NASA Student Launch
2016-2017

Preliminary Design Review

1000 W. Foothill Blvd.
Glendora, CA 91741

Project Aegis

Fragile Material Protection

November 4, 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

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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3. Safety Officer

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4. Team Leader

Yvonne
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5. Team Members and Proposed Duties

Table 1 gives the title and proposed duties 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 Rocket Owls team is structured.
Figure 1: Team Organization Chart

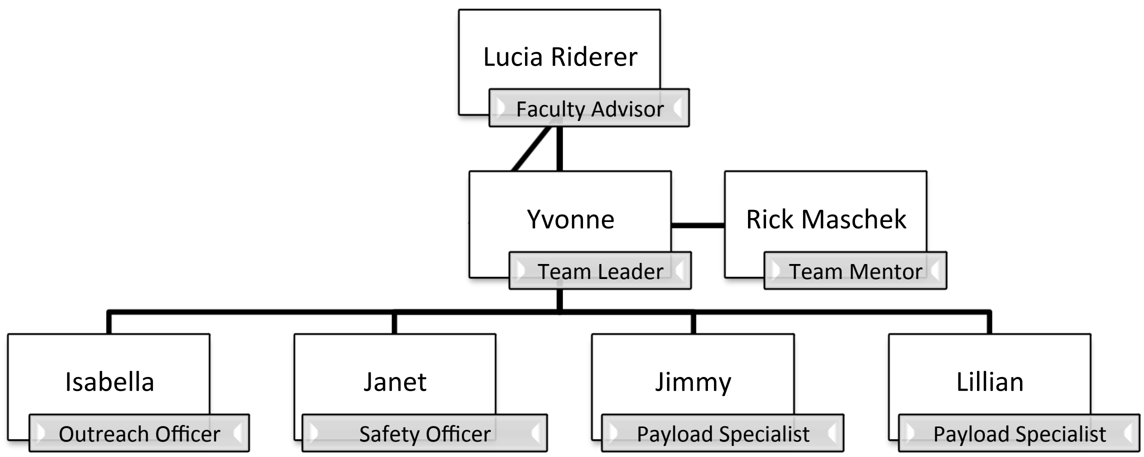

Figure 1 outlines the Rocket Owls team organization chart

6. 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 PDR Report

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

Launch Vehicle Summary
Vehicle Dimensions
Length: 119”
Diameter: 6.08”
Mass (without motor): 23.12 lbs
Mass (with motor): 34.12 lbs
Motor Choice
Aerotech L1170-FJ
Recovery System
All flight events will be initiated by the Redundant Missile Works RRC2+ altimeters. A black powder charge will separate the rocket and deploy a 30” drogue parachute at apogee. The rocket will fall as two tethered sections with a descent rate of 53.12 ft/s. A second black powder charge will eject the 144” main parachute at 800 ft. The rocket will descend as three tethered sections at a rate of 11.48 m/s. Both parachute deployments will utilize redundant black powder charges with a 1s delay.

Milestone Review Flysheet
• The milestone review flysheet is available as a separate document.

Payload Summary
Payload Title
“Fragile Materials Protection”
Payload materials
- Polycarbonate
- Silicone/Silicone dioxide
- Metal

Payload Experiment Overview
The team will design and construct a container to protect one or more a fragile samples before, during, and after flight. The container will be able to safely hold a maximum amount of eight separate samples. The main container components are: radiation shield, outer shell, inner chamber, and inner chamber rack. The main role of the container is to protect the sample(s) from impact, shock, contamination, temperature change, pressure change, and radiation. The container was designed with the main objective being sample retrieval from the surface of Mars.

II. Changes Made Since Proposal

Changes Made to Vehicle Criteria

1. One avionics bay has been removed from launch vehicle.
2. A different motor has been selected.
3. Length of launch vehicle has decreased.
4. The number of fins on the launch vehicle increased from three to four.

Changes Made to Payload

There have been no changes to the payload design since the proposal, as the payload's proposed dimensions as well as the anticipated fabrication materials remain the same.

Changes Made to Project Plan

Timeline and activity lists

1. The beginning of the construction phase of the sub-scale rocket and payload prototype has been moved from 10/13/16 to 11/7/16 in order to allow for additional time to complete the PDR, with the new date of submission (see below). These activities were also delayed because some of the materials needed for construction have not yet been purchased and/or received.
2. The submission of the PDR has been postponed from 10/31/16 to 11/4/16.
3. The PDR Teleconferences have been moved from 11/2/16-11/18/16 to 11/7/16-11/18/16.
4. The payload prototype testing day has been postponed from 11/4/16 to 11/21/16 in order to allocate sufficient time for the prototype construction.
5. The Gantt charts presented in this document with the changed dates listed above have replaced the charts introduced in the proposed project plan.

Budget

There were no changes made to the budget, since budget items have not been added or removed from the list of expenses presented in the proposal.

III. Vehicle Criteria

Selection, Design, and Rationale of Launch Vehicle

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.

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 section 6.1 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 compartments throughout the duration of the entire flight
- The unknown samples return in its original state after flight

Further details on payload success criteria are provided in section 5.1.3. of this document.

Design Review

Current Design
The launch vehicle is designed to satisfy the requirements of the project. Figure 2 displays the fully assembled launch vehicle.

Table 2 provides the general vehicle dimensions for the current launch vehicle design and illustrates its specifications alter based on the motor utilized.

Table 2: General Vehicle Dimensions			
Aspect	**Without Motor**	**With L1170-FJ Motor**	**With L1420-R Motor**
Length (in)	119.00	119.00	119.00
Diameter (in)	6.08	6.08	6.08
Length/diameter ration	19.57	19.57	19.57
Mass (lbs)	23.12	34.12	33.18
C.P. (from top)	93.8405	93.8405	93.8405
C.G. (from top)	66.2587	79.0035	79.5948
Stability (caliber)	4.60	2.47	2.37
Average thrust (N)	-	1140	1424

Figure 2 below shows the launch vehicle and its main components.
Figure 2: Launch Vehicle Design

