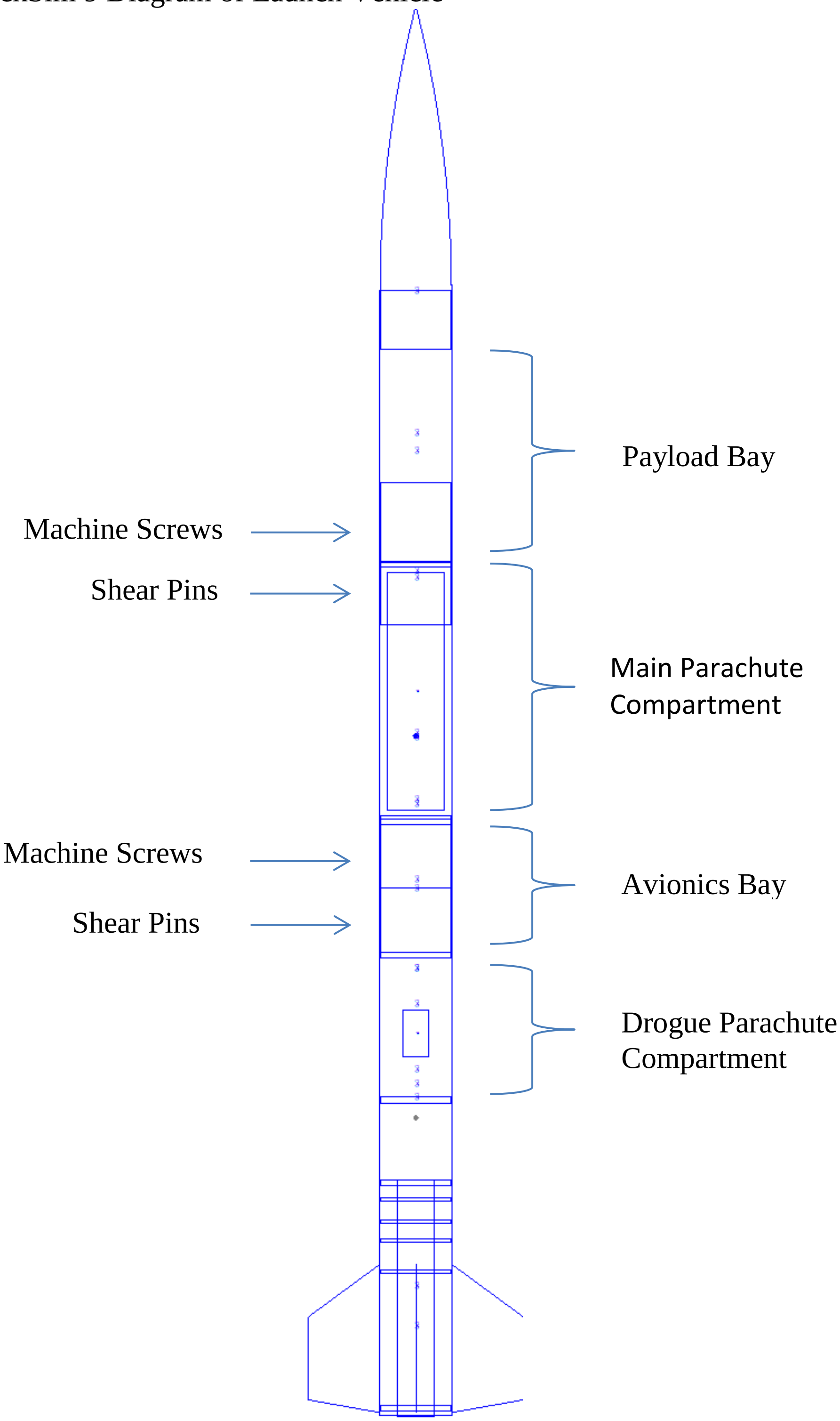

Figure 2 shows the RockSim 9 diagram of the final launch vehicle design

Figure 3: Fully Assembled Launch Vehicle (External View)

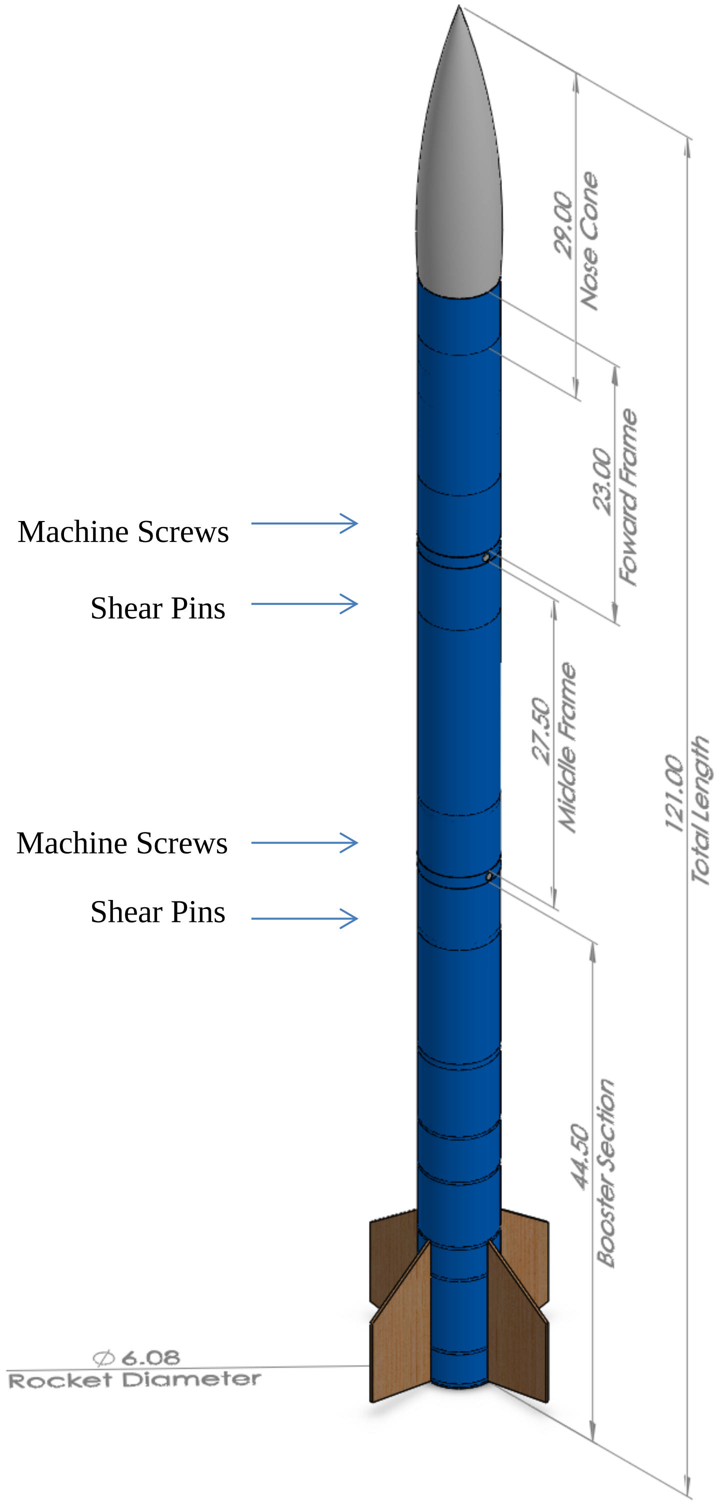

Figure 3 shows an isometric view of the fully assembled launch

Figure 4: Launch Vehicle (Internal/Exploded View)

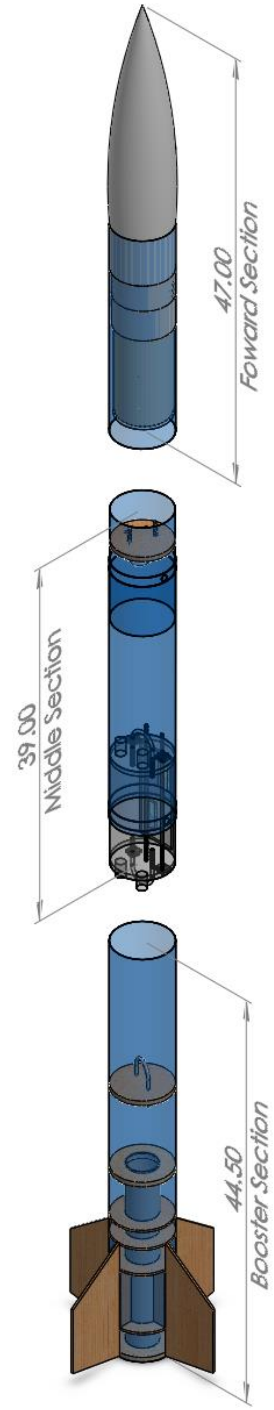

Figure 4 shows an exploded isometric view of the launch vehicle with transparent subsections.

Figure 5: Launch Vehicle (Exploded View)

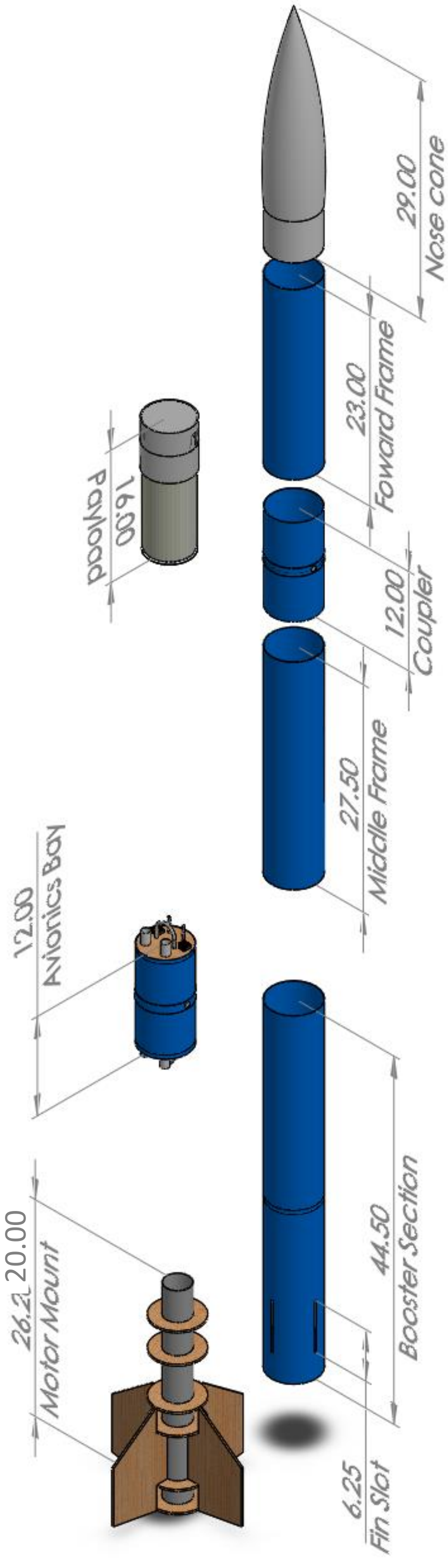

Figure 5 shows an isometric exploded view of the launch vehicle.

Figure 6: Launch Vehicle (Base View)

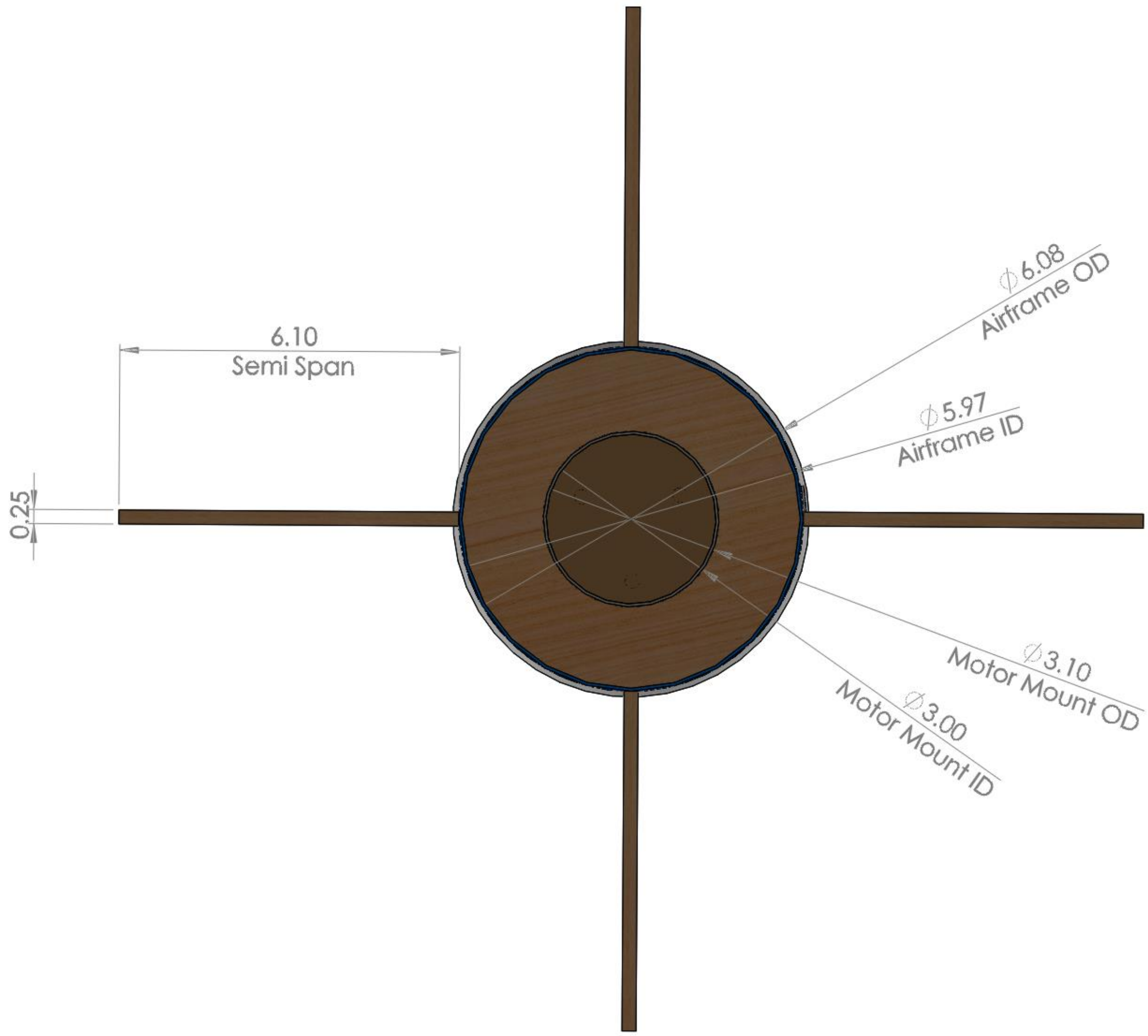

Figure 6 shows the base view of the launch vehicle

Figure 7: Booster Section

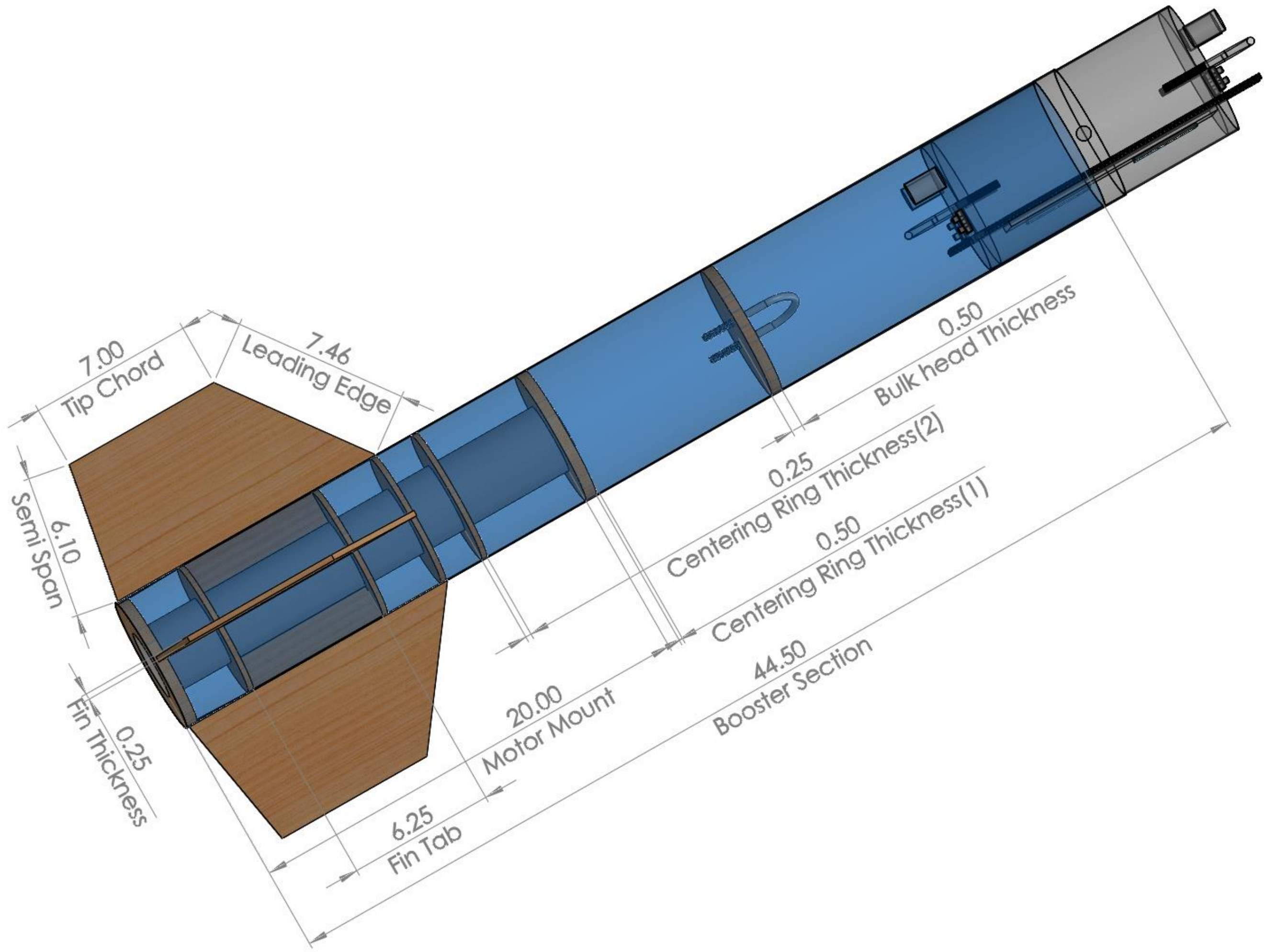

Figure 7 shows an isometric transparent view of the launch vehicle's booster section.

Figure 8: Payload Bay

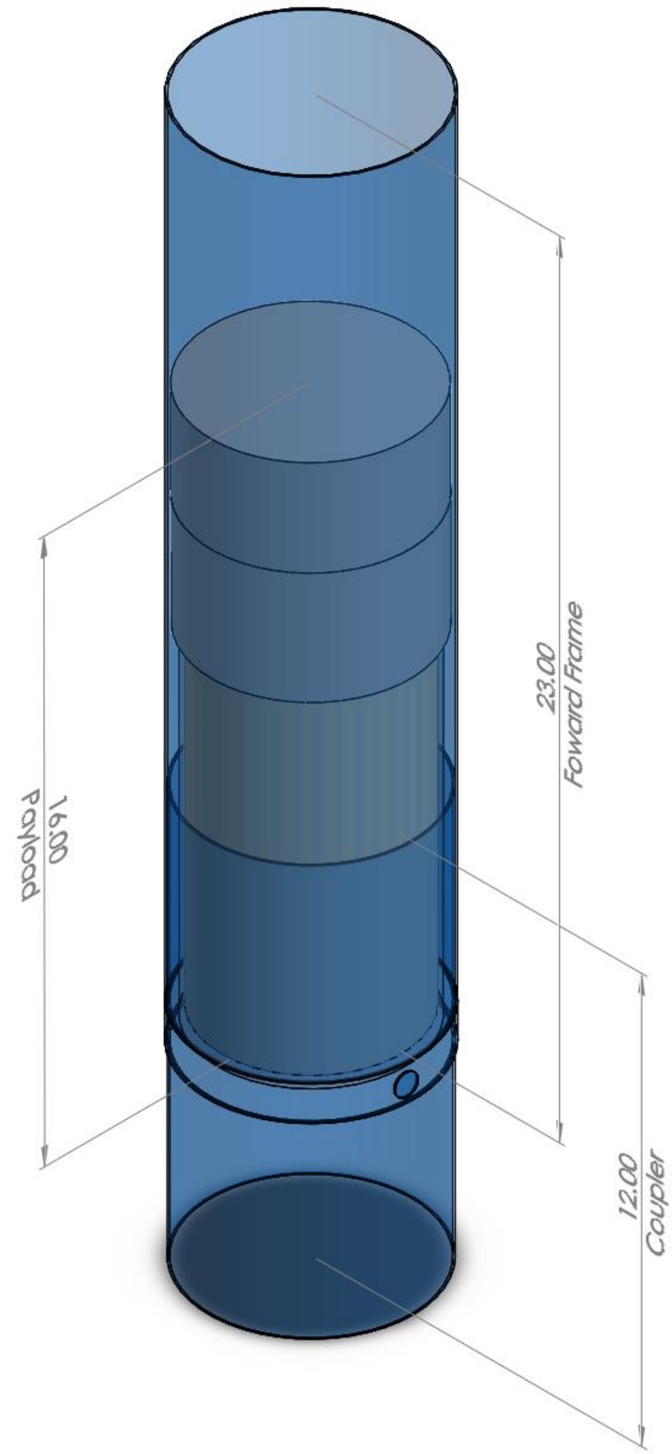

Figure 8 shows an isometric transparent view of the payload bay.

Figure 9: Bulkhead with U-Bolt

Figure 9 shows the bulkhead that will be used in the booster section and payload bay.

Figure 10: Bulkhead for avionics bay

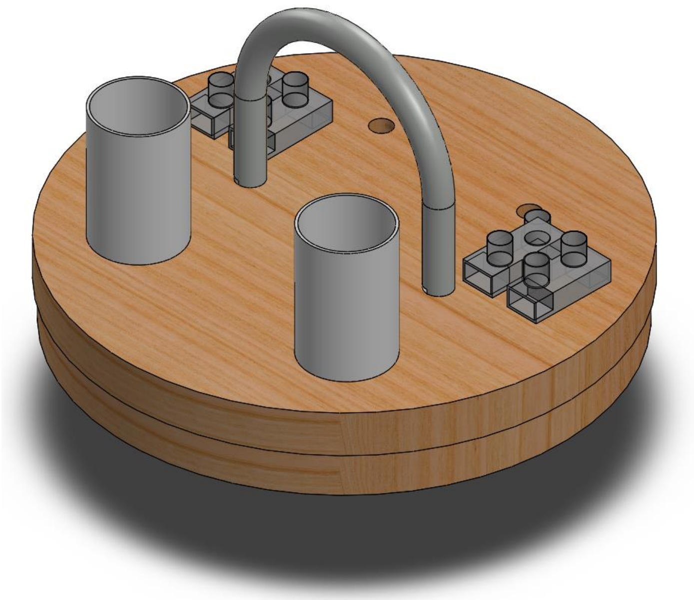

Figure 10 shows the bulkhead for the avionics bay

Figure 11: Nose Cone

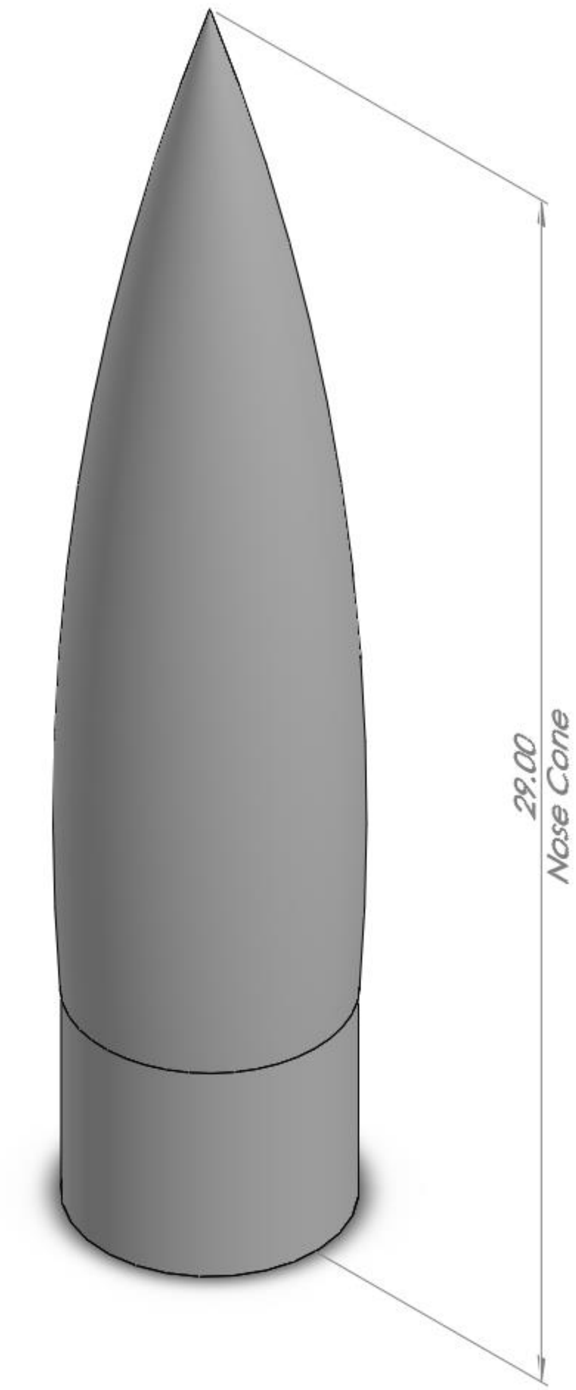

Figure 11 shows the nose cone used in the launch vehicle design.

Figure 12: Launch Vehicle Fin (1 of 4)

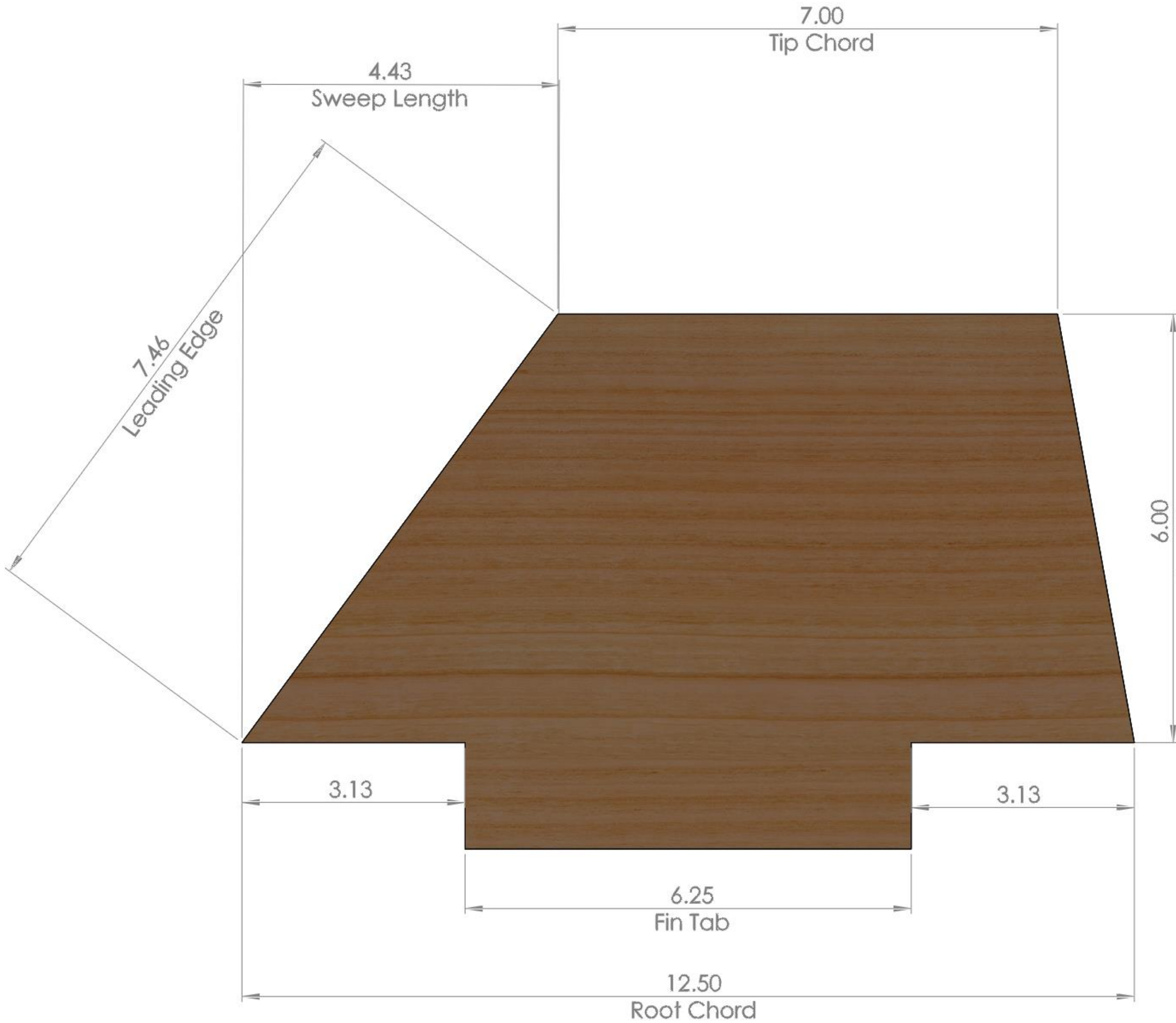

Figure 12 shows the fin shape and dimensions for the launch vehicle.

Figure 13: Forward Section of the Launch Vehicle

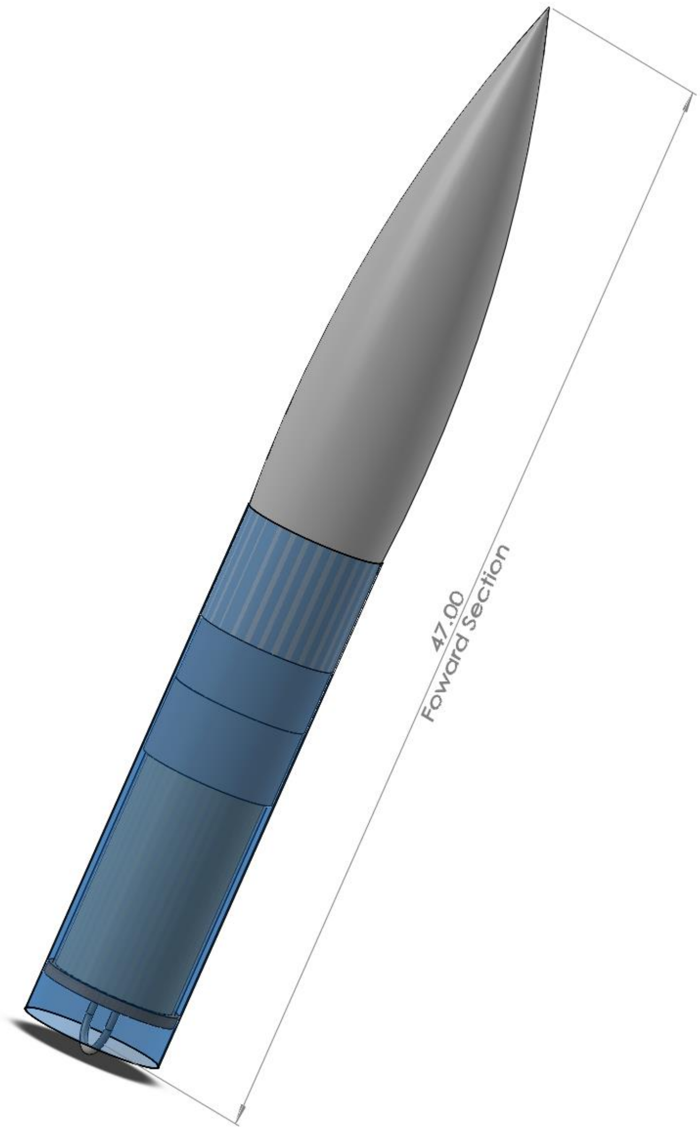

Figure 13 shows the forward section of the launch vehicle with the payload incorporated.

3.1.6 *Fin Flutter Analysis*

During flight, fins naturally vibrate. Once the speed of the launch vehicle reaches and exceeds that of the flutter speed, the resonance between the fin and air will cause flutter and potential fin failure. The speed at which the designed fins are expected to experience flutter was calculated using the flutter boundary equation below [1].

The variables used in the equations are defined below:
V_f=fin flutter speed
a= speed of sound
G= shear modulus
β= aspect ratio
P= air pressure
λ= fin taper ratio
t= thickness of fin
C_R= fin root chord
C_T= fin tip chord
S= fin semi-span
A_f= area of fin
h= altitude in feet (at which maximum speed will occur)

$$a\left({}^{ft}/_{s}\right) = \sqrt{1.4\ \times 1716.59 \times (T(°F) + 460)}$$
$$= \sqrt{1.4 \times 1716.59 \times (60°F + 460)}$$
$$= 1117.9\ {}^{ft}/_{s}$$

$$\beta = \frac{S^2}{A_f} = \frac{(6\ in)^2}{58.5 in^2}$$
$$= 0.615$$
$$\lambda = \frac{C_T}{C_R} = \frac{7in}{12.5in}$$
$$= 0.56$$
$$P\left({}^{lbs}/_{ft^2}\right) = 2116 \times (\frac{60 - 0.00356h + 459.7}{518.6})^{5.256}$$
$$= 1767.7\frac{lbs}{ft^2}$$
$$V_f = a\sqrt{\frac{G}{\frac{1.337\beta^3 P(\lambda+1)}{2(\beta+2)(\frac{t}{C_R})^3}}} = (1117.9\,{}^{ft}/_{s})\sqrt{\frac{102000\ \frac{lbs}{in^2}}{\frac{1.337(0.615)^2(12.28\frac{lbs}{in^2})(0.56+1)}{2(0.615+2)(\frac{0.25\ in}{12.5\ in})^3}}}$$
$$= 742\ {}^{ft}/_{s}$$

RockSim 9 predicated a maximum speed of 702 fps for the launch vehicle. The possibility of inflight failure due to an unstable flight and/or destruction of the fins is not expected to occur, however, the room for error is only 40 fps and thus the fins will be reinforced. This is described in Section 3.1.8.1 Fin Suitability.

3.1.7 Integrity of Design

3.1.7.1 *Fin Suitability*

There will be four trapezoidal shaped fins (Figure 12). The fins will be constructed out of 0.25 in thick 10-ply aircraft grade plywood cut with a CNC router. The grain of the wood will be positioned normal to the airframe of the launch vehicle. There will be fin tab slots in the booster sections of the airframe of the rocket to allow the tabs of the fins to be secured to the motor mount with rocket epoxy. Internal and external epoxy fillets will be added to increase the strength of the joint. An epoxy fiberglass layer, utilizing 3 oz weaved fiberglass cloth, will laminate both sides of the fins and fin joints in order to prevent in flight instability created by flutter and to strengthen the fins to avoid chipping upon landing.

The nozzle end of the booster section is expected to be the first section to collide with the ground upon landing. The fin design in combination with the fiberglass laminate was selected to ensure minimal chipping of the fins upon landing. The shape of the fins allow them to be pointed away from the point of impact between the booster and the ground, thus reducing the risk of fin damage upon landing. In addition, the small size of the fins will reduce the drag experienced by the launch vehicle, but still bring the center of pressure far enough aft of the center of gravity to obtain a stability caliber over two.

3.1.7.2 *Proper Use of Materials*

Table 5 outlines the materials used in the launch vehicle along with their justification for using.

Table 5: Launch Vehicle Materials and Justification

Launch Vehicle Component	Material	Justification
Nose cone	Fiberglass filament wound	Strong and durable.
Airframe	Blue Tube 2.0	Rigid, stronger than phenolic tubing while the outer layer of fiberglass provides additional strength.
Bulkheads	5-ply plywood, 0.50 in	Strong, easy to cut, sand and bond. Plywood is affordable and easy to work with. The thickness of the components ensures that they can withstand the stresses on them during flight and parachute deployment.
Centering rings	10-ply aircraft plywood, 0.25 in	Strong, easy to cut, sand and bond. Plywood is affordable and easy to work with. The quantity of the components ensures that they can withstand the stresses on them during flight.
Fins (fiberglass laminated)	10-ply aircraft plywood, 0.25 in	Strong, stiff, resists flutter. Plywood is affordable and easy to work with; while the outer layer of fiberglass provides additional strength.

Parachutes	Ripstop nylon	Light-weight, tear resistant.
Shock cords	1 in Tubular nylon	High-breaking strength.
Coupler	Blue Tube 2.0	Blue Tube requires no reinforcement for subsonic speeds.
Motor Mount	Blue Tube 2.0	The Blue Tube motor mount is durable enough to withstand the force from the motor without reinforcement.

3.1.7.3*Assembly, Attachment, Alignment, and Solid Connection of Elements*

12 in Blue Tube coupler tubes are used to assemble the three main launch vehicle sections. At the junctions, the airframe will overlap the coupler by 6 in. The overlapping length was chosen to ensure that the launch vehicle will remain straight and rigid during flight.

2-56.25 in nylon shear pins will be used to prevent premature separation. #6, 0.5 in sheet metals screws will be used in joint areas not meant to separate. Three nylon shear pins will be used between the drogue parachute compartment and the side of the avionics bay inserted into the drogue parachute compartment. Nylon screws will also be used on the main parachute and payload bay junction, the quantity will be determined through ground ejection tests. A total of 15 sheet metal screws will be utilized to fix the nose cone onto the payload bay, fix the payload bay onto the main parachute compartment, and fix the main parachute compartment onto the avionic bay (5 screws per interface). The metal screws are necessary for secure attachment of compartments that are not intended to separate throughout the entire flight.

After dual deployment, the three main launch vehicle sections will be tethered to each other with tubular nylon harnesses. The harnesses are attached to 0.3125 in U-bolts. The U-bolts run through the 0.5 in thick bulkheads and are secured with lock washers, flat washers, nuts, and epoxy.

The “through the wall” fin attachment method will be utilized. Fin tabs and fin tab slots will help to correctly align the four fins 120° apart from each other. In addition, a fin alignment guide will be used to verify the fins are normal to the body of the rocket.