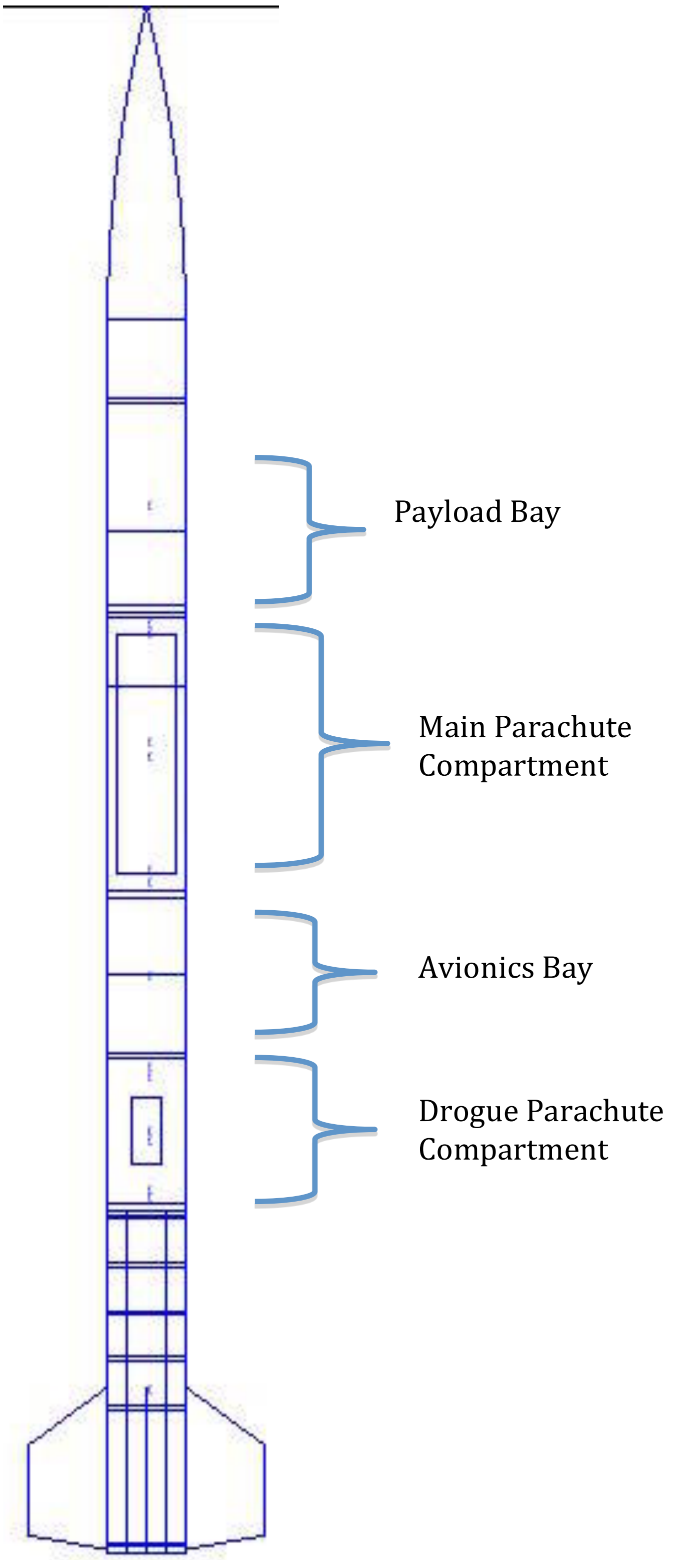

Figure 2 shows the RockSim design of the launch vehicle

Table 3 lists the main rocket components, the materials used in their construction, and their corresponding manufacturing methods.

Table 3 : Rocket Materials and Construction Methods			
Main Vehicle Components	**Material**	**Justification**	**Construction Method**
Nose cone	Fiberglass filament wound	Strong and durable	Commercially available
Airframe	Blue Tube 2.0	Rigid, stronger than phenolic tubing	Cut with miter saw, sand by hand, fiberglass, bond with epoxy
Bulkheads	5-ply plywood, 0.50"	Strong, easy to cut, sand and bond	CNC cut
Centering rings	10-ply aircraft plywood, 0.25"	Strong, easy to cut, sand and bond	CNC cut
Fins	10-ply aircraft plywood, 0.25"	Strong, stiff, resists flutter	CNC cut
Parachutes	Ripstop nylon	Light-weight, tear resistant	Commercially available
Shock cords	1" Tubular nylon	High-breaking strength	Commercially available

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" tubular webbing harnesses. The most aft part of the launch vehicle is the booster section.
The middle section of the launch vehicle is comprised of the avionics bay and two parachute compartments. Figure 2 shows the design for this section. The Blue Tube airframe for both parachute compartments is held together by metal screws to both sides of the coupler tube which houses the avionics bay.
The fragile material protection payload is 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.

Figure 3 gives an external view of the fully assembled launch vehicle, followed by Figure 4 that offers an internal view and Figure 5 providing an exploded view of the launch vehicle.

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Figure 3: Fully Assembled Launch Vehicle (External View)

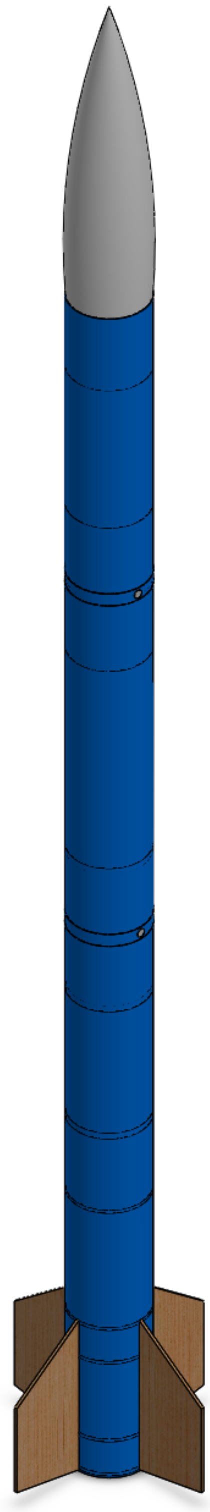


Figure 3 shows an external view of the completely assembled rocket.

Figure 4: Fully Assembled Launch Vehicle (Internal View)

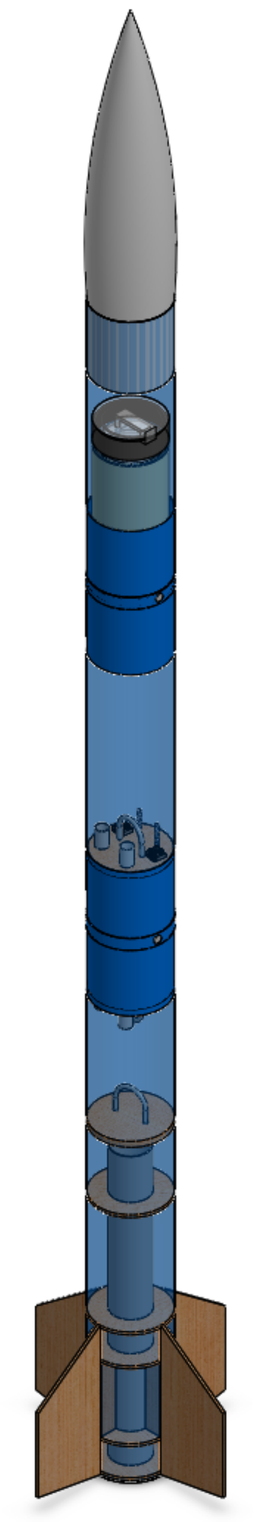


Figure 4 shows an internal view of the assembled rocket, including views of the booster section, mid frame, and payload bay.

Figure 5: Launch Vehicle (Exploded View)

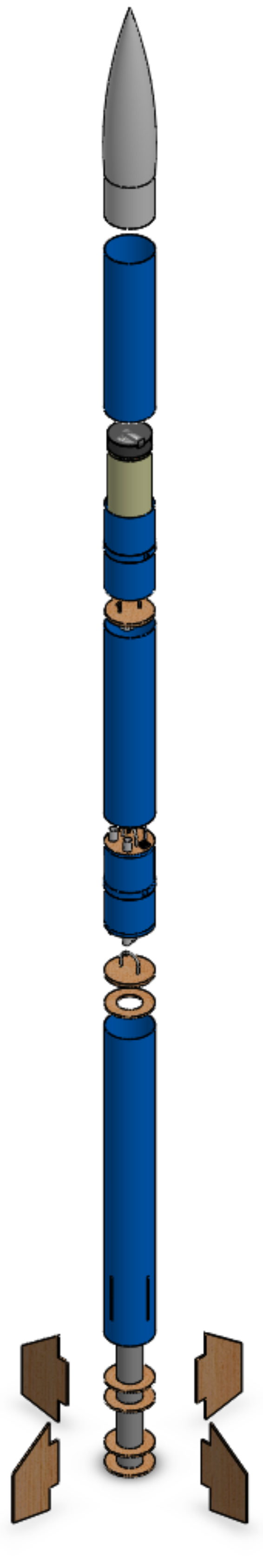


Figure 5 shows an exploded view of the launch vehicle

Figure 6 below provides a cross-section view of one of the launch vehicle's fins, with labeled dimensions (inches).