The 1515 size rail buttons will be securely attached to the airframe of the launch vehicle, one near the edge of the booster section closest to the retainer and the other near the center of gravity of the launch vehicle. The bolt of the rail button will be threaded through a nut placed inside the airframe. Epoxy will be placed over the bolt and nut to secure the attachment. The rail buttons will not be secured through a centering ring to prevent structural damage to the centering ring.

3.1.7.4 *Motor Mounting and Retention*

The total length of the motor mount is 20 in and is constructed out of 75 mm Blue Tube. The motor mount will be secured into the booster section with six CNC cut centering rings made out of aircraft-grade plywood. Two 0.5 in thick centering rings will be located at the ends of the motor mount and four 0.25 in thick centering rings will be distributed in between the two (Figure #). Rocket epoxy mixed with fiberglass cloth fibers will be used to securely bond the centering rings onto the motor mount and into the airframe. Epoxy fillets will be added to the inside corners where two parts meet in order to increase the strength of the connections. These connections will be strong enough to withstand the thrust of the motor.

The motor hardware is made of aircraft-grade aluminum [2]. This hardware encases the propellant while protecting the launch vehicle from the hot gases produced during combustion. The aft closure of the casing has a diameter slightly larger than that of the motor mount, which prevents the casing from moving further into the launch vehicle during combustion. The AP75 flanged motor retainer also prevents the casing from falling out of the motor mount [3]. The threaded portion of the motor retainer will be attached to the most aft centering ring of the booster section using 6-32 stainless cap screws and threaded inserts. The cap will be threaded onto the attached portion of the motor retainer to ensure secure housing of the motor.

A 75 mm motor mount was selected in order to accommodate L-type motors. A motor with a smaller diameter would not provide the total impulse necessary to reach 5,280 ft above ground level. Information on the selected motor, the Aerotech L1170-FJ, can be found in section 3.4, Mission Performance Predictions.

3.1.7.5 *Mass Statement*

Table 6 presents the mass estimate of the full scale launch vehicle and payload.

Table 6: Mass Statement

Section	Estimated mass (lbs)
Aft section	18.60
Middle section	6.95
Forward section	13.80

The aft section of the launch vehicle includes the booster section (with motor), drogue parachute compartment, and drogue parachute with harness and connections. The combined mass of the main parachute and their recovery harnesses are included in the mass of the middle section. The mass of the forward section includes the nose cone and fragile material protection payload.

Table 7 lists all rocket components and their estimated mass values.

Table 7: Rocket Component Mass Estimates

Rocket Component	Mass Estimates (oz)
Nose cone	51.12
Forward body tube	12.79
Payload	136.00
Bulkhead	5.51
Tube coupler	6.37
Mega foam	4.00
Mid body tube	15.29
Avionics bay	21.30

Avionics bay coupler	6.37
Main parachute	22.00
Shock cord (45 ft)	19.88
Quick-link	2.65
U-bolt	4.16
Aft body tube	24.79
Fin set	12.11
Shock cord (35 ft)	15.72
Centering ring (0.25 in thick)	1.39
Centering ring (0.50 in thick)	5.51
Engine casing	35.63
Motor mount	5.31
Drogue parachute	2.20

The mass of each component was found using one of the following methods:

- Dimensional analysis using volumetric or linear density
- Digital scale
- Online product information provided by manufacturer or vendor

A detailed mass statement can be found in in table 8 as the mass of each individual component was used to calculate the center of gravity of the launch vehicle.

Table 8 below provides the estimated masses for the three subsystems of the launch vehicle.

Table 8: Subsystem Masses			
Subsystem	**Section**	**Estimated Mass (lbs)**	**Estimated Mass with 25% Increase (lbs)**
Propulsion	Booster section (without motor)	8.54	10.68
	Booster section (with motor)	18.60	23.25
	Engine casing	2.25	2.81
	Aerotech L1420R	10.06	12.58
	Centering ring 0.25 in (4)	0.22	0.28
	Centering ring 0.5 in (2)	0.68	0.85

	75mm Blue Tube	0.33	0.41
Structural and aerodynamic stability	Fins	0.76	0.95
	Nose cone	3.20	4.0
	Airframe	3.31	4.14
Recovery	Avionics bay	2.41	3.01
	Drogue parachute	0.14	0.18
	Main parachute	1.38	1.73

Table 9 provides the total estimated mass for the launch vehicle with and without the L1420R motor.

Table 9: Total Mass of Launch Vehicle		
Launch Vehicle	**Estimated Mass (lbs)**	**Estimated Mass with 25% Increase (lbs)**
Launch vehicle (on launch pad)	40.09	50.11
Launch vehicle (before landing)	34.44	43.05

The mass provided is the most accurate estimation possible without having all of the components on hand. While the method used to estimate the mass was very comprehensive, there is still a possibility that the mass of the launch vehicle will increase. The L1420R motor can safely accommodate an increase of 24 lbs. However, the team will strive to minimize the weight of the launch vehicle so that the launch vehicle can obtain a maximum height close to the target altitude.

3.2 Sub-scale Flight Results

A redundant altimeter was on board and fully functional during the sub-scale launch. Upon successful recovery of the sub-scale launch vehicle, the RRC2+ altimeters reported an apogee altitude of 4237 ft with the K550W Aerotech motor.

3.2.1 Scaling Factors and Variables

The scaling factor of the sub-scale launch vehicle is 2/3 of the full scale launch vehicle.The airframe of the sub-scale launch vehicle has a 4 in diameter compared to the full scale airframe which has a 6 in diameter.

2/3 Sub-scale Launch Vehicle Summary:

- Diameter: 4.014 in
- Stability (with motor): 2.85 Caliber
- Mass (without motor): 213.94 oz
- Weight (with motor): 267.39 oz
- Motor: Aerotech K550W
- Thrust/ Weight Ratio: 5.34

Figure 14: Sub-scale Launch Vehicle

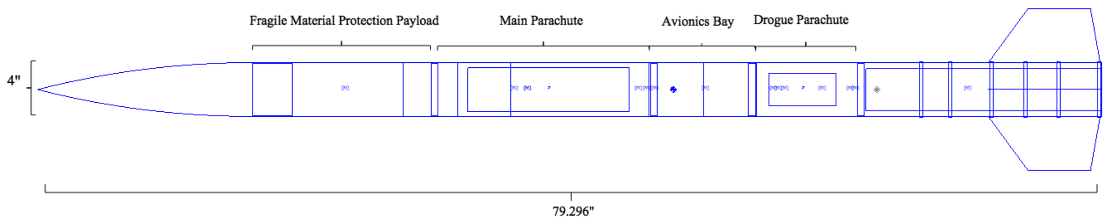

Figure 14 shows the RockSim design of the sub-scale launch vehicle.

3.2.1.1 *Scaled Components and Rationale*

Table 10 presents all components scaled down from the full scale launch vehicle as well as the corresponding justifications.

Table 10: Jusitification of Scaled Components	
Component	**Justification**
Nose cone	Verify stability of launch vehicle design and weight dirtribution
Airframe, length and diameter	Verify stability of launch vehicle design and maintain weight distribution
Fin size	Verify stability of launch vehicle design and maintain weight distribution
Motor mount	Accommodate motor dimensions and maintain weight distribution
Tube couplers	Accommodate airframe dimensions and maintain weight distribution
Airframe bulkhead diameters	Accommodate inner airframe dimensions
Payload	Accommodate payload bay dimensions and maintain weight distribution
Centering ring diameters	Accommodate motor mount dimensions

Shock cords	Accommodate parachute compartment dimensions and maintain weight dirtribution
Quicklinks	Maximize space and maintain weight distribution
U-bolts	Maximize space and maintain weight distribution
Avionics bay sleigh	Accommodate avionics bay dimensions
Avionics bay bulkhead diameters	Accommodate avionics bay dimensions
Avionics bay metal rods	Accommodate avionics bay dimensions

A 72 in main parachute and a 30 in drogue parachute were utilized during the sub-scale test launch. The mass of the sub-scale launch vehicle without a motor is less than the mass of the full scale launch vehicle without a motor, 213.94 oz and 494.54 oz, respectively. The 72 in main parachute was chosen in order to prevent the kinetic energy experienced by the launch vehicle from exceding 75 ft-lbf.

3.2.1.2 *Non Scaled Components and Rationale*

Table 11 presents all components not scaled down from the full scale launch vehicle as well as the corresponding justifications.

Table 11: Justification of Non Scaled Components

Component	Justification
Altimeters	Fixed manufacturer dimensions
Batteries	Fixed manufacturer dimensions
Battery clips	Fixed manufacturer dimensions
Centering ring thickness	Avoid compromising component strength
Bulkhead thickness	Avoid compromising component strength

3.2.2 Launch Day

The sub-scale rocket was constructed in order to verify the integrity of the full scale launch vehicle design. A test launch was conducted on December 18, 2016 at Lucerne Valley, California to test the aerodynamic design, motor selection, and the effectiveness of the payload. This section overviews the launch day conditions, the flight results, and the estimated coefficient of drag that was calculated using the data from the sub-scale launch.

3.2.2.1 *Launch Day Conditions*

Table 12 lists the launch day conditions present during the sub-scale test launch.

Table 12: Launch Day Conditions	
Conditions	**Values**
Temperature (°F)	35.6
Time of launch	1:35pm
Wind speed and direction	3 mph headed east
Humidity (%)	21.04
Cloud coverage	Clear sky
Precipitation	None
Pressure (psi)	14.76

A scaled down prototype of the payload was inserted into the payload bay of the launch vehicle to accurately represent the mass distribution of the full scale rocket as well as to test the effectiveness of the payload. The payload prototype did not incorporate the radiation shielding, expandable foam, and aerogel insulator as only the inner compartment integrity and overall strength of the container were tested. Quail eggs were utilized inside the payload to represent the "fragile material" and test the effectiveness of the compartment design. Two eggs were inserted into the payload and secured within the inner rack in the same fashion intended for the full scale, a detailed description of this procedure can be found in section 7.1.1.1of this document. The launch vehicle was then fully assembled and launched off of a 1515 10 ft long launch rail using a 54 mm Aerotech K550W motor. The figure below shows the set up for the launch vehicle prior to launch.

Figure 15: Actual Sub-scale Launch Vehicle (Pre-Launch)

Figure 15 shows the set up for the rocket prior to launch.

A RockSim launch simulation was performed prior to the launch to compare to the actual flight results. The results from the RockSim 9 simulation are displayed below.

RockSim Simulation Data:

Engine selection

[K550W-None]

Simulation control parameters

- Flight resolution: 800.00 samples /sec
- Descent resolution: 1.00 samples /sec
- Method: Explicit Euler
- End the simulation when the rocket reaches the ground.

Launch conditions

- Altitude: 2953.00 ft
- Relative humidity: 21.04 %
- Temperature: 35.60 °F
- Pressure: 14.76 psi

Wind speed model: Light (3-7 mph)

- Low wind speed: 3.00 mph
- High wind speed: 7.90 mph

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.01 rad /sec
- Wind starts at altitude: 0.00 ft
- Launch guide angle: 5.00°
- Latitude: 0.00°

Launch guide data:

- Launch guide length: 119.99 in
- Velocity at launch guide departure: 75.63 fps
- The launch guide was cleared at: 0.26 sec
- User specified minimum velocity for stable flight: 43.99 fps
- Minimum velocity for stable flight reached at: 37.71 in

Max data values:

- Maximum acceleration: Vertical (y): 337.76 ft/sec^2 Horizontal (x): 29.55 ft/ sec^2 Magnitude: 339.05ft/ sec^2
- Maximum velocity: Vertical (y): 563.88 fps, Horizontal (x): 13.80 fps, Magnitude: 564.00 fps
- Maximum range from launch site: 1496.97 ft
- Maximum altitude: 4063.49 ft

Recovery system data

- P: Main Parachute Deployed at: 84.28 sec
- Velocity at deployment: 48.47 fps
- Altitude at deployment: 799.99 ft
- Range at deployment: 983.46 ft
- P: Drogue Parachute Deployed at: 15.75 sec
- Velocity at deployment: 7.38 fps
- Altitude at deployment: 4063.49 ft
- Range at deployment: 195.51 ft

Time data

- Time to burnout: 3.50 sec
- Time to apogee: 15.75 sec
- Optimal ejection delay: 12.25 sec

Landing data

- Successful landing
- Time to landing: 132.05 sec
- Range at landing: 1496.97 ft
- Velocity at landing: Vertical: -18.66 fps , Horizontal: 10.16 fps, Magnitude: 21.25 fps

3.2.3 *Flight Analysis*

The simulation data above indicates the estimated apogee of the sub-scale launch vehicle to be 4063.49 ft. The actual recorded apogee value was 4237 ft, which only deviates 173.51 ft from the predicted value. This is possibly because the simulated rocket incorporated more added mass, from epoxy, fiberglass, and hardware than originally predicted. This would mean that the actual sub-scale was slightly lighter than anticipated and thus allowing it to reach a higher apogee. Upon assembly of the launch vehicle the team realized more tape was needed to protect the shock cords and parachute connections. The increased amount of tape was not anticipated which led to a reduced available volume within the drogue parachute compartment. Due to this unforeseen reduction, the shock cord connected to the drogue parachute was replaced with a thinner and shorter shock cord. The original 35 ft 1.0 in tubular nylon shock cord was exchanged with a 0.75 in 30 ft long shock cord of the same material. This exchange resulted in an increase of the drogue parachute compartment and a decrease of the overall launch vehicle mass, which contributed to the overshot of the original mass estimate.

The drogue parachute was set to deploy at apogee with a redundant charge set to fire 1 second afterwards. The main parachute was set to deploy at 800 ft AGL with a redundant charge set to fire at 500 ft AGL. During the test launch the drogue parachute was deployed at apogee and the main parachute at 800 ft AGL. It was visually confirmed that the redundant charges occurred at their set times. This indicates that the proper mass of black powder was calculated for proper parachute ejection and the correct number of shear pins was utilized. The sub-scale was designed to accurately represent the full scale launch vehicle indicating that proper calculation methods were utilized. The same methods will be applied to determine the proper amount of black powder and number of shear pins that will be used on the launch vehicle. These successful parachute deployments imply that all wiring and construction of the avionics bay was done correctly.

RockSim 9 simulations predicted a range of 1496.97 ft, but the actual range was recorded to be 2112 ft from the launch pad. This is possibly due to the decreased weight of the sub-scale, which would have resulted in an increase in drift. The deviation between actual and simulated mass led the team to weigh and manually input the components of the full scale launch vehicle into RockSim 9 instead of using mass values generated by the program. The apogee indicated after launch simulations for the full scale launch vehicle decreased to 4,725 ft after inputting the measured masses. This decrease in altitude led to a new motor choice, the L1420R, ensuring a closer apogee of 5,278 ft to the target altitude of 5,280 ft.

The sub-scale launch vehicle did not receive any damage upon landing or during the flight which demonstrates that the proper motor, K550W, was selected for this launch vehicle. The motor was initially selected because of its similar characteristics to the Aerotech L1170-FJ. However, the L1170-FJ was replaced with the Aerotech L1420R due to the new simulation results from RockSim 9. The motor thrust curve for the Aerotech K550W and the Aerotech L1420R are shown in the figures below :

Figure 16: Aerotech K550W Motor Thrust Curve

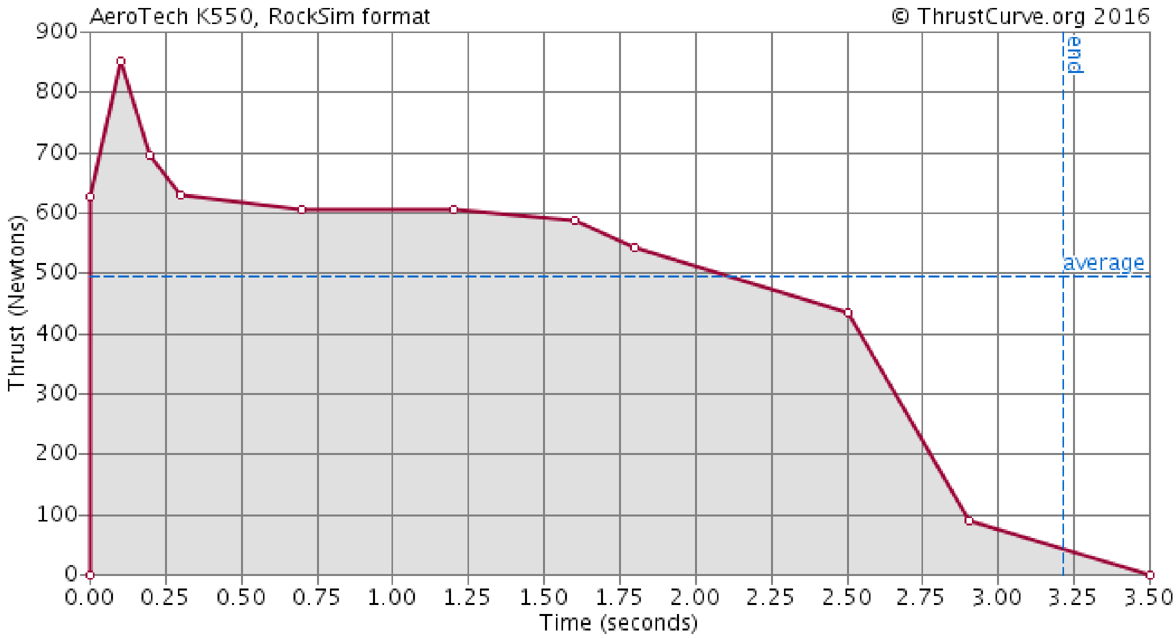

Figure 16 displays the thrust curve for the Aerotech K550W motor. This motor rapidly increases in thrust during the first 0.125 sec of burning. During 0.125 sec-0.25 sec the motor rapidly decreases thrust from approximately 850 N to approximately 650 N. From 0.25 sec until burn out at 3.24 sec the K550W the motor steadily decreases thrust.

Figure 17: Aerotech L1420R Motor Thrust Curve

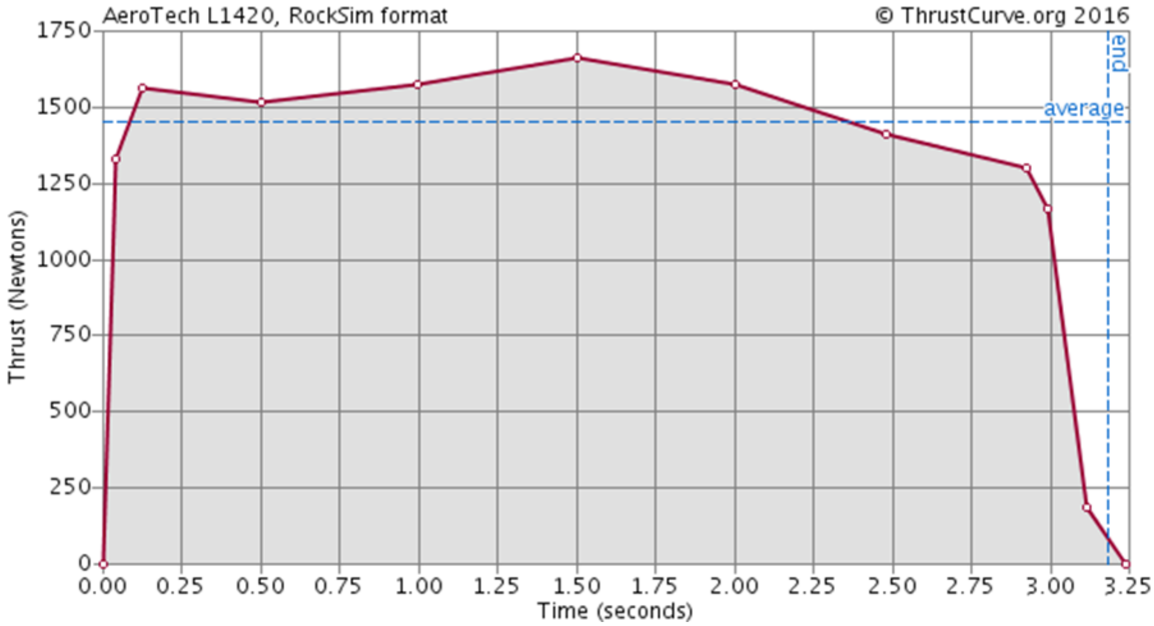

Figure 17 displays the motor thrust curve of the Aerotech L1420R motor. The thrust initially peaks slightly above 1500 N and then decreases from 0.125-0.50 sec. After this point the thrust steadily increases till 1.50 sec when the thrust begins to decrease again.

Although the K550W was meant to mimic the behavior of the L1170-FJ it does not differ much from the motor thrust curve of the L1420R.
The Aerotech K550W and the Aerotech L1420R both rapidly increase in thrust within the first 0.125 sec after ignition. However, the K550W rapidly decreases in thrust between 0.125-0.25 sec while the L1420R has a more stable thrust curve. The K550W allowed the team to test whether or not the launch vehicle was capable of handling great burst of thrust from the motor. Since the sub-scale rocket was able to endure the initial thrust it is expected that the full scale will perform well with the more stable thrust of the Aerotech L1420.

The payload prototype container was undamaged from the launch revealing the design to be durable and well-constructed. However, the quail eggs were lightly cracked. This indicates that while the outside of the container is capable of withstanding the impact from the parachute deployments and landing the samples required better protection and support inside the container. It is possible that the eggs were not held tightly in place and were able to move during the flight allowing them to come in contact with the metal rods. This would mean that a more flexible silicone padding is needed to form to the shape of the samples and restrict their movement. The metal rods could also be thinner to allow more space for the samples. This was all considered when building the full scale payload. Further detail on the final payload design can be found in section 5.1.

3.2.3.1 *Coefficient of Drag Estimation*

The coefficient of drag of the sub-scale is estimated to be 0.67. This was done via the backtracking method described by an Apogee Peak of Flight newsletter [4]. In order to do this the Cd of the sub-scale design was altered in RockSim until the estimated apogee reached the recorded apogee of 4237 ft. The sub-scale was designed to be an accurate scaled down version of the full scale launch vehicle so it is predicted that the Cd of the full scale launch vehicle will match the estimated value of 0.67. This however is just an estimate; there are many factors that could result in a Cd of a different value. If the sub-scale was not properly scaled down or the selected motor produces a slightly different thrust than predicted the Cd of the launch vehicle will no longer be accurate. This estimated Cd was also done assuming that all launch conditions are the same as the conditions of the day of the sub-scale flight.

3.2.4 *Impact on Full scale Design*

The sub-scale flight results reassured the team in the launch vehicle's design, only directing a couple of changes. The sub-scale launch vehicle was launched with a mock payload in a modified payload bay. The payload bay did not include the originally intended 0.5 in bulkheads to enclose the bay, but rather used the main parachute compartment bulkhead and the nose cone to enclose the payload bay. The container itself returned fully intact, this confirmed that the final launch vehicle design will not include the additional bulkhead to enclose the payload.

Fiberglass lamination of the fins and full airframe were also incorporated into the test launch to see if adding structural strength would drastically impact the flight trajectory, predictions, and stability. The sub-scale flight was stable with minimal mass gain on the launch vehicle. This allowed the full scale design to include fiberglass lamination of its airframe and fins, the additional strength was desired since the full scale model will be heavier and thus have the potential of landing with a higher energy.

3.3 Recovery Subsystem

This section introduces the recovery subsystem for Project Aegis, including:

- Final Recovery Subsystem Design
- Description of the Parachute, Harnesses, Bulkheads, and Attatchment Hardware
- Electrical Components and Coordination
- Drawing/Sketches, Block Diagrams, and Electrical Schematics
- Locating Tracker Operating Frequency

3.3.1 Final Recovery Subsystem Design

The final design of the recovery subsystem consists of two parachutes, recovery harnesses, parachute attachment hardware, and parachute deployment electronics along with their mechanism. The designed recovery subsystem will perform the following operation:

- Detect apogee and 800 ft AGL
- Deploy the drogue and the main parachute at the above altitudes
- Reduce the kinetic energy of the tethered forward, middle, and aft section to less than 75 ft-lbf at landing

The selected 24 in drogue parachute and 120 in main parachute for Project Aegis feature low packing volumes, light-weight ripstop nylon canopies, low permeability fabric, stabilizing spill holes, and high coefficients of drag (Main – 2.2, Drogue – 1.5). Spill holes that are 20 % of the parachute diameters are cut on the canopies for the stability of the parachutes. The high coeffiecient of drag allows the launch vehicle to obtain a low terminal velocity. The details of the recovery components chosen for the recovery subsystem are listed below.

Table 13 summarizes the selected components for the final recovery subsystem design along with justifications for their selection.

Table 13: Recovery Materials			
Recovery System Component	**Material**	**Justification**	**Strength**
Drogue parachute	24 in Elliptical Ripstop Nylon	Light weight and low packing volume, Cd of 1.5	3.3 lbs@20 fps
Main parachute	120 in Toroidal Ripstop Nylon	Light weight and low packing volume, Cd of 2.2	64 lbs@15 fps
Shroud lines	Spectra Fiber	Strong and duarble	1400 lbs
Drogue Parachute Recovery Harness (45 ft)	1 in Tubular Nylon Ripstop	High breaking strength	9 kN
Main Parachute Recovery Harness (35 ft)	1 in Tubular Nylon Ripstop	High breaking strength	9 kN
Shock Cord Protector	High Temperature Nomex Sleeve	Able to withstand the high temeratures of the ejection gases	N/A
Drogue Parachute Protector	18 in Square Nomex	Material used to protect firemen from fire able to withstand high temperatures	N/A
Main Parachute Protector	24 in Square Nomex	Material used to protect firemen from fire able to withstand high temperatures	N/A
Bulkhead	0.5 in thick 5-ply Baltic Birch Plywood	Robust and does not break easily	N/A
Recovery Harness Interface	0.5 in Quicklink	Easy connection and removal of recovery harness	3000 lbs

		from launch vehicle	
Bulkhead and Quicklink Interface	0.5 in Metal U-bolt	Strong	7000 lbs
Shock Cords and Shroud Lines Interface	Stainless Steel Swivel	Strong and will not tangle shock cord or shroud lines	3000 lbs

3.3.1.1 *Terminal Velocity, Kintic Energy, and Drifting Distance*

The forward, middle, and aft section of the launch vehichle shall have a kinetic energy no greater than 75 ft-lbf to ensure that the sections remain undamaged. To determine the kinetic energy, the terminal velocity for each section was calculated using the equation below[5]:

$$V = \sqrt{\frac{m_{lv}g}{(.5)\rho C_d A}}$$

$$V = \sqrt{\frac{(15.48kg)(9.8m/s^2)}{(0.5)(1.225kg/m^3)(2.2)\pi(1.524m)^2}}$$

where,
m_{lv} is the mass of the launch vehicle
g is the acceleation due to gravity
ρ is the density of air
C_d is the drage coefficient of the parchute
A is the area of the parachute.

The kinetic energy was then calculated using the following equation[6]:

$$K = \frac{1}{2}m_s V^2$$

$$K = \frac{1}{2}(6.78kg)(23.78m/s)^2$$

where,
V is calucated from the first equation
m_s is the mass of independent section.

The kinetic energy from this formula gives the results in Jouleswhich were then converted to ft-lbf using the conversion factor of 1J = 0.738 ft-lbf. The calculated results are shown in Table 14.

Table 14: Terminal Velocity and Kinetic Energy

Launch Vehicle Section	**m_s (lbs)**	**$V_{(drogue)}$ (ft/s)**	**$V_{(main)}$ (ft/s)**	**$K_{(drogue)}$ (ft-lbf)**	**$K_{(main)}$ (ft-lbf)**
Forward Section	14.95	78.02	15.62	1413.91	37.84
Middle Section	6.31	78.02	15.62	596.43	15.96
Aft Section	12.88	78.02	15.62	1217.88	32.59

The drifting distance from the launch pad and the apogee of the launch vehicle differs under different wind conditions. RockSim has simulated the drifting distance and the apogee of the launch vehicle. The results are shown in table 15.

Table 15: Drifting Distance and Apogee		
Wind Speed (mph)	**Drifting Distance (ft)**	**Apogee (ft)**
0	894.38	5248.23
5	2046.97	5283.3
10	1659.12	5294.13
15	2660.48	5278.05
20	2288.43	5233.86

3.3.2 Parachutes, Harnessses, Bulkheads, and Attatchement Hardware
The recovery subsytem consists of a 24 in diameter drogue parachute and a 120 in diameter main parchute as shown in Figure 18 and 19. All 1.15 in diameter shroudlines attached to the parachutes terminate are held together by a strong metal eye swivel.

Figure 18: Drogue Parachute

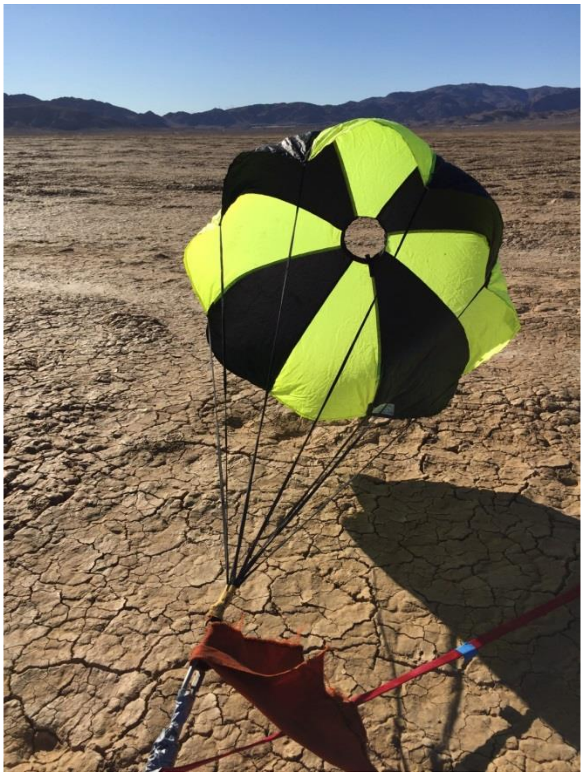

Figure 18 shows the 24 in diameter elliptical ripstop nylon drogue parachute that will be used in Project Aegis.

Figure 19: Main Parachute

Figure 19 shows the 120 in diameter toroidal ripstop nylon main parachute that will be used in Project Aegis.

The drogue and main parachutes will be attached to the launch vehicle via two high strength 1 in wide nylon tubular shock cords. The drogue is attached to the booster section and the middle airframe with a 45 ft long shock cord and the main is attached to the middle and forward airframes with a 35 ft shock cord. Each shock cord will be attached to the airframe and the parachute using three 0.5 in quicklinks. The first quick link connects to a knot at the end of the shock cord and a 0.25 in heavy duty U-bolt as seen in Figure 20. This bulkhead is secured into a 0.5 in thick 5-ply wood bulkhead which is expoxied into the 6 in diameter airframe. The bulkhead is displayed in Figure 21. The second quick link attaches to a knot near the center of the shock cord and the parachute eye swivel. A square nomex parachute protector is also attached to this quicklink as shown in Figure 22. The third quicklink is attached to a U-bolt that is connected to the bulkhead that is secured in the avionics bay.

Figure 20: Quicklink and U-bolt Connection

Figure 20 shows the 0.25 in quicklink attached to the U-bolt secured onto the bulkhead of the avionics bay.

Figure 21: U-Bolt and Bulkhead

Figure 21 shows the 0.3125 in U-bolt that will be secured onto a 0.5 in thick 5-ply wood bulkhead to be attached to the 6 in diameter airframe

Figure 22: Eyeswivel

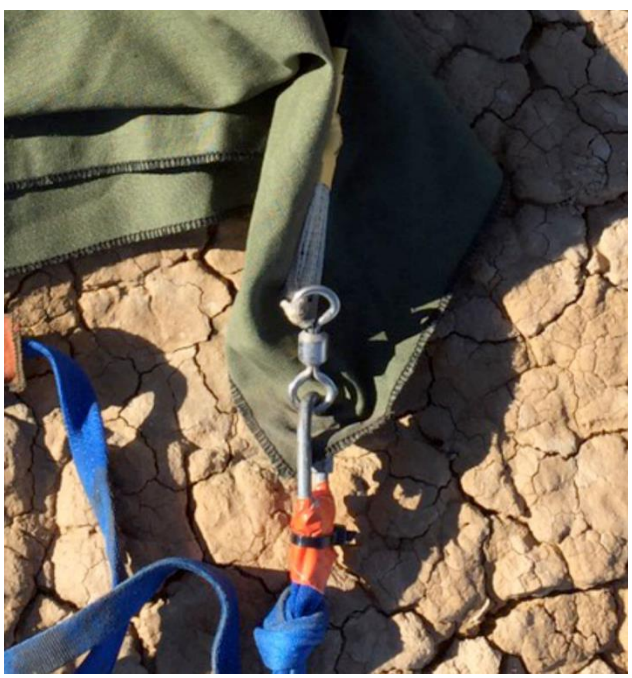

Figure 22 shows the interfaces of the shroud lines, eyeswivel, quicklink and shock cord.

The 18 in nomex drogue cover and the 24 in main parachute cover are used to protect the parachutes from high temperature ejection gases. The ejection gases can cause the parachutes to melt together resulting in parachute deployment failure. The shock cords are also covered in nomex to prevent them from burning and becoming weaker. The nomex sleeves can be seen in Figure 23.

Figure 23: Nomex Sleeves

Figure 23 shows the nomex sleeves that protect shock cords from the high temperatures of the ejection gases.

Order of Deployment:

1. The drogue parachute deploys when the launch vehicle reaches apogee and seperates between the booster section and the avionics bay which is attached to the middle section.
2. The main parachute deploys when the launch vehicle reaches 800 ft and seperates between the forward section (fragile material protection payload included) and the middle section of the launch vehicle.

3.3.3 Electrical Components and Coordination

The parachute deployment electronics consist of redundant Missile Works RRC2+ Altimeters, 9-V batteries, wirings, e-matches, and key switches. The redundant Missle Works RRC2+ Altimeters, which features a barometric dual deployment system, will be attatched to a 12 in long, 5 in wide wood sled. 9-V batteries will be secured in battery casings and attached to the wood sled. 22-gauge wires connect the altimeters to the batteries and key switches. The drogue and main parachute wiring starts from the altimeter and goes to the terminal blocks that are externaly attached to the bulkheads enclosing the avionics bay. Opposite of this connection the stripped end of the e-matches are connected to the terminal blocks while the pyrogent end is inserted into the loaded black powder ejection canisters . Figures 24-37 display a detailed design of the avionics electronic deployment system found in section 3.3.4 Drawings/ Sketches, Block Diagrams, and Electrical Schematics.

Redundant Missile Works RRC2+ altimeters will initiate all flight recovery events. The first black powder charge will deploy the 24 in elliptical drogue parachute at apogee. Once the rocket descends to 800 ft AGL, a second black powder charge will eject the 120 in toroidal main parachute. The drogue parachute deployment system incorporates a redundant black powder charge with a 1-second delay, while the main parachute has a redundant black powder charge at 500 ft AGL.

4F black powder will be used to deploy the drogue and main parachute. Black powder ignition creates ejection charges that build pressure within the parachute compartments of the airframe in order to shear the nylon screws and deploy the parachutes at their programed altitudes. The mass of the black powder is calculated by using the following equation [7]:

$$m_b = .006(d_c)^2(L_c)^2$$

where,
m_b is the mass of the black powder in grams
d_c is the length of the inner diameter of the parachute compartment in inches
L_c is the length of the compartment in inches

Table 16 shows the calculated mass of the black powder required for proper parachute deployement.

Table 16: Calculated Black Powder

Parachute	Black Powder Mass (g)
24” Drogue	2.42
120” Main	4.34

To ensure that the proper amount of black powder is used, ground ejection tests will be conducted starting with 0.5 g less than the calculated amount of black powder. In the event of insufficient black powder mass it will be increased in increments of 0.5 g until the correct amount is determined.

3.3.4 Drawings/Sketches, Block Diagrams, and Electrical Schematics
This section includes drawings/sketches of the drogue parachute deployment configuration, main parchute deployment configuration, and an electrical schematic of the deployment system. Figures 24-37 depicts the drawings listed above.

Figure 24: Drogue Parahute Deployment

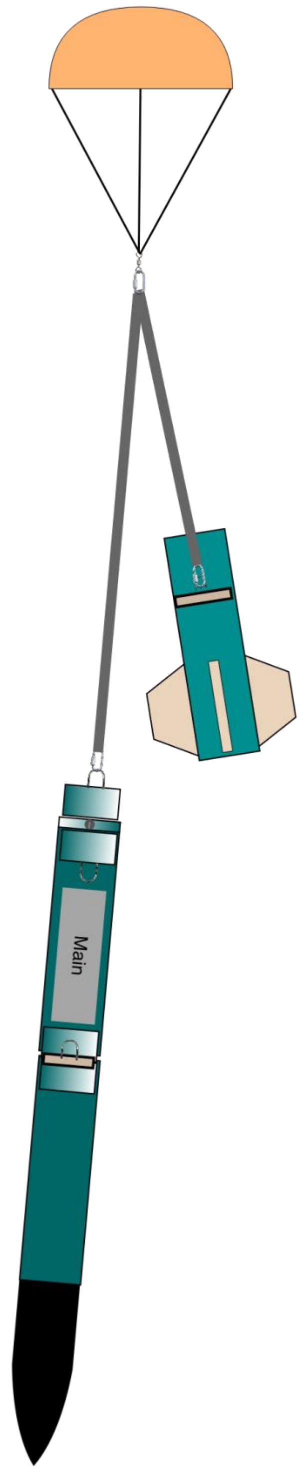

Figure 24 shows the launch vehicle configuration after the deployment of the drogue parachute.

Figure 25: Main Parachute Deployment

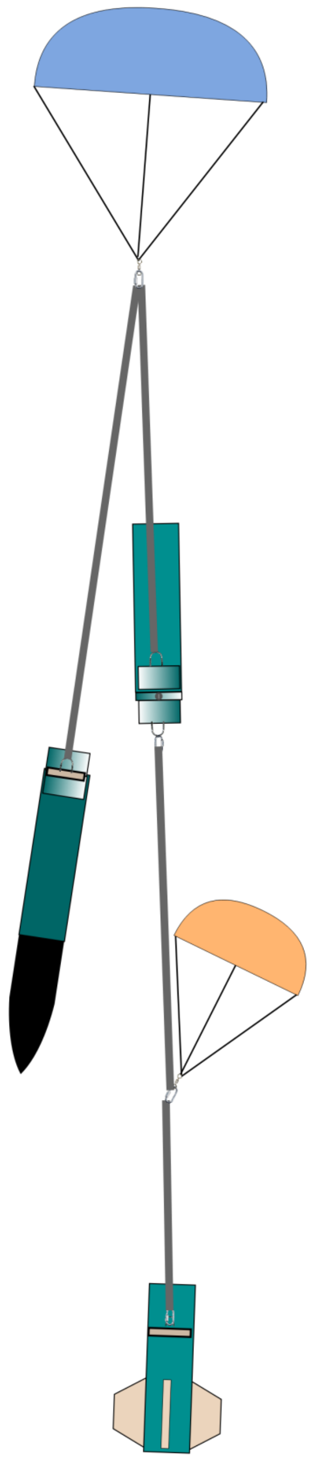

Figure 25 shows the launch vehicle configuration after the deployment of the main parachute.