Figure 6: Launch Vehicle Fin (Cross Sectional View)

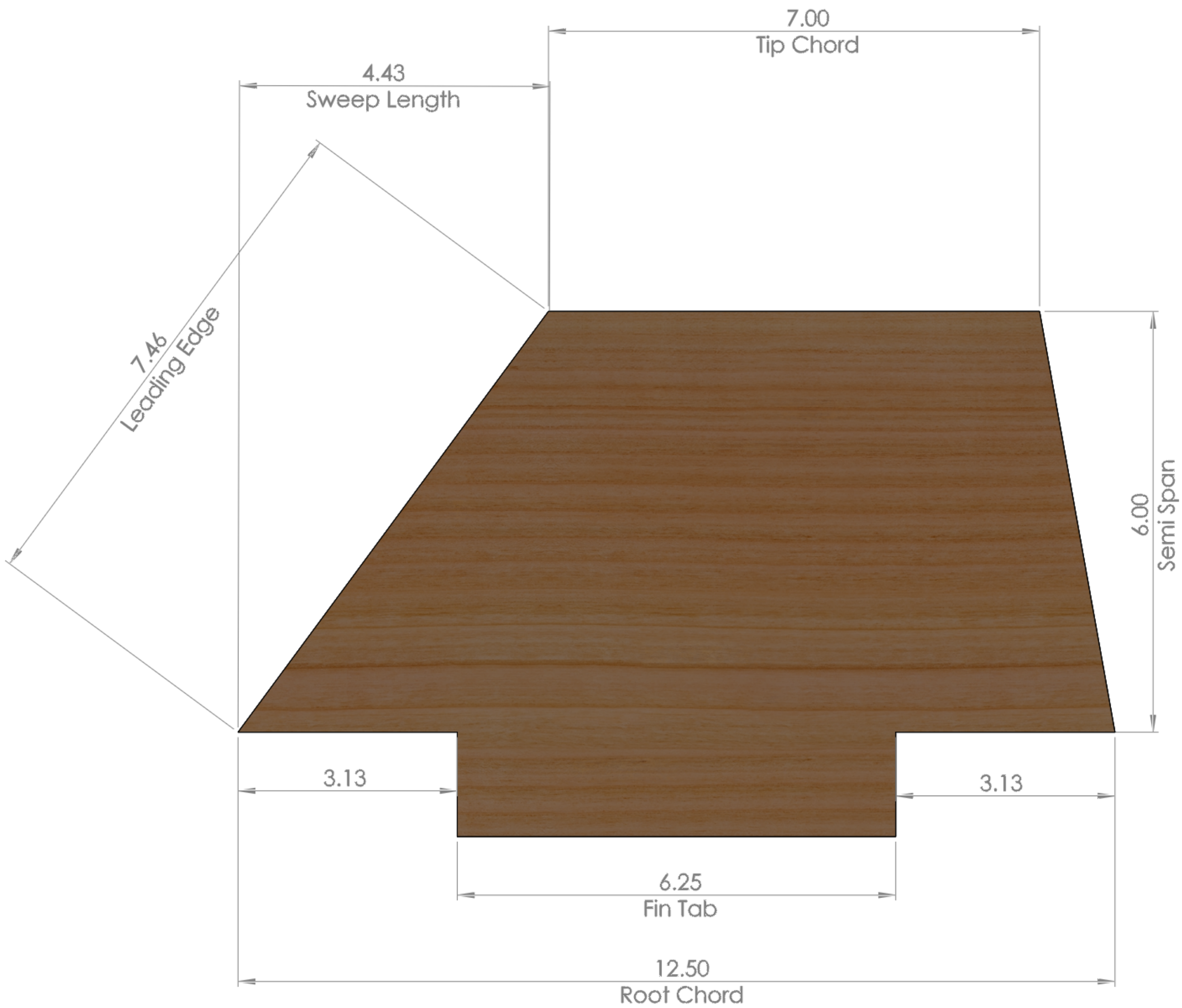


Figure 6 shows one of the launch vehicle's fins labeled by dimensions in inches, including dimension of the leading edge, sweep length, tip chord, root chord, semi span, and fin tab

Alternative Design
Figure 3 below gives the alternative design of the launch vehicle designed for the NSL competition, followed by an evaluation of this design and its main systems and including the possible scenarios when this design could be advantageous over the leading one.

Figure 7: Launch Vehicle Alternative Design

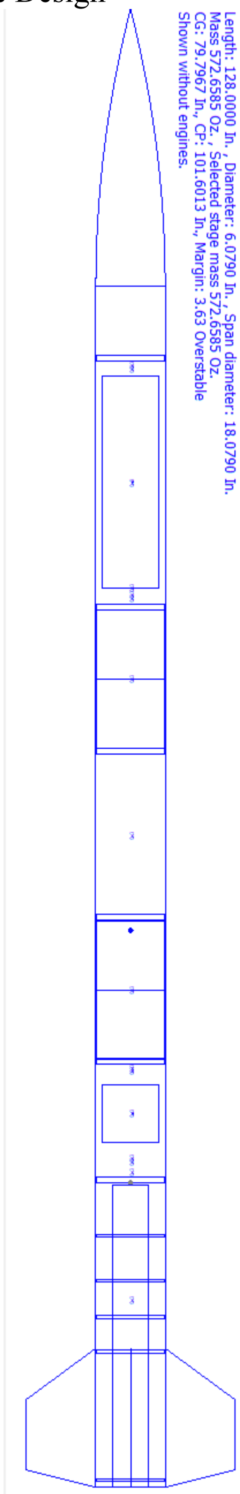


Figure 7: displays the alternative design of the launch vehicle.

The alternative launch vehicle design has a similar structure and utilizes the same materials as the current leading design. In this design, the position of the payload bay and the position of the main parachute compartment are switched. In addition, this option incorporates an additional avionics bay forward of the main parachute compartment. The uppermost avionics bay is not essential in the current design of the launch vehicle; however, this component would become advantageous in the event that new electronics are incorporated into the launch vehicle or payload. The additional distance for black powder charge ignition would also be beneficial in the event that the main and drogue parachutes are ejected simultaneously during flight due to a short distance of separation within the launch vehicle.

Launch Vehicle Subsystems

The current launch vehicle 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.

Propulsion Subsystem

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 5,280ft AGL.
2. The rail exit velocity must be sufficient for the launch vehicle to have a stable flight (see section 3.4 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, and the L1170-FJ. The motor hardware is made of aircraft-grade aluminum [1]. 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 motor retainer also prevents the casing from falling out of the motor mount. The threaded portion of the motor retainer will be bonded to the aft end of the motor mount with rocket epoxy. The cap is twisted onto the portion attached to the motor mount to ensure secure housing of the motor.

The propulsion subsystem is located in the booster section of the rocket. The Blue Tube motor mount will be epoxied to six, thick centering rings, 0.25" in diameter (see Figure 8). The centering rings will be made of aircraft plywood, which will be cut with a CNC router. The centering rings will be epoxied to the inside of the Blue Tube airframe. Epoxy fillets will be added to the inside corners where two parts meet in order to increase the strength of the connections.

Figure 8 below provides an internal view of the motor mount, followed by Figure 9 that shows a cross-section perspective of the booster section.