Figure 26: Electrical Schematic

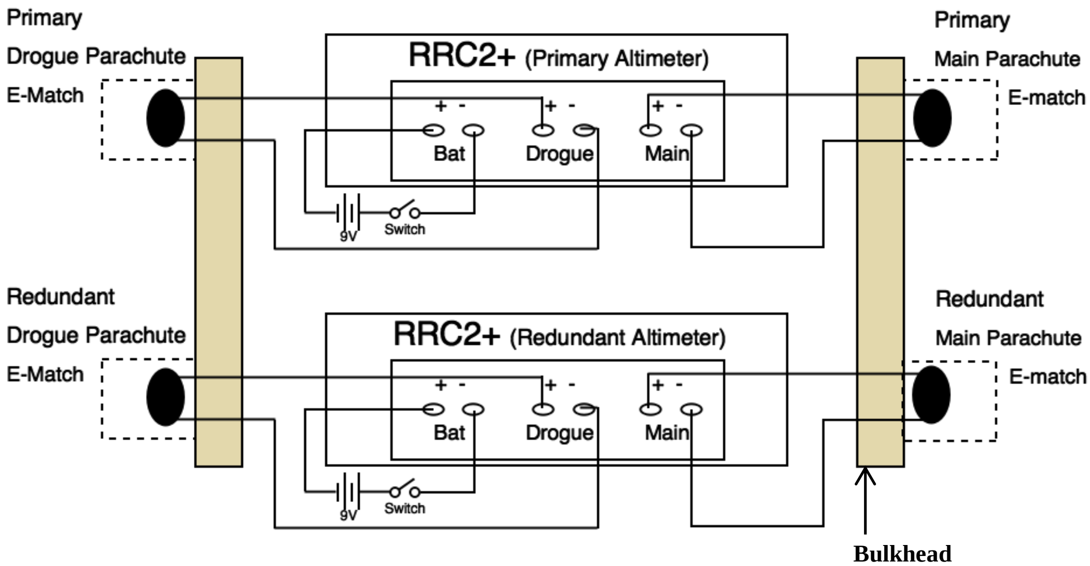

Figure 26 shows the electrical schematic of the redundant electronic dual deployment recovery system.

Figure 27: Avionics Bay Bulkhead

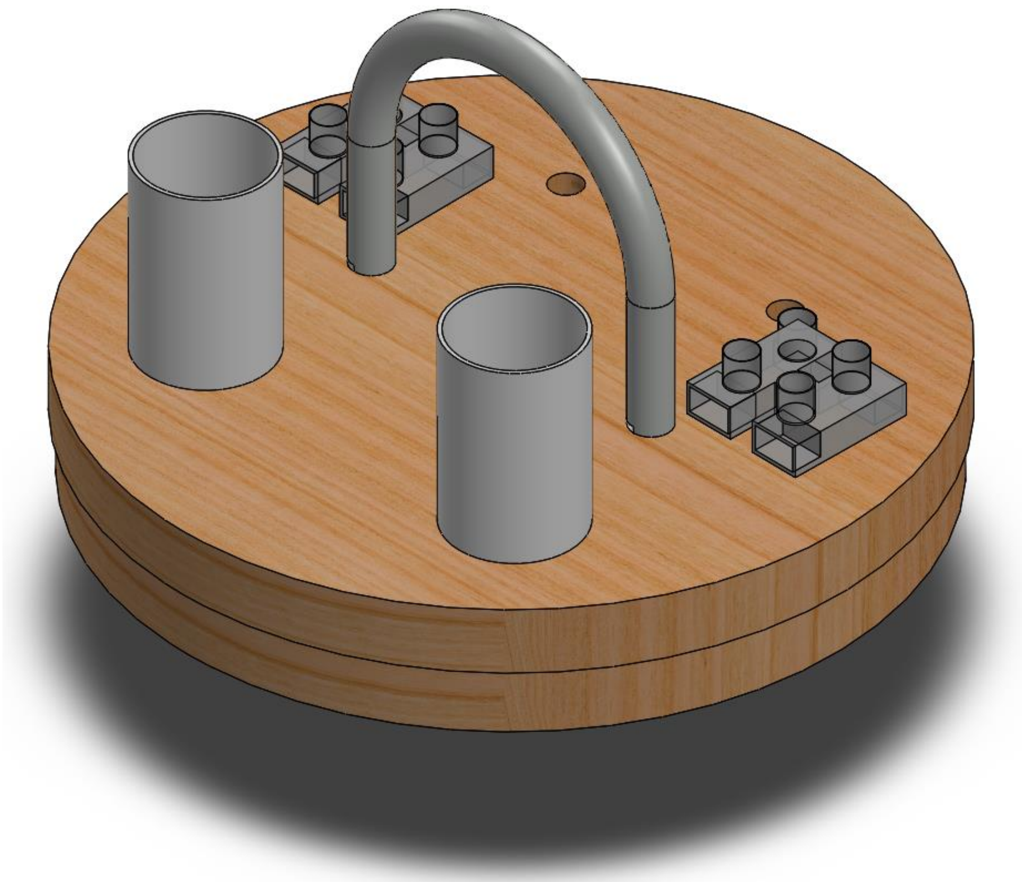

Figure 27 shows a 0.3125 in U-bolt secured onto a 0.5 in thick 5-ply wood bulkhead with terminal blocks and ejection canisters attached.

Figure 28: Avionics Bay

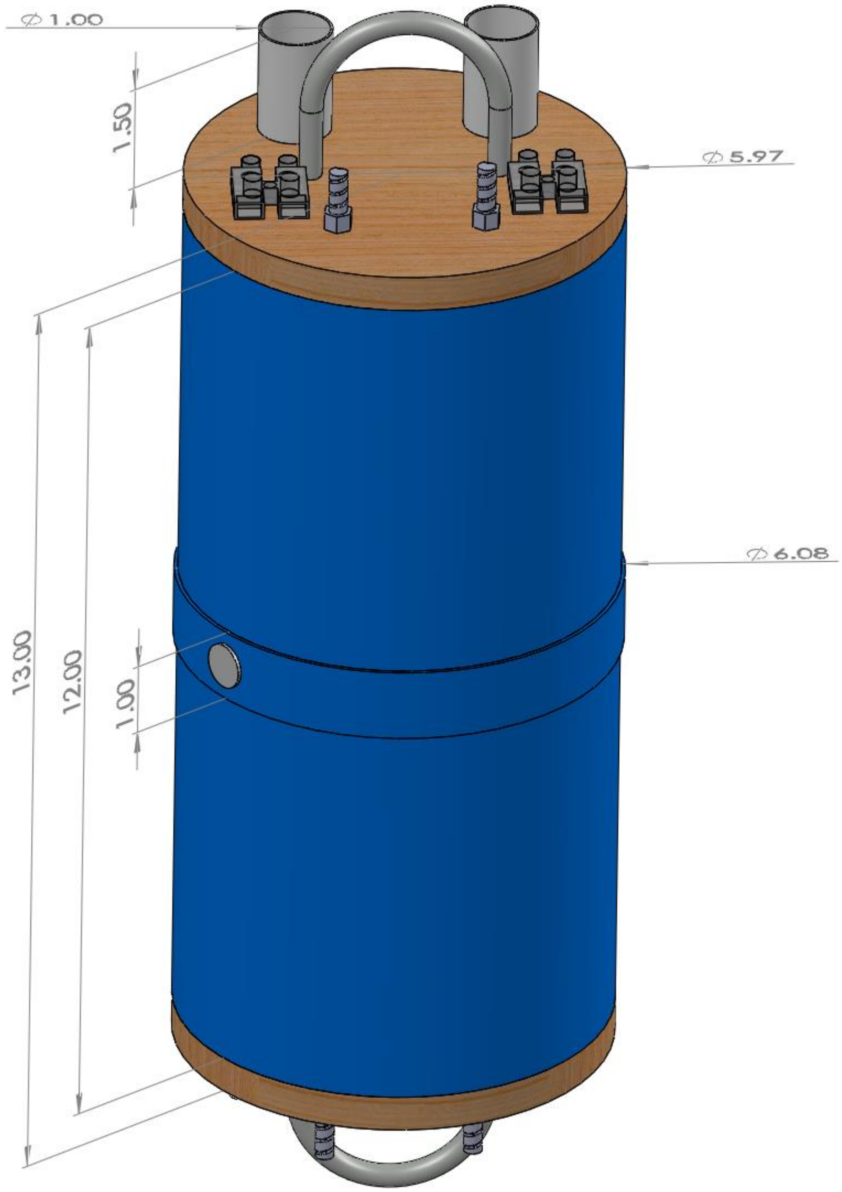

Figure 28 shows an isometric view of the fully assembled avionics bay that stores all electrical components in a 6 in wide BlueTube enclosed by two bulkheads

Figure 29: Avionics Bay (Internal View)

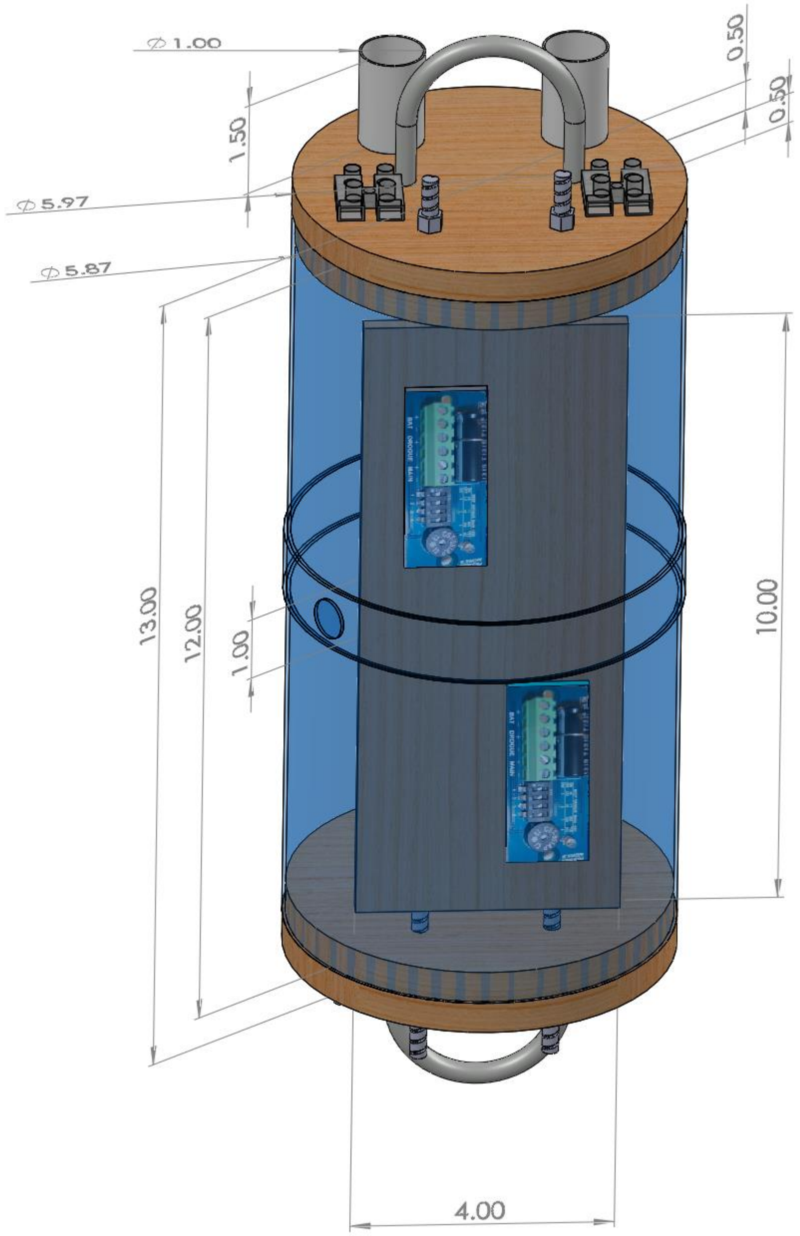

Figure 29 shows a transparent lateral view of the avionics bay

Figure 30: Avionics Bay (Exploded View)

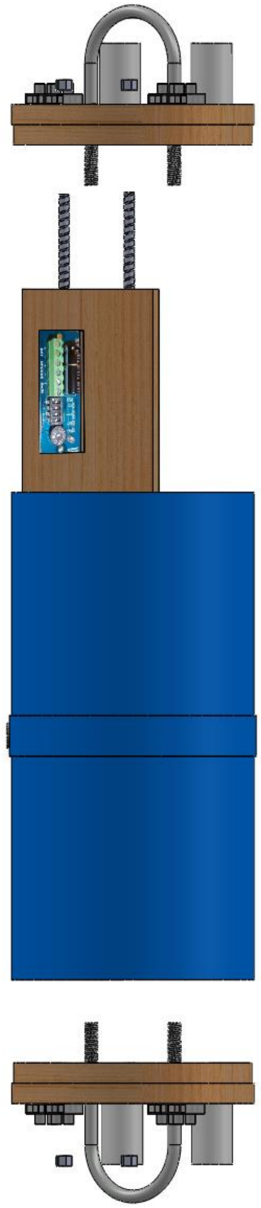

Figure 30 shows lateral view of the exploded avionics bay with RRC2+ barometric altimeters attached to a 12 in long 5 in wide wood sled.

Figure 31: LSM9DS1 Altimeter Electrical Schematic

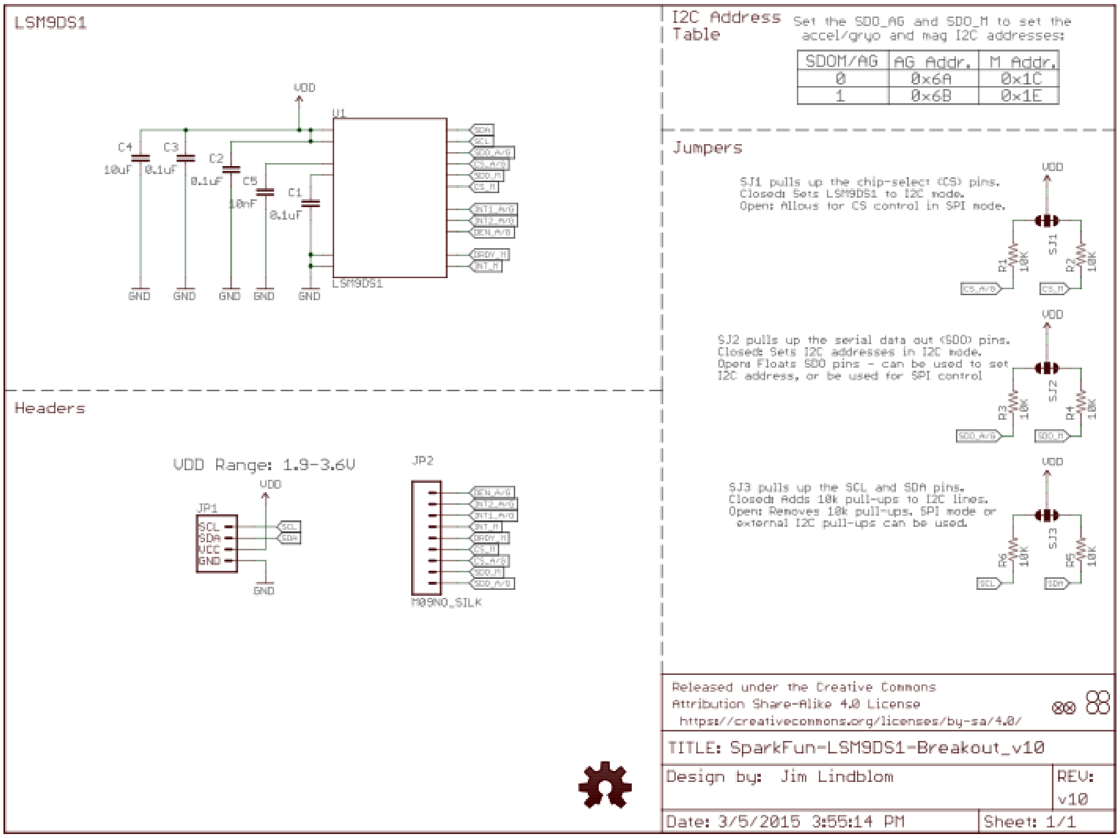

Figure 31 shows a detailed electrical schematic for the LSM9DS1 altimeter

Figure 32: LSM9DS1 Altimeter

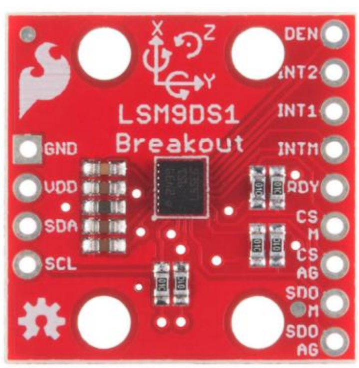

Figure 32 shows the unsoldered LSM9DS1

Figure 33: Arduino Uno Electric Schematic

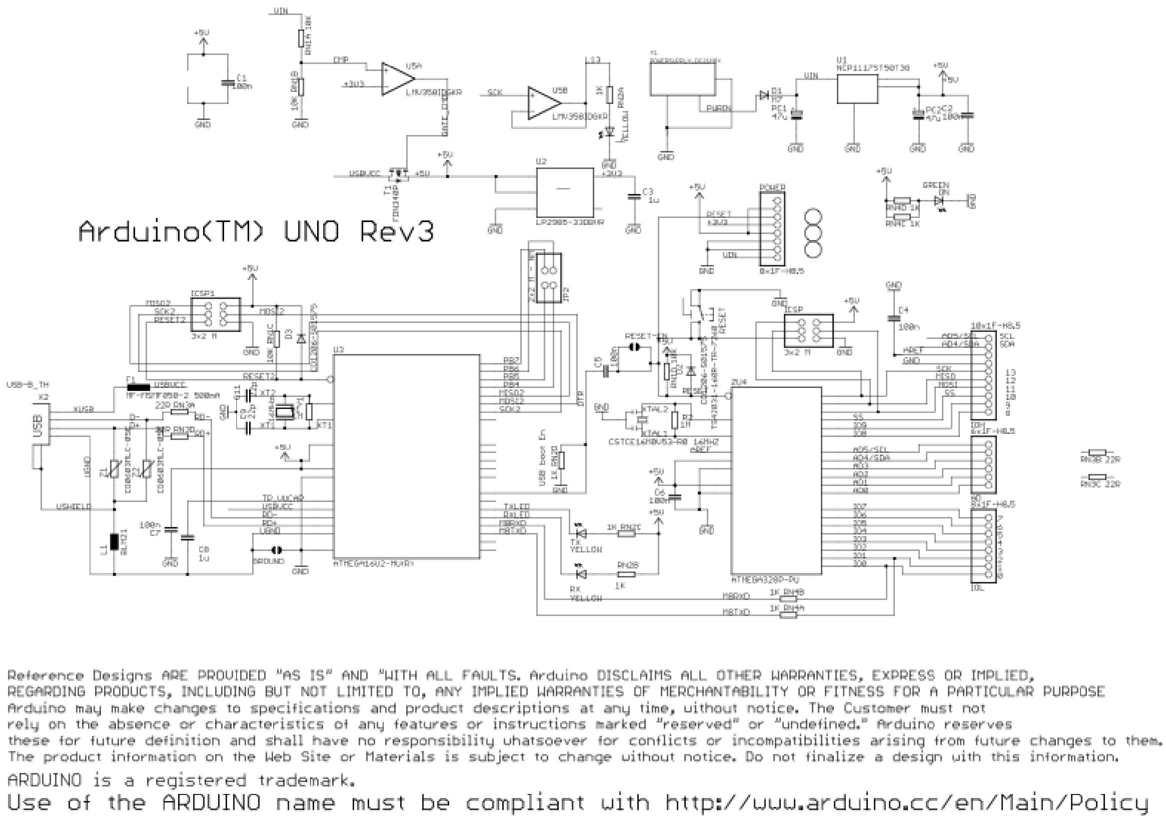

Figure 33 shows a detailed electric schematic for the Arduino Uno

Figure 34: Arduino Uno

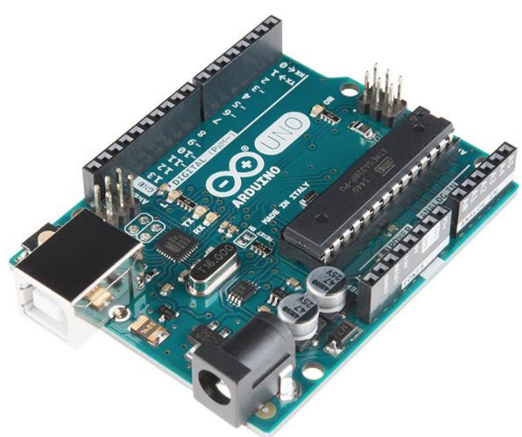

Figure 34 shows the Arduino Uno that will be used in the launch vehicle

Figure 35: SD Shield Electrical Schematic

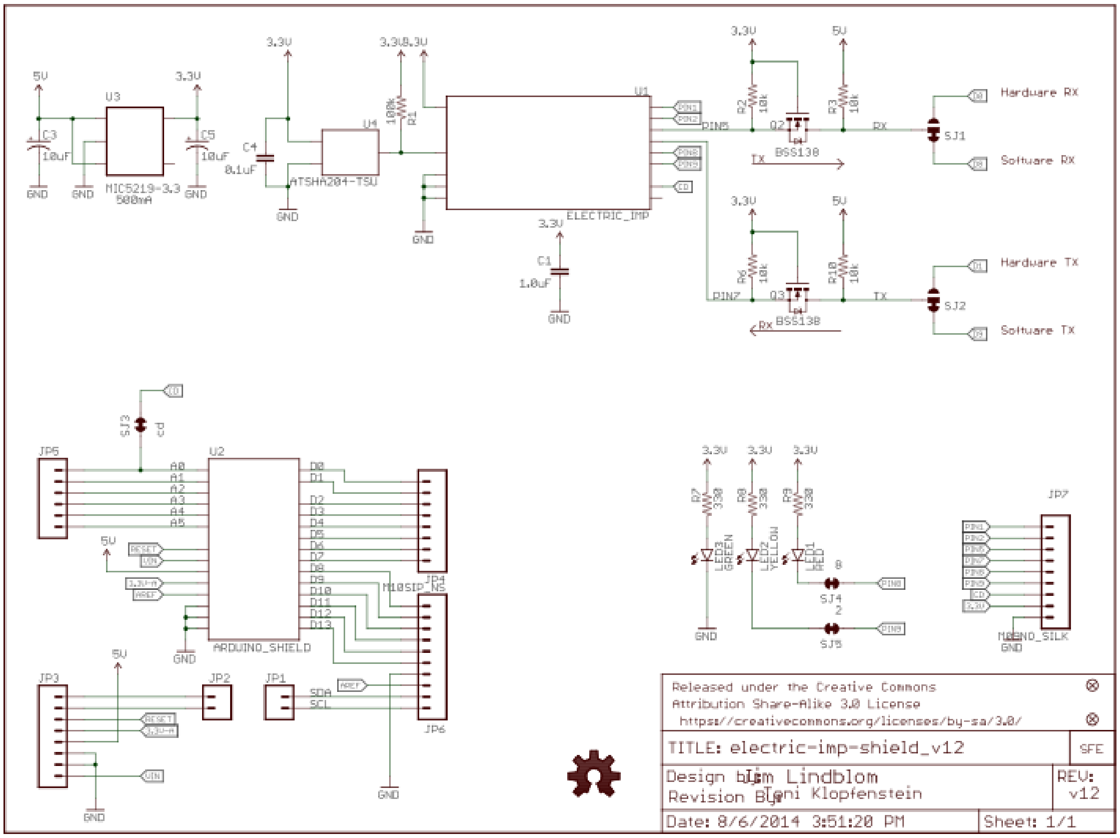

Figure 35 shows a detailed electrical schematic for the SD shield

Figure 36: SD shield

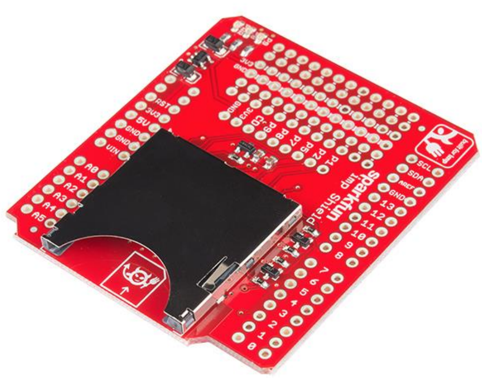

Figure 36 shows the unsoldered SD shield

Figure 37: Accelerometer Algorithm

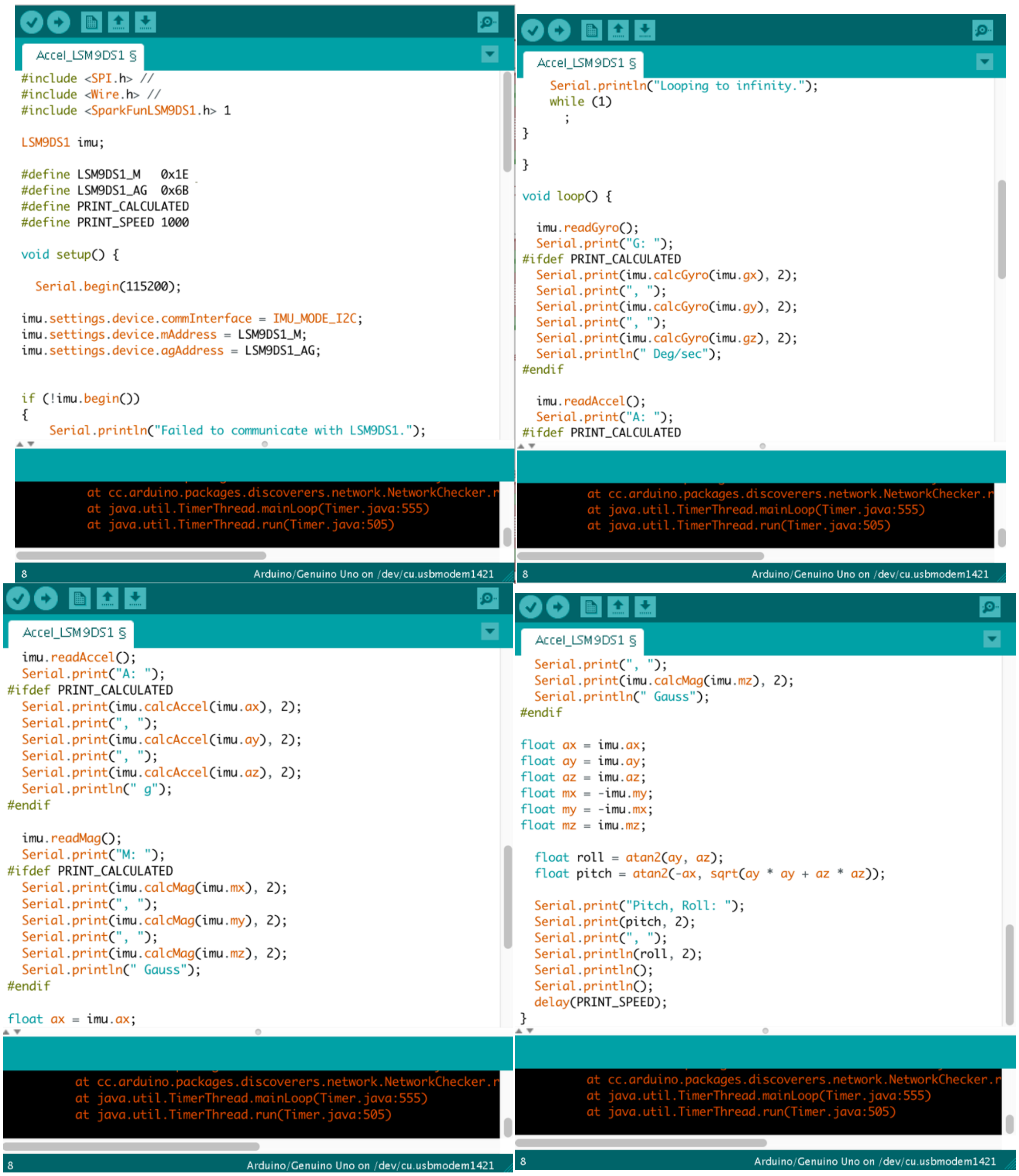

Figure 37 shows the algorithm for the accelerometer

The team will be using a SparkFun 9DoF IMU Breakout - LSM9DS1(figure #) accelerometer equipped with a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer. The accelerometer will be connected to an Arduino Uno(figure #) using an SD shield(figure #). The team will use the algorithm shown in figure # to calculate the launch vehicle’s Accel, Mag, gyro, pitch, and roll throughout its flight. The accelerometer setup will be located on the sled of the avionics bay and will be held in place with four nylon screws.

3.3.5 Locating Tracker and Operating Frequency

The Altus Metrum TeleGPS shown in Figure 38 is a position tracker and logger. This GPS will be utilized in the launch vehicle in order to track the location of the rocket to ensure its recovery. The Altus Metrum TeleGPS will be placed in the nosecone of the launch vehicle and has an operating frequency of 434.55 MHz. The GPS is shown in Figure 38.

Figure 38: Altus Metrum TeleGPS

Figure 38 shows the locating tracker for Project Aegis.

Figure 39: Operating Frequency

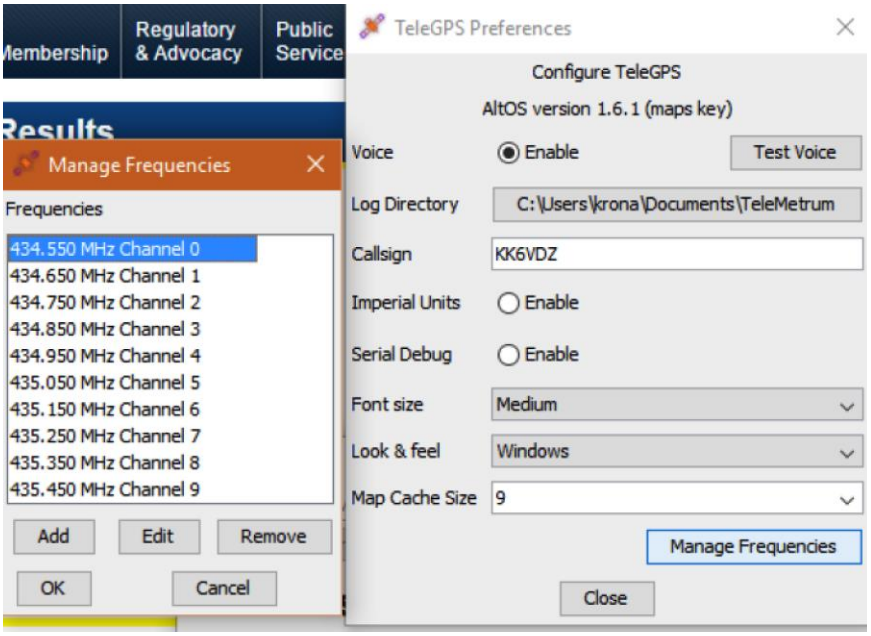

Figure 39 shows a screenshot of the TeleGPS frequeny setting

3.4 Mission Performance Predictions

This section overviews the simulation data, stability, kinetic energy and drift values of the launch vehicle. The launch vehicle was designed and simulated in RockSim 9. Below is the flight simulation data from RockSim when using an Aerotech L1420R motor and a 12 ft launch rail. The expected conditions of the launch day such as the altitude, temperature, humidity, and pressure were all incorporated into the following simulation.

Engine selection
[L1420R-None]
Simulation control parameters

- Flight resolution: 800.00 samples/sec
- Descent resolution: 1.00 samples/sec
- Method: Explicit Euler
- End the simulation when the rocket reaches the ground**.**

Launch conditions

- Altitude: 600.00 ft
- Relative humidity: 50.00 %
- Temperature: 90.00°F
- Pressure: 29.9139 In.

Wind speed model: Slightly breezy (8-14 mph)

- Low wind speed: 8.00 mph
- High wind speed: 14.90 mph

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.01 rad/sec
- Wind starts at altitude: 0.00 ft
- Launch guide angle: 0.00°
- Latitude: 0.00°

Launch guide data:

- Launch guide length: 144.00 in
- Velocity at launch guide departure: 77.29 fps
- The launch guide was cleared at : 0.34 sec
- User specified minimum velocity for stable flight: 43.99 fps
- Minimum velocity for stable flight reached at: 48.10 in

Max data values:

- Maximum acceleration: Vertical (y): 1167.40 ft./s/s Horizontal (x): 10.18 ft./s/s Magnitude: 1167.40 ft /s/s
- Maximum velocity: Vertical (y): 701.51 fps, Horizontal (x): 21.85 fps, Magnitude: 708.44 fps
- Maximum range from launch site: 1205.97 ft
- Maximum altitude: 5209.22 ft

Recovery system data

- P: Main Parachute Deployed at : 65.90 ft
- Velocity at deployment: 95.01 fps
- Altitude at deployment: 799.97 ft
- Range at deployment: 60.77 ft
- P: Drogue Parachute Deployed at : 17.49 sec
- Velocity at deployment: 54.80 fps
- Altitude at deployment: 5209.22 ft
- Range at deployment: -957.73 ft

Time data

- Time to burnout: 3.24 sec
- Time to apogee: 17.49 sec
- Optimal ejection delay: 14.25 sec

Landing data

- Successful landing
- Time to landing: 118.45 sec
- Range at landing: 1205.97 ft
- Velocity at landing: Vertical: -14.97 fps, Horizontal: 21.74 fps , Magnitude: 26.40 fps

As indicated by the simulation data above it is predicted that the launch vehicle will reach an apogee of 5209.22 ft which is 70.78 ft under the target apogee of 5280 ft. It is also predicted that the launch vehicle will achieve a descent velocity of -14.97 fps which suggest minimal to no damage upon landing. As the wind speed values were altered in the simulation the maximum altitude values fluctuated. Table 17 lists the different apogees at varying wind speeds.

Table 17: Maximum Altitudes at Varying Wind Speeds	
Wind Speed (mph)	**Maximum Altitude (ft)**
5	5287.63
10	5249.87
15	5186.29
20	5097.90

The average wind speed is expected to be around 9 mph with a high of 16 mph on the day of the launch in Huntsville, Alabama [8]. After incorporating the launch conditions stated above and more accurate mass values into the launch simulations, the L1170-FJ motor was replaced by the Aerotech L1420R, as it was found to be best suited to deliver the launch vehicle to the desired altitude. The original motor choice, the Aerotech L1170-FJ, launched the vehicle to a maximum altitude of 4567 ft, 713 ft under the target apogee whereas, the L1420R yielded a maximum altitude of 5278 ft, 2 ft under the target apogee.

3.4.1 *Motor Selection*

The thrust to weight ratio determines whether a motor is capable of successfully launching a specific mass [9], the minimum ratio required being 5:1[10]. The thrust to weight ratio was calculated to verify that the selected motor is capable of launching the vehicle. The mass of the launch vehicle with the motor is estimated to be 18.18 kg. Multiplying this value by 9.8 m/s^2 gives a weight of 178.16 N. The average thrust of the selected motor is 1420 N, dividing this by the weight of the launch vehicle gives a thrust to weight ratio of 7.97. This value indicates that the motor produces enough thrust to launch the vehicle. Table 18 lists the characteristics of the selected motor.

Table 18 outlines the specifications for the final motor selected.

Table 18: Final Motor Specifications	
Make	Aerotech
Code	L1420R
Diameter (in)	2.95
Length (in)	17.44
Propellant weight (lbs)	5.64
Loaded weight (lbs)	10.06
Burn time (s)	3.24
Average thrust (N)	1424
Total impulse (Ns)	4616
Maximum thrust (N)	1662

Figure 40 displays the motor thrust curve for the motor [11].

Figure 40: Aerotech L1420R Motor Thrust Curve

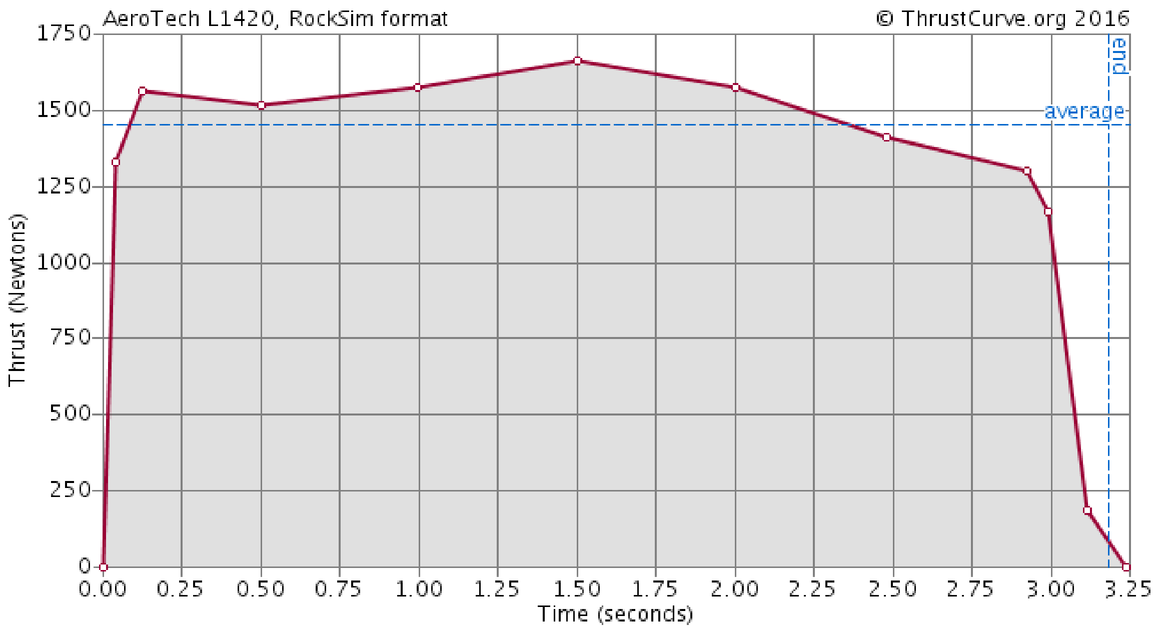

Figure 40 shows the amount of thrust the Aerotech L1420R produces overtime.