Figure 8: Motor Mount (Internal View)

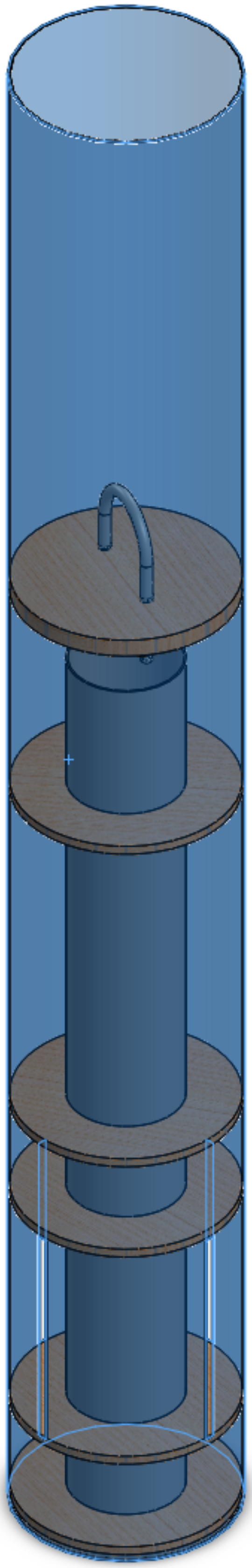


Figure 8 shows an internal view of the motor mount

Figure 9: Booster Section (Cross Section View)

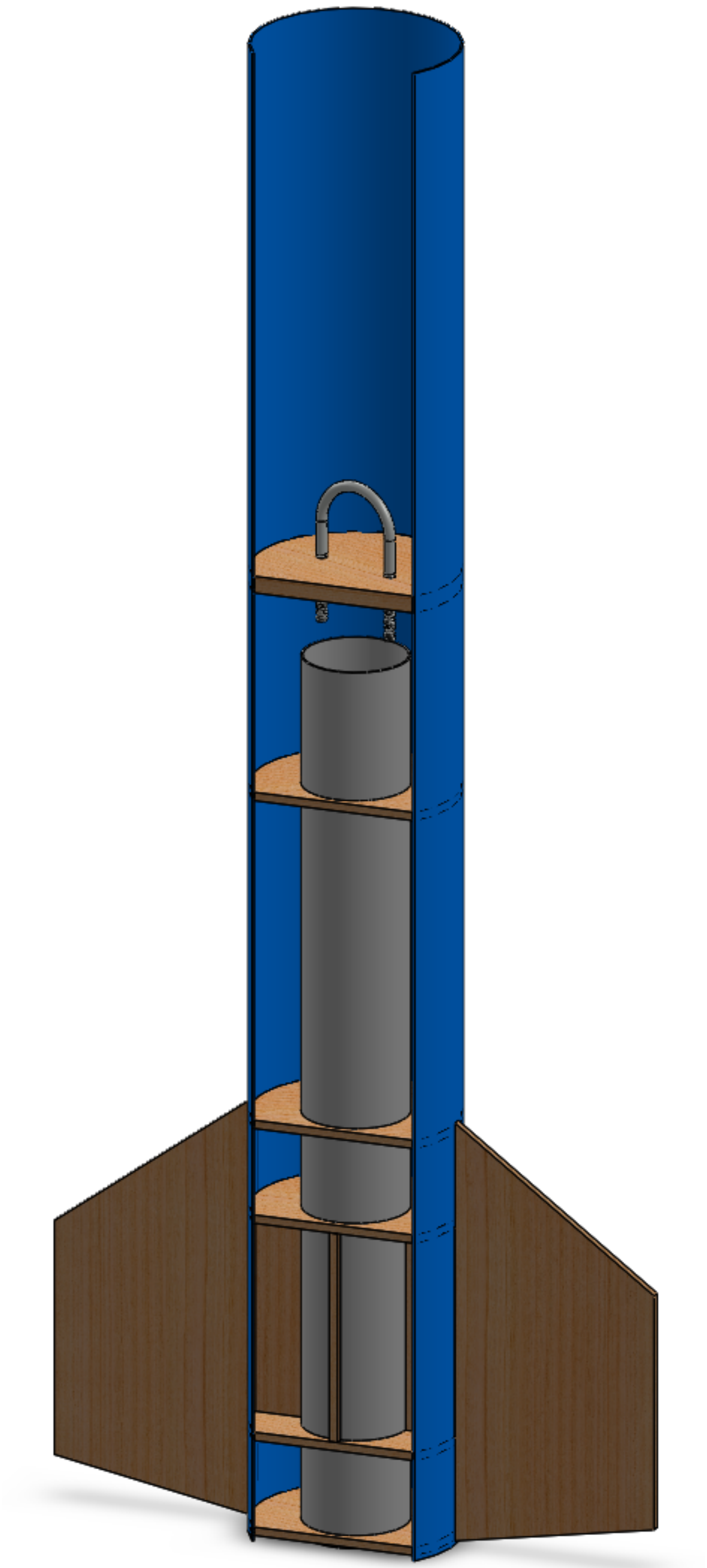


Figure 9 shows a cross section view of the booster section

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.

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 made out of Blue Tube (Figures 5). Blue Tube, a vulcanized phenolic tubing manufactured by Always Ready, easier and safer to work with than fiberglass [2]. It will be cut with a miter saw. Blue Tube has shallow spiral grooves that will be filled with wood filler. The three airframe sections are joined together with 12" sections of Blue Tube coupler. For sections that must separate during parachute deployment, the coupler and airframe will be secured with several 2-56 x 0.25" nylon shear pins. For sections that do not need to separate, they will be secured together with metal screws.

The fiberglass nose cone will be sanded until it is aerodynamically suitable for integration with the launch vehicle. There will be four CNC cut fins with trapezoidal cross sections as shown in Figure 6, made out of 0.25" thick, aircraft plywood. The grain of the wood will be normal to the airframe of the launch vehicle. Slots in the airframe of the rocket will allow the tabs of the fins to be securely attached to the motor mount. Rocket epoxy will be used as the bonding agent. The fin design was selected to ensure minimal chipping of the fins upon landing as there are no sharp tips that would break off during landing. In addition, the small size of the fins will reduce the drag on the launch vehicle, but still bring the center of pressure far enough aft.

Recovery Subsystem

The recovery subsystem consists of the following elements:

- 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 800ft 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.

Mass Statement

Table 4 below provides the estimated masses for the three subsystems of the current launch vehicle.

Table 4: Subsystem Masses			
Subsystem	**Section**	**Estimated Mass (lbs)**	**Estimated Mass with 25% Increase (lbs)**
Propulsion	Booster section (without motor)	7.00	8.75
	Booster section (with motor)	13.17	16.46
	Engine casing	2.25	2.81
	Aerotech 1170-FJ	6.17	7.71
	Centering rings (6)	0.33	0.41
	75mm Blue Tube	1.26	1.58
Structural and Aerodynamic Stability	Fins	0.73	0.91
	Nose cone	0.17	0.21
	Airframe	6.50	8.13
Recovery	Avionics bay	2.28	2.85
	Drogue parachute	0.19	0.24
	Main parachute	2.25	2.81

Table 5 provides the total estimated mass for the launch vehicle with and without a L1170-FJ motor.

Table 5: Total Mass of Launch Vehicle		
Launch Vehicle	**Estimated Mass (lbs)**	**Estimated Mass with 25% Increase (lbs)**
Launch vehicle (on launch pad)	34.12	42.65
Launch vehicle (before landing)	27.95	34.94

Motor Alternative

The motor alternative to the current L1170-FJ motor to be used in the current launch vehicle is the L1420-R Aerotech motor. Specifications for L1170-FJ and L1420-R Aerotech motors [3] are summarized in Table 6 below, noting the higher average thrust in the Aerotech L1420-R motor, but higher burn time of the Aerotech L1170-FJ motor.

Table 6 : Motor Specifications		
Manufacturer	**Aerotech**	**Aerotech**
Model	L1170-FJ	L1420-R
Diameter (mm)	75	75
Length (in)	26.18	17.45
Launch weight (lbs)	9.68	10.06
Empty weight (lbs)	3.51	4.42
Total impulse (Ns)	4183	4616
Average thrust (N)	1140	1424
Maximum thrust (N)	1473	1662
Burn time (s)	3.7	3.2

The Aerotech L1170-FJ will be utilized if the mass of the rocket stays as predicted or decreases lightly. Figure10 below shows the thrust curve for this motor.

Figure 10: Aerotech L1170-FJ thrust curve

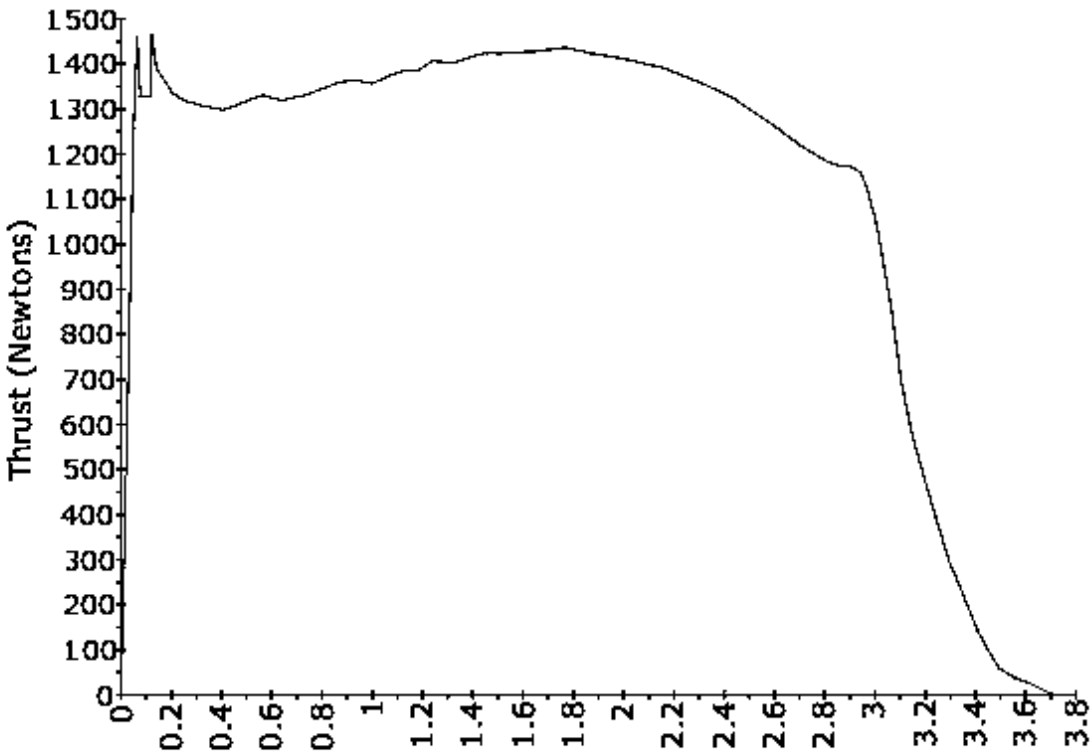


Figure 10 shows the thrust curve for the Aerotech L1170-FJ. The thrust of this motor rapidly increases during the first 0.1s of flight. The motor then rapidly decreases thrust for approximately 0.1s then increases again until it reaches its maximum at approximately 0.3s and then slowly decreases until burn out at approximately 3.7s.

If the predicted mass of the launch vehicle increases significantly, the Aerotech L1420-R would be a more efficient motor. Figure 11 shows the thrust curve for this motor.

Figure 11: Aerotech L1420-R thrust curve

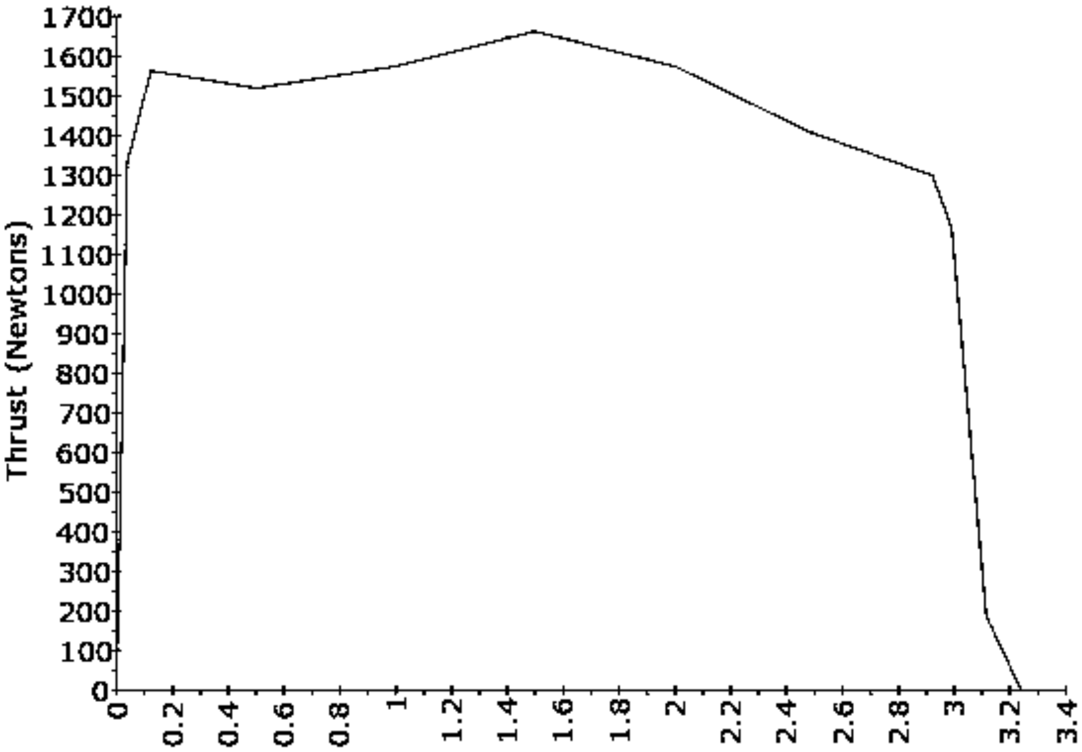


Figure 11 shows the thrust curve for the Aerotech L1420-R. The thrust of this motor increases rapidly within the first 0.2s of flight and slightly dips for approximately 0.3s then increases until its maximum at approximately 1.6s and slowly decreases until it fully burns out at approximately 3.2s.

Recovery Subsystem

Design Review

Current Design

The recovery subsystem of the current design includes two parachutes, an avionics bay, electrical components, and the interfaces between these components. There will be a main parachute and a drogue parachute for dual-deployment. The avionics bay consists of two 13.75" diameter rods, a 10" long sled, and redundant black powder charges. All these components are housed in a 12" long and 6"diameter Blue Tube coupler. The electrical components of the recovery system include altimeters, batteries, wiring, and key switches.

The alternative design of the recovery subsystem's components is discussed in the next section, followed by the description of the components of the current design's recovery subsystem along with the justification for their selection in the subsequent section, Leading Components.

Alternative Design

Tables 7 - 12 list the alternative components to the current deployment system, along with their pros and cons, followed by a description of the current leading alternative. The descriptions include researched based facts related to the leading choices.

Table 7 introduces the shroud lines alternatives.