The Aerotech L1420R motor has a burn time of 3.24 sec and a maximum thrust of 1662 N. The thrust for this motor rapidly increases within the first 0.125 sec of flight to a peak of approximately1560 N and then decreases between 0.125 sec and 0.50 sec to approximately 1500 N. A steady increase in thrust is then visible between 0.5 sec and 1.50 sec of flight until reaching its maximum thrust of 1662 N. From 1.50 sec to 2.88 sec the thrust steadily decreases to about 1300 N, then thrust rapidly decreases until time of burn out at 3.24 sec. This information indicates that the launch vehicle will experience a steady thrust for the majority of the flight and thus help ensure a steady flight.

3.4.2 *Center of Gravity and Center of Pressure*

The center of gravity (CG) and the center of pressure (CP) are important in determining the stability of the flight and were estimated using RockSim 9. These values can be seen in the figures below.

Figure 41: Center of Gravity and the Center or Pressure (without the motor)

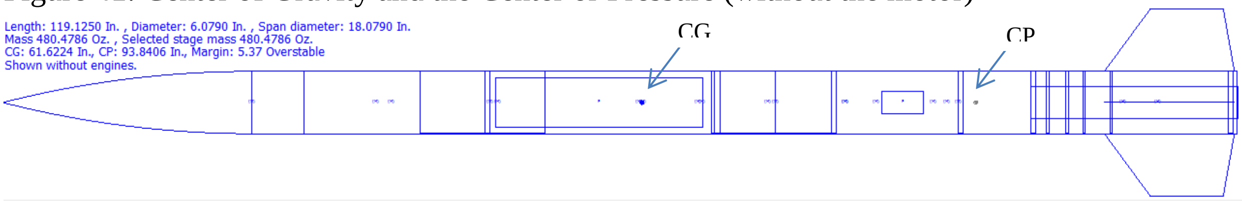

Figure 41 shows the center of gravity and the center of pressure without the motor.

Figure 42: Center of Gravity and the Center of Pressure (with the motor)

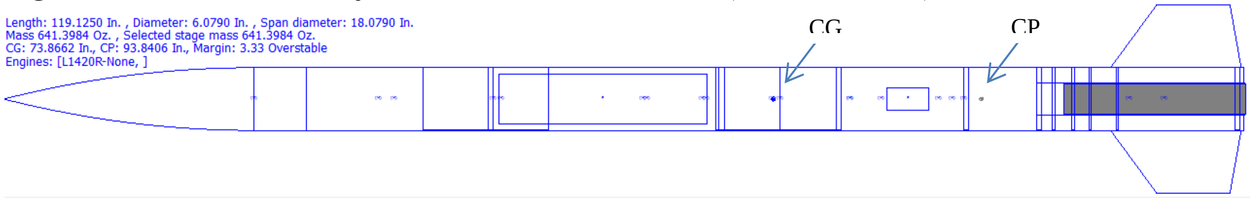

Figure 42 shows the center of gravity and center of pressure with the L1420R motor.

The figures above show a constant center of pressure location regardless of whether or not the motor is loaded. However, the center of gravity changes location from 61.62 in from the tip of the nose cone to 73.87 in when the motor is loaded into the launch vehicle.

Table 19 presents the center of gravity, stability margin, and center of pressure of the launch vehicle with and without the motor.

Table 19: Center of Gravity, Center of Pressure, and Stability			
Launch Vehicle	**CG from Nose Cone (in)**	**CP from Nose Cone (in)**	**Stability Margin (caliber)**
With motor	73.87	93.84	3.33
Without motor	61.62	93.84	5.37

The stability margin of the launch vehicle demonstrates how well it can restore its balance after experiencing a disruption in flight. A launch vehicle with a center of pressure aft of the center of gravity will experience a restoring moment in order to stabilize itself [12]. The static stability margin of the launch vehicle was also calculated using the equation:

$$\frac{CP - CG}{D}$$

where D is the diameter of the airframe.
The stability of the launch vehicle was calculated to be 3.29 calibers with the motor and 5.30 calibers without the motor. The calculated and simulated stability margins of the launch vehicle without the motor or differ by 0.07 calibers and the calculated and simulated stability margins with the motor differ by 0.04 calibers. However, the static stability margin is not the only factor to consider when analyzing the overall stability of the launch vehicle. Factors such as () were also considered when designing the launch vehicle

3.4.3 *Kinetic Energy*

The kinetic energy of each section was calculated to ensure that it does not exceed the 75 ft.-lbs limit and thus avoid damage at landing. The formula displayed below was used to calculate the terminal velocity of each section in order to calculate their corresponding kinetic energies.

$$V = \sqrt{\frac{2gm_{lv}}{C_d \rho A}}$$

where,
g is the force of gravity in m/s^2
m_{lv} is the mass of the launch vehicle in kg
C_d is the coefficient of drag of the parachute
A is the area of the parachute
ρ is the air density.

The C_d of the parachute was calculated by the manufacturer to be 2.2 [10]. The air density was estimated to be 1.225 $\frac{kg.}{m^3}$ [13].

The weight of the aft section of the rocket was calculated using the empty weight of the motor instead of the loaded weight. This was done because the parachutes are deployed after the motor propellant has burned out and only the empty weight of the motor remains. The predicted weight of each section of the rocket can be found in section 3.1.1.

The calculated terminal velocity of each section was then used in the equation below to calculate the independent kinetic energies.

$$k = \frac{1}{2} m_s v^2$$

where,
m_s is the mass of the independent section in kg
v is the terminal velocity in m/s.

Table 20 lists the kinetic energy of each independent section.

Table 20: Individual Kinetic Energies

Section	Kinetic Energy with Main Parachute (ft-lbs)	Kinetic Energy with Drogue Parachute (ft-lbs)
Forward	36.92	1350.75
Middle	17.60	643.75
Aft	34.46	1260.71

The calculations demonstrate that no section of the rocket will be experiencing kinetic energy values over 40 ft-lbf, thus ensuring that they will not be damaged when landing.

3.4.4 *Drift from Launch Pad*

Table 21 lists the different wind speed values input into the simulation and their corresponding predicted maximum range values due to drift.

Table 21: Wind Speed and Drift	
Wind Speed (mph)	**Maximum Drift (ft)**
5	328.10
10	738.88
15	954.96
20	2111.76

The table above displays an increase in drift for the launch vehicle as the wind speed increases. The drift of each independent section was estimated using RockSim 9 simulations with a 12 ft long launch rail positioned at a 0° angle from the vertical.

The drift of the launch vehicle was calculated using 10 mph wind speed conditions using the following equations:

$$t_1 = \frac{(5249.87 - 800)ft}{v_d} = \frac{4449.87}{78.18fps} = 56.92\ sec$$
$$d_1 = v_w \times t_1 = 14.667fps \times 57.48\,\text{sec} = 834.99ft$$
$$t_2 = \frac{800ft}{v_m} = \frac{800ft}{12.92\ fps} = 61.92sec$$
$$d_2 = v_w \times t_2 = 14.667fps \times 61.92 = 908.36ft$$
$$d_1 + d_2 = 1743.35\ \text{ft}$$

where,
v_d is the descent velocity of the drogue in fps
v_m is the descent velocity with the main parachute in fps
v_w is the velocity of the wind in fps.

Table 22 lists the calculated drift values with their corresponding wind speeds.

Table 22: Wind Speed and Drift (Calculated)	
Wind Speed (mph)	**Maximum Drift (ft)**
5	874.62
10	1743.35
15	2596.53
20	3424.99

The simulated range values in Table 21 show that the launch vehicle is expected to drift to a range of 2111.76 ft if the wind speed reaches 20 mph. It is unlikely that the launch vehicle will reach this distance because the wind speed in Huntsville Alabama in the first two weeks of April is on average 9 mph. However, the high wind speed is estimated to be 16 mph so it is possible that the launch vehicle will exceed 954.96 ft but it will remain within the 2500 ft range limit. The discrepancies in the calculated and simulated values can be due to the different variables taken into consideration by RockSim that were not incorporated in the calculations. Only the terminal velocity, constant wind speed, and descent time of the launch vehicle were incorporated into the calculations. The wind speed can vary at different altitudes and may not be constant; which could significantly affect the actual range value of the launch vehicle.

Figures 43-46 illustrates the relationship between altitude and range at fixed, but varying, wind speeds.

Figure 43: Range and Altitude with 5 mph Wind Speed

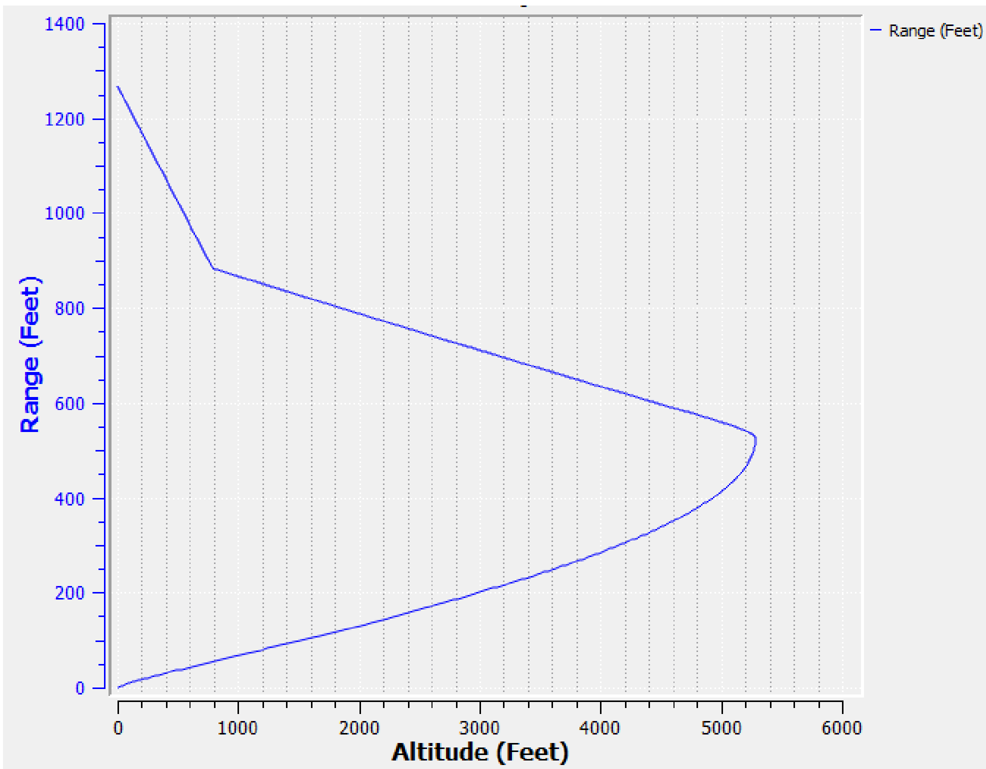

Figure 43 shows the range and altitude of the launch vehicle with 5mph wind speed.

Figure 44: Range and Altitude with 10 mph Wind Speed

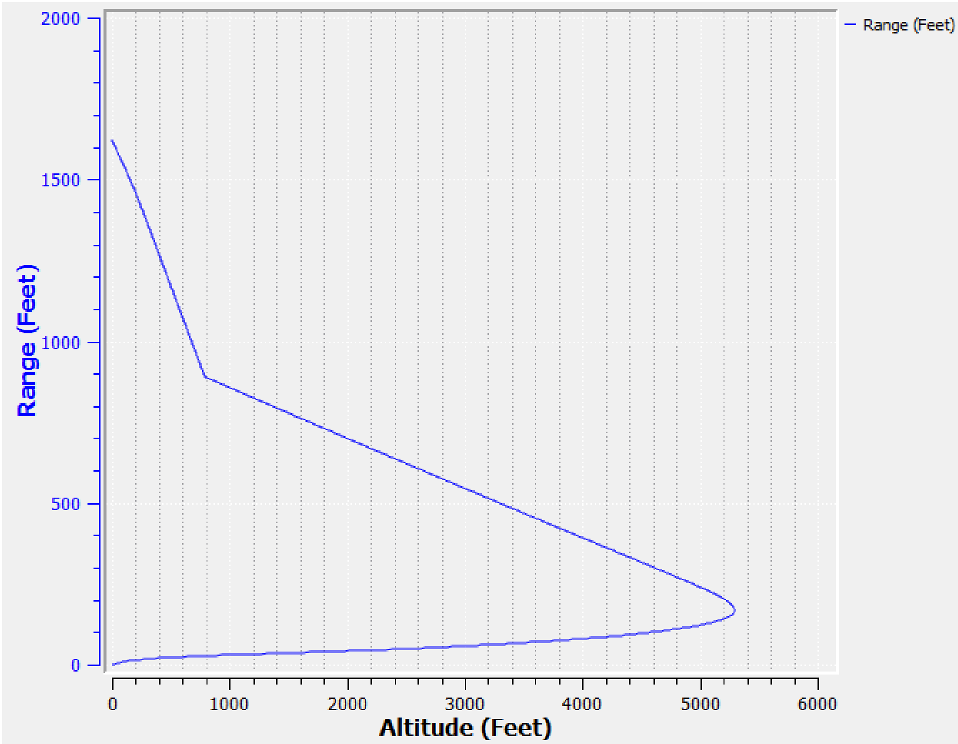

Figure 44 shows the range and altitude of the launch vehicle with 10mph wind

Figure 45: Range and altitude with 15 mph wind

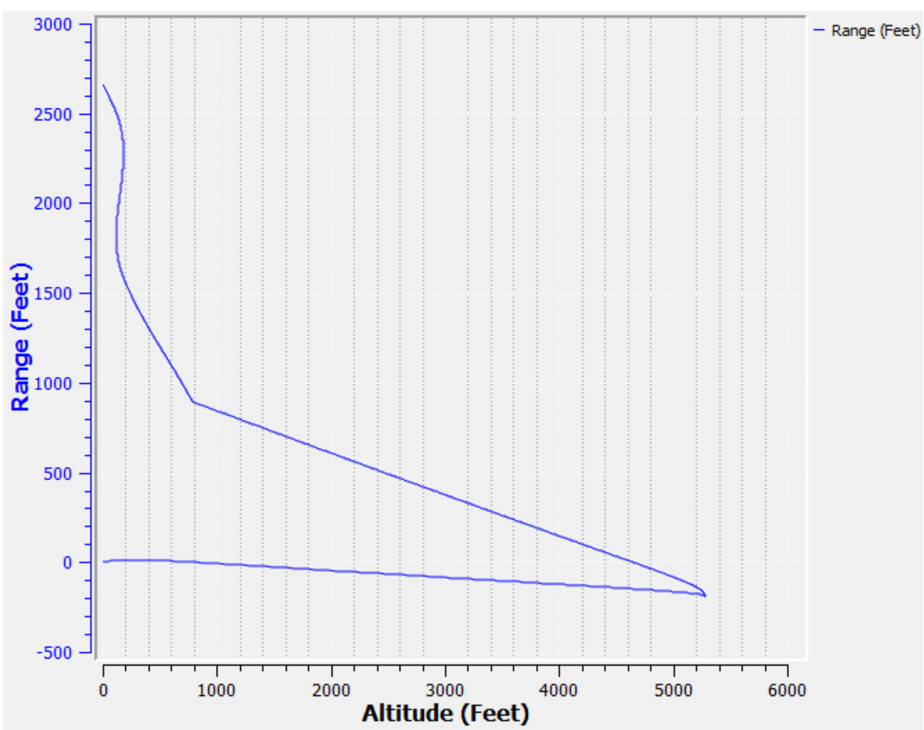

Figure 45 shows the range and altitude of the launch vehicle with 15 mph wind.

Figure 46: Range and altitude with 20 mph wind

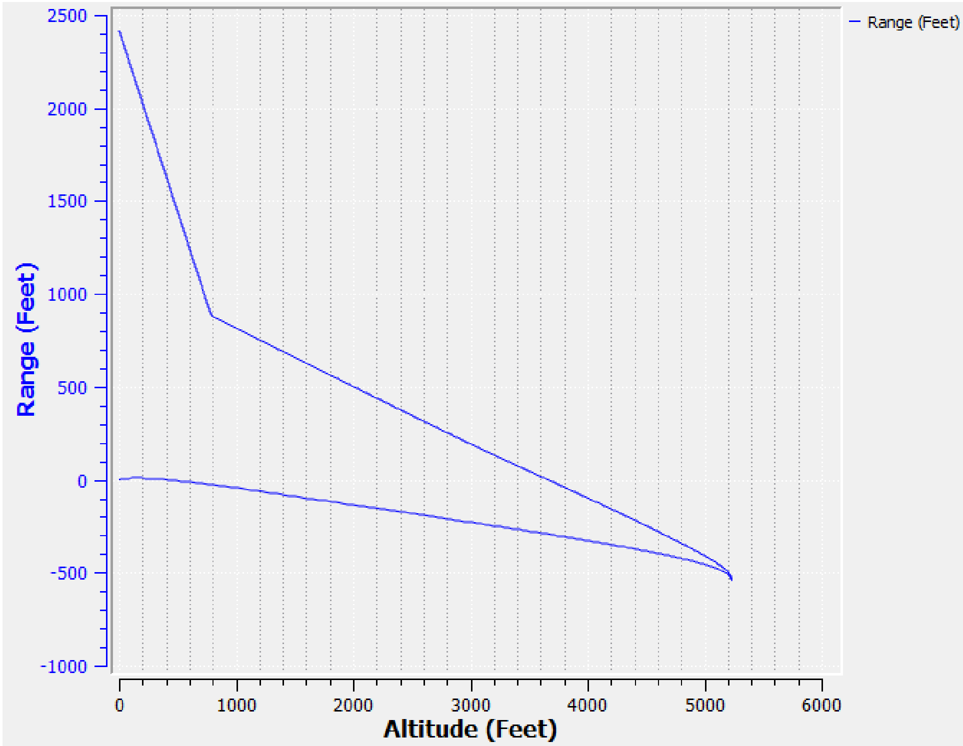

Figure 46 shows the range and altitude of the launch vehicle with 20 mph wind.

These figures above illustrate that the maximum range increase occurs at approximately 1000 ft AGL. This shows how critical it is to have the drogue and main parachutes deploy at their set altitudes in order to prevent and increase in drift.

IV. Safety

4.1 Safety and Environment (Vehicle and Payload)

4.1.1 Safety Officer Responsibilities

The Citrus College Rocket Owls safety officer, Janet, will ensure that the safety plan is followed and up to date. She will make sure that the team members, as well as the participants of the outreach events, are safe during all activities conducted or facilitated by the Rocket Owls as part of the NASA Student Launch. The safety officer's responsibilities are:

- Certify that the safety plan corresponds with federal, state, and local laws.
- Address the team members about any safety concerns.
- Inform the team members of expected safety concerns for the upcoming week at the team's weekly meeting.

- Request that the team member express any safety concerns during weekly meetings, or as they arise.
- Train the team on proper use of Personal Protective Equipment (PPE).
- Ensure that all team members understand and sign the team safety contract (see Appendix B).
- Be aware of all hazardous chemicals and machinery accessed by team members and ascertain that all safety precautions are followed before and after usage.
- Conduct safety briefings before the usage of any new equipment and/or materials.
- Write, update, and review a Material Safety Data Sheet (MSDS) for each hazardous chemical used, and safeguard that information in a safety binder, along with safety checklists and protocols.
- Ensure that the safety binder is accessible to all team members at all times.
- Identify and assess safety violations and eliminate the hazard appropriately.
- Have detailed knowledge of the TRA code for High-Powered Rocketry.
- Ensure compliance of all TRA regulations.
- Oversee testing and construction to ensure that risks are mitigated.
- Inform the team advisor, mentor, and members if the safety plan is violated by a team member.
- Provide a plan for proper storage, transportation and use of energetic devices.
- Ensure all participants in the outreach events are safe throughout all activities.

*MSDS sheets can be found in Appendix C and safety protocols in Appendix D.

A hazard is a potential threat to life, health, property or environment. Assessment of a hazard is made by combining the severity of the consequence with the likelihood of its occurrence in a matrix. Hazard analysis is the first step to assessing risk levels with the goal of controlling and/or eliminating the risk. Table 27 shows the risk matrix used to analyze the severity and probability of a hazard for the entire duration of the NASA SL. From this analysis, various tables related to personnel hazards have been constructed. The team members will come into contact with various materials, facilities and equipment that may present hazards to personnel. In order to understand and reduce the risks of hazards that may occur during the duration NASA SL MSDS, operator's manuals and NAR regulations were utilized in order to develop various mitigations. MSDS safety overviews, operation instructions and review of safety protocols will be covered during briefing conducted before construction, test and launches. These briefing will lead by the safety officer in order to reduce the probability of hazards and accidents occurrences.

Table 23 shows the qualitative assessment chart. There are several risks that pose a danger to the completion of the project. The risks are evaluated based on their likelihood and impact.

Table 23: Project Risk Qualitative Assessment			
Likelihood	**Impact Level**		
	1-High	2-Medium	3-Low
A-High	1A	2A	3A
B-Medium	1B	2B	3B
C-Low	1C	2C	3C

The items in red are very dangerous to the project's completion and must be mitigated early and effectively. The items in yellow pose less risk than those on red but should still be monitored. Items in green pose very little threat to the project completion.

Table 24 defines the impact levels.

Table 24: Impact Level Definitions	
Rating	**Definition**
1-High	High impact risk is define as having a severe effect on the overall continuation of the project and would require substantial effort, time and/or money to resolve.
2-Medium	Medium impact risk is define as having a moderate effect on the overall continuation of the project but would be reversible with modest effort, time and/or money.
3-Low	Low impact risk is define as having a minor effect on the overall continuation of the project but would be easily resolve with minimal effort, time and/or money

Table 25 describes the definition of likelihood.

Table 25: Likelihood Definitions	
Rating	**Definition**
A-High	Extremely likely the risks will occur.
B-Medium	Possible but not likely the risks will occur.
C-Low	Very unlikely the risks will occur.

Table 26 lists and describes the cause and effects that specific risks pose to the project's completion. A qualitative assessment is give before and after mitigation.

Table 26:Project Risk and Mitigation

Risk	Cause	Effect	Pre-RAC	Mitigation	Post-RAC	Verification
Insufficient building time	Overruns of schedule and cost, poor time management, lack of clear roles and responsibilities among team members	Launch vehicle will be constructed in a rush therefore decreasing the quality of the launch vehicle	1A	Construction of launch vehicle will begin 01/13/17 Duplicate parts of the vehicle will be constructed simultaneously, team members responsibilities and roles will be define during the team's weekly meetings	1C	The team remained on the designated construction schedule. The scale rocket was built on schedule and with quality work.
Unable to launch	Unpredictable weather, not all components of the rocket are brought to the launch site.	Entire line will get pushed back, team will be behind schedule	2A	More than one back-up launches has been schedule for the full scale rocket if unpredictable	2C	Checklists have been created to ensure all components of the rocket are packed

	RSO, team mentor or safety officer deems the launch vehicle unsafe to launch			where to occur, a checklist has been created for all supplies needed for a launch, careful attention to all safety concerns will be give before, during and after construction		and brought to the launch site.
Insufficient writing time	Poor time management, the amount of time scheduled for writing and editing the design review may be inadequate	Insufficient and/or inaccurate information may be presented in the design review	1B		2C	The team remained on the designated writing schedule.
Manufacturing time	A manufacturer may not have a part finished in the time required	Delay in construction of the launch vehicle and/or payload	1B	Backup plans for the fabrication of a part will be created, manufacturer will be contacted several weeks in advance	3C	The team has order necessary components for the rocket and payload several weeks before construction
Low funds	Too much money used to buy unnecessary material for construction	The team may run out of money to purchases necessary material to complete the project	2B	Extra fundraising will be done if necessary	3B	The team has not deviated from the previously created budget.
Low resources	Insufficient funds	Amount of materials purchased might not be enough to	2B	Extra material will be purchased	2C	The team budget has been followed carefully to

		complete construction				avoid insufficient funds
Loss of team members	Team member lost interested or become overwhelmed, or lack of work from team member, team member fail to meet the responsibilitie s given to them	Increase the work load of remaining time members, increase the amount of time for an assignment to be completed	2B	The lost team members responsibilities will be distrusted among the remaining team members, weekly meeting will be conducted to keep all time members up to date on all aspects of the project so taking over a lost team member's responsibility will not be overwhelming	2C	Hazards has not occurred, all participants remained on the team.

4.2 Hazards Analysis

4.2.1 Updated Personal Hazard Analysis and Mitigations

The following tables deals with hazards to personnel and their respective mitigations. Mitigations have been implemented for hazards that may occur. The following tables have been expanded to include verification as hazards are encountered. The risks are evaluated based on their probability and severity.

Table 27 shows the qualitative assessment chart.

Table 27: Risk Matrix				
Probability	**Severity**			
	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
A-Frequent	1A	2A	3A	4A
B-Frequent	1B	2B	3B	4B
C-Occasional	1C	2C	3C	4C
D-Remote	1D	2D	3D	4D
E-Improbable	1E	2E	3E	4E

Table 28 lists and defines the severity of a hazard ranging from negligible (4) to catastrophic (1).

Table 28: Severity Definitions		
Severity	**Values**	**Definition**
Catastrophic	1	Permanent injury or loss of life; loss of facilities, systems, or associated hardware; irreversible or severe environmental damages that violate laws and regulations.
Critical	2	Severe injury; major damages to facilities, system or associated hardware; reversible damages that cause a violation of law or regulations.
Marginal	3	Moderate injury; moderate damages to facilities, equipment, or systems; moderate environmental damages that can be repaired and do not cause a violation of a law or regulation.
Negligible	4	Minor injury that can be treated immediately only requiring first aid treatment; negligible environmental damages that do not violate laws or regulation.

Table 29 lists and defines risks based on their likelihood. Each hazard is assigned a probability of occurrence ranging from improbable (1) to frequent (5).

Table 29: Likelihood of Occurrence Definitions	
Description	**Definitions**
A-Frequent	High likelihood to occur repeatedly or expected to be experienced continuously.
B- Probably	Expected to occur frequently within time.
C- Occasional	Expected to occur occasionally within time.
D-Remote	Unlikely to occur frequently.
E- Improbable	Very unlikely to occur.

Table 30 has been expanded to included verification as hazards are encountered.

Table 30: Facility Hazard Analysis and Mitigation					
Facility	**Hazard**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification**
Citrus College Computer Lab	Lost or corrupted data Damaged facilities	**4E**	The lab will not be used for any construction pertaining to the project. Drinks or food will not be allowed in the computer lab.	**4E**	No damage to facilities has occurred
Launch Sites 1. Rocketry Organization of California (ROC) 2. Friends of Amateur Rocketry (FAR) 3. Mojave Desert Advanced Rocketry	Bodily harm	**2D**	NAR High Powered Rocket Safety Code will be followed at every launch. Before launches, a certified team member	**2E**	No severe injuries have occurred. The safety officer has ensured that the proper safety gear is being utilized at all times. Minor cuts and burns are treated with first aid.
	Damaged facilities	**4E**		**4E**	

Society (MDARS)			will use a team created checklist to confirm that the rocket is safe for launch. The Range Safety Officer (RSO) will determine if the rocket is safe for launch and the team will comply with their assessment.		
Citrus College Machine Shop	Physical injury, skin or eye irritation	**2D**	Gloves, masks, goggles, and closed toe shoes will be worn at all times. Team members will be trained to properly handle and operate the machinery and tools.	**2E**	No injuries have occurred

Table 31 provides the preliminary risk levels. MSDS is used to understand the potential hazards of the materials mentioned in the table below.

Table 31: Material Hazards Analysis and Mitigations							
Materials	**Hazard**	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification**
Wood	Splinters and cuts	Failure to wear gloves	Mild infection and discomfort	**4B**	Gloves and protective masks will be worn at all times when handling the material.	**4C**	Wood and wood dust have been encountered. No hazards have occurred. Proper safety attire has been worn.
Fiberglass	Skin and eye irritation; hazardous fume inhalation	Failure to wear gloves, masks, and goggles	Mild dizziness, sneezing, coughing, and sore throat	**4D**	Gloves, masks, goggles, and lab coats will be worn at all times when handling the material. Any skin that comes in contact with the material will be washed immediately under running cold water for at	**4E**	Fiberglass has been encountered. No hazards have occurred. Proper safety attire has been worn when handling the material.

					least 15 minutes.		
Acetone	Lung, eye, or throat irritation; highly flammable	Failure to wear gloves, masks, and goggles	Coughing, red and watery eyes	**2C**	Acetone will be used in designated ventilated areas and away from potential sources of ignition.	**3D**	Acetone has been used. No hazards have occurred.
Epoxy	Skin, eyes, and respiratory irritation; rashes and allergic reactions	Failure to wear gloves, masks, and goggles	Wheezing, coughing , sore throat, and red itching eyes	**4C**	Appropriate safety gloves and masks will be worn when working with the material.	**4D**	Epoxy has been used for the construction of the sub-scale rocket but no hazards have been encountered. Safety, gloves, masks, and goggles were used when working with the material.
Black Powder	Burns, severe physical injury, and property damage	Failure to keep black powder away from heat sources	Mild to severe burns, blistering, discomfort	**1E**	Black powder will be handled solely by the team mentor.	**2E**	Black powder has been utilized but no hazards have been encount

							ered. Proper safety equipment was worn.
Solder	Damage to equipment while soldering	Soldering iron is too hot, prolonged contact with heated iron	The equipment become damage and unusable	**2B**	The temperature of the soldering iron will be controlled and set to an appropriate level that will not damage equipment	**3C**	Solder has been utilized and no hazards have occurred. Proper protective equipment such as goggles, mask and protective clothing were used when working with the material in a well-ventilated area. Team member have be trained on appropriate soldering techniques.
	Dangerous fumes while soldering	Toxic fumes are produce because of the utilization of leaded solder	Sickness or irritation of the lungs due to inhalation of toxic fumes		Team member will use appropriate soldering techniques and solder in well ventilated areas		
	Burns while soldering	Team members do not pay attention while soldering	Minor to severe burns may occur		Team member will use appropriate soldering techniques		

Paint	Respiratory irritation	Failure to wear protective masks	Wheezing, coughing, and shortness of breath	**3C**	Protective masks will be worn. Painting will be done in well-ventilated areas.	**4C**	Paint has not been used as of yet. Proper safety equipment will be worn when working with paint.
Batteries	Chemical burns and skin irritation	Failure to place the batteries in a cool dry place	Mild skin peeling, burning sensation, and moderate pain	**3C**	Batteries will be stored in a cool and dry place and kept away from heat sources. Batteries will also be disconnected when not in use.	**3D**	Batteries have been used for ground testing and the sub-scale test launch but no hazards have occurred. All batteries used have been stored in cool and dry places.
Super Glue	Eye and skin irritation	Failure to wear gloves, masks, and eye protection	Eye irritation, rashes, dryness and itchiness of skin	**3B**	Gloves, masks, and eye protection will be worn when handling the material.	**3D**	Super glue has been utilized but no hazards have been

							encountered. Proper safety equipment was worn

Table 32below lists the equipment required in the construction of the launch vehicle that poses sufficient risk to require mitigation.

Table 32: Equipment Hazards Analysis and Mitigation

Equipment	**Hazards**	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification**
Power Tools	Physical injury	Failure to use the power tool correctly and/or improper training on power tools and improper use of PPE	Mild to severe burn to the exposed areas and damage to equipment	**3B**	Team members will be trained to properly handle all necessary power tools. The operation of any power tool will only occur in appropriate lab facilities.	**3D**	Hazards occur when the team members fail to comply by the safety rules. Proper safety equipment such as respirators, gloves, and eyes protection are used when power tools are in use. Power tools such as jig saw, sander, and drill press have been used. No hazards have occurred,

Sanding Tools	Physical injury damage to equipment	Improper use of PPE Improper usage of sanding tools	Team members may experience mild to severe rash, irritation of the eyes, nose, or throat	3B	Proper safety attire such as protective clothing, safety goggles, mask and glove will be worn	3E	Sanding tool such as a sander and Dremel have been used while constructing the sub-scale. Hazards have not occurred. Team member were instructed by a trained individual. Team member wore appropriate PPE while sanding.
	Damage to rocket or rocket components	Improper usage of sanding tools due to inadequate training	The team will fall behind schedule due to rebuilding the damage component of the rocket		Team members will be trained on the tool being used		
Machinery	Bodily harm	Failure to correctly use the machinery and/or improper training, improper use of PPE	Mild to severe burn to the exposed areas, damage to equipment	1D	Team members will abide by all safety rules that correspond to the machinery in use. Team members will not be allowed to work alone and/or under fatigue.	3E	Hazards occur when the team members fail to comply by the safety rules. Proper safety equipment such as respirators, gloves, and eyes protection are used when power tools are in use.

Rocket Motor	Bodily harm, burns, property damage	Failure to properly handle or install the motor	Mild to severe burn to the exposed areas, damage to equipment	**2D**	Only team members certified by the Tripoli Rocketry Association will handle the motor. All personnel will be at a required safe distance from the rocket during every launch events.	**3E**	Team members clear the required distance when the motor was tested.

Table 33 lists hazards that may occur during launch preparation and flight of the launch vehicle.

Table 33: Launch Vehicle Hazard Analysis and Mitigation

Hazards	Cause	Effect	Pre-RAC	Mitigation	Post-RAC	Verification Status
Absence of deployment, premature or delayed deployment	Malfunction of altimeters which results in inaccurate deployment	Launch vehicle will descend rapidly to the ground resulting in significant damage to the rocket, in the case of premature deployment the launch vehicle will drift to great a distance	**1D**	Redundant altimeters and black powder charges will be used to ensure deployment. A safety checklist will be made to confirm that the proper electronics are installed and activated.	**2E**	**Complete:** The launch checklist ensure everything is installed correctly. The sub-scale launch test verified the altimeters are accurate.

				Verify the altimeters are preset to the correct altitude.		
Unstable flight	Crooked, forward, asymmetrical, and/or loose fin, CG shift during flight	Launch vehicle will not achieve highest altitude	**1D**	Rocket simulation software will be used to determine the CP before launch. Fins will be cut using a CNC machine to ensure precision of cuts.	**2E**	**Complete:** Sub-scale test launch has been conducted and has verified that the rocket did not undergo an unstable flight.
Injury during ground or launch testing	Black powder charges go off prematurely when expose to open flames and heat sources	Minor to serious injuries to personal near the launch vehicle	2C	Team members will be at a required safety distance from the launch vehicle when conducting ground or launch testing.	2D	**Complete:** Ground test have been conducted and hazards have not occurred. Team member had stayed the required distance when ground testing was conducted.
Failure to recover rocket	Ballistic descent could cause destruction of rocket. Premature deployment of the main parachute will cause the launch	Loss of launch vehicle	**1D**	Rocket simulation software will be used to ensure rocket stability. Ground ejection tests will be conducted	**1E**	**Complete:** The sub-scale launch test has verified that the proper parachute sizes have been selected. The sub-scale rocket has been

	vehicle to drift further than expected			to verify that the correct amount of shear pins and black powered are used. The rocket must pass launch safety inspection. A GPS system will be used to locate the rocket.		recovered.
Catastrophic takeoff (CATO)	Failure to properly assemble and install the motor. Selecting a motor incapable of providing a stable rail exit velocity.	Loss and/or destruction of launch vehicle and minor to serious injuries to personal near the launch vehicle	**1C**	Only certified motors will use. The mentor will oversee the installation of the motor.	**3E**	**Complete:** Sub-scale launch test has verified that CATO has not occurred.

Table 34 lists the potential hazards posed from the construction of the payload and their corresponding mitigations.

Table 34: Payload Hazards and Mitigation

Risk	Pre-RAC	Cause	Effect	Mitigation	Post-RAC	Verification Status
Bodily harm	2D	Misuse of safety equipment.	Cuts and/or burns	Mitigation Protective clothing, gloves, masks, and goggles will be worn while constructing the payload.	**2D**	**Complete:** Proper safety attire has been worn while constructing a subscale payload. MSDS and safety protocol

				Protective clothing, gloves, masks, and goggles will be worn while constructing the payload.		checklist were reference before weekly construction.
Skin and eye irritation	3B			Protective clothing, gloves, masks, and goggles will be worn while	4C	Proper safety attire has been worn while constructing a subscale payload. MSDS and safety protocol checklist were reference before weekly construction
Fumes and/or particle inhalation	3C			Protective masks will be worn while constructing the payload.	4C	Proper safety attire has been worn while constructing a subscale payload. MSDS and safety protocol checklist were reference before weekly construction

Updated Failure Modes and Effects Analysis

The design, payload and lunch operations of the proposed vehicle has been analyzed in order to study every possible malfunctions and failures that might occur with all systems and subsystems involved in the project. Components, subsystems and assembly of the launch vehicle were reviewed in order to identify the cause and effect of various failures. The following mitigations were developed in order understand and reduce the risk of these failure that may occur during the assembly, development and construction of the launch vehicle.

Table 35 shows the possible failure modes of the launch vehicle with their corresponding mitigations and verification status.

Table 35: Launch Vehicle Hazard Failure Modes						
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**	**Verification Status**
Center of gravity is too far aft	**2B**	Mass distribution is greater in the aft section of the rocket	Unstable flight	RockSim simulations will confirm that the center of gravity is at least 1.5 calibers above the center of pressure. Test flights will also be used to verify the stability of the rocket.	**2D**	**Complete:** RockSims predicts a stability margin of and calculations predict a stability margin as
Fin failure	**1B**	Fins are not properly attached to the motor mount and/or they do not have equal radial spacing	Unstable flight, potential rocket damage	Fins slots in the airframe and epoxy will be used to secure the fins onto the wall of the motor mount. The grain of the wood will be perpendicular to the body of the rocket.	**1D**	**Complete:** The fins have been made and laminated with fiberglass.
Premature separation of rocket components	**1D**	Insufficient amount of shear pins or faulty altimeters	Failure to reach target altitude, damage to rocket and various other components	Calculations and ground ejection tests will be used to determine and verify the necessary amount of shear pins and black powder. Tests will be conducted to ensure that the altimeter is functioning properly. Static	**1E**	**Complete:** Sub-scales test launch verifies that shear pins can properly secure airframe and that altimeters are functional and accurate.

				port holes will be correctly sized to ensure proper altimeter readings.		
Lack of separation of the rocket components	**1D**	Nonessential amount of shear pins or insufficient pressure in parachute bay	Absence of parachute deployment and ballistic descent of the launch vehicle	Calculations and ground ejection tests will be used to determine and verify the necessary amount of shear pins and black powder.	**1E**	**Complete:** Sub-scale test launch verifies that the proper amount of shear pins were used and that there was sufficient pressure in the parachute bay
Centering rings failure	**2D**	Centering ring(s) detach from the motor mount and/or airframe	Damage to rocket, possible motor ejection, or unstable flight	6 centering rings will be attached to the motor mount. Tests will be conducted to ensure the centering rings are properly secured to the airframe and motor mount.	**2E**	**Complete:** Sub-scales test launch visually verifies that the centering rings are intact.
Bulkhead failure	**2D**	Bulkheads detach from the airframe	Recovery system failure, damages to rocket	0.50 in thick Birch plywood will be bonded to the airframe. Tests will be conducted to ensure that the bulkheads are secured.	**2E**	**Complete:** No signs of stresses were seen after sub-scale test launch
Airframe shredding	**1D**	Miscalculation tensile strength of the airframe	Damages to rocket	High shearing strength Blue Tube will be used.	**1E**	**Complete:** No sign of airframe shredding were seen

						after sub-scale test launch

Table 36 shows the possible failure modes of the payload and the mitigation of those failures.