Table 7: Shroud Lines Alternatives		
Component Alternatives	**Pros**	**Cons**
Spectra Fiber	- High-strength polyethylene fiber - Used extensively in sport parachutes for suspension lines - Low coefficient of friction - Tenacity of 380 – 440 ksi - Excellent abrasion resistance	- Subject to loss of strength at temperature 212˚F
Kevlar	- High-strength para-aramid fiber - Tenacity 370 ksi - Does not melt or burn - Abrasion resistant	- Sensitive to ultraviolet (UV) radiation - Abrasive to the lines itself
Nylon 6-6	- A primary parachute material - Tenacity 96 ksi	- Sensitive to UV light
Dacron	- Resistant to stretch - Deterioration from sunlight - Tenacity 96 ksi - Better temperature resistance than nylon	- Similar to nylon, but requires more treatment for stability - Lower elongation

The current leader shroud line alternative is Spectra Fiber. Spectra Fiber shroud lines are made of High Modulus Polyethylene (HMPE) fiber. HMPE fiber is excellent in abrasion resistance and has low coefficient of friction [4]. This will help reduce friction with air in deployment events. In addition, the HMPE fiber's high tenacity of 380-440 ksi [5] suggests that it is the most durable material for shroud lines when compared to the alternatives.

Table 8 below shows the component alternatives for shroud lines and shock cord interface.

Table 8: Shroud Lines and Shock Cord Interface Alternatives		
Component Alternatives	**Pros**	**Cons**
Quick Link	- High-strength	- Does not pivot
Double Eye Ball Bearing Swivel	- Reduces the amount of twisting in the lines - Made of high-strength stainless steel - The ball bearing diminishes friction	

The parachute shroud lines will end at an interface that provides connection to the shock cord. Quick link is found to be durable due to its high strength, yet it does not pivot along with the shroud lines, which can cause tangled shroud lines that deter parachutes from fully open out and inflate. The double eye ball bearing swivel was chosen to be the alternative current leader as it ensures strength and reduces friction, allowing the parachute to pivot freely with a swiveling link between the shroud lines and the shock cord [6].

Table 9 shows the shock cord alternatives.

Table 9: Shock Cord Alternatives		
Component Alternatives	**Pros**	**Cons**
Tubular Nylon	- Breaking strength ranges from 2000 to 5000 lbs - Light weight - Flame retardant	- Loses its shape easily
Natural Rubber	- Flat elastics - Treated with fire retardant liquid	- The fire retardant liquid can be washed off

The alternative current leader is the tubular nylon shock cord. The main facts taken into consideration for this selection were: durability, reusability, breaking strength of 2000 to 5000 lbs, and a melting point of 480˚F [7]. The natural rubber shock cord with the unstable flame retardant feature was not selected since the shock cord will be exposed to high temperatures from the firing ejection charges.

Table 10 shows the shock cord and bulkhead interface alternatives.

Table 10: Shock Cord and Bulkhead Interface Alternatives		
Component Alternatives	**Pros**	**Cons**
U-bolt	- Long-lasting (stainless steel-made) - Heavy load support - Corrosion resistant - High temperature resistant (above 450˚F)	
Unwelded eye bolt	- Corrosion resistant - Durable (stainless steel-made)	- Opening of the eye bolt
Welded eye bolt	- Corrosion resistant - Durable (stainless steel-made)	- Tightened by only one nut

The shock cord and bulkhead interface must be resistant to high temperatures resulting from black powder ignition. In addition, the interface will experience strong forces as the shock cord stretches out due to parachute deployment. Because of these significant factors, the U-bolt is the alternative current leader for the shock cord and bulkhead interface. U-bolts are versatile fasteners used to secure pipes, conduit, cables, and machinery, or as an anchor in foundations [8]. This component will require the use of four nuts and washers (two nuts and washers for the top and the bottom), adding extra stability and enhance security from loosening.

Table 11 introduces the alternatives of the bulkhead material selection.

Table 11: Bulkhead Alternatives		
Component Alternatives	**Pros**	**Cons**
0.50" Baltic birch plywood	- Higher density than Balsa wood - Elevated strength - Within budget - Exceptional gluing and screw-holding	- Slightly heavier than balsa wood
0.50" Balsa wood	- Light weight - Durable - Within budget	- Lower density than Baltic birch plywood

Since both alternatives presented in Table 11 can be easily cut to the designated 0.5" thickness, have the ability to protect the payload from the heat resulting from the ejection charge, as well as the capability to block the air flow through the tube, the decision for the leading alternative was made based on the density of the material. The Baltic birch plywood is the current leader for the bulk plate component of the recovery subsystem due to its density of 42 lb/ft^3, significantly higher than the Balsa wood's density of 7-9 lb/ft^3.The higher density provides a better choice for the payload bay and a superior protection of the payload from the heat of the ejection charge [9].

Table 12 outlines the alternatives of the altitude detection component.

Table 12: Altimeter Alternatives		
Component Alternatives	**Pros**	**Cons**
Missile Works RRC2+	- Barometric dual-deploy altimeter - User-friendly and painless to install - Easy to read switch settings - Reports peak altitude - Apogee +1 second drogue event - Within budget	
DDC22	- Barometric dual-deploy altimeter - Seven choices of jumper selectable altitude to fire a second charge - Within budget	- Does not report maximum altitude - Choices of selectable altitude do not include the selected 800ft required by the currently designed launch vehicle

The Missile Works RRC2+ altimeter is the current leader due to its features appropriate for project Aegis, including the barometric-dual deployment aspect, reporting of maximum altitude and user-friendliness [10].

Current Recovery System Components

The leading components of the recovery system were chosen for their appropriateness with the project characteristics. Table 13 below outlines the current leaders and the justification of choosing them to be the present leader components of the current launch vehicle's recovery subsystem. These components will contribute to the successful performance of the following functions:

- Detect apogee and 800ft AGL accurately
- Deploy both parachutes at their designated altitudes
- Reduce the landing kinetic energy of each independent vehicle section to less than 75 ft-lbf

Table 13 introduces the leading components of the current launch vehicle's recovery subsystem, their function, fabrication materials and rationale for selection.

Table 13: Recovery System Verification

Recovery System Component	Function	Material	Rationale for Selection
Main parachute (144" toroidal)	Decreases launch vehicle descent rate for safe landing	Ripstop nylon	- Light weight - Low packing volume - Tear-resistant - Drag coefficient of 2.2 that maintains a low terminal velocity while using a smaller parachute
Drogue parachute (24" toroidal)	Decreases launch vehicle descent rate and excessive drift	Ripstop nylon	- Light weight - Low packing volume - Tear-resistant - Drag coefficient of 1.5 that maintains a low terminal velocity while using a smaller parachute
Shroud lines	Provide effective parachute air entrapment	Spectra fiber	- Strong and durable
Shock cord	Absorbs shock created by parachute deployment	Tubular nylon	- Light weight - High strength (9 kN)
Shock cord protector	Prevents damage from black powder ejection charge gases	High-temperature Kevlar sleeve	- Protection against heat resulting from ejection charges
Drogue and main	Prevents	Nomex	- Excellent thermal protection

parachute protectors	damage from black powder ejection charge gases		- High strength and durability
Bulk plate	Divides the launch vehicle airframe into compartments and provides a platform for the U-bolt	Baltic birch plywood	- Robust - Does not break easily
Quick link	Connects the shock cord to the U-bolt and the shock cord to the swivel	Steel	- Easily connected and removed to and from the recovery harness of the rocket
U-bolt	Connects the bulkhead to the quick link	Steel	- High tensile strength - Double set of nuts tighten for stabilization
Eye and eye swivel	Links shroud lines and shock cord	Steel	- Strong - Ensures that shock cords and/or shroud lines do not tangle
Altimeter	Detects altitude	Missile Works RRC2+ Altimeter	- Dual deployment system - Report apogee altitude

Isometric views of the bulk plates to be used in the booster section and in the avionics bay are provided in Figures 12 and 13, respectively.

Figure 12: Bulk Plate with U-Bolt (Isometric View)

Figure 12 shows the bulk plate to be used in the booster section and payload bay

Figure 13: Bulk Plate for Avionics Bay (Isometric View)

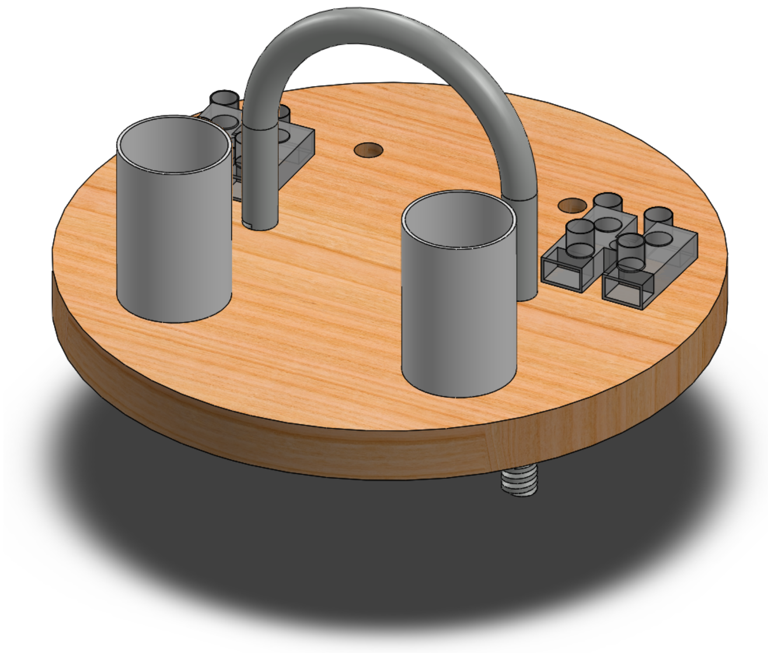


Figure 13 shows the bulk plate that will be used on both sides of the avionics bay

Preliminary Parachute Analysis
This section introduces parachute sizing calculations based on the estimated mass of the launch vehicle, followed by a preliminary parachute specifications for both the drogue and the main parachute, and considerations for a safe descent velocity.

As a general rule, it is suggested that the designed parachute should be able to assist the rocket to perform a descent velocity of 3.5 to 4.5 meters per second. The designated velocity is 3.5 meters per second for reducing the rocket impact while landing.
The area of the main parachute was calculated using the following equation [11]:

$$S = \frac{2 \cdot g \cdot m}{r \cdot C_d \cdot V^2}$$

The diameter of the main parachute was calculated using the following equation[11]:

$$D = \sqrt{\frac{4 \cdot S}{\pi}}$$

The following provide the calculations for the main parachute's area and diameter:

$$S = \frac{2 \cdot (9.8m/s) \cdot (12.68kg)}{(1.225kg/m^3) \cdot (1.5) \cdot (3.5m/s)^2} = 11.04 \text{ m}$$

$$D = \sqrt{\frac{4 \cdot 11.04(m)}{\pi}} = 3.75\ m = 148''$$

The equation below provides the method of calculating the drogue parachute's diameter, followed by the actual calculation of the diameter.

$$D = \sqrt{\frac{4 \cdot L \cdot d}{\pi}}$$

$$D = \sqrt{\frac{4 \cdot 128(in) \cdot 6.08(in)}{\pi}} = 31.48''$$

The list below outlines the physical meaning of the variables used in the equations above, along with their units:

- *m* stands for the mass of the rocket (kg)
- *g* is the acceleration due to gravity(m/s^2)
- *r* stands for the air density (kg/m^3)
- C_d is for the drag coefficient of the parachute
- *v* represents the designated impact speed (m/s)
- L is the length of the rocket (in)
- d is the diameter of the rocket (in)
- S is the area of the parachute (in)
- D is the diameter of the parachute (in).

Table 14 below presents the drogue and main parachute specifications, including their diamter, fabrication material, drag coefficient values and estimated descend rates.

Table 14: Parachute Specification				
Parachute	**Diameter**	**Material**	**Cd**	**Approximate Descend Rate (ft/s)**
Drogue	30"	Ripstop Nylon	1.5	53.12
Main	144"	Ripstop Nylon	2.2	11.48

In order to ensure safe landing of the launch vehicle, its landing kinetic energy must less than 75ft-lb$_f$. The proposed launch vehicle will land with a kinetic energy of 57.27ft-lb$_f$, calculated using the ideal descent rate of the launch vehicle, discussed in the main parachute calculation, and the mass of the rocket without motor (*m* =27.95lbs, see Table 5). The following equation was used to calculate the landing kinetic energy of the launch vehicle [11]:

$$K = \frac{1}{2}mv^2$$

The symbols used in the above equation stand for:

- K is the landing kinetic energy of the launch vehicle
- m is the mass of the rocket without motor
- v is the ideal descend velocity with the deployment of the main parachute.

The calculation of the landing kinetic energy (K) of the launch vehicle is shown below:

$$K = \frac{1}{2}(12.678kg)(3.5m/s)^2 = 77.65275 \text{ J} = 57.27\text{ft-lb}_f$$

Electrical Components and Redundancy
All deployment events will be initiated by a redundant altimeter system. Redundant electrical components include RRC2+ altimeters, batteries, and igniters. Figures 14 – 16 introduce the redundant electrical components utilized for a reliable deployment system. Redundant ejection charges will be connected to a primary altimeter and a redundant altimeter in order to avoid the probability of altimeter malfunction while operating dual deployment. There will be a 1-second delay for the redundant altimeter.

RRC2+ Altimeters
Missile Works RRC2+ is a barometric dual-deployment altimeter and an in flight data recorder, which will be used to detect the altitude and initiate the deployment of the drogue and main parachute. The RRC2+ altimeter is easy-to-use, functional, reliable, and commercially available. There will be 2 altimeters in one avionics bay: the main altimeter and a redundant altimeter. Each altimeter is capable of activating the main and drogue parachute deployment. Figure 14 shows the Missile Works RRC2+ altimeter that will be used to initiate parachute deployment.

Figure 14: Missile Works RRC2+ Altimeter

Figure 14 shows a photograph of the Missile Works RRC2+ altimeter

E-match Igniter
The RRC2+ altimeters initiate the ignition of black powder ejection charges through the use of e-matches in order to deploy the parachutes. In the anticipation of e-match malfunction there will be an e-match designated to the primary deployment system and one to the redundant deployment system. Figure 15 shows the e-matches that will be utilized in the deployment system.

Figure 15: E-matches

Figure 15 shows a photograph of the e-matches to be used in the deployment system

9V Batteries

9V Batteries are the power system of the avionics bay. There are two altimeters installed in the avionics bay, each require a battery to function. The batteries will be replaced prior to each launch to ensure that the proper amount of voltage is available to the altimeters. Figure 16 shows the type of battery used in the avionics bay.

Figure 16: 9V Battery

Figure 16 shows a photograph of the 9V battery to be used in the avionics bay

4F Black Powder

4F black powder is required to deploy the drogue and main parachute. Figure 17 shows the black powder utilized for firing the ejection charges.

Figure 17: 4F Black Powder

Figure 17 shows a photograph of the type of black powder to be used for firing ejection charges

The following equation was used to calculate the mass of black powder needed for the parachute deployments [12]. Calculated results are shown in Table 15.

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

The list below outlines the physical meaning of the variables used in the equations above, along with their units:

m_b is the mass of the black powder (g)

d_c is the inner diameter of the parachute compartment (in)

L_c is the length of the compartment (in)

Table 15 shows the calculated mass (in grams) of the black powder required for the ejection of each parachute.

Table 15: Calculated Black Powder Mass	
Parachute	**Amount of Black Powder (g)**
Drogue	2.42
Main	4.34

Figures 18-20 present the avionics bay of the launch vehicle from various perspectives (external, internal and exploded).