Table 36: Payload Failure Modes						
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**	**Verification Status**
Nuts, bolts and washer become loose	**1D**	Nuts, bolts, washers have not been tighten correctly	Platforms will move around in the container causing the sample to become unsecured	Correct sizing of nuts and washers will be used. The nuts and washers will be tightened manually	**3C**	**Complete:** Nuts, bolts and washer stayed in place on the metal rods
Silicone platforms tear	**1D**	Silicone platforms was to thin	Platforms tear under the weight of the sample and cause the sample to bounce around the container	Thickness of silicone platforms was calculated to ensure platforms will not tear under the weight of the sample	**3D**	**Complete:** No sign of tears on the silicone platform were seen after subscale test launch.
Stiff springs	**1D**	The distance between coil separation is too small	Platforms will move around in the container causing the sample to become unsecured	Proper calculations have been performed in order to ensure that the distances between coils are adequate	**3D**	**Complete** Subscale test flight confirms springs used were not too stiff.
Peeling of radiation shield	**1D**	Radiation shield is not properly	Radiation shield is not	Properly install the radiation	**3D**	**Plan:** See payload section for

		adhered to the container	effective	shielding		further detail
Cap not properly sealed	**1D**	The cap is not the proper size for the container	Liquid sample will leak out of the container	Hermetically seal the cap	**3D**	**Complete:** Subscale test flight confirms that the springs were not too stiff

Table 37 shows the failure mode of the propulsion system and the mitigation for such failures.

Table 37: Propulsion Failure Modes

Risk	Pre-RAC	Cause	Effect	Mitigation	Post-RAC	Verification Status
Motor ignition failure	**3D**	Faulty motor, disconnected e-matches	Failure to launch. Rocket fires at an unexpected time	Only commercially available E-matches will be used. In case launch vehicle fails to launch the team will follow NAR safety code and will wait a minimum of one minute before attempting to approach the launch vehicle	**3E**	**Planned:** The ease of motor ignitions with commercial e-matches will be examined during the full scale test flight
Motor failure	**1D**	Faulty motor, rocket is too heavy, motor impulse is too low	Failure to reach target altitude, unstable flight, loos of motor casing	Commercially available motors will be used	**1E**	**Planned:** The motor has been purchased and will be used for the full scale test flight
Exploding of the motor during ignition	**1D**	Faulty motor	Loss of rocket and/or motor	Commercially available motors will be	**1E**	**Planned:** The motor has been

				used		purchased and will be used for the full scale test flight
Motor igniter not reaching the end of the motor	**2C**	Failure to properly measure the length of the motor	Failure to complete motor burnout	Length of motor will be measured and the location marked on the outside of the rocket to ensure proper length and placement of igniter	**2E**	**Complete:** Sub-scale test flight has verified the method of installing a motor igniter.
Motor mount failure	**1D**	Motor retainer was not proper reload	Loss of rocket	Motor retainer will prevent the motor from penetrating into the body of the rocket, rocket will be inspected by safety officer and team mentor before launch	**1E**	**In Progress:** The full scale test flight will confirm the effectiveness pf the motor retainer
Premature burnout	**3C**	Faulty motor	Failure to reach target altitude	Commercially available motors will be used	**3E**	**Planned:** The motor has been purchased and will be used for the full scale test flight
Improper transportation or mishandling	**1D**	Motor was left in unfavorable conditions,	Unusable motor, failure to launch	All team members are TRA level 1 certified. Higher grade motors will be handled by certified members and/or the	**1E**	**Complete**: The motor was transported correctly to the sub-scale launch site and was handled by team

				team mentor according to guidelines outlined in the motor handling and storage section		members that had the appropriate certification

Table 38 shows recovery failure modes and mitigations for such failures.

Table 38:Recovery Failure Modes						
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**	**Verification Status**
Rapid decent	**1C**	Parachute is the incorrect size	Damage to airframe and payload, loss of rocket	RockSim9 along with various other calculations will be used to determines and estimate the decent rate.	**1D**	**Complete**: the descent rate under the drogue parachute will be 78.18 fps and 12.92 fps under the main parachute
Parachute deployment failure	**1C**	Parachute gets stuck in the coupler, parachute lines become tangle	Loss of rocket, extreme damage to airframe, fins and other components	Parachute will be packed properly, RRC2+ altimeters will be tested before any launch to ensure they properly deploy the parachute	**1E**	**Complete**: Sub-scale test launch verified the method of packing the parachute was efficient. See RRC2+ ground test for further

						informatio n.
Parachute separation	1C	Parachute disconnects from the U-bolt	Damage to rocket and all components	Parachute will be properly secure to the bulkheads with quick links and welded eye bolts, various test will be conducted to ensure parachute remains attached	1E	**Compete:** Sub-scale test launch verified that the method of securing the parachutes was efficient
Tear in parachute	2D	Poor quality of parachute	Damage to rocket, rapid decent resulting in an increase of kinetic energy	Parachute will be inspected before each launch Only commercially available parachutes will be used	2E	**Complete :** Parachute were inspected before sub-scale flight and will be inspected during the full scale flight.
Parachute becomes burn	1C	Parachute was improperly setup. Parachute is less effective or completely ineffective base on the severity of the damage inflicted on the parachute.	Damage to rocket due to increase of kinetic energy resulting in a rapid decent, loss of parachute	Nomex will be used to protect the parachute form burning	2D	**Complete :** The sub-scale test flight verified the correct Nomex blanket size was used, parachute was not harm.
Slow decent	2C	Parachute is the incorrect size	Rocket drifts out of intended lading zone resulting in loss of rocket	RockSim9 along with various other calculations will be used to	2D	**Complete**: The maximum drift will keep the

				determines and estimate the decent rate		rocket within the acceptable 2500 ft range
Gases from drogue deployment pressurize avionics bay and deploy main parachute	2B	Hole made to run wires are not sealed	Early deployment of main parachute will cause rocket to drift far	All holes made to run wires will be sealed with epoxy. Flat washers and silicone grease will seal the spaces around all threads.	3C	**Complete:** This method was tested and verified on the sub-scale rocket. Method was found to be efficient.
Avionics electronics unarmed	1A	Parachutes will not deployed	Destruction of launch vehicle injury to team or bystanders	Recovery launch checklist will be used to ensure that the recovery electronics are armed before the igniter is installed in the motor.	1D	**Complete:** A launch checklist has been made that included arming the recovery electronics
Parachute shroud line become tangled during deployment.		Parachute was not correctly packed.	Destruction of launch vehicle upon impact due to the potential of the rocket becoming ballistic.			**Complete:** The sub-scale test launch confirmed that the method of packing the parachute was effective
Altimeter or e-match failure		Manufacture error	Parachute will not deploy. Rocket follows ballistic path.	Redundant altimeters and e-matches are incorporated into the recovery system to reduce this failure		**Complete:** Sub-scale test launch verified redundant recovery

				mode.		system was practical.
Parachute does not inflate		Incorrect sized parachute was used.	Parachute does not generate enough drag	The parachute has been carefully selected based on multiple calculation and simulation via RockSims9.		**Planned:** Parachute for the full scale launch vehicle will be tested on the 5th of February.

Table 39 lists the operations failure modes.

Table 39: Operations Failure Modes

Risk	Pre-RAC	Cause	Effect	Mitigation	Post-RAC	Verification Status
Laptop is non functional	**3D**	Laptop batteries des or not charge	GPS locator cannot be used, code cannot be modified	The batteries will be charged the night before, and the laptop will be powered down until the required day.	4E	**Complete:** The launch supply checklist is complete
Battery used to ignite motor does not provide sufficient charge	**3C**	Insufficient firing voltage	Launch vehicle does not launch	Redundant power sources will be used	4D	**Complete**: the sub-scale launch verified that the battery used to ignite the motor was efficient.

Launch Procedures
Pre-launch day

Table 40 shows the checklist that will be utilized prior to launch days to ensure all required equipment is taken on site.

Table 40: Preliminary Safety Checklist: Pre-launch day					
Required Items	**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
Wireless Drill and bits					
Soldering iron					
De-soldering equipment					
Hot glue gun					
Saw					
Screw driver (multiple sizes)					
Dremel					
Dremel pieces					
Adjustable Wrench					
Exacto knife					
Heavy duty file					
Wire strippers					
Multimeter					
Batteries					
Extra altimeters					
Laptop and TeleGPS					
LiPo battery charger					
E-matches					
Tape					
Scissors					
Rocket Epoxy					
5 minute Epoxy					
Super glue					
Extra shear pins					
Extra rail buttons					
Motor hardware					
Sand paper					
Recovery wadding					
Battery connectors					
Jst connector					
Heat shrinks					
Safety glasses					
Safety gloves					

Table 41 is a tentative checklist of the required steps to be taken by the team to ensure a quick and efficient launch day location setup.

Table 41: Preliminary Checklist: Location Setup						
Required Steps		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
1	Unload rocket and equipment					
2	Establish base of operations					
3	Set up work station					
4	Layout rocket section for setup					

Recovery preparation

Safety Checklist: Drogue Bay Setup

Required Equipment/Supplies:

- Clamp
- Drogue parachute
- Shock cords
- Masking tape
- Duct tape
- Quick links
- Nylon cable tie
- 18 in Nomex parachute protector
- Shock cord protector

Required PPE:

- Safety glasses
- Gloves

Table 42 shows the checklist that will be used by the team for final assembly of the drogue parachute bay to prepare it for launch.

Table 42: Drogue Parachute Bay Checklist						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
	Ensure that the harnesses are secured with quick-links to the drogue and avionics bay.					
	Verify the absence of snags and obstructions inside of the drogue bay visually and manually.					
	Inspect drogue parachute for any cuts, burns, lose stitching and any other damage Note: If damaged is identified, the team lead and safety officer will be immediately informed.					
	Lay parachute flat out					
	Inspect shroud line and endure lines are taut and not tangled					
	Fold drogue parachute as shown on a					

	folding procedure video located on the team website					
	Attach shroud line to the quick-link					
	Wrap the Nomex blanket around the parachute					
	Secure the shock cords to their respective U-bolts in the drogue bay					
	Cover the knots on the shock cords where the quick-links are attached with masking tape and secure with zip ties					
	Roll the shock cords into loops and secure them with masking tape.					
	Insert prepared shock cords along with drogue parachute into the drogue bay.					

Safety Checklist: Avionics Bay

Required Equipment/ Supplies:

- Multi-meter
- Pre-weighed black powder
- 9-V batteries
- Screwdrivers (philips and flat)
- Duct tape
- E-matches

Required PPE:

- Safety glasses
- Gloves

Table 43 shows the checklist that will be used by the team for final assembly of the avionics bay to prepare it for launch.

Table 43: Final assemble for the Avionics Bay						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
	Ensure the batteries have a 9-V charge with a multi-meter					
	Verify wires are properly attached.					
	Tug on wires to ensure they are properly secure.					
	Verify that the altimeters are mounted above the sled with a minimum of 0.125 in on standoffs and fastened on the electronics sled properly. barometric sensor is mounted on the bottom of the altimeter to ensure the tiny holes use to sample the air are not blocked by mounting the altimeter too tight on the sled a credit card will be slip.					
	Connect the wire terminal for switches.					

	Attach batteries to battery clips					
	Verify that the arming switches engage all subsystems.					
	Slide the electronics sled into the avionics bay					
	Attach bulkhead at both ends with threaded rods, washers and wing nuts ensure that the hardware is properly assembled and secure					
	Connect the wire terminal for the drogue and the main ejection charge					
	Turn switches to on positon in order to verify continuity and battery voltage					
	Return switches to off position					
	Grease and secure bulkheads.					
	Unwind the E-matches, and place the pyrotechnic end of the E-match into the ejection canisters					
	Secure the e-match with duct tape					
	Place pre-measure black powder into the ejection canisters					
	Ensure the					

	pyrotechnic end is submerged in the black powder					
	Place wadding paper inside the ejection charges to eliminate excess space					
	Seal with duct tape					
	Connect e-matches to the terminal located on the bulkhead					

Safety Checklist: Main Bay Setup

Require Equipment:

- Clamp
- Drogue parachute
- Shock cords
- Masking tape
- Duct tape
- Quick links
- Nylon cable tie
- 24 in Nomex parachute protector
- Shock cord protector

Required PPE:

- Safety glasses
- Gloves

Table 44 shows the checklist that will be used by the team for final assembly of the main parachute bay to prepare it for launch.

Table 44: Main Parachute Bay Checklist

Step		Verified by	Verified by	Date	Time of Verification	Final Verification by Safety Officer
	Ensure that the harnesses are secured with quick-links to the main and avionics bay.					

	Verify the absence of snags and obstructions inside of the main bay visually and manually.					
	Inspect main parachute for any cuts, burns, lose stitching and any other damage Note: If damaged is identified, the team lead and safety officer will be immediately informed.					
	Lay main flat out					
	Inspect shroud line and endure lines are taut and not tangled					
	Fold main parachute as shown on a folding procedure video located on the team website					
	Attach shroud line to the quick-link					
	Wrap the Nomex blanket around the parachute					
	Secure the shock cords to their respective U-bolts in the main bay					

	Cover the knots on the shock cords where the quick-links are attached with masking tape and secure with zip ties					
	Roll the shock cords into loops and secure them with masking tape.					
	Insert prepared shock cords along with main parachute into the main bay.					

Motor Preparation

Required Equipment

- Grease
- Paper towels
- Motor retainer
- Motor casing

Final Assembly safety checklist:

- Safety goggles
- Gloves

Table 45 shows the checklist that will be used by the team for final assembly of the motor to prepare it for launch.

Table 45: Motor Assembly Checklist						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
	Prepare motor as described by the Aerotech user manual					
	Verify motor assembly with team mentor					
	Find appropriate igniter length and add tape to mark place on igniter					
	Loaf motor into launch vehicle					
	Install motor retention system					

Set Up on Launcher

Required Equipment:

- Writing equipment
- Certification card
- Keys to the switches

Table 46 shows the final assembly steps used by the team on the launcher

Table 46: Launch Vehicle Final Assembly Checklist						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
	Slide vehicle onto launch rail					
	Ensure vehicle is properly secured to launch rail					
	Raise rail to vertical position					
	Arm recovery electronics					

Table 47 shows the procedures for igniter installation.

Table 47: Igniter Installation Checklist						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
	Tread igniter through plastic cap					
	Install igniter, ensuring that the igniter is inserted completely into the motor and apply tape at the bottom					
	Secure cap to prevent igniter from falling out					
	Check ignition system alligator clips for live wires					

	Attach ignition system clips to igniter, wrapping the stripped igniter wires around the clip					

Once the vehicle has been properly inspected and is ready for launch, the safety officer will check for the following launch conditions. The team will comply with all TRA and NAR safety code. The following list will be followed and verified by the safety officer.

- Sky is clear
- Range is clear
- Safe location:
  - Outdoor in an open area
  - Wind speed are no greater than 20 mph
  - No dry grass near launch pad
  - No risk of grass fires
  - Countdown

Safety Officer: _____________ Date: _____________

Launch time: ______________

Troubleshooting

The outlines shown below highlight certain issues that may arise and ways in which to fix those issues. Various tests will be performed to verify that all system and components operate properly before launch.

Recovery System/ Altimeters(s)

The team will ensure that the altimeter is wired properly. The team will ensure that the altimeter relays a pattern of beeps that indicates continuity. In addition, a multimeter will be used to determine the location of discontinuity and new e-matchers will be used.

Igniter Installation

In case the motor fails to ignite then the igniter will be examined after a few minutes have passed.

Recovery System

The launch will be aborted if damage that occurs to any of the following the recovery components list below

- Main or drogue parachute
- Shock cords
- Altimeters
- GPS recovery system

Motor preparation
The test launch will be aborted if damage occurs to the motor or if it is missing components. The launch will only proceed of the motor can be repaired or replace. The motor will be prepared according to the user manual and the team mentor will ensure that the motor is properly assembled.

Launch Pad
In case the launch pad is broken or damaged, the launch might be aborted depending on the severity of the damaged. If the damaged or broken unit can be easily repaired or replace the launch will continue after a final inspection by the team lead and safety officer. Additional tools that are necessary for assembly and repairs will be brought to launch in case of an emergency.

Post flight Inspection
The post-flight inspection will consist of various inspection in order to determine the events that occurred during the flight. The inspection conducted after flight consist of examining all sections of the vehicle for damage and proper operation (all charges ignited), inspecting the altimeter for the altitude reading, and inspecting the payload for any damaged within the systems.

All the components on the launch vehicle will examined in order to determine if any damaged sustained by vehicle will prevent it from being reusable. A visual inspection will be conducted, ensuring that all system operated as planned. The compartment of the air frame such as the main and drogue parachute compartment will be inspected for any indentations, cracks and other damages. The parachutes will be examined for any hole or tears, the shroud lines will be inspected for any burns and snaps. The fins located on the booster section will be examined for any damages. Once this inspection is completed, the altimeters will be removed and inspected for damage.

The outer surface of the payload compartment will be inspected for any indentation or cracks. The payload will be removed from the bay and they system inside the payload will be inspected to ensure they are all systems are intact. The sample (egg) inserted inside the rack system will be inspected for cracks.

First, the altimeter will be removed in order to determine the altitude that the launch vehicle researched. The altimeter will reply the altitude via a series of beeps. The altimeters will be shut off once the altitude is obtained and recorded. Once the data is collected the rocket will be prepared for re-launch which consist of cleaning the motor, removing the eggs from the payload.

Table 48 outlines the procedures for inspection.

Table 48: Inspection for Damage and Collection of Data	
Steps	**Verified By**
Disarm recovery elections	
Examine launch vehicle for any cosmetic damage that may prevent re-launch	
Check igniters, determined successful charge ejection Igniters (Main 1): Yes/ No Igniter (Drogue 1): Yes/No Igniter (Main 2): Yes/No Igniter (Drogue 2): Yes/No *Note: "yes" indicates a successfully ignition charge and "no" indicates the igniter does not successfully ignite the charge*	
Examine parachutes and recovery system for any damage	
Examine parachutes and recovery system for any damage	
Examine altimeters and electronics for damage	
Turn on RRC2+ altimeters individually	
Check and record altitude reading from altimeters Altitude (Altimeter 1): ___________ Altitude (Altimeter 2): ___________	
Inspect the GPS to ensure damage has not occurred	

Table 49 shows the procedures for Launch Vehicle re-launch.

Table 49: Prepare Rocket for Re-launch	
Steps	**Verified by**
Clean motor and motor casing	
Remove fluids from payload	
Prepare parachutes, repair small tears	
Prepare all other system (refer to launch checklist to ensure proper assembly and preparation)	

NAR/TRA procedures

NAR/TRA Procedures
All team members are responsible for acknowledging and following the NAR High Power Rocketry Safety Code. Rick, the Rocket Owls team mentor has many years of experience in handling and constructing rockets and will inform the team members of any hazards and risk involved. The safety officer will work with the team mentor to enforce the required safety procedures. The mentor's responsibilities are as follows:

- Ensure compliance with the NAR High Power Rocketry Safety Code
- Assist in purchasing, transporting and handling of motors
- Oversee handling of hazardous material and operations
- Ensure the recovery system are installed properly
- Handling and wiring all ejection charge igniters
- Accompany the team to Huntsville, Alabama

Table 50 introduces a description of the team's compliances with the NAR Safety Code.

Table 50: NAR/TRA Safety Code and Compliance		
	NAR Code	**Compliance**
1	**Certification**: I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only team members with the appropriate level of certification and the team mentor, Rick, who has a Level 2 TRA certification, will be allowed to handle rocket motors.

2	**Materials**: I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	All team members are responsible for using appropriate material on the rocket.
3	**Motors**: I will use only certified, commercially-made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, or heat sources within 25 ft of these motors.	Only rocket motors certified by TRA/NAR will be purchased and be handled by TRA certificated members of the team. Rocket motors will be stored in appropriate locations.
4	**Ignition System**: I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The team leader and safety officer are responsible for ensuring that the integration at the launch site is performed following the TRA safety code.
5	**Misfires**: If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket in question.	The Range Safety Officer (RSO) will have final say over all misfires that may occur at the launch site. The team members will follow all final ruling of the RSO.
6	**Launch Safety**: I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket, I will observe the additional requirements of NFPA 1127.	The rocket will be presented to the RSO, who will determine if the rocket is safe to launch.

7	**Launcher**: I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour, I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5, clearing that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	All launches will occur at the launch site(s) listed in Table 5 and under appropriate launch conditions. Launches at other launch sites beside those listed in the proposal will not be allowed The RSO will determine if the rocket is safe to launch.
8	**Size**: My rocket will not contain any combination of motors that total more than 40,960 Ns (9208 lb-sec) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	The team leader will be responsible to ensure the rocket follows these constraints.
9	**Flight Safety**: I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	The RSO will have final say regarding the rocket being allowed to be launched.
10	**Launch Site**: I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 ft, whichever is greater, or 1000 ft for rockets with a combined total impulse of less than 160 Ns, a total liftoff weight of less than 1500 g, and a maximum expected altitude of less than 610 m	All launches will occur at the launch site(s) listed in Table 5, Launches at other launch sites beside those listed in the proposal will not be allowed. The RSO will determine if the rocket is safe to launch.

	(2000 ft).	
11	**Launcher Location**: My launcher will be 1500 ft from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	All launches will occur at the launch site(s) listed in Table 5, Launches at other launch sites beside those listed in the proposal will not be allowed. The RSO will determine if the rocket is safe to launch.
12	**Recovery System**: I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The team leader and safety officer will ensure that the recovery system adhere to all of these requirements.
13	**Recovery Safety**: I will not attempt to recover my rocket from power lines, tall trees, or other dangerous locations, or fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The safety officer will ensure that the team members follow this requirement.

Table 51 shows the minimum distance required to ensure the safety of participants and spectators during a rocket launch.

Table 51: Minimum Distance for Launch Safety

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or Smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Hazard Recognition and Pre-Launch Briefing

Before any construction, test, and launches the team will have a safety meeting. At this meeting the safety officer will brief all team members of safety regulations. The briefing will consist of an MSDS safety overview, as well as a review of safety protocols described in the safety manual. Team members will also be briefed on the purpose of using new materials and/or equipment. If safety risks are observed at any time, the team members will take the required steps to mitigate the risks. In addition, the safety officer will be informed so that he can proceed to resolving the situation and educating the parties responsible for the incident, in order to prevent the same situation from happening again. Moreover, all team members are expected to keep up to date with the regulations as changes and revision are made to protocols and regulation within the safety manual. The team safety manual covers the following topics:

- Lab Safety
- Material Safety Procedures
- Safety Protocols for Equipment Operation
- MSDS Sheets
- Launch Safety Procedure
- PPE Regulations

All MSDS forms for the proposal and the safety manual will be kept in binders located in the lab space where the rocket construction is being performed. Team members will refer to the binders before the handling of any hazardous material or chemicals. Furthermore, to avoid accidents, each team member must agree to and follow the rules outlined in Appendix B and the regulations and protocols outlined in the safety manual.

Pre-launch Briefing

Before any launches the team will have a pre-launch briefing. The briefing will consist of an overview of the safety procedures and rules associated with the launch site. In order to ensure the proper assembly and engagement of all project components, the team will create a protocol checklist. The checklist will include the necessary steps needed to prepare the rocket for launch. Several of the TRA certified team members will inspect the rocket and check off the list before presenting the rocket to the RSO. Team members will be reminded that all RSO rules are final and anyone displaying inappropriate behavior will not be allowed to launch the rocket and/or leave the launch site.

Caution Statements

The Rocket Owls will include caution statements for all plans, procedures, and other working documents. The safety Officer will ensure that these documents are available during the construction of the launch vehicle to reduce potential risk. Potential hazards during the construction process will be identified. Team members are expected to read, understand, follow, and enforce precautions stated in the MSDS report for every material used during construction. The Safety Officer will refer to the appropriate MSDS for specific safety guidelines and will remind all team members of proper usage of any machinery and/or chemicals prior to their use. Team members will not be allowed to work under fatigue or by themselves. Team members will remain focused on the task at hand and will be aware of their surroundings at all times. Prior to construction, the safety officer will demonstrate the proper use of PPE. Team members will dress appropriately for the lab space, including removal of loose clothing and jewelry, tying back long hair, putting on necessary gloves, and wearing appropriate eye protective glasses, and respiratory masks. Team members will act appropriate in the lab space, including cleaning the work space of any obstacles, turning off machinery when finished, properly storing chemicals and cleaning the work place when finished.

Rocketry Laws and Regulations

The Rocket Owls will perform test launches leading up to the NASA Student Launch competition at one of the following sites: Rocketry Organization of California (ROC), Friends of Amateur Rocketry Inc. (FAR), or Mojave Desert Advanced Rocket Society (MDARS). The aforementioned facilities work with the FAA to meet the following guidelines listed in the Federal Aviation Regulations 14 CRR, Subchapter F, Part 101:

- No person may operate an unmanned rocket:
- In a manner that creates a collision hazard with other aircraft
- In controlled airspace
- At an altitude where the horizontal visibility is less than five miles
- Into clouds
- Within five miles of the boundary of any airport

- Within 1.500 ft of any person or property that is not associated with the operations
- Between sunset and sunrise (Sec.6(c). Department of Transportation Act (49 U.S.C. 1655(c)) [Doc.No. 1580, 28 FR 6722, June 29, 1963, as amended by Amdt. 101-4, 39 FR 22252, June 21, 1974]

Any time an unmanned rocket is launched, the person operating it is required to contact the nearest FAA ATC facility 24-28 hours prior to the beginning of the operation to give them critical information. The facilities utilized by the team will provide the following information to the FAA ATC facility in compliance with this act:

- The name and address of the person designated as the event launch coordinator
- The estimated number of rockets operated
- The largest size rocket planned to be launched
- A maximum altitude which none of the rockets can surpass
- The location, date, time, and duration of the operation
- Any other pertinent information requested by the ATC facility [Doc. No. 1580, 28 FR 6722, June 29, 1963, as amended by Amdt. 101-6, 59 FR 50393, Oct. 3, 1994]

The team mentor will handle the low-explosives used by the team. Rick will closely follow the Code of Federal Regulation 27 Part 55: Commerce in Explosive as summarized below:

- Unless exempted by law, federal permits are needed to transport, ship, or receive explosive material. Permit must keep complete and accurate records of the acquisitions and dispositions of explosive material
- Obtaining a Federal license or permit does not permit any one from violating any state or local ordinance
- No person shall store any explosive material in any matter that violates applicable regulations

The Rocket Owls understand the importance of fire prevention and will do the following in accordance with the NFPA 1127 “Code for High Power Rocket Motors”:

- Material that are explosive and flammable will not be stored in a detached garage or outside
- Explosive material will be stored in a noncombustible container
- All storage of explosive will be with accordance with federal, state, and local laws
- Igniters will not be stored with explosives

Title 19, California Code of Regulations, Chapter 6, Article 3, §981.5(b)(6) defines the Pyrotechnic Operator -- Rockets Third Class license, which is relevant for the launching of high-power rockets in California. The California State Fire Marshall has established regulations that identify at least one pyrotechnic operator license at each launch event. This license permits the licensee to handle, supervise, and discharge rockets which produce an audible or visual effect in connection with group entertainment

Rocket Motor Usage Plan
Motors will be purchased, stored, transported, and handled by the team mentor, Rick, who is a Level 2 certified member by the TRA. Energetic devices, including e-matches and black powder will also be handled by Rick. Only rocket motors certified by TRA/NAR will be purchased from online stores. Motors will not be purchased from on-site vendors.

Storage
Motors will stay disassembled and be kept in the original packaging until launch day. If stored in secondary container, the container will be clearly labeled (including the NFA diamond). Ammonium Perchlorate composite motors will be stored in a cool, dry place away from sources of heat, flame or sparks. Igniters will be stored separately from the motor.

Transport
The main ingredient in a high-power rocketry motor is solid Ammonium Perchlorate Composite Propellant (APCP). As of January 2010, APCP is no longer included in the list of explosive material in the U.S. Bureau of Alcohol, Tobacco, Firearm and Explosive (ATFE). The motor will not require a permit or licenses to be transported to the launch sites. Therefore, the team will transfer the motor in the original packaging via an air conditioned vehicle. At the launch site, the motor will be kept in a shaded area. The motor used for the NASA Student Launch will be shipped to the launch site.

Use of Rocket Motor
Only TRA/NAR certified members will handle the rocket motor. Before using a rocket motor, simulation of the flight using that specific motor will be done.

Safety Contract
The Rocket Owls consent to and will adhere to the relevant regulations to high-power rocketry and project team safety as stated in the Student Launch Handbook, distributed by NASA. The rules listed below are included in the safety contract.

1.6.1 Range safety inspections of each rocket before it is flown: each team shall comply with the determination of the safety inspection or may be removed from the program.
1.6.2 The RSO has final say on all rocket safety issues. Therefore, the RSO has the right to deny the launch of any rocket for safety reasons.
1.6.3 Any team that does not comply with the safety requirement will not be allowed to launch their rocket.

All members of the Rocket Owls are required to sign a safety contract in order to engage in any construction or participate in launches. The safety contract can be found in Appendix B.

Table 52 lists the team's possible risks to the successful completion of the project, likelihood of those risks, impact of those risks, mitigations, and impact of those mitigations.

Table 52: Project Risk and Mitigations				
Risk	**Likelihood**	**Impact**	**Mitigation**	**Impact of Mitigation and Resolution**
Project falls behind scheduled	Low	High	The team has strict timelines that must be followed. Inability to complete designated work in the permitted time will result in possible termination.	If a team member is removed the work load will significantly increase for the remaining team members, but precautions have been taken to limit the severity of this transition.
Unavailable equipment	Low	Low-High	The team has made sure that all items needed for the project are available and can be shipped in a timely manner to meet projected completion dates.	No significant impact results from this mitigation.
Lose of equipment	Medium	High	The team will have several copies of each piece of equipment that will be used throughout the project.	If too many piece of equipment are broken or lose the budget will increase, but the team is prepared to fundraise any additional fund that may be necessary to complete the project.
Equipment malfunction	Medium	Low-High	The team will test the equipment multiple times	No significant impact results from this mitigation.

			before inserting it into the rocket to ensure that the equipment's performance is at the desired level.	
Project exceeds budget	Low	High	The team has planned their project budget lower than the total funding invested in the team. Also, the team is willing to hold fundraisers to receive any additional funds that will be needed if the team does exceed the budget limit.	If the team is required to host a fundraiser the time taken to organize and conduct the event will affect the team's set timeline, but a new timeline will be made quickly to recalculate the dates and times of items must be finished by, if needed.
Failure to launch	Medium	High	The team will set multiple launch dates to ensure that a successful launch will be recorded in time for the competition checkpoints.	If the team must reschedule the launch date the entire timeline will get pushed back, but the team has designed the timeline to allow multiple launch dates.
Unsuccessful recovery	Low	High	The team will build two rockets simultaneously in case the rocket is totaled or lost.	If the team must build more than the two planned rocket the budget may go over, but the team is prepared to host fundraisers to purchase the required materials.
Lose of team member	Low	High	The team has constructed the project tasks in	If the team must increase their individual work

			such a way that if a team member were to leave the work load could be easily distributed amongst the remaining team members.	load there is a slight chase the project may fall behind schedule, but new timelines will be made to accommodate changes to redirect the project back on schedule.

Environmental Concerns

The harmful effects the project may have on the environment must be considered. Safety precautions will be taken to limit or remove these harms form the environment and its surroundings. Plausible environmental harms and their mitigation are discussed next.

While working on site the team will create some waste. Examples of waste the team may create include but are limited to: fiber glass resin and hardener, combination of fiber glass resin and hardener, plastic (i.e. water bottles, bags, etc.), epoxy resin and hardener, combination of epoxy resin and hardener, steel nuts, copper springs, black powder, sheer pins, and e-matches. Negative outcomes due to waste include but are not limited to: soil and water contamination, damage to wildlife. To prevent contamination and wildlife endangerment the team will adequately dispose of the waste in a designated container.

The team will be handling an unknown material. This material may be able to cause sever harm to anything it comes in contact with. In order to prevent possible harm to, or caused by the unknown material the team has constructed a container that will protect the material, as well as anything surrounding the unknown material (container discussed in next section).

During and after launch there are several environmental hazards that may occur. When the rocket it taking off the motor will create a strong flame and thrust. This flame has the power to create a wildfire. To avoid this the team will be launching in designated areas away from dry brush. The motors thrust will cause damage to the ground below it. The team will minimize the overall effect of the motors thrust to the ground below the launch rail by only launching the necessary amount of time to meet the requirements of the NASA student launch competition. After the rocket has launched there is a slight possibility that it may collide with aircraft or surrounding buildings. The team will steer clear of launching while there are low clouds or aircraft in launch area. Additionally, the rocket will not exceed the permitted max altitude to avoid collisions with aircraft that may not be visible from the ground. Furthermore, the launch area is located in a field that is a safe distance from any buildings. After launching the rocket could possibly fly directly into an object in the near vicinity. The team will construct the rocket to assure that this will not happen (rocket construction safety discussed in previous section). Additionally, the team will make sure the launch rail is in the correct position and is secured before launching the rocket. Equally important, after the rocket reaches apogee the parachutes have a small chance of failing causing the rocket to come down ballistic resulting in harm to the environment and/or wildlife.

The team will have a redundant altimeter system in the avionics bay to ensure deployment of the parachutes (discussed in recovery section).

It is important to consider the how the environment might affect the rocket. Actions will be taken to reduce the effect the environment has on the rocket. Weather-related concerns may cause damage to the vehicle. To prevent this, the rocket will not be launched if the weather is not permitting. These weather concerns include: wind speeds greater than 20 mph, heavy rain, lightning, and severe storms. In addition, the rocket will be launched in an open area where the vehicle cannot be damaged by the surroundings.

Table 53 lists the hazards and mitigations relating to the environment and the dangers it poses both to the team members and a successful launch.

Table 53: Environmental Hazards and Mitigations						
Hazards	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification**
Aircraft overhead (helicopters, planes, drones)	N/A	Inability to launch	1A	The team will Check the skies for any overhead aircraft and wait until they pass if one is present.	4A	Prelaunch procedures
Wild animal encounters	N/A	Injury to team member(s), possibly death	1C	The team will pay close attention to the dangers of the surrounding environment including any poisonous or threatening wildlife that may be in the surrounding area. The team will wear close-toed shoes and long pants at all times when working in such an environment.	3C	N/A
UV damage	Sun	Inability to launch rocket, damage to	2A	The team will work in shaded area and keep	2E	Safety procedures

		electronics, and possible explosions		all components from being exposed to the sun for too long.		
Dangerous weather conditions (wind, rain, extreme heat, extreme cold)	N/A	Inability to launch, damage to electronics and rocket	2C	The team will plan ahead and check weather conditions for the launch day. Keep rocket electronics and parts in the shade when not in use.	3E	Prelaunch procedures
Heavy and/or low clouds	N/A	Inability to launch rocket	2C	The team will plan ahead and check the forecast for set launch days.	4E	Prelaunch procedures
Heat stroke	Sun	Unconsciousness and possible bodily harm	1D	The team's work will be conducted in a shaded area if possible and water will be available when exposed to extreme weather conditions.	4D	Safety procedures
Hazard to successful rocket retrieval (trees, telephone/power lines, highways or moving vehicles)	N/A	Damage to rocket and/or loss of rocket	1D	The team's rocket will be launched in an unpopulated area away from trees, telephone/power lines, highways or moving vehicles to ensure its safe retrieval.	4D	Prelaunch procedures
Sunburn	Sun	Skin Irritation and pain	3D	The Team will apply Sunscreen when necessary and work will be conducted in	4E	Safety Procedures

				the shade whenever possible		
Humidity	N/A	Inability to light motor or black powder	3D	The team will keep the ematches, motors, and black powder stored in a safe location away from the humidity.	4E	Prelaunch procedures
Muddy ground	Rain	Inability to launch, possible injury to team members due to failing or getting stuck in mud	3D	The team will Check the forecast for heavy rains, if the rain was too strong the team will reschedule the launch date.	4E	Prelaunch procedures
Bodies of water (lakes, ponds, rivers)	N/A	Loss of rocket, and damage to electronics	1E	The team will check the landscape to make sure there are no large bodies of water near the launch site.	4E	Prelaunch procedures
Motor overheating or exploding	Sun	Injury to team member(s) and/or surrounds	1E	The team will keep the motor in a cool area at all times before launch.	4E	Safety procedures

V. Payload Criteria

5.1 ***Design of Payload Equipment***

The team has chosen to go with the second payload design shown in figure 47. The cylindrical shape of the container makes it easy to insert and extract into the payload bay of the launch vehicle. Figure 8 displays how the payload will rest inside of the payload bay. After many considerations and trials, the lid adapter and lid shown in figure 48 were found to be the optimal choice both financially and resourcefully. The lid adapter will be cemented onto the outer shell wall using rocket epoxy. The outer shell and inner chamber will be made of polycarbonate tubing. The base of the outer shell will be created by cutting out a disk with a 5.25" diameter out of a 0.25" polycarbonate sheet and sealed onto the bottom of the 5.50"x5.25" tube using rocket epoxy. The 4.50"x4.25" tube will be used to make the inner chamber that will be attached to the base of the outer shell using rocket epoxy. Polycarbonate was the most favorable material choice because "It has high strength, toughness, heat resistance, and excellent dimensional and color stability [and] One of the biggest advantages of polycarbonate is its impact strength." [14] The 9% borated flexi panel shown in figure 51 was chosen because it "is a flexible light-weight sheet material with relatively high boron content of 9% (natural isotope distribution) that produces an attenuation factor of 22 for thermal neutrons. [The borated flexi panel] also includes a hydrogenous additive that helps slow the fast neutrons and can reduce the overall radiation field." [15] The flexi panel is also easily cut and can be wrapped around a small circumference which gave the team the opportunity to place the flexi panel wherever it may be needed. Due to budget limitations the team will use a substitute material for the borated flexi panel. The substitute material will have the same density and physical properties as the original flexi panel to insure the integrity of the design is held. The aerogel isolator shown in figure 52 was chosen because according to NASA it is the best and lightest insulator on the planet with a thermal conductivity of 0.016 – 0.03 (W/mK) at 25 deg C. [16] The flexi panel and aerogel layer will be placed inside the outer shell wall (shown in figure 56) to increase the protection of these layers while also decreasing the total diameter of the container. The Borated substitute material will be attached to the outer shell using a thin layer of rocket epoxy. The 0.25" gap in between the aerogel and inner chamber will be utilized as a liquid compartment. A maximum volume of $21.05in^3$ can be held inside the liquid compartment. To keep the liquid from getting contaminated by the flexi panel and/or aerogel a thin plastic sheet will enclose the flexi panel and aerogel layers. The top of the liquid compartment will be sealed with a cover made from a 0.25" polycarbonate sheet. To increase the capability of the seal on the liquid compartment the cover will have rubber applied to the inner and outer diameter. Figure 53 shows the final design of the team's inner rack. The silicon disks will be stationed by three 0.125"x12.25" steel rods. Silicon was chosen as the material for the disks because of its flexibility, high heat resistance, and strength. 16 separate silicon disks will be used to make the eight separate compartments. The compartments will be held in place by three nuts on the bottom of the bottom disk and 3 nuts on the top of the top disk to hold them in place. In between the disks there will be three springs on each metal rod to increase the overall tension and grip of the disks on the desired material this process will be further explained in the payload integration section. A handle will be made out of 0.25" plywood and will be placed at the top of the inner chamber rack to allow the rack to be inserted and removed from the container quickly and easily.

4.2 *Sample Placement Process*

Upon retrieval of the unknown sample(s), if the sample(s) is a solid, the inner rack of the container (shown in figure #) will begin outside of its corresponding inner chamber compartment. Then the silicone disks of the inner rack will be adjusted manually by sliding the metal nuts holding the silicon disks in place, up or down over the threaded metal rods, to have the correct number of compartments and space for each object being placed inside. As well as isolating each sample from the rest. The silicone disk compartments may be manually adjusted to fit 1-8 objects. The objects will be placed into their individual compartments one at a time. The team will then manually screw the metal nuts on the threaded rods, both above and below the silicone disks, until the silicone disks are taut over and under the sample(s). This process will be repeated until all of the objects are secured between the silicone disks of the inner rack. Once the inner rack is full and secured, it will be inserted into the inner chamber of the container and sealed closed with threaded fitted cap. If the sample is a liquid, it will be carefully poured into the liquid compartment, then the cover will be secured, and lastly the entire container will be sealed with the fitted cap.

5.3 *Payload Incorporation*

The container assembled as outlined above is manually inserted into the payload bay of the rocket between a single bulk plate and the nosecone shoulder (see Figure 13). The bulk plate will be constructed from 0.50" thick birch plywood, and will be cut using a CNC router. The bulk plate will be located forward of the main parachute. The nosecone shoulder and bulk plate will aid in the stability of the proposed container within the body of the rocket. To further increase the stability of the payload during flight a thin layer of mega foam will be added to the payload bay.

5.4 Final Design Drawings (all measurements in inches)

Figure 47: Fully Assembled Payload

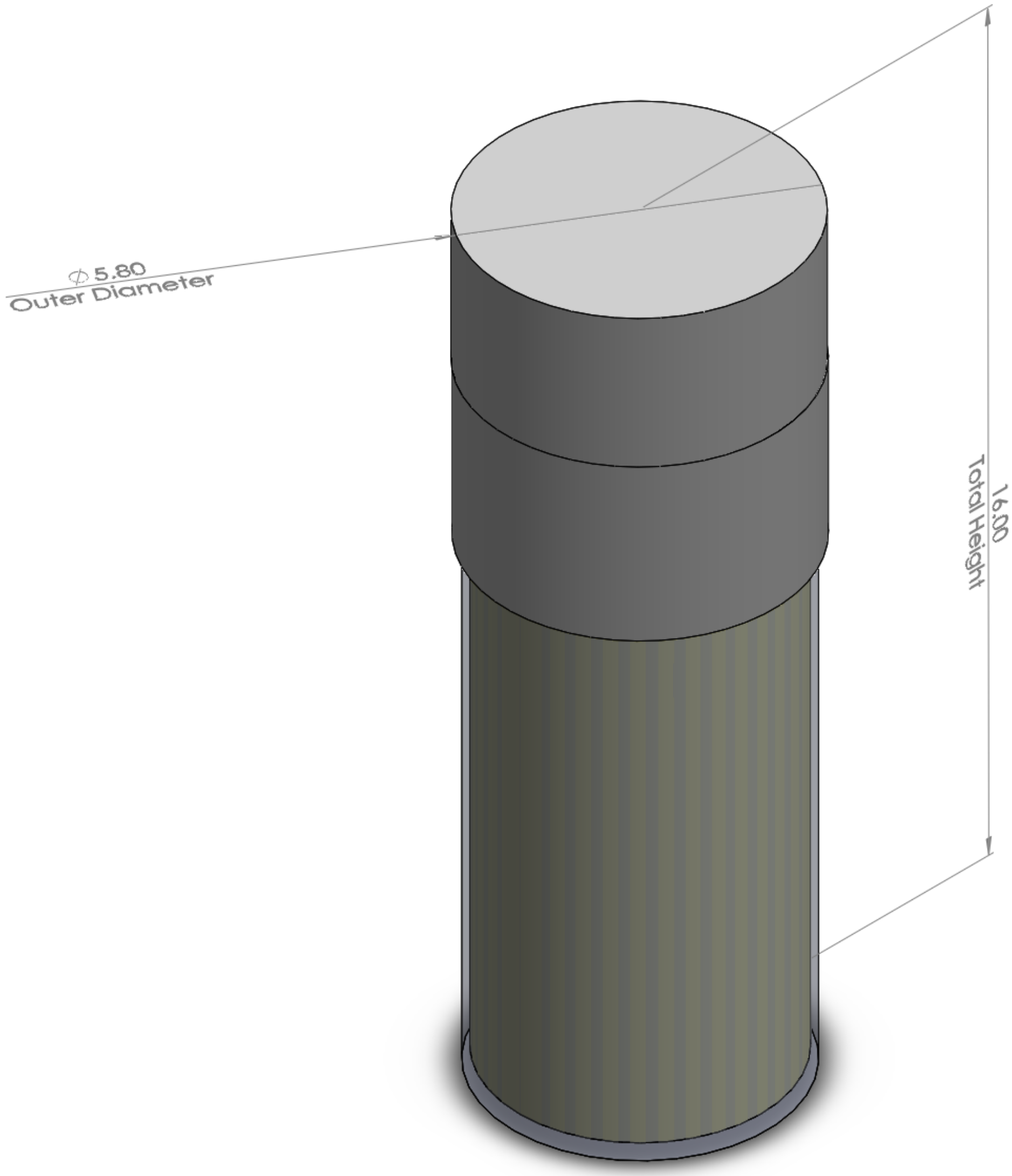

Figure 47 shows an isometric view of the fully assembled final payload design

Figure 48: Lid and Adapter

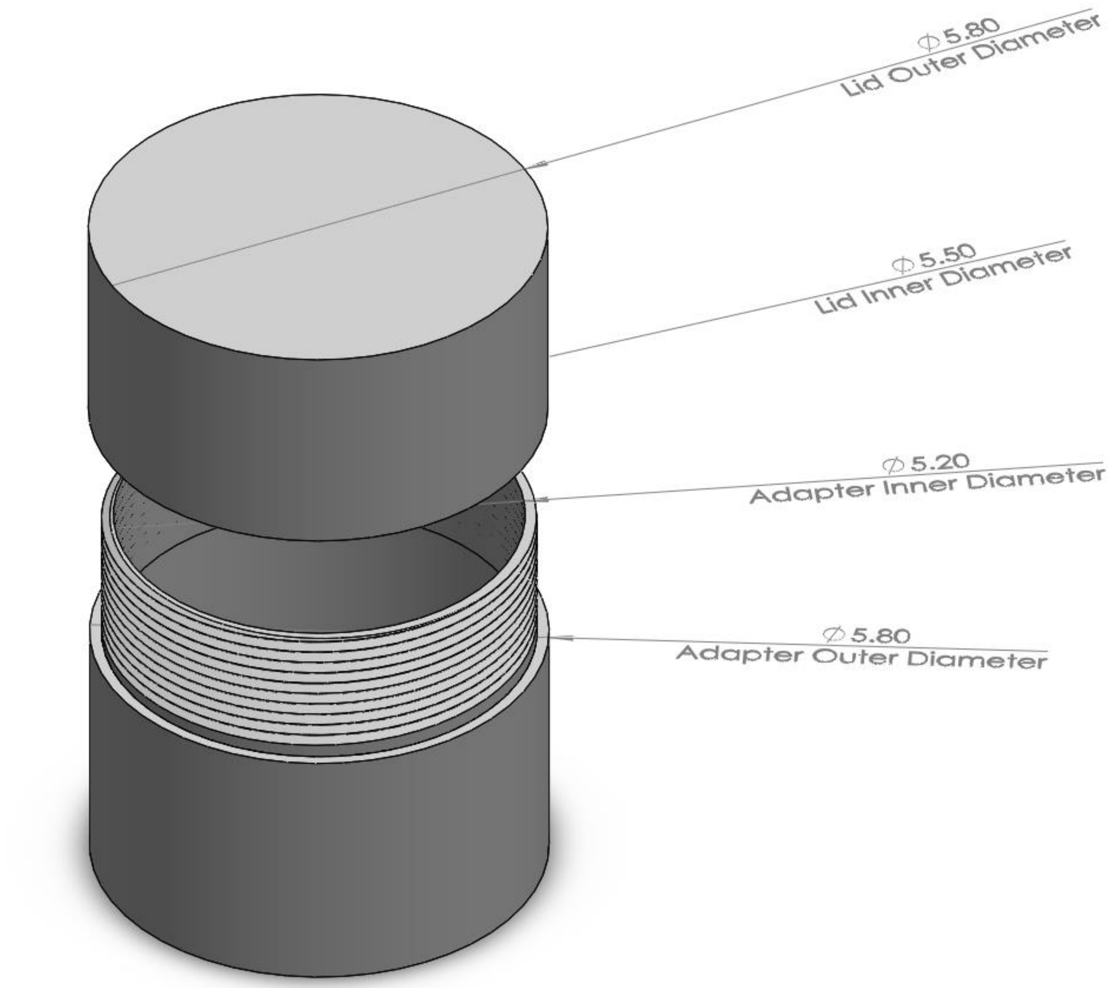

Figure 48 shows the lid and adapter for the final payload design

Figure 49: Outer Shell

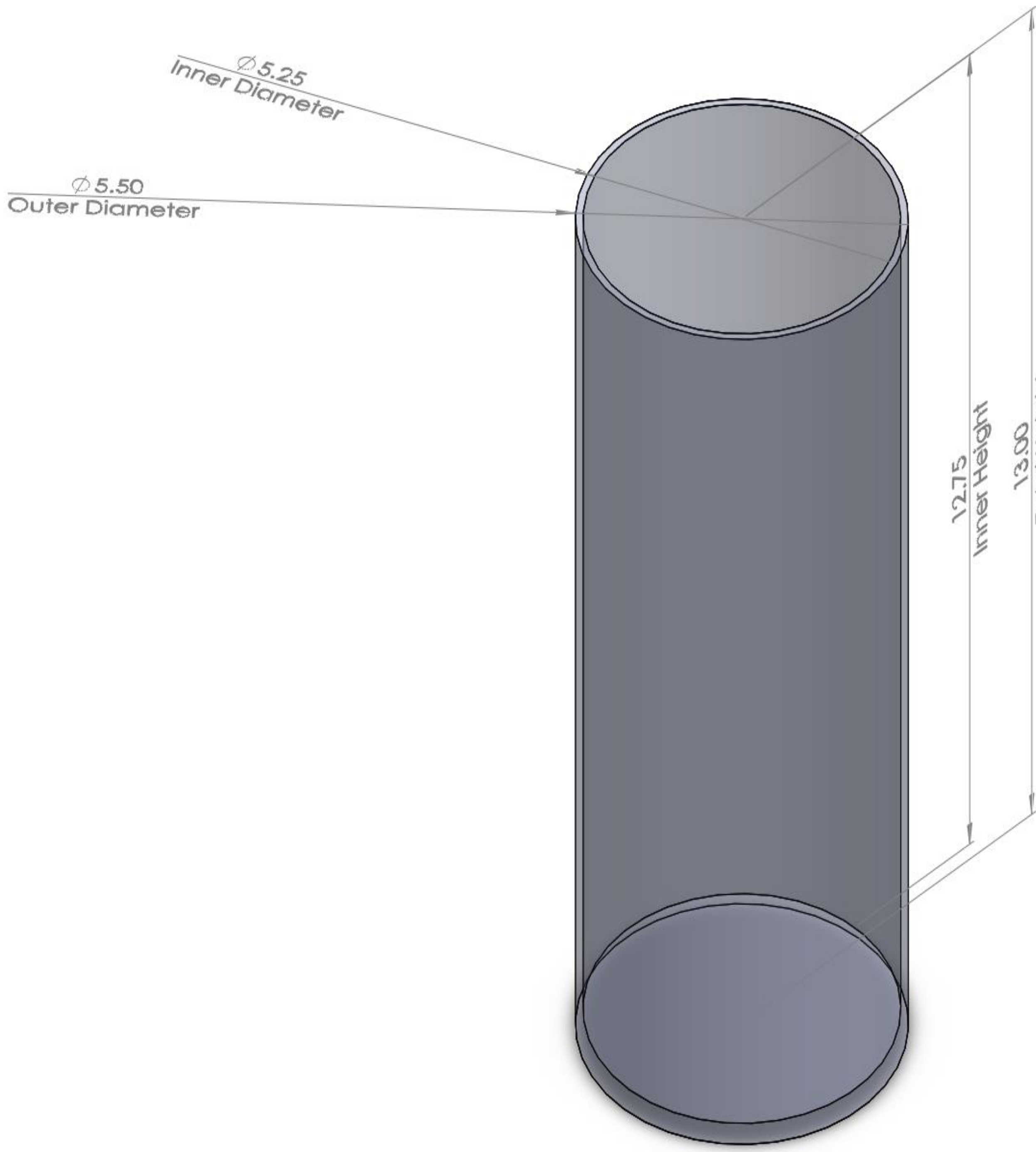

Figure 49 shows an isometric view of the outer shell for the final payload design

Figure 50: Inner Chamber

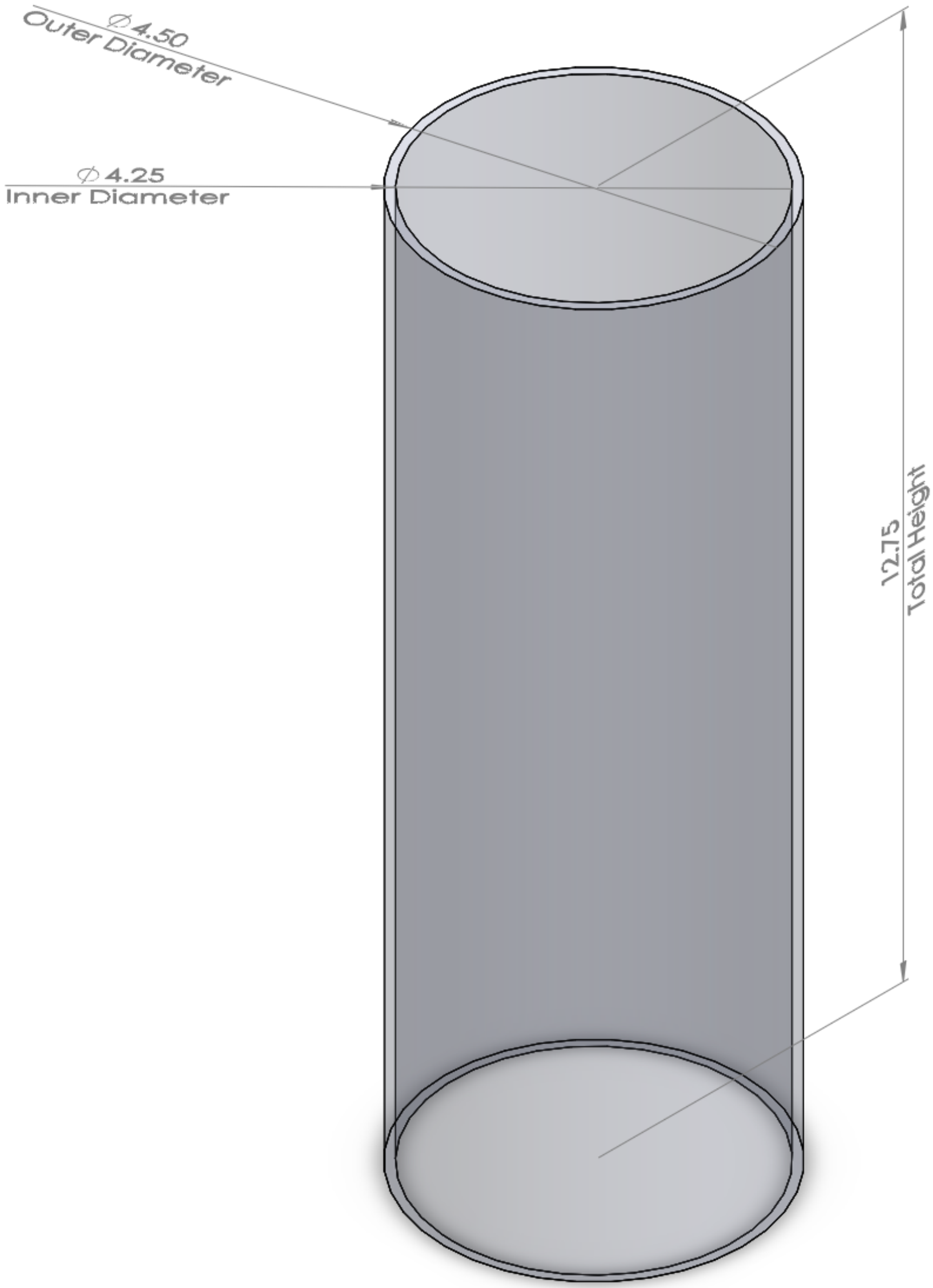

Figure 50 shows the inner chamber of the final payload container design

Figure 51: Radiation shield

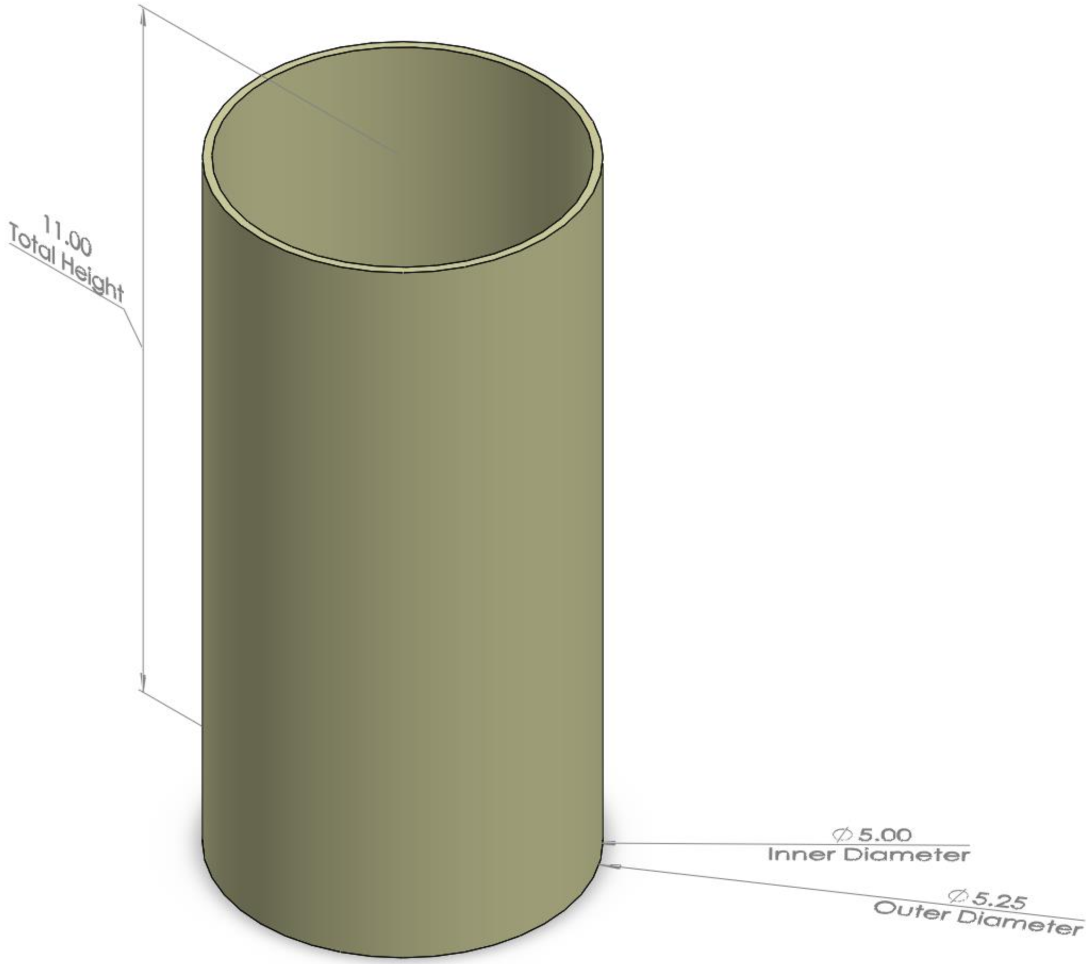

Figure 51 shows the radiation shield of the final payload container design

Figure 52: Aerogel

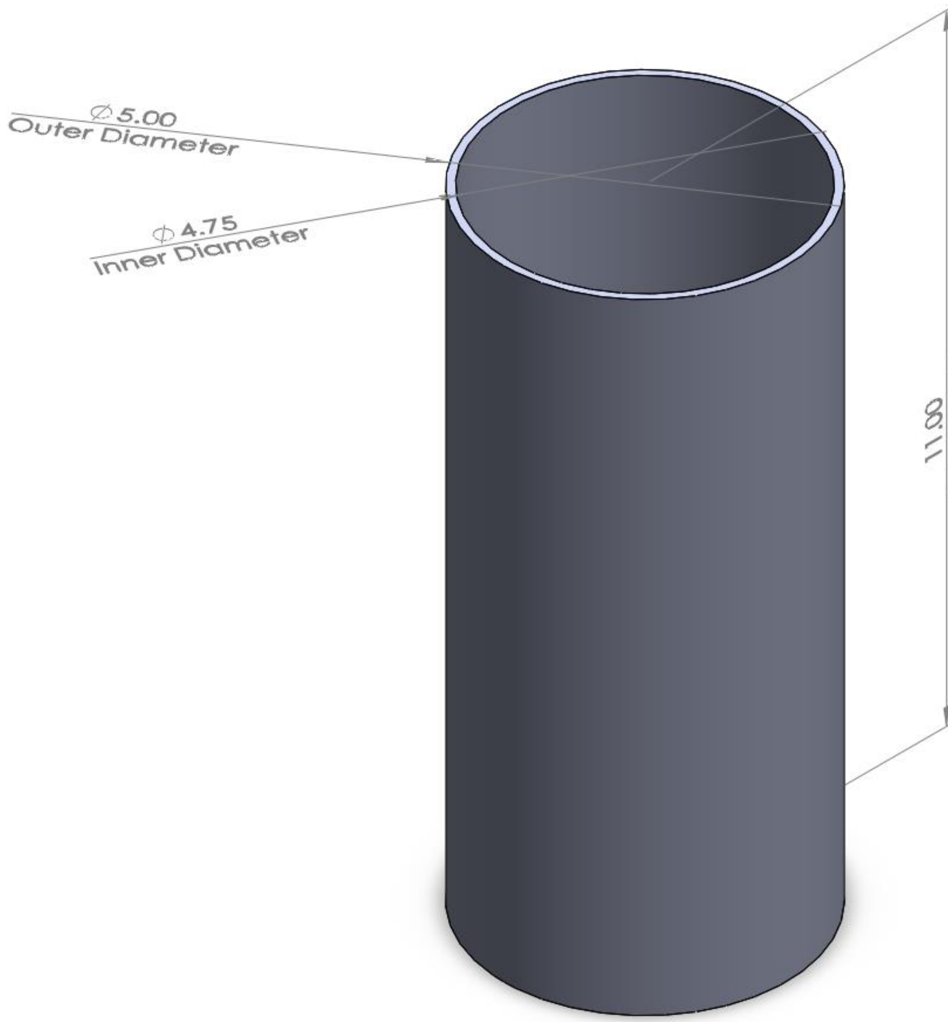

Figure 52 shows the aerogel layer for the final payload container design

Figure 53: Inner Rack

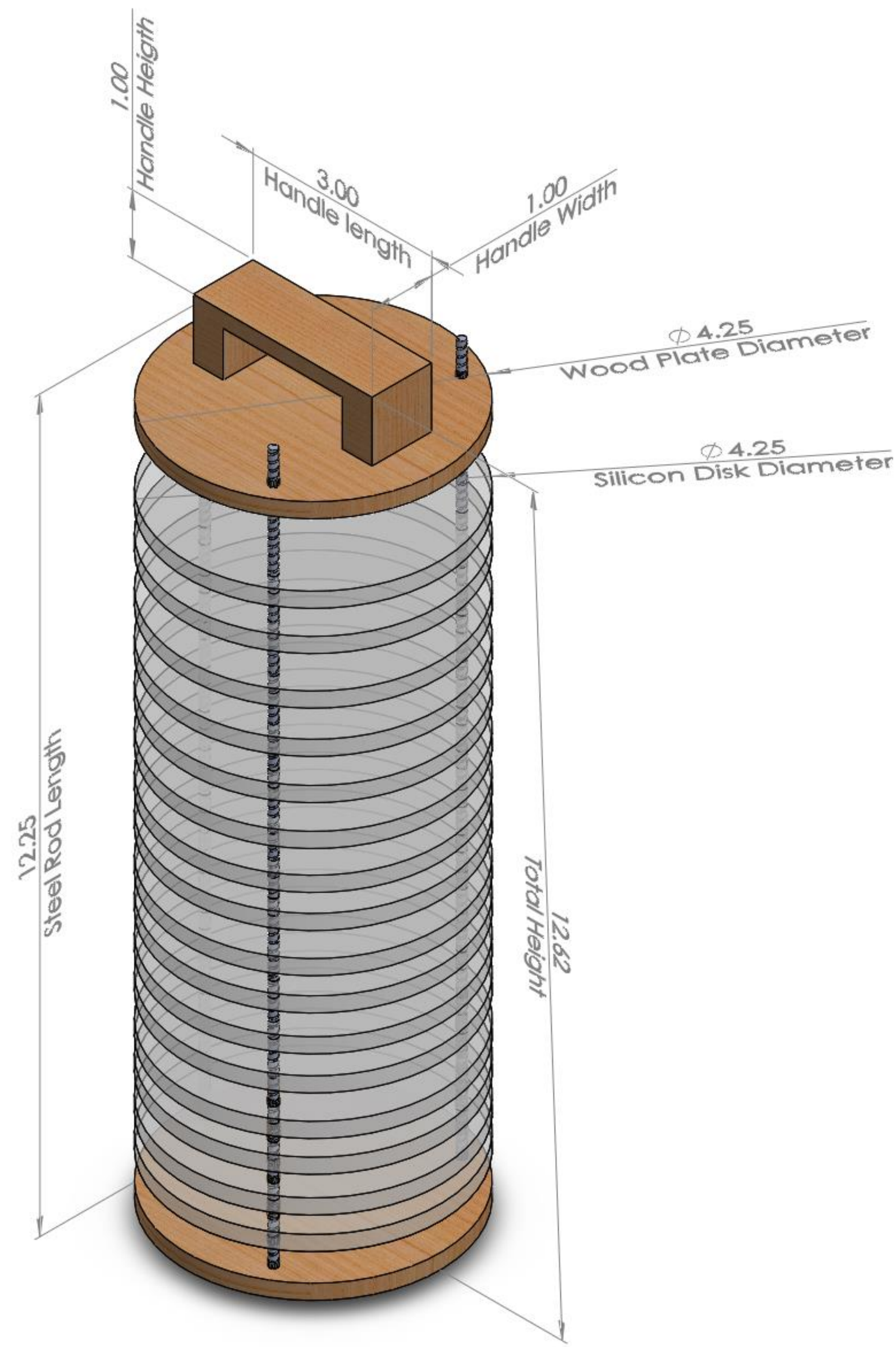

Figure 53: Shows the Inner rack of the proposed container.

Figure 54: Inner Rack (close up view)

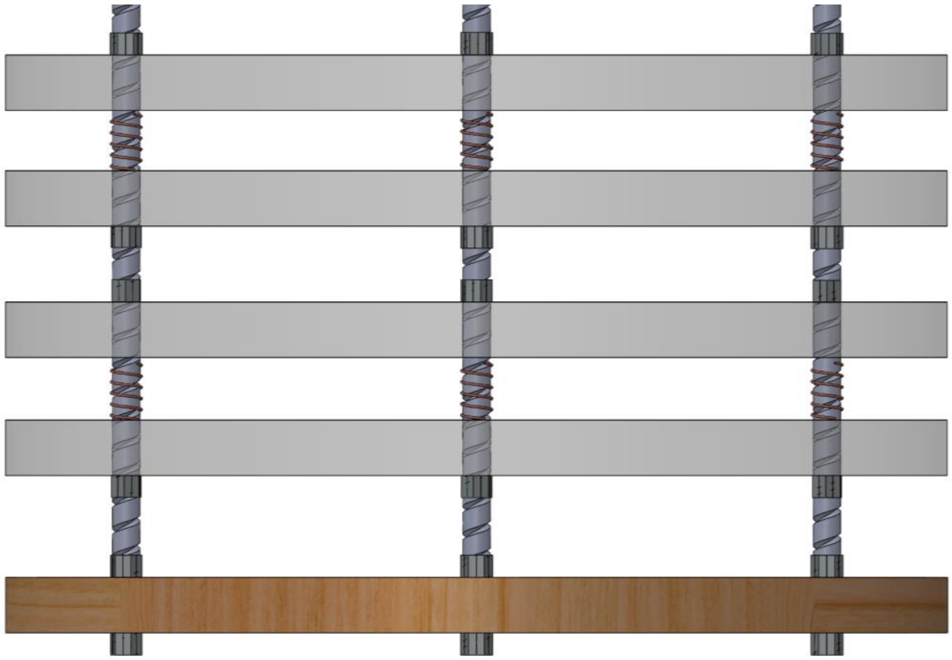

Figure 54 shows a close up view of the subsections within the inner rack of the container

Figure 55: Inner Rack Spring

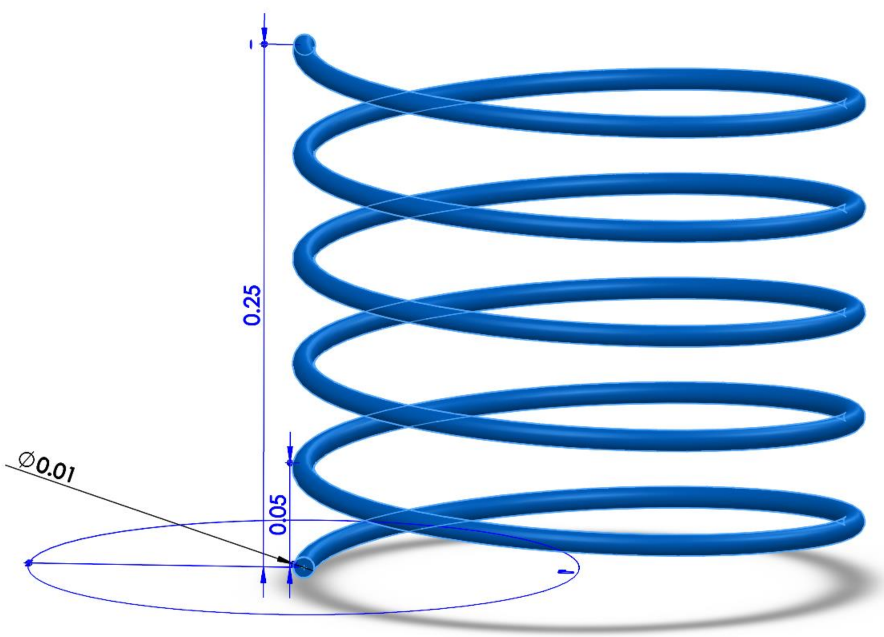

Figure 55 shows the spring(s) being used in the final payload design

Figure 56: Cross Section of Final Payload Container Design

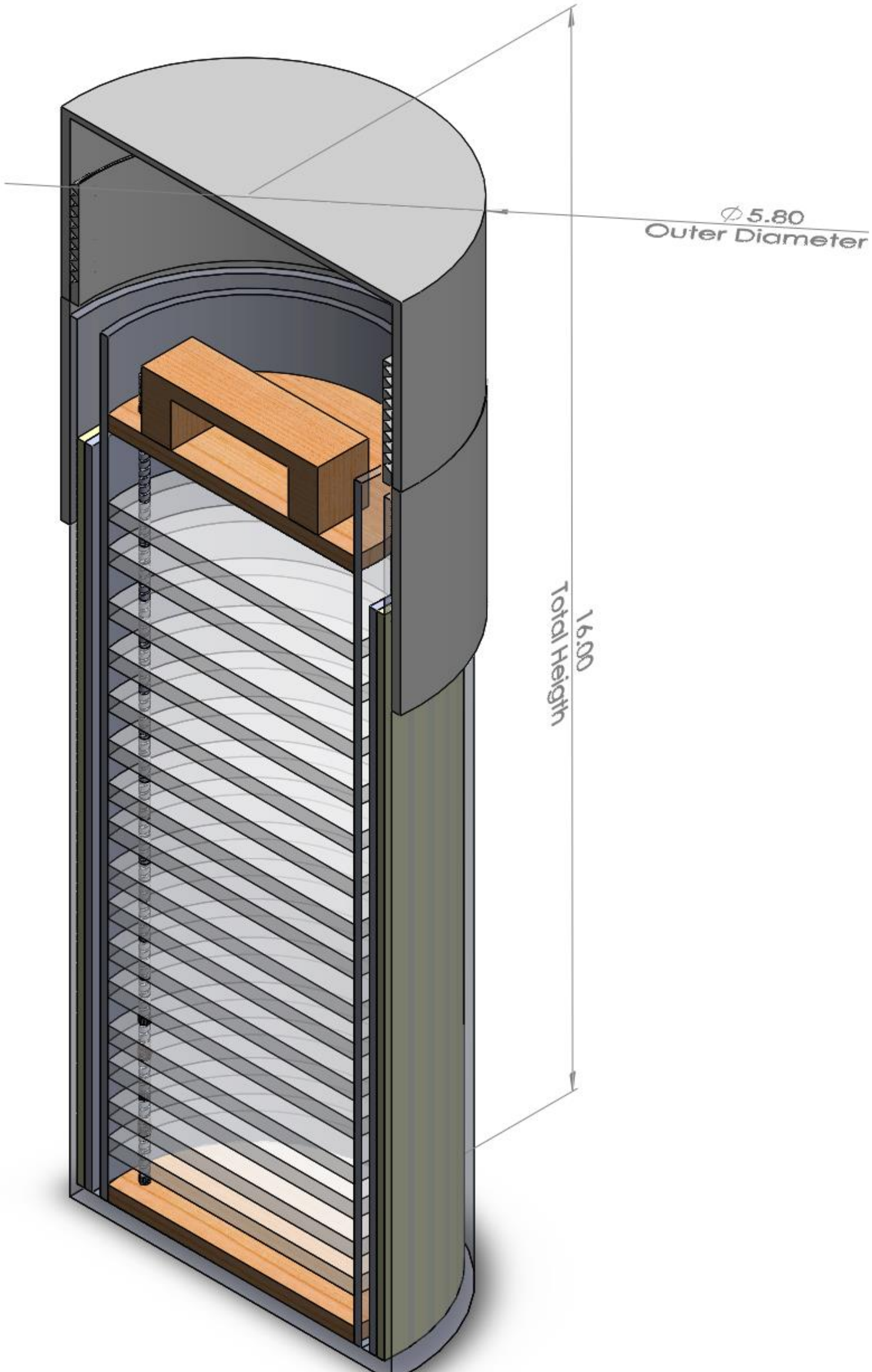

Figure 56 shows a cross section of the final payload container design

Figure 57: Final Payload Container (Exploded View)

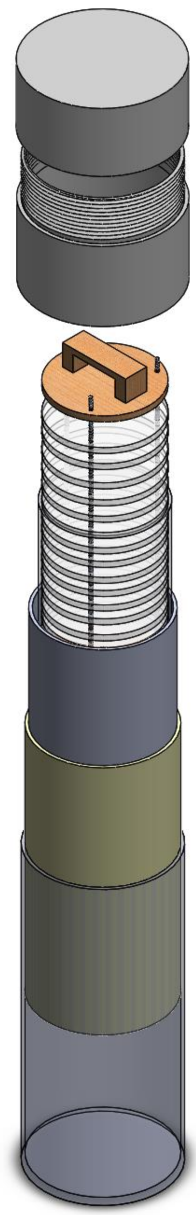

Figure 57 shows an exploded view of the final payload container design

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VI. Launch Operations Procedures

6.1 *Launch Operation Procedures*

Tables 54-60 outline the preliminary procedures required for all launch vehicle systems along with the corresponding potential hazards caused by disregarding a step. The safety gear and personnel required to complete and verify the steps are listed in the tables below.

6.1.1 *Recovery Preparation*

Table54 lists the preliminary procedures for the recovery preparation as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 54: Recovery Preparation			
Parachutes			
PPE	**Preliminary Procedure**	**Hazards**	**Verified By**
-Nitrile gloves -Safety glasses	Calculate volume of airframe to ensure the correct amount of black powder is utilized	Miscalculating the mass of black powder can result in the airframe not detaching at the set altitudes which can result in damage to the launch vehicle. If too much black powder is used the airframe may be damaged when the parachutes are ejected.	Safety officer
-N/A	Run launch simulations to determine the proper parachute size	Improper parachute choice can result in a drift or terminal velocity increase. This may result in a loss of or damage to the launch vehicle.	Two team members
-N/A	Conduct parachute compartment volume calculations to ensure that the folded parachute and its corresponding attachments fit within the compartment	Improper parachute choice may result in necessary alterations to the launch vehicle design.	Two team members
-N/A	Run launch	If the drift value is not	One team member

	simulations to determine the maximum drift	determined the launch vehicle may exceed the 2500 ft radial drift limit.	
-N/A	Use descent velocity of parachutes to determine the kinetic energy of each independent section of the launch vehicle	Not verifying the descent velocity may result in using parachutes that cause high descent rates resulting in a kinetic energy that exceeds the 75 ft-lbf limit. This may result in the launch vehicle being damaged upon landing. The descent velocity may also be too low, which will result in an increase of drift and a possible loss of the launch vehicle.	Two team members
Electrical Components			
-N/A	Store altimeters and GPS devices in ESD bags and handle them carefully	Failure to do so may result in clogged barometric pressure holes potentially leading to inaccurate or absent altitude relays.	One team member
-N/A	Secure altimeters and GPS devices onto sled with zip ties	Improperly secured electronic devices may result in them becoming damaged or disconnected from their power sources.	One team member
-Respiratory masks -Safety glasses	Secure wire connections with solder or with snap-together JST connectors	Improperly secured wires may become disconnected and result in failure of electronics. This may lead to parachute deployment or GPS failure causing an unsuccessful recovery of the launch vehicle.	One team member

-N/A	Connect the electric components to the JST connectors independently	Connecting more than two wires per JST unit will short circuit the electronics.	One team member
-N/A	Tape female and male JST connectors to each other prior to launch	Improperly secured JST connectors may result in disconnection from the circuit and prevent the current from flowing which will results in electrical failure. This may lead to parachute deployment or GPS failure causing an unsuccessful recovery of the launch vehicle.	One team member
-N/A	Twist standard wires into a 180° hook in a clockwise direction, before connecting them to a screw terminal	Improper wire connections may result in failure of electronics. This may lead to parachute deployment or GPS failure causing an unsuccessful recovery of the launch vehicle.	One team member
-N/A	Secure batteries with zip ties	Improperly secured batteries may result in failure of electronics. This may lead to parachute deployment or GPS failure causing an unsuccessful recovery of the launch vehicle.	One team members
-Safety glasses	Secure bundled wiring with heat shrink tubing	Improperly secured wire bundles inside the avionics bay may result in disconnection due to strain on the wire connections. This may lead to a failure of electronics or parachute deployment and GPS failure causing an	One team member

		unsuccessful recovery of the launch vehicle.	
-N/A	Utilize stranded 22-gauge wire	Improper wire selection may result in an inefficient flow of current.	One team member
-Temperature resistant gloves	Insulate bare wires and soldered joints with heat shrink tubing	Improperly insulated wires may result in short circuitry due to wires crossing. Wires may also become disconnected.	One team member
-N/A	Strip wires to expose 0.4 in of the wires	Improperly stripped wires may result in poor connection which may impede the electrical current from flowing.	One team member
-N/A	Test continuity of circuits with a multi-meter	Improper inspection of the circuit may result in defective circuits being undetected. This may result in a failure of the electrical system.	One team member
Avionics Bay			
-Safety gloves -Full face shield -CNC enclosure	Utilize the CNC machine to cut two bulkheads with a 6.0 in diameter and two bulkheads with a 5.9 in diameter.	Improperly cut bulkheads may not fit into the airframe resulting in an improper connection between the couplers and the airframes.	One team member
-Safety goggles -Nitrile Gloves -Respiratory masks	Utilize rocket epoxy to adhere the 6.0 in bulkhead to the 5.9 in bulkhead	Improperly secured bulkheads will weaken the seal of the avionics bay and may not be able to withstand the force of parachute ejection which may lead to the parachute being disconnected from the launch vehicle.	One team member
-Safety glasses -Safety gloves	Drill holes in the bulkheads for the	Improperly drilling holes into the	One team member

-Masks	threaded metal rods and wiring	bulkhead may lead to an excess of holes, which will weaken the bulkhead and allow foreign materials to enter into the avionics bay.	
-Safety glasses -Nitrile gloves -Respiratory masks	Epoxy terminal blocks to bulkheads	Improperly epoxying the terminal blocks will cause terminal blocks to fall off of the bulkhead which will result in having a nonfunctional recovery system.	One member
-Eye protection -Safety gloves -Full face shield	Use miter saw to cut 0.25 in brass tubing to proper length and epoxy to electronics sled	If brass tubing is cut too small, the surface area available for bonding to the sled would not be sufficient.	One team member
-Safety glasses -Safety gloves	Drill holes onto the electronic sled for the Nylon standoff	Nylon standoff will not be properly mounted onto the electronic sled, and/or damaged to nylon will occur.	One team member
-N/A	Insert nylon standoffs into pre-drilled holes on the electronics sled	Failure to incorporate the standoffs will result in improper mounting of the RRC2+ altimeters and thus impede its function.	One team member
-N/A	Secure RRC2+ altimeters to respective standoffs	Failure to properly mount the RRC2+ altimeters will result in improper mounting of the RRC2+ altimeters and thus impede its function.	One team member
-Safety glasses -Safety gloves	Drill holes on the avionics sled for zip ties	Zip tie reinforcements on components would not be possible.	One team member
-N/A	Place batteries on the electronics sled and	Improperly secured batteries will	One team member

	secure with zip ties	disconnect from the altimeters rendering the recovery system will be obsolete.	
-Safety glasses -Nitrile gloves	Epoxy two 2 in PVC tubes(ejection canisters) onto the avionics bulkheads	Failure to secure the ejection canisters with epoxy could spill the black powder and thus not ignite.	One team member
-N/A	Color coordinate the wired electronics (a color per component)	The absence of color coded wires will increase the overall time to fix any arising issue with wire connections.	One team member
-N/A	Bundle loose wires into a harness	Failure to bundle the wire in a neat fashion could result in wire entanglement causing unnecessary stress on the wires resulting in tearing and/or snapping at the junctions.	One team member
-Safety glasses -Safety gloves	Drill holes on the avionics bay bulkheads for e-matches	Absence of these holes would yield difficulty in conducting ground ejection tests.	One team member
-Safety glasses -Nitrile gloves	Cover e-match holes on the bulkheads with epoxy upon successful ground ejection test completion.	Failure to cover the hole on top of the avionics bay could cause the altimeters to give an improper reading of the altitude, due to potential pressure fluctuation.	One team member
-N/A	Mount electronics sled to threaded rods with necessary bolts and washers	Failure to mount electronics sled to threaded rods with bolts and washers could cause the sled to move around in the avionics bay and damage the electronics on the	One team member

		sled.	
-Safety glasses -Safety gloves	Drill properly sized static ports to the altimeter bay	Improper amount and/or size of a static port will affect the altimeter altitude readings. Failure to have multiple ports evenly spaced around will not help cancel the effect of strong winds.	Two team member
Main Parachute Bay			
-N/A	Measure and mark Blue Tube to 27.5 in in length	Failure to measure out the proper length could cause the launch vehicle dimensions to deviate from its design	One team member
-N/A	Wrap the Blue Tube with masking tape along the marked length	Failure to wrapped tape on the location mark could cause the Blue Tube to be cut at the wrong location.	One team member
-Face shield -Safety gloves	Cut Blue Tube to the marked length with miter saw	Failure to cut coupler tube with a miter saw will cause the cut to become slanted.	One team member
-Face shield -Safety gloves -CNC enclosure	Cut bulkheads with CNC machine	Failure to use CNC machine to cuts could result in uneven cuts.	One team member
-Safety glasses -Nitrile gloves	Epoxy a u-bolt onto outward facing edge of avionics bulkhead	Failure to add epoxy to the u-bolt could cause the u-bolt to detach or become loosely attached.	One team member
-Safety glasses -Nitrile gloves	Epoxy a u-bolt with nuts and flat washers onto a CNC cut bulkhead with nuts and flat washers	Failure to properly secure the u-bolt could cause the u-bolt to detach or become loosely attached.	One team member
-Safety glasses -Nitrile gloves	Epoxy bulkhead into a coupler tube at the middle mark	Failure to properly secure the bulkhead with epoxy could cause it to detach upon parachute	One team member

		deployment and compromise the recovery system.	
-Safety glasses -Safety gloves	Drill holes for shear pins at the forward section of the middle airframe after fully assembling the launch vehicle and mark across airframe sections	Failure to drill holes for shear pins will result in the absence of shear pins. Failure to mark across the airframe could result in difficulty aligning the airframe when fully assembling the launch vehicle.	Two team member
-N/A	Insert shear pins into pre-drilled holes	Failure to use shear pins could result in premature separation of airframe	One team member
-Safety glasses -Safety gloves	Screw 0.25 in metal screws to connect the aft section of the middle section with the avionics bay	Failure to add metal screws to the overlap sections could cause unwanted separation. This undesired separation could result in a ballistic landing.	Two team member
-Safety glasses -Safety gloves	Drill three 0.125 in vent holes to the main parachute compartment near the forward bulkhead	Failure to add vent holes to parachute compartments will prevent pressure inside the launch vehicle to equalize to the external atmospheric pressure.	Two team member
Drogue Parachute Bay			
-N/A	Measure and mark Blue Tube to 44.5 in in length	Failure to measure out the proper length will cause the rocket to become longer/shorter than desired	One team member
-N/A	Wrap the Blue Tube with masking tape along the marked length	Failure to wrapped tape on the location mark could cause the Blue Tube to be cut at the wrong location.	
-Face shield -Safety gloves	Cut Blue Tube to the marked length with miter saw	Failure to cut coupler tube with a miter saw will cause the cut to	One team member

		become slanted.	
-Face shield -Safety gloves -CNC enclosure	Cut bulkheads with CNC machine	Failure to use CNC machine to cuts could result in uneven cuts.	One team member
-Safety glasses -Nitrile gloves	Epoxy a u-bolt with nuts and flat washers onto outward facing edge of avionics bulkhead	Failure to add epoxy to the u-bolt could cause the u-bolt to detach or become loosely attached.	One team member
-Safety glasses -Nitrile gloves	Epoxy bulkhead into the booster section	Failure to properly secure the bulkhead with epoxy could cause it to detach upon parachute deployment and compromise the recovery system.	One team member
-Safety glasses -Safety gloves	Drill holes for shear pins at the forward section of the section after fully assembling the launch vehicle and mark across airframe sections	Failure to drill holes for shear pins will result in the absence of shear pins. Failure to mark across the airframe could result in difficulty aligning the airframe when fully assembling the launch vehicle.	Two team member
-N/A	Insert shear pins into pre-drilled holes	Failure to use shear pins could result in premature separation of airframe	One team member
-Safety glasses -Safety gloves	Screw 0.25 in metal screws to connect the aft section of the avionics bay to the forward section of the booster	Failure to add metal screws to the overlap sections could cause unwanted separation. This undesired separation could result in a ballistic landing.	Two team member
-Safety glasses -Safety gloves	Drill three 0.125 in vent holes to the main parachute compartment near the forward bulkhead	Failure to add vent holes to parachute compartments will prevent pressure inside the launch vehicle to equalize to the external atmospheric pressure.	Two team member

6.1.2 *Motor Preparation*

Table 55 lists the preliminary procedures for the motor preparation as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 55: Motor Preparation Procedures			
PPE	**Preliminary Procedure**	**Hazards**	**Verified By**
Booster Section			
-Safety goggles -Safety gloves	Cut the Blue Tube airframe to 44.5 in and motor mount to 20 in using a miter saw	The launch vehicle motor mount and air frame will not be able to be use in the construction of the vehicle.	One team member
-Safety goggles -Safety gloves	Cut the fin slots in the airframe with the rotary tool	Failure to properly cut the fin slots could result in uneven fin attachment and thus an instable flight.	One team member
-Safety goggles -Safety gloves -Respiratory mask	Laminate both sides of the fins with fiberglass	Failure to fiberglass the fins could result in fin flutter or chipping upon landing.	One team member
-Safety goggles -Safety gloves -Respiratory	Sand the fiberglass laminated fins slightly	Failure to smoothen the fiberglass could result in higher drag experienced by the launch vehicle.	One team member
-CNC Enclosure	Cut two 0.50 in thick centering rings and four 0.25 in centering rings with the CNC machine	Failure to use a CNC machine could result in a decrease of precision leading to an increase in the time taken to make the proper centering rings.	One team member
-Safety goggles -Nitrile gloves -Respiratory mask	Attach the centering rings to the motor mount using a mixture of rocket epoxy and fiberglass cloth fibers	Failure to secure the centering rings with epoxy could result in centering ring dislocation due to the thrust from the motor and severely damage	One team members

		the launch vehicle.	
-Safety goggles -Nitrile gloves -Respiratory mask	Attach the centering rings to the inside of the Blue Tube airframe with a mixture of rocket epoxy and fiberglass cloth fibers. Utilized epoxy fillets	Failure to secure the centering rings with epoxy could result in centering ring dislocation due to the thrust from the motor and severely damage the launch vehicle.	One team members
-Safety goggles -Safety gloves	Attach the threaded component of the motor retainer to the bottom centering ring of the booster section using cap screws and threaded inserts	Failure to properly secure the motor retainer could result in motor ejection or damage to the launch vehicle.	One team member
-Safety goggles -Safety gloves -Respiratory mask	Insert fin tabs into fin slots and secure onto motor mount with a mixture of epoxy and fiberglass cloth fibers (120° between each fin)	Uneven fin spacing attachment could lead to fin flutter or flight instability. Improper fin attachment could result in fin detachment and launch vehicle damage to an instable flight.	One team member
-Safety goggles -Safety gloves -Respiratory mask	Laminate the airframe and fins with fiberglass	Failure to fiberglass the fins and airframe could result in fin flutter, detachment or chipping upon landing.	One team member
Motor			
-N/A	Perform RockSim 9 simulations with the Aerotech L1420R motor	Failure to run accurate launch simulations could result in a large deviation from the target apogee or an unsuccessful flight.	Five team members
-N/A	Calculate the thrust to weight ratio to ensure the selected motor is capable of launching the vehicle	Failure to obtain a 5:1 ration could result in an unsuccessful launch.	One-five team members

-N/A	Order the selected motor selected with a minimum of three weeks prior to launch day	Failure to order the motor with ample time in advance could result in a motor delivery delay and thus postpone the scheduled launch.	Team leader
-N/A	Verify that all components of the motor are enclosed upon delivery of reload	Failure to verify inventory could result in the team missing an essential component for launch and thus delay the scheduled launch.	Team leader
-N/A	Store the motor in a cool, dry place away from any heat source until launch day	Failure to properly store the motor could result in a damaged motor or and exploded motor causing severe damage to its surroundings and delaying launch.	Safety officer

6.1.3 *Setup on Launcher*

The safety officer determines and enforces the launch procedures that will be followed when installing the launch vehicle on the launch rail. The safety officer will review all operations on the procedure checklist to ensure all necessary steps are incorporated.

6.1.4 *Igniter Installation*

Table 56 lists the preliminary procedures required to install the igniter into the launch vehicle as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 56: Igniter Installation

PPE	Preliminary procedures	Hazards	Verified By
-N/A	Order igniters with a minimum of three weeks prior to launch day	Failure to order in a timely manner may result in late arrival and thus delay the scheduled launch.	Team leader

-N/A	Pack additional igniters for the launch day	Failure to bring additional igniters could result in a postponed launch if the original igniter is damaged.	A minimum of two team members
-N/A	Store the igniters in a cool, dry place away from all heat sources	Failure to properly store the igniters may result in damaged igniters.	One team member

6.1.5 *Launch Procedures*

Table 57 lists the preliminary launch procedures as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed. All procedures listed will be accomplished within 1.5 hours the day prior to the launch.

Table 57: Preliminary Launch Procedures

PPE	Preliminary Procedure	Hazards	Verified By
-Safety glasses -Safety gloves	Weigh and package black powder for: Main1:_____(4.34g) Drogue1:____(2.42g) Main 2:_____(4.34g) Drogue2:____(2.42g)	Failure to properly store the black powder could result in leakage leading to additional black powder being required.	Safety officer
-N/A	Pack all equipment/supplies listed on the launch supply list Note: Launch supply list is located in Safety section	Failure to use the supply list could result in missing tools or materials needed for launch day preparation or last minute repairs.	Team leader and two additional team members
-N/A	Follow the list of preliminary procedures created by the safety officer during each launch	Failure to follow the procedures may result in missed crucial steps, thus compromising	Team leader

		project safety and integrity.	
-N/A	Check and record the voltage of batteries for altimeters (9V min) Battery 1: ________ Battery 2: _________	Failure to inspect battery voltages may result in batteries with insufficient voltages for launch. This could lead to parachute deployment or GPS failure.	Safety officer

6.1.6 ***Troubleshooting***

Table 58 outlines the necessary steps required to trace resolve any problems that may arise.

Table 58: Troubleshooting			
PPE	**Preliminary Procedure**	**Hazards**	**Verified By**
Altimeters			
-N/A	Connect the altimeters to batteries to ensure the altimeters are functional	Failure to verify that the altimeter as functional could result in parachute deployment failure.	One team member
-N/A	Verify conductivity of wires used to connect the electronic components	Non-conductive wires will not allow current to flow and will result in a failure of all electrical components.	Safety officer
-N/A	Inspect that the altimeters are properly wired	Altimeters that are not properly wired will likely not deploy the parachutes	Safety officer

-N/A	Verify that the key switches are properly installed	Improper key switch installation could result in failure of electronics.	One team member
-N/A	Check battery voltage to ensure they are capable of powering the avionics bay	Failure to verify that the batteries have a minimum of 9V could result in batteries incapable of powering the avionics bay and will result in a parachute deployment failure.	One team member
Igniter Installation			
-Full face shield -Safety gloves	Check proper igniter installation	Improper installation of the igniter can result in an unsuccessful launch.	Safety officer
Recovery Section			
-N/A	Verify that properly sized parachutes are utilized	Incorrect parachute sizes can result in damage and/or loss of the launch vehicle.	Two team members
Motor Preparation			
-Nitrile gloves	Clean and assemble the engine casing and motor reload	An obstructed or incorrectly assembled engine casing can result in improper motor grain incorporation.	Team leader
-Nitrile gloves	Verify that the motor is installed properly	Improper motor installation may result in damage to the launch vehicle, people or property.	Team mentor
Launch Pad			
-N/A	Inspect the launch pad prior to launch to ensure there is no damage	A damaged launch pad may result in an unsuccessful vehicle launch.	Safety officer and team leader

6.1.7 *Post-flight Inspection*

Table 59 lists the preliminary procedures required for the post flight inspection of the launch vehicle and payload as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 59: Post-flight Inspection			
PPE	**Preliminary Procedures**	**Hazards**	**Verified By**
Day of launch			
-N/A	Inspect surface of the booster section, middle section and forward section	Failure to inspect the surface of the launch vehicle can result in launching an unsafe launch vehicle.	Two team members
-N/A	Verify that the rail button is aligned with the launch rail	Failure to inspect the alignment between the rail and rail button can result in a cancelled launch.	One team member
-N/A	Arm altimeters and listen for proper beeps	Failure to have the altimeters properly armed may result in undesired time of deployment of the main and/or drogue parachute	Team leader and safety officer
-N/A	Inspect all tubes interface connections	Failure to check all tube interfaces may result in premature separation or no separation	Minimum of two team members
-N/A	Verify that the sample(s) is secured within the payload properly	Failure to properly secure the sample(s) may result in payload malfunction and thus a damaged sample.	Payload specialist

VII. Project Plan

7.1 Testing

Required Tests

Tests required to prove the integrity of the design:

- Sub-scale payload impact test
- Sub-scale payload heat resistance test
- Sub-scale parachute test
- Altimeter test
- Ground ejection test for sub-scale launch
- Sub-scale launch
- Determine center of gravity
- Full scale payload impact test
- Full scale payload heat resistance test
- Parachute test
- Ground ejection test for full scale launch
- Full scale test launch
- GPS testing
- Payload compartment adjustment test
- Payload compartment weight test

7.1.1 *Sub-scale Payload Impact Test*

Objective

- Observe if the proposed sub-scale design will withstand the impact of a fall from 4ft

Success criteria

- No severe damage to any of the components of the payload

Variable

- Payload impact strength

Methodology

- Manually drop the payload from a measure height of 4ft

Results:

Initially the test failed because the bottom plate and inner chamber disconnected from the outer shell. To improve the design of the payload the team changed how the bottom plate was connected. With the improvement the test results were successful. This insured the team that the proposed payload design has a high chance of working once built at full scale.

7.1.2 *Sub-scale Payload Heat Resistance Test*

Objective

- Observe the max temperature the proposed material used to hold the payload can withstand without being affected.

Success criteria

- The material must be able to withstand a minimum temperature of 1500°F

Variable

- Payload heat resistance

Methodology

- Apply the heat of a standard lighter to the various materials used for the payload

Results:

The test was a success. This showed the team that these materials can be used for the full scale payload.

7.1.3 *Sub-scale Parachute Test*

Objective

- Observe if the parachute is able to full open easily

Success criteria

- Parachute fully opens without assistance

Variable

- Difficulty of opening parachute

Methodology

- Run with parachute

Results:

The test was successful. Both parachutes opened easily during the sub-scale launch. The combination of these two events assures the team that this method can be used to test the full scale parachutes.

7.1.4 *Altimeter Test*

Objective

- Check if the altimeters are recording the correct altitudes

Success criteria

- Altimeters record the correct altitudes

Variable

- Altitudes record by the altimeters

Methodology

- Place altimeters in a pressurized chamber controlled by a team member

Results:

N/A

7.1.5 *Ground Ejection Test for Sub-scale Launch*

Objective

- Check if the amount of black powder used for the parachute ejection charges is sufficient

Success criteria

- Booster section is fully detached and shock cord is fully exposed
- Forward section is fully detached and shock cord is fully exposed
- All sheer pins are completely sheered
- No severe damage to any components of the rocket or payload

Variable

- Black powder used for ejection charges

Methodology:

To test the ejection charges used to separate the booster section the launch vehicle will be place horizontally on top of a box to simulate conditions felt at apogee. The box will then be arranged vertically and the launch vehicle will be places against it at a 60° angle to simulate conditions felt at the deployment of the main parachute.

Results:

The first test was a failure. The team recalculated the amount of black powder need and repacked the ejection charges. The second test was a success with both sections separating fully and shock cords being fully exposed as well as all the sheer pins being sheered. During the sub-scale launch the parachutes ejected successfully. These results assure the team that this method of testing the ejection charges will work for the full scale launch vehicle.

7.1.6 *Sub-scale Launch*

Objective

- Test complete sub-scale launch vehicle and payload

Success criteria

- Motor works properly
- Parachutes deploy at the desired altitudes
- Fragile material inside the payload is unharmed
- No significant damage to the launch vehicle

Variable

- Overall design of launch vehicle and payload

Methodology

- Launch vehicle at a dry lake bed

Results:

The motor worked properly and the parachutes deployed at their desired altitudes. After the rocket made contact with the ground a full inspection was done. The inspection showed no signs of significant damage to the launch vehicle. Unfortunately, while examining the payload the fragile materials placed inside (quail eggs) had both been damaged. This test gave the team confidence to move forward to the full scale build of the launch vehicle and the information needed to make the proper changes to the full scale payload.

7.1.7 *Determine Center of Gravity*

Objective

- Determine the center of gravity

Success criteria

- Accurately determine the center of gravity for the launch vehicle

Variable

- Center of gravity of the launch vehicle

Methodology

- Suspend the launch vehicle in the air with a rope and adjust the vehicle until it holds up on its own in a horizontal position

Results:

N/A

7.1.8 *Full Scale Payload Impact Test*

Objective

- Observe if the proposed sub-scale design will withstand the impact of a fall from 4ft

Success criteria

- No severe damage to any of the components of the payload

Variable

- Payload impact strength

Methodology

- Manually drop the payload from a measure height of 4ft

Results:

N/A

7.1.9 *Full Scale Payload Heat Resistance Test*

Objective

- Observe the max temperature the proposed material used to hold the payload can withstand without being affected.

Success criteria

- The material must be able to withstand a minimum temperature of 1500°F

Variable

- Payload heat resistance

Methodology

- Apply the heat of a standard lighter to the various materials used for the payload

Results:

N/A

7.1.10 *Sub-scale Parachute Test*

Objective

- Observe if the parachute is able to full open easily

Success criteria

- Parachute fully opens without assistance

Variable

- Difficulty of opening parachute

Methodology

- Run with parachute

Results:

N/A

7.1.11 *Ground Ejection Test for Full Scale Launch*

Objective

- Check if the amount of black powder used for the parachute ejection charges is sufficient

Success criteria

- Booster section is fully detached and shock cord is fully exposed
- Forward section is fully detached and shock cord is fully exposed

- All sheer pins are completely sheered
- No severe damage to any components of the rocket or payload

Variable

- Black powder used for ejection charges

Methodology:

To test the ejection charges used to separate the booster section the launch vehicle will be place horizontally on top of a box to simulate conditions felt at apogee. The box will then be arranged vertically and the launch vehicle will be places against it at a 60° angle to simulate conditions felt at the deployment of the main parachute.

Results:

N/A

7.1.12 *Full Scale Launch*

Objective

- Test complete sub-scale launch vehicle and payload

Success criteria

- Motor works properly
- Parachutes deploy at the desired altitudes
- Fragile material inside the payload is unharmed
- No significant damage to the launch vehicle

Variable

- Overall design of launch vehicle and payload

Methodology

- Launch vehicle at a dry lake bed

Results:

N/A

7.1.13 *GPS Testing*

Objective

- Test the accuracy and reliability of the GPS

Success Criteria

- GPS gives accurate coordinates at several different locations
- GPS does not disconnect for the duration of the test

Variable

- GPS accuracy and reliability

Methodology

- The GPS will be connected to ground station
- One team member will watch the live feed
- One team member will walk around with the GPS
- Coordinates will be recorded at specific locations
- The recorded coordinates will be cross referenced with the actual coordinates provided by Google maps

Results:

N/A

7.1.14 *Payload Compartment Adjustment Test*

Objective

- Ensure each compartment is accessible and can be adjusted to different sizes

Success Criteria

- Each compartment is accessible and adjust to different sizes

Variable

- Compartment adjustment

Methodology

- Each compartment will be adjusted to different sizes
- One compartment will be expanded to its maximum size to ensure it satisfies the official requirement

Results:

The compartment design was tested with the sub-scale payload. The test was a success and the team chose to keep the same design for the full scale payload.

7.1.15 *Payload Compartment Weight Test*

Objective

- Determine if each compartment can support a maximum weight of 1 lb

Success Criteria

- Each compartment is able to support 1 lb

Variable

- Compartment weight capacity

Methodology

- A team member will place a 3 lbs weight inside each compartment
- The container will be rotated and shaken to simulate flight conditions

Results:

N/A

7.2 Requirements Compliance

7.2.1 *Launch Vehicle Requirements and Verification Plan*

Table 60 lists the launch vehicle requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 60: Launch Vehicle Requirements

Requirement	Design Feature	Verification Method	Verification Plan	Status Update
1.1. The vehicle shall deliver the science or	An Aerotech L1420R motor will launch the 40	Simulations, calculations, and tests	Simulations, calculations (see Mission	Simulations and calculations are complete. Tests are

engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	lb rocket and its payload to 5,280 ft AGL.		Performance Criteria), and flight tests will verify that the Aerotech L1420R is the most efficient motor to deliver the launch vehicle and payload to 5,280 ft AGL.	planned.
1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	The official altitude will be recorded by a Missile Works RRC2+ altimeter.	Inspection	The Missile Works RRC2+ altimeter will be inspected after all test launches to ensure that it is recording the altitude of the launch.	Planned
1.2.1. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.	The Missile Works RRC2+ altimeters report the AGL altitude via a series of beeps, each corresponding to a specific number.	Tests and inspection	The Missile Works RRC2+ altimeter will be tested and inspected after test launches as well as before the main launch to verify that it is operating correctly.	In progress
1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiment(s).	Only a redundant altimeter will be utilized for recovery.	N/A	No verification plan is needed because additional altimeters will not be utilized.	Complete

1.2.3. At the Launch Readiness Review, a NASA official will mark the altimeter that will be used for the official scoring.	A NASA official will have the official altimeter available at the launch readiness review to be marked.	Inspection	The altimeter will be inspected by the team to ensure that it has been marked by the NASA official.	In progress
1.2.4. At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.	The Missile Works RRC2+ altimeters relay the maximum altitude via audible beeps.	Inspection	After flight only a NASA official will be allowed to inspect the Missile Works RRC2+ altimeter.	In progress
1.2.5. At the launch field, to aid in the determination of the vehicle's apogee, all audible electronics, except for the official altitude determining altimeter shall be capable of being turned off.	The official scoring altimeter will remain on at all times. All other audible electronics, if any, may be turned off.	Inspection	All electronic devices except for the altimeter will be inspected prior to the launch to ensure that they are turned off.	In progress
1.2.6. The following circumstances will warrant a score of zero for the altitude portion of the competition.	See below	See below	See below	N/A
1.2.6.1. The	The Missile	Tests and	The altimeter will	In progress

official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.	Works RRC2+ will be housed securely inside the avionics bay to prevent damage.	inspection	be tested during the test launches to confirm that it is durable enough for the flight. The launch vehicle's recovery system will also be tested and inspected prior to the main launch to ensure that the launch vehicle is not damaged during landing.	
1.2.6.2. The team does not report to the NASA official designated to record the altitude with their official, marked altimeter on the day of the launch.	The team will report to the NASA official after their launch and recovery.	Inspection	The team will verify with each other via inspection that the recorded altitude is reported to the NASA official.	In progress
1.2.6.3. The altimeter reports an apogee altitude over 5,600 feet AGL.	An Aerotech L1420R motor will launch the 23.12 lb rocket and its payload to 5,280 ft AGL.	Simulations, calculations, and tests	Simulations, calculations (see Mission Performance Criteria), and test flights will verify that the Aerotech L1420R is the most efficient motor to deliver the launch vehicle and payload to an altitude less than 5,600 ft AGL.	In progress

1.2.6.4. The rocket is not flown at the competition launch site.	N/A	Tests, inspection, and analysis	The team will pay utmost attention when following all specified requirements in constructing and testing the rocket so that the launch vehicle is cleared to launch during the competition.	In progress
1.3. All recovery electronics shall be powered by commercially available batteries.	Commercially available 9V batteries shall power all recovery electronics.	Inspection	All batteries used in the launch vehicle will be inspected by the safety officer to establish that they are commercial batteries.	In progress
1.4. The launch vehicle shall be designed to be recoverable and reusable.	Current RockSim Pro 9 simulations predict that all rocket components will be recovered within a 1140 ft. range from the launch pad. All launch vehicle components are designed to be reusable.	Demonstrations and tests	The launch vehicle's flight and recovery will be tested several times before the main launch. The launch vehicle recoverability and reusability will be demonstrated during these test launches.	In progress
1.5. The launch vehicle shall have a maximum of four (4) independent sections.	The launch vehicle has three (3) independent sections.	Analysis and inspection	Analysis of the RockSim9 design and inspection of the launch vehicle will verify that it consists of three independent sections.	Complete

1.6. The launch vehicle shall be limited to a single stage.	The launch vehicle only has one stage.	Analysis and inspection	Analysis of the RockSim design and inspection of the launch vehicle will verify that it is single stage.	Complete
1.7. The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	A compiled checklist will be utilized to ensure that flight preparation is efficient, thorough, and completed in less than four(4) hours.	Tests and demonstration	The team will measure and record the speed at which the launch vehicle can be assembled during test flights and make adjustments if necessary to demonstrate it is under four (4) hours.	In progress
1.8. The launch vehicle shall be capable of remaining in the launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	All onboard electronics draw little power.	Tests and inspection	All electronics will be tested and inspected prior to the launch to ensure that they can remain in a launch-ready configuration for several hours.	In progress
1.9. The launch vehicle shall be capable of being launched by a standard 12-volt firing system.	The launch vehicle will use a commercial, APCP motor that will ignite with a 12- volt direct current.	Tests	A standard 12-volt firing system will be tested during test launches to confirm that it is capable of launching the vehicle.	In progress

1.10. The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	The launch vehicle does not utilize external circuitry or special ground support to initiate launch.	N/A	N/A	In progress
1.11. The launch vehicle shall use commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The team will utilize a TRA certified L1420R motor from Aerotech	Inspection	Inspection of the motor being used will verify that it is a solid fuel commercial motor using APCP.	Complete
1.11.1. Final motor choices must be made by the Critical Design Review (CDR).	The final motor choice will be stated in the CDR.	Analysis	Analysis of the RockSim9 design and simulations will verify that the proper motor was selected prior to the submittal of CDR	Complete
1.11.2. Any motor changes	The team will only make a	N/A	N/A	N/A

after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin.	motor change request if it increases the safety margin significantly.			
1.11. Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:	Pressure vessels are not utilized.	N/A	N/A	N/A
1.12.1. The minimum factor of safety (Burst of Ultimate Pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.	Pressure vessels are not utilized.	N/A	N/A	N/A
1.12.2. The low-cycle fatigue life shall be a minimum of 4:1.	Pressure vessels are not utilized.	N/A	N/A	N/A
1.12.3. Each pressure vehicle shall include a pressure relief valve that sees the full pressure of	Pressure vessels are not utilized.	N/A	N/A	N/A

the tank.				
1.12.4. Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including number of pressure cycles put on the tank, by whom, and when.	Pressure vessels are not utilized.	N/A	N/A	N/A
1.13. The total impulse provided by a Middle and/or High School launch vehicle shall not exceed 5,120 Ns (L-class).	An L1420R motor, with 4182.83 Ns total impulse, will be utilized.	Inspection	The team will inspect the motor data to ensure its total impulse does not exceed 5,200 Ns.	Complete
1.14. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	The launch vehicle will have a 2.47 stability margin with the Aerotech L1420R at the point of rail exit.	Analysis and simulations	Analysis of the RockSim9 simulations and vehicle design will verify that static stability margin is at least 2.0.	Complete
1.15. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The launch vehicle will accelerate to a velocity of 71.20 fps at rail exit.	Analysis and simulations	Analysis of the RockSim9 simulations and vehicle design will verify that the vehicle will have a minimum velocity of 52 fps at rail exit.	Complete

1.16. All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR.	The team will launch and recover a 2/3-scale model of the full-scale rocket prior to CDR.	Analysis	The results of the subscale launch will be analyzed prior to the CDR to determine whether or not another test launch is needed.	Complete
1.16.1. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.		Inspection, calculations, and analysis	Inspection, calculations, and analysis of the subscale components will be done to confirm that they perform as similarly as possible and are scale models of the full-scale design.	Complete
1.16.2. The subscale model shall carry an altimeter capable of reporting the model's apogee altitude.	The subscale model will have a redundant commercially available altimeter system.	Testing	The altimeter will be tested during test launches to determine whether or not it is capable of recording the launch vehicle's altitude.	Complete
1.17. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on the launch day.	The team will launch and recover the full-scale (6 in diameter) rocket successfully prior to FRR in its final flight configuration	Demonstration	The full-scale rocket will be launched and recovered prior to launch day. This will be repeated if necessary until a successful launch is achieved.	In progress

1.17.1. The vehicle and recovery system shall function as designed.	The vehicle and recovery systems will be constructed according to the designs.	Testing	The vehicle and recovery system will be tested during test launches to ensure that they are working as designed.	In progress
1.17.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	See below	See below	See below	N/A
1.17.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass.	A mock payload matching the mass of the true payload will fly with the launch vehicle.	N/A	N/A	In progress
1.17.2.1.1. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.				In progress
1.17.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the	The payload does not alter the external surfaces or manage any energy of the launch vehicle.	N/A	N/A	N/A

vehicle, those systems shall be active during the full-scale demonstration flight.				
1.17.4. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor to be used to demonstrate full flight readiness and altitude verification.	An Aerotech L1420R will be flown during full-scale test launches.	Inspection	The team will inspect the launch vehicle during test flights to verify that the L1170-FJ is utilized.	In progress
1.17.5. The vehicle shall be flown in its fully ballasted configuration during the full-scale test.	The vehicle will be flown in its fully ballasted configuration during the full-scale test.	Inspection	The launch vehicle will be inspected before flight to ensure that it is in its full ballasted configuration.	In progress
1.17.6. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer.	The launch vehicle will not be modified after the full-scale demonstration flight with the concurrence of the NASA RSO.	Inspection	Inspection of the launch vehicle prior to the main launch will verify that there have been no alterations.	In progress

1.17.7. Full scale flights must be completed by the start of FRRs (March 6th, 2017).	Full scale flights of the launch vehicle will be completed by the start of FRRs.	Inspection and demonstration	Inspection of the timeline will verify that a full-scale test launch will be completed prior to the FRR. The team will demonstrate full scale flights by the start of FRRs.	In progress
1.18. Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	The launch vehicle will not have structural protuberances.	N/A	N/A	N/A
1.19. Vehicle prohibitions	See below	See below	See below	N/A
1.19.1. The launch vehicle shall not use forward canards.	The fins are only located in the booster section of the launch vehicle.	Inspection	Inspection of the launch vehicle verifies that no forward canards are utilized.	Complete
1.19.2. The launch vehicle shall not use forward firing motors.	The launch vehicle utilizes a single commercial Aerotech motor in the booster section of the rocket.	Inspection	Inspection of the launch vehicle verifies that no forward firing motors are being utilized.	Complete
1.19.3. The launch vehicle shall not utilize motors that expel titanium sponges.	The Aerotech L1420R motor does not expel titanium sponges.	Inspection	Inspection of the launch vehicle verifies that no motors that expel titanium sponges are utilized.	Complete
1.19.4. The launch vehicle	The Aerotech L1420R motor	Inspection	Inspection of the launch vehicle	Complete

shall not utilize hybrid motors.	utilized is a solid fuel APCP motor.		verifies that no hybrid motors are utilized.	
1.19.5. The launch vehicle shall not utilize a cluster of motors.	A single motor is used for the launch vehicle.	Inspection	Inspection of the launch vehicle verifies that no cluster motors are utilized.	Complete
1.19.6. The launch vehicle shall not utilize friction fitting for motors.	The launch vehicle will use a threaded metallic flange with a fitting threaded cap for motor retention.	Inspection	Inspection of the launch vehicle verifies that the motor does not utilize friction fitting.	Complete
1.19.7. The launch vehicle shall not exceed Mach 1 at any point during flight.	The launch vehicle is expected to reach a maximum velocity of 753.37 fps.	Inspection and analysis	Inspection and analysis of RockSim9 verifies that the launch vehicle will not exceed Mach 1 at any point during the flight.	Complete
1.19.8. Vehicle ballast shall not exceed 10% of the total weight of the rocket.	The launch vehicle ballast does not exceed 10% of total weight of the rocket.	Inspection	Inspection of the ballast will verify that it does not exceed 10% of the total weight of the rocket.	Complete

Table 61 lists the team derived launch vehicle requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 61: Team Derived Launch Vehicle Requirements			
Requirements	**Design Feature**	**Verification Method**	**Verification**
1.1. The vehicle shall deliver the science or engineering payload to an apogee altitude of 5278.02 ft above ground level (AGL).	An Aerotech L1420R motor will launch the 23.12 lb rocket and its payload to 5,278.02 ft AGL.	Simulations, calculations, full scale launch	Being limited in motor selection the team found this motor to be the best fit to satisfy the requirements. Although the motor does not meet the official target apogee this was the closest the team could get after many trials.

7.2.2 *Recovery System Requirements and Verification Plan*

Table 62 lists the recovery system requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 62: Recovery System Requirements				
Requirement	**Design Feature**	**Verification method**	**Verification plan**	**Status Update**
2.1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	Missile Works RRC2+ altimeters will eject the drogue parachute at apogee, and the main parachute at 800 ft.	Testing	Tests flights will verify that the drogue will deploy at apogee and the main will deploy at a lower altitude of 800 ft.	In progress
2.2. Each team must perform a successful ground ejection	Successful ground ejection tests will be conducted prior to all initial	Inspection	The parachutes and nylon shear pins will be inspected after ground	Subscale: complete Full scale: in progress

test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	subscale and full scale launches.		ejection tests to verify that the correct amount of black powder was used for deployment. See recovery subsection for more details.	
2.3. At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Based on current simulations and calculations, each independent section of the launch vehicle is currently predicted to land with less than 75 ft-lbs of kinetic energy.	Simulations and calculations	The team will theoretically calculate and utilize test-flight data to calculate the kinetic energy of landing for each rocket section. The combined descent rate of the rocket and untethered payload experiment will be adjusted as necessary to ensure that all components land with less than 75 ft-lbf of kinetic energy.	In progress
2.4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Each altimeter will be independent of any payload electrical circuits, including other recovery altimeters.	Inspection	Inspection of the recovery system electrical components will verify that they are wired independently of other electrical components.	In progress
2.5. The recovery system shall contain redundant,	The recovery system will contain redundant Missile Works RRC2+	Inspection	Inspection of the launch vehicle will verify that commercial	In progress

commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	altimeters to deploy the parachutes.		altimeters are being used.	
2.6. Motor ejection is not a permissible form of primary or secondary deployment.	N/A	Inspection and analysis	Inspection and analysis of the RockSim designs will verify that no motor ejection is utilized.	N/A
2.7. Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	All RRC2+ altimeters will have separate external arming switches accessible when the rocket is in launch position.	Inspection	Inspection of the RRC2+ altimeters will verify that they have separate external arming switches accessible when the rocket is in its launch position.	In progress
2.8. Each altimeter shall have a dedicated power supply.	Each altimeter will have a dedicated 9 V power supply.	Inspection	Inspection of the altimeters and their wiring verifies that they have a dedicated power supply.	In progress
2.9. Each arming switch shall be capable of being locked	The arming switches will require a key to lock them in the	Inspection	Inspection of the arming switches shows that they require a key to	In progress

in the ON position for launch.	ON position.		lock then in the ON position.	
2.10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	All parachutes compartments will be attached with 2-56 x 0.25 in nylon shear pins.	Inspection	Inspection of the launch vehicle will verify that the main and drogue compartment are attached to the rocket using shear pins.	In progress
2.11. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	The launch vehicle will have two (2) GPS tracking devices.	Inspection and testing	Inspection of the launch vehicle verifies that two GPS devices will be in use. These devices will also be used for test flights to test their effectiveness.	In progress
2.11.1. Any rocket section, or payload component, which lands untethered to the launch vehicle, shall also carry an active electronic tracking device.	All sections of the launch vehicle will be tethered together. All payload components will be fixed inside of the launch vehicle.	N/A	N/A	N/A
2.11.2. The electronic tracking device shall be fully functional during the	The GPS tracking device will be fully functional at the launch site competition.	Testing and inspection	The GPS will be ground tested and inspected prior to the launch day to ensure that it is	In progress

official flight on launch day.			functional.	
2.12. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (launch to landing).	The recovery system electronics will be independently wired.	Inspection	Inspection of the recovery system electronics will verify that their wiring is independent from the other onboard electronics.	In progress
2.12.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery system altimeters will be physically separated from the GPS transmitter by being installed in their own avionics bay compartment.	Inspection	The altimeters will be separated from the GPS by being installed in their own compartment of the avionics bay. Inspection of the launch vehicle verifies this.	In progress
2.12.2. The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	The recovery system electronics will be located in their own avionics bay compartment.	Inspection	Inspection of the electronics will verify that they are properly shielded from the GPS transmission and any other devices that may affect their operation.	In progress
2.12.3. The recovery system electronics shall	Equipment generating magnetic waves	N/A	N/A	In progress

be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	will not be utilized.			
2.12.4. The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery system electronics will be secured inside the avionics bay without interference of other electronics.	Inspection and tests	The position of the recovery system electronics will be inspected by the team to ensure that they are secured inside the avionics bay. Tests of other onboard electronics will ensure no interference occurs.	In progress

7.2.3 *Experiment Requirements and Verification Plan*

Table 63 lists the experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 63: Experiment Requirements

Requirements	Design Feature	Verification Method	Verification	Status Update
3.1.1. Each team shall choose one design experiment option from the following list.	The team has chosen Option 3: Fragile Material Protection.	N/A	N/A	Complete
3.1.2. Additional experiments (limit of 1) are encouraged, and may be flown, but they will contribute to scoring.	The team will not have additional experiment.	N/A	N/A	N/A
3.1.3 If the team chooses to fly additional experiments, they shall provide the appropriate documentation in all design reports so experiments may be reviewed for flight safety.				N/A

Fragile Material Experiment Requirements and Verification Plan

Table 64 lists the fragile material protection experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 64: Fragile Material Protection Requirements

Requirements	Design Feature	Verification Method	Verification	Status Update
3.4.1. Teams shall design a container capable of protecting an object of an unknown material and of unknown size and shape.	The proposed container will be adjustable to accommodate multiple shapes, sizes, and quantities.	Protection system components adjustment test.	Placing solid objects of various sizes between the adjustable laminated silicon disks will test the storage and protection system of the unknown size and shape of the material. Liquid sample will be inserted in between the outer shell and the inner rack.	Complete
3.4.1.1. There may be multiple of the object, but all copies shall be exact replicas.				N/A
3.4.1.2. The object(s) shall survive throughout the entirely of the flight.	The team will design and construct a container that protects the unknown object(s) throughout the entire flight.	Simulation.	Eggs will present the solid sample and water will present the liquid sample. Dropping the container that contains the solid and liquid samples from 4th floor will simulate possible collision of the container from launch vehicle landing.	In progress
3.4.1.3. Teams shall be given the object(s) at the team check in table on launch day.	The team will test the protection caliber of the proposed container with other fragile	N/A	N/A	In progress

	materials.			
3.4.1.4. Teams may not add supplemental material to the protection system after receiving the object(s). Once the object(s) have been provided, they must be sealed within their container until after launch.	Supplemental material for protection will not be added after receiving the object. The container will have a threaded cap closure seal that will remain closed until after launch.	Sample collection storage process simulation.	A solid object will be placed in the inner rack and secured by the component of the protection system that are kept within the proposed container; the container will then be sealed without any supplemental material added.	In progress
3.4.1.5. The provided object can be any size and shape, but will be able to fit inside an imaginary cylinder 3.5 in in diameter, and 6 in in height.	The proposed container will be able to accommodate a volume of 57.70 in^3 and withstand a minimum of 4 ounces for the unknown object(s).	Simulation.	Place a 4 ounces solid object in the inner rack that is design to hold a storage space of 3.5” in diameter, and 6” in height. Insert 4 ounces of liquid sample between the outer shell and the inner rack. The container shall be durable for the total weight of the object(s).	N/A
3.4.1.6. The object(s) shall have a maximum combined weight of approximately 4 oz.				N/A

Table 65 lists the team derived fragile material protection experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 65: Team Derived Fragile Material Protection Requirements			
Requirements	**Design Feature**	**Verification Method**	**Verification**
3.4.1. The team shall design a container capable of protecting eight objects of an unknown material and of unknown size and shape.	The proposed container will have eight separate compartments.	The team will place objects with many different physical characteristics into the compartments.	Being limited by the size of our launch vehicle the team found it reasonable to plan for at most eight identical unknown objects.
3.4.1.5. The maximum	The adjustable	The team will	Having a little extra room

compartment volume will hold an imaginary cylinder with a diameter of 3.6 in, and a height of 6.5 in.	compartments will be able to accommodate this size.	expand a single compartment to its maximum capacity and measure the total volume.	was agreed to be better than having the exact amount of volume need for the maximum capacity.
3.4.1.6. The separate compartments shall have a maximum weight capacity of 3 lbs.	The nuts will hold the silicon disks in place, while the flexibility of the silicon disks will enable it to hold the desired max weight.	The team will place 3lb objects with many different physical characteristics inside each compartment.	Being able to hold a greater weight than the maximum weight required was agreed to be a better design.

7.2.4 *Safety Requirements and Verification Plan*

Table 66 lists the safety requirements.

Table 66: Safety Requirements

Requirement	Design Feature	Verification Method	Verification Plan	Status Update
4.1 Each team shall use a launch and safety checklist.	N/A	By inspection	The safety officer will ensure that the safety checklist is used before every launch.	In progress
4.2 Each team must identify a student safety officer who shall be responsible for all items in section.	N/A	By inspection	The team has selected a safety officer.	Complete
4.3. The roles and responsibilities of each safety officer shall include, but not limited to 4.3.1.1. Design of vehicle and launcher 4.3.1.2. Construction of vehicle and launcher 4.3.1.3. Assembly of	N/A	By inspection	The safety officer will be held accountable for all of these responsibilities, failure to do so will result in demotion of safety officer and possible termination.	In progress

vehicle and launcher 4.3.1.4. Ground testing of vehicle and launcher 4.3.1.5. Sub-scale launch test(s) 4.3.1.6. Full-scale launch test(s) 4.3.1.7. Launch day 4.3.1.8. Recovery activities 4.3.1.9. Educational Engagement Activities				
4.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities	N/A	By inspection	The officer safety will ensure that safety procedures developed by the team will be followed	In progress
4.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	N/A	By inspection	The safety officer will have schedule maintains and review for the following items; team's hazard analyses, failure mode analyses, procedures and MSDS/chemical inventory data	In progress
4.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	N/A	By inspection	The safety officer will lead the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	In progress

4.4. Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle, and the rocketeer shall have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the	N/A	By inspection	The team will inspection the mentor credential to ensure that he meets the qualifications.	Complete

team and mentor attends launch week in April.				
4.5. During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	N/A	By inspection	The safety officer will ensure team members will abide by the rules and guidance of the local RSO	In progress
4.6. Teams shall abide by all rules set forth by the FAA.	N/A	By inspection	The safety officer will ensure that team members are familiar and abide with rules set by the FAA	In progress

7.2.5 *General Requirements and Verification Plan*

Table 67 lists the general requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 67: General Requirements

Requirements	Verification Method	Verification	Status Update
5.1. Students on the team shall do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling back power or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor)	Member responsibility and mentor support.	Team members will be responsible and knowledgeable for all aspect of the project in order to complete the project, including, design, construction, written reports, presentations, and flight preparation.	In progress
5.2 The team shall provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Documentation.	The team will document all the project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigation in the project review documents.	In progress
5.3 Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	N/A	N/A	In progress
5.4 The team shall identify all team members attending launch week activities by the Critical Design Review (CDR).	Documentation.	The team members that will be attending launch week activities will be identified in the Critical Design Review (CDR).	In progress

5.4.1. Students actively engaged in the project throughout the entire year.	Weekly mandatory meeting.	Team members will have a mandatory meeting on every Friday throughout the entire year.	In progress
5.4.2. One mentor (see requirement 4.4)	Mentor identification.	One certified adult mentor will be liable for the team through the project year.	In progress
5.4.3. No more than two adult educators.	Adult educator identification.	One adult educator will be supporting the team throughout the project year.	Complete
5.5. The team shall engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report shall be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 28 of the handbook.	Documentation.	Outreach officer will be responsible to the report and documentation of all educational engagement.	In progress
5.8. All deliverables must be in PDF format.	Document formatting.	All review documents will be present as a PDF file.	In progress
5.9. In every report, teams shall provide a table of contents including major sections and their respective sub-sections.	Document formatting.	Tables of contents will be created for the navigation of major sections and their respective sub-sections.	In progress
5.10. In every report, teams shall include the page number at the bottom of the page.	Document formatting.	Page number will be included at the bottom of all deliverable reports.	In progress
5.11. The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. If possible, the team shall refrain from use of cellular phones as a means of	Teleconference equipment accessibility.	The team will have accessibility to equipment that are necessary to perform a video teleconference.	In progress

speakerphone capability.			
5.12. All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch filed. Launch services will have 8 ft 1010 rails, and 8 ft and 12 ft 1515 rails available for use.	Utilization of launch pads provided by Student Launch's launch service provider.	The team will use the launch pads provided by Student Launch's launch service provider for flight vehicle launch.	In progress
5.13. Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards (http://www.section508.gov): • 1194.21 Software applications and operating system. • 1194.22 Web-based intranet and Internet information and applications.	Electronic and information technology accessibility standards.	Team will complete the project with implementation of the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards (http://www.section508.gov): • 1194.21 Software applications and operating system. • 1194.22 Web-based intranet and Internet information and applications.	In progress

7.2.6 *Team Derived Requirements*

Table 68 shows a set of team derived requirements for mission success along with their corresponding verification methods.

Table 68: General Team Derived Requirements

Requirements	Verification Method	Verification
1. All five students remain on the team during the entirety of the competition	Mandatory meetings	All five students are required to attend a mandatory meeting on every Friday during the project year.
2. All design reviews are passed and the vehicle is launched successfully in Huntsville	NASA score sheet	NASA score sheet will be given after each design review and vehicle launch in Huntsville; it will determine if the team passes the design reviews and if the launch was successful.

3. All students have a GPA of 3.0 or greater during the project	Grade Report	Team members will report their grades to the advisor of the team for ensuring students are successful in the project and in academic.
4. The team has left over budget at the end of the project	Final spending calculation	The team will calculate the final spending of the project and compare it to the funded budget.
5. Team member complete the project without injuries	Safety contract	Team members will acknowledge the importance of safety and should complete the project without conducting any dangerous behaviors that may potentially cause harms.
6. All members should be familiar with every aspect of the project.	Mandatory meeting	All members are required to attend a mandatory meeting on every Friday for updating each other on the progress of the project. Team members are also required to understand every aspect for being able to address different sections of the project.

7.3 Budgeting and Timeline

This section introduces the Citrus College Rocket Owls team's budget, timeline and funding plan for participation in the NSL. The budget lists all items necessary for the completion of this project along with the required quantity and unit prices. The timeline includes the schedule and Gannt chart of the project activities, along with a separate schedule and Gannt chart outlining the team's outreach events. Lastly, the funding plan lists the project fund sources and how those funds will be used.

7.3.1 *Budget Plan*

Table 69 below provides a list of the materials needed to complete the NSL project as well as estimated individual and total cost for each item, including tax and shipping costs.

Table 69: Budget Plan					
Items	**Quantity of Items**	**Unit Price**	**Tax (~9%)**	**Shipping**	**Total price**
Full scale Launch Vehicle Construction Expenses					
6" diameter Blue tube	4	$66.95	$0.00	$104.27	$372.03
6" diameter coupler tubes	1	1	$19.95	$1.80	$12.10
6" Ogive 4:1 nose cone	1	$129.00	Included	$12.90	$141.90

1” tubular webbing	40	$0.45	$1.62	$5.99	$25.61
18” Nomex blanket	2	$10.49	$0.00	$5.09	$26.07
24” Nomex blanket	2	$13.99	$0.00	$5.85	$33.83
Altimeter	4	$44.95	$0.00	$7.00	$186.80
Terminal blocks	1	$9.05	$6.03	$0.00	$15.08
22-gauge stranded wire pack	1	$19.95	$2.41	$6.83	$29.19
Heat shrink tubing	1	$10.99	$0.70	$5.33	$17.02
Key switch	4	$4.62	$2.13	$5.14	$25.75
6” E-bay	2	$71.95	$12.95	$19.51	$178.12
¼” Aircraft plywood	1	$112.75	$10.15	In store	$122.90
1515 Rail buttons	2	$4.65	$0.00	$4.88	$9.98
Shear Pins (size)	5	$3.10	$0.00	$4.88	$20.38
Machine screws	1 pack	$1.98	$0.02	$0.00	$2.00
Rocket epoxy (pt)	1	$38.25	$0.00	$11.82	$50.07
Fiberglass cloth 3 oz.. satin weave	3 yrds	$9.96	$8.07	$9.12	$42.51
Fiberglass resin	1	$42.99	$3.87	$10.96	$58.81
Fiberglass hardener	1	$21.99	$1.98	$9.92	$34.78
Motor retainer	1	$53.50	$4.82	$5.47	$63.79
Motor	2	$249.99	$2.25	$60.00	$312.24
Engine casing	1	$235.40	$2.12	$10.75	$248.27
Forward closure	1	$101.65	$9.15	$0.00	$110.80
Aft closure	1	$80.25	$7.22	$0.00	$87.47
Forward seal disk	1	$32.00	$2.88	$15.00	$49.88
Sub-Scale Launch Vehicle Construction Expenses					
4” Blue Tube	2	$38.95	$0.00	$26.89	$104.79
98 mm E-bay	2	$42.95	$7.73	$9.13	$103.58
4” Ogive 4:1 nose cone	1	$65.00	Included	$8.95	$73.95
Tube coupler	1	$10.95	$0.99	$7.36	$19.30
Motor	1	$159.99	$1.44	$60.00	$221.43
Payload Expenses					
Polycarbonate	1	$215.25	$19.37	$12.00	$246.62

tubing					
Silicone sheet	1	$156.55	$12.52	$9.58	$178.65
Zinc threaded rails	3	$5.11	$0.46	In store	$16.71
Epoxy plastic bonder	2	$4.26	$0.38	In store	$9.28
9% Borated flexi-panel	1/2	$75.00	$0.75	$12.00	$92.75
Polycarbonate tubing	2	$15.20	$1.37	$10.00	$43.14
Tools and Safety Supplies					
Palm sander	1	$29.99	$2.70	$6.99	$40.31
Nitrile gloves	1	$8.16	$1.22	$5.48	$14.86
Sand paper 80 grit	1	$15.38	$1.38	$5.99	$22.75
Sandpaper 5" 120 grit	1	$14.40	$1.30	$5.99	$21.69
Synthetic grease	1	$5.89	$0.53	$5.99	$12.95
Dremel(cordless)	1	$89.99	$8.09	$0.00	$98.08
Outreach Expenses					
Outreach supplies	12,000.00				
Food and Travel Expenses					
Airfare	6	$518.00	$46.62	$0.00	$3387.72
Hotel expenses	2	$134.00	$12.06	$0.00	$292.12
Food expenses	15	$20.00	$0.00	$0.00	$500.00
Total Expenses	$19,751.89				

7.3.2 *Project Timeline*

This section lists the main project deadlines and milestones as well as the expected date of task completion. The Gantt chart below also lists the start date and expected duration of each task.

Figure 58: Main Event Timeline

ID ↑	Task Name	Dura	Start	Finish
1	Rocket and payload c	6d	8/15/2016	8/22/2016
2	Designs are finalized	14d	8/23/2016	9/9/2016
3	Proposal rough draft	7d	9/2/2016	9/10/2016
4	Proposal rough draft	6d	9/9/2016	9/16/2016
5	Autocad and rocksim	1d	9/16/2016	9/16/2016
6	Proposal is submitted	1d	10/7/2016	10/7/2016
7	Proposal winners ann	1d	10/12/2016	10/12/2016
8	Rocket and payload c	37d	11/7/2016	12/27/2016
9	Sub-scale constructio	17d	11/14/2016	12/6/2016
10	Payload construction	17d	11/7/2016	11/29/2016
11	PDR Q&A	1d	10/14/2016	10/14/2016
12	PDR writing	7d	10/17/2016	10/25/2016
13	Payload prototype te	6d	11/21/2016	11/28/2016
14	PDR draft is due	1d	10/26/2016	10/26/2016
15	PDR draft review	4d	10/28/2016	11/2/2016
16	PDR is submitted	1d	11/4/2016	11/4/2016
17	PDR Teleconferences	10d	11/7/2016	11/18/2016
18	CDR planning	2d	11/19/2016	11/21/2016
19	CDR Q&A	1d	11/30/2016	11/30/2016
20	CDR draft is written	23d	12/1/2016	12/31/2016
21	Sub-scale launch at F	1d	12/3/2016	12/3/2016
22	CDR first review	1d	1/2/2017	1/2/2017
23	CDR second review	7d	1/2/2017	1/10/2017
24	CDR is submitted	1d	1/13/2017	1/13/2017
25	CDR Teleconferences	11d	1/17/2017	1/31/2017
26	FRR Q&A	1d	2/8/2017	2/8/2017
27	Full scale rocket cons	1d	2/11/2017	2/11/2017
28	Full scale launch at L	1d	2/11/2017	2/11/2017
29	FRR writing begins	1d	2/13/2017	2/13/2017
30	FRR draft reviewed	1d	3/4/2017	3/4/2017
31	FRR is submitted	1d	3/6/2017	3/6/2017
32	FRR Teleconferences	13d	3/8/2017	3/24/2017
33	Team travels to Hunt	2d	4/5/2017	4/6/2017
34	LRR is completed	1d	4/5/2017	4/5/2017
35	Launch Day	2d	4/8/2017	4/9/2017
36	PLA writing	11d	4/10/2017	4/23/2017
37	PLA reviewed by tear	1d	4/19/2017	4/19/2017
38	PLA is submitted	1d	4/24/2017	4/24/2017

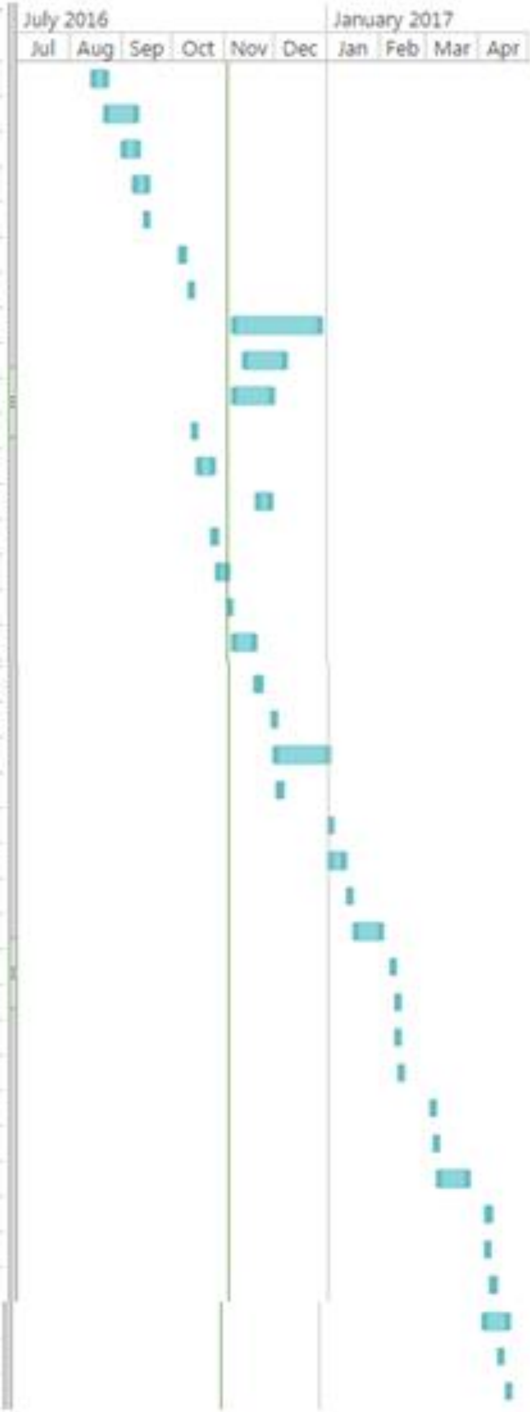


Figure 58 shows the Gantt chart detailing the NASA SL main events and their planned deadlines. Included are all project milestones and construction deadlines.

Table 70 below provides the timeline of the main NSL-related activities, along with a brief description of each task. The schedule of the NSL educational engagement activities along with a brief description of those activities are also provided.

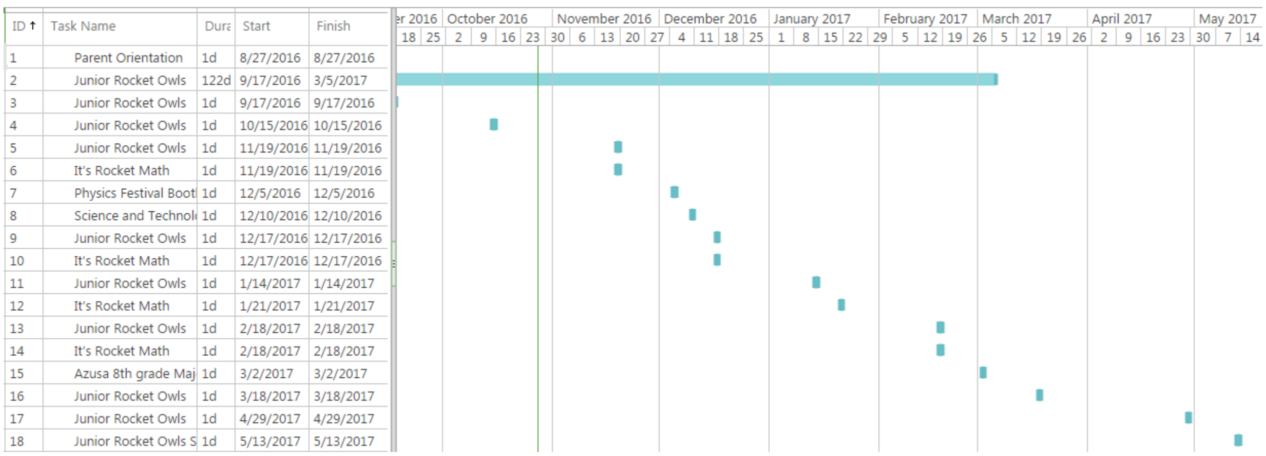
Table 70: NSL Timeline and Task Description		
Task	**Description**	**Due**
Rocket and payload are designed	Team designs rocket and payload	8/22/16
Designs are finalized	Final decisions are made regarding the designs of the rocket and payload	9/9/16
Proposal rough draft is due	Proposal sections are due for review	9/10/16
Proposal draft is reviewed	The proposal is edited by the team	9/16/16
AutoCAD and RockSim diagrams are due	All diagrams pertinent to the proposal are due	9/16/16
Proposal is submitted	Proposal is submitted to NASA	10/7/16
NSL selected team are announced	NASA announces NSL teams selected to participate in the 2016-2017 competition	10/12
PDR Q&A	Teams ask questions pertaining to the PDR	10/14/16
PDR is planned and writing begins	PDR sections are distributed and writing begins	10/17/16
PDR draft is due	PDR sections are due for revisions	10/26/16
PDR draft is edited by team	PDR draft is edited collectively by the team	10/28/16
PDR is submitted	PDR is submitted	11/4/16
PDR Teleconferences are held	NASA holds teleconferences	11/7/16-11/18/16
Construction begins	Construction of sub-scale rocket and payload prototype starts	11/7/16
Sub-scale construction is completed	Sub-scale rocket construction is completed	11/14/16
CDR is planned and writing begins	CDR sections are distributed and	11/19/16

	writing begins	
Payload prototype is tested	Payload strength and isolation components are tested	11/21/16
Construction of the full scale rocket begins	Full scale rocket construction begins	11/22/16
CDR Q&A	Teams ask questions pertaining to CDR	11/30/16
Sub-scale launch	Sub-scale is launched and its flight is analyzed	12/3/16
CDR draft is due	CDR sections are due for revisions	12/31/16
CDR draft is edited by team	CDR draft is edited collectively by the team	1/2/17
CDR is reviewed by team	CDR is revised (if necessary)	1/9/17
CDR is submitted	CDR is submitted to NASA	1/13/17
CDR Teleconference are held	NASA holds teleconferences	1/17/17-1/31/17
FRR Q&A	Teams ask questions pertaining to FRR	2/8/17
Full scale rocket construction is finalized and the rocket is launched	Construction of full scale rocket is completed and rocket is launched, followed by an analysis of the flight	2/11/17
FRR is planned and writing begins	FRR sections are distributed and writing begins	2/13/17
FRR is completed and reviewed by the team	FRR is completed and edited collectively by the team	3/4/17
FRR is submitted	FRR is submitted to NASA	3/6/17
FRR Teleconferences are held	NASA holds teleconferences	3/8/17-3/24/17
The team travels to Huntsville	Team travels to Huntsville	4/5/17
LRR is completed	LRR is completed	4/5/17
NASA SL teams launch the rockets	Launch Day	4/8/17

PLA is planned and writing begins	PLA sections are distributed and writing begins	4/10/17
PLA is completed and reviewed by team	PLA is completed and edited collectively by the team	4/19/17
PLA is submitted	PLA is submitted to NASA	4/24/17

Educational Engagement Timeline
Figure 59 below provides the timeline of the Citrus College Rocket Owl team's educational engagement events. Included are the individual outreaches as well as the entire duration of the Junior Rocket Owls program.

Figure 59: Educational Engagement Timeline:



ID ↑	Task Name	Dura	Start	Finish
1	Parent Orientation	1d	8/27/2016	8/27/2016
2	Junior Rocket Owls	122d	9/17/2016	3/5/2017
3	Junior Rocket Owls	1d	9/17/2016	9/17/2016
4	Junior Rocket Owls	1d	10/15/2016	10/15/2016
5	Junior Rocket Owls	1d	11/19/2016	11/19/2016
6	It's Rocket Math	1d	11/19/2016	11/19/2016
7	Physics Festival Boot	1d	12/5/2016	12/5/2016
8	Science and Technol	1d	12/10/2016	12/10/2016
9	Junior Rocket Owls	1d	12/17/2016	12/17/2016
10	It's Rocket Math	1d	12/17/2016	12/17/2016
11	Junior Rocket Owls	1d	1/14/2017	1/14/2017
12	It's Rocket Math	1d	1/21/2017	1/21/2017
13	Junior Rocket Owls	1d	2/18/2017	2/18/2017
14	It's Rocket Math	1d	2/18/2017	2/18/2017
15	Azusa 8th grade Maj	1d	3/2/2017	3/2/2017
16	Junior Rocket Owls	1d	3/18/2017	3/18/2017
17	Junior Rocket Owls	1d	4/29/2017	4/29/2017
18	Junior Rocket Owls S	1d	5/13/2017	5/13/2017

Figure 59 lists all educational engagement events and their corresponding dates.

Table 71below provides a list of the educational engagement events that were and will be hosted by the Rocket Owls over the course of the NSL as well as their scheduled dates and brief descriptions.

Table 71: NSL Educational Engagement Activities

Event	Date	Description
Junior Rocket Owls: Parent Orientation	8/27/16	Rocket Owls meet the parents of the new generation of Junior Rocket Owls
Junior Rocket Owls: Outreach Workshop	9/17/16	Junior Rocket Owls are introduced to the program
Junior Rocket Owls: Outreach Workshop	10/ 15/16	Rocket Owls introduce the 5^{th} grade students to basic rocketry concepts
Junior Rocket Owls: Outreach Workshop	11/19/16	Junior Rocket Owls build and launch Estes model rockets
Science and Technology Day	12/10/16	Elementary and middle school children from local school districts participate in STEM hands-on activities facilitated by the Rocket Owls
Junior Rocket Owls: Outreach Workshop	12/17/16	Junior Rocket Owls design and create their payloads for the LoadStar rockets
It's Rocket Math Workshop	12/17/16	Rocket Owls introduce the 7^{th} grade students to math concepts related to rocketry, followed by building and launching Estes model rockets
Junior Rocket Owls: Outreach Workshop	1/14/17	Junior Rocket Owls build the LoadStar rockets
It's Rocket Math Workshop	1/14/17	Rocket Owls introduce the 7^{th} grade students to more mathematical relationships related to rocketry, followed by building and launching LoadStar rockets
Junior Rocket Owls: Outreach Workshop	2/18/17	Junior Rocket Owls launch the LoadStar rockets and analyze their flights using RockSim

It's Rocket Math Workshop	2/18/17	The 7th grade students discuss their payloads, then launch the LoadStar rockets and analyze their flights using RockSim
Azusa 8th Grade Majors Fair	3/17/17	Rocket Owls introduce the Azusa Unified School District 8th grade students to basic physics and rocketry concepts
Junior Rocket Owls: Outreach Workshop	3/18/17	Junior Rocket Owls analyze and discuss the data collected during the flight of the LoadStar rockets.
It's Rocket Math Workshop	3/18/17	The 7th grade students design and create their professional posters in preparation for the symposium
Junior Rocket Owls: Outreach Workshop	4/22/17	Junior Rocket Owls design and create their professional posters in preparation for the symposium
Junior Rocket Owls Symposium It's Rocket Math Symposium	5/13/17	The Junior Rocket Owls and It's Rocket Math symposia take place at Citrus College

7.3.3 *Funding Plan*

Table 72 below provides a list of the funds needed for the successful completion of the NSL project as well as traveling and accommodations expenses for the Rocket Owls team participation in the NSL launch week in Huntsville, AL. In addition, Table 73 introduces the private and governmental organizations along with the amount of funds provided by those organizations in sponsorship of the Citrus Rocket Owls participation in NSL.

Table 72 : NSL Funding Plan

Funding Source	Amount ($)	Designation
GUSD	8,850.00	Supplies for the Junior Rocket Owls program
Citrus College Foundation Innovation Grant	1,000.00	Sponsor Rocket Owls' activities

Race to STEM Federal Grant	$2,000.00	Rocket supplies
California Space Grant Consortium	$2,000.00	Supplies for rocketry projects
Private donations	$6,000.00	Sponsor Rocket Owls' activities
Mathematical association of America-Tensor Foundation	$6,000.00	Supplies for the It's Rocket Math! program and traveling expenses for the Rocket Owls
Total	$25,850.00	

As indicated in Table 72, the total funds allocated for the project add up to $25,850, while Table 69 in the Budget section of this document shows that the cost of the project in its entirety is estimated to be $19,751.89. This indicates that the team has an excess of over $6,000.00. This amount may be used for unexpected expenses, such as an increase in material cost or expenditures related to traveling.

References

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[6]Knight, Randall Dewey. Physics for Scientists and Engineers: A Strategic Approach : with Modern Physics. San Francisco: Pearson Addison Wesley, 2008.

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[14]http://www.ptsllc.com/intro/polycarb_intro.aspx

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[16]http://stardust.jpl.nasa.gov/aerogel_factsheet.pdf

Appendix A: Citrus College Profile

Since 1967, Citrus College has been offering a quality educational experience for the communities of Azusa, Glendora, Duarte, Claremont and Monrovia. It is currently home to over 12,000 students, the majority of whom are considered ethnic minorities, and is dedicated to creating a diverse and welcoming learning environment that supports educational achievement for all of its students.

Citrus College offers many programs that promote community awareness in numerous STEM related fields. Biological and Physical Sciences is the second most common major in the school. There are also numerous extracurricular programs aimed at increasing interest in STEM subjects within the community, such as the SIGMA (Support and Inspire to Gain Motivation and Achievement) peer mentor program; the PAGE (Pre- Algebra, Algebra, Geometry Enrichment) summer K-12 mathematics enrichment program; and the Secrets of Science Summer Camp that provides K-12 students with practical experience in biology, chemistry, astronomy and physics laboratories.

Students at Citrus College are active participants in many STEM-related activities. In past years, students have participated in NASA’s Reduced Gravity Education Flight Program (RGEFP), have launched a near-space sounding balloon, and have also traveled to Huntsville, Alabama and to Salt Lake City, Utah as participants in the 2013, 2014, and 2015 USLI SLP (University Student Launch Initiative Student Launch Projects). In 2015, three teams of students participated in the NASA/CASGC Microcomputer and Robotics Internship.

Appendix B: Safety Contract

Safety Contract

All members of the team understand and agree to the following safety rules and regulation provided by the NASA Student Launch Proposal documentation:

1.6. Safety Regulations

1.6.1 Range safety inspection of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program

1.6.2. The RSO has the final say on all rocket safety issues. Therefore, the RSO has the right to deny the launch of any rocket for safety reasons.

1.6.3 Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

All team members will also understand the safety procedures outlined in pervious section pertaining to:

- The risk and mitigation of hazardous materials
- Using power tools
- General Safety

All team members must understand and abide by the following as mention above:

- State and local laws
- FAA rules and regulation
- Fire prevention code

By signing this contract, the team members acknowledge that they have read and understood the information detailed in the safety section. And agree to abide by the aforementioned rules outlined in the safety contract. Team members will not be allowed to work on this project without signing the contract.

Yvonne Villapudua
Name (Printed)
Yvonne Villapudua
Signature
Date: 09/26/16

Isabella Molina
Name (Printed)
Isabella Molina
Signature
Date: 09/26/16

Lillian Chang
Name (Printed)
Lillian Chang
Signature
Date: 09/26/16

Janet Blancas Alonso
Name (Printed)
[signature]
Signature

Date: 09/26/16

Jimmy Lopez
Name (Printed)
[signature]
Signature

Date: 09/26/16

Lucia Riderar
Name (Printed)
[signature]
Signature

Date: 9/26/2016

Appendix C: MSDS

Appendix C is available as a separate document in the Rocket Owl's website including the complete MSDS information for the following items:

- Acetone
- Alkaline Batteries
- Ammonium Perchlorate Composite Motors
- Black Powder
- Epoxy
- Fiberglass
- Isopropyl Alcohol
- Lithium Batteries
- Nitrile Gloves
- Nylon
- Paint
- Plastic
- Solder
- Steel wood
- Sunscreen
- Superglue
- Wire
- Wood dust

Appendix D: Safety Protocols

Appendix D is available as a separate document in the Rocket Owl's website and includes the protocols developed by the team. The protocols will be continuously be update during the duration of the project and will be kept inside the safety binder, which will be located where construction will take place

- Epoxying
- Hot glue gun
- Hand Drill
- Soldering Iron
- Painting
- Table Saw
- CNC machine
- Jigsaw
- Dremel
- Sanders

**Appendix C and D can be located through the following link:*
http://citruscollegerocketowls5.weebly.com/