Figure 18: Avionics Bay (External View)

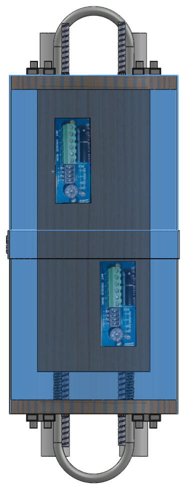


Figure 18 shows an external view of the avionics bay

Figure 19: Avionics Bay (Internal View)

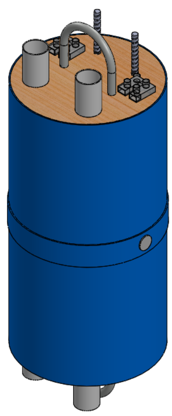


Figure 19 shows an internal of the avionics bay

Figure 20: Avionics Bay (Exploded View)

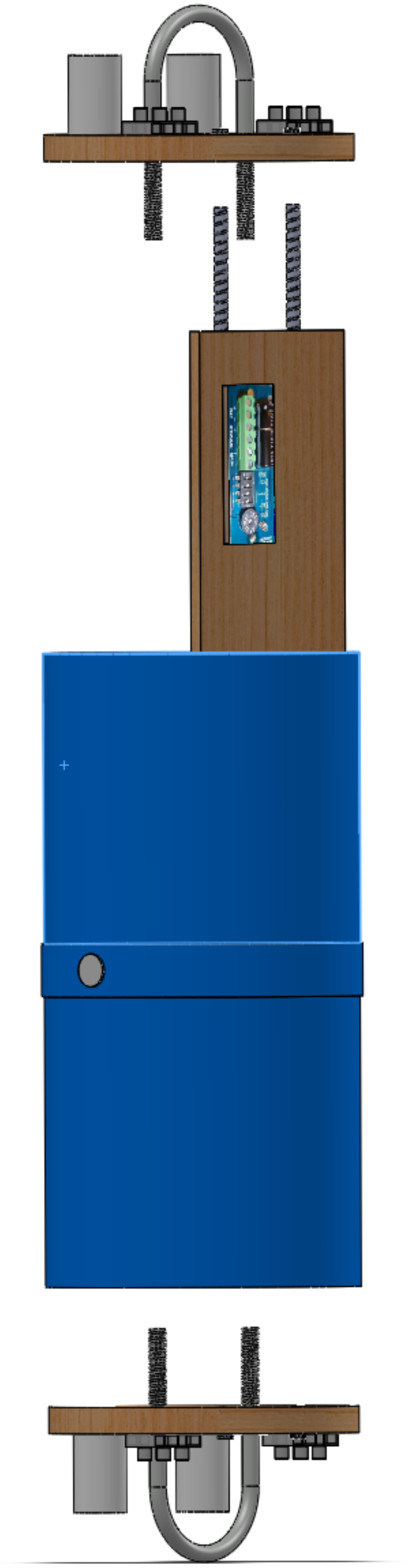


Figure 20 shows the exploded view of the avionics bay

Recovery System Electrical Schematics

The electrical representation of the recovery system is introduced in Figure 21 below.

Figure 21: Recovery System Electrical Schematics

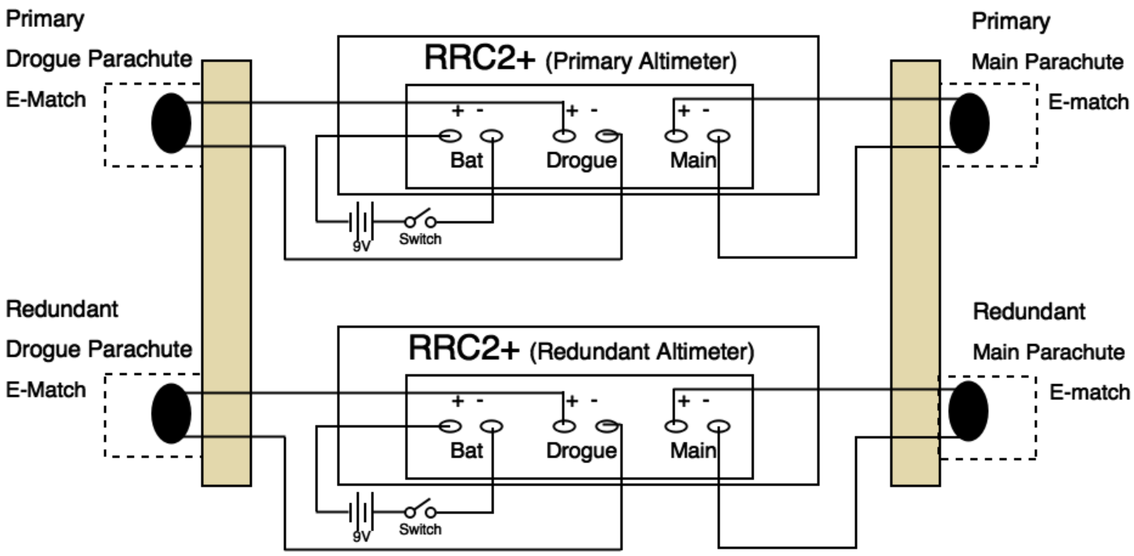


Figure 21 shows the electrical schematics of the launch vehicle's recovery syste.

Mission Performance Predictions

This section lists and reviews the launch vehicle's flight simulation data, the predicted weight of the major components, motor thrust and kinetic energy of the launch vehicle components as well as the predicted range of the launch vehicle at different wind speeds. All simulations, diagrams, the velocity versus time and the static stability margin versus time graphs were performed using RockSim9.

Flight simulations

The launch vehicle is predicted to reach a maximum altitude of 5173.59 ft. and a maximum velocity of 738.96 ft/s when using the Aerotech L1170-FJ motor. The launch vehicle reaches the minimum velocity required for a stable flight at 44.00".

Simulation results

Engine selection: [L1170-FJ-None]

Simulation control parameters:

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

Launch conditions:

- Altitude: 0.00 Ft.
- Relative humidity: 50.00 %
- Temperature: 59.00°F
- Pressure: 14.34psi
- 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/s
- Wind starts at altitude: 1000.00 ft
- Launch guide angle: 0.00 Deg.
- Latitude: 0.00 Deg.

Launch guide data:

- Launch guide length: 36.00”
- Velocity at launch guide departure: 39.53 ft/s
- The launch guide was cleared at : 0.18 s
- User specified minimum velocity for stable flight: 44.00 ft/s
- Minimum velocity for stable flight reached at: 45.19”

Maximum data values:

- Maximum acceleration: Vertical (y): 281.21 ft./s/s Horizontal (x): 0.44 ft./s/s Magnitude: 281.21 ft./s/s
- Maximum velocity: Vertical (y): 738.97 ft./s, Horizontal (x): 21.85 ft./s, Magnitude: 738.96 ft./s
- Maximum range from launch site: 1133.06 ft
- Maximum altitude: 5173.59 ft

Recovery system data:

- Main Parachute Deployed at : 75.17 s
- Velocity at deployment: 0.00 ft/s
- Altitude at deployment: 0.00 ft
- Range at deployment: 1133.06 ft
- Drogue Parachute Deployed at : 16.98 s
- Velocity at deployment: 1.67 ft/s
- Altitude at deployment: 5173.59 ft
- Range at deployment: 107.87 ft

Time data:

- Time to burnout: 3.72 s
- Time to apogee: 16.98 s
- Optimal ejection delay: 13.27 s
- Time to wind shear: 2.81 s

Landing data:

- Successful landing
- Time to landing: 75.17 s
- Range at landing: 1133.06 ft
- Velocity at landing: Vertical: -89.56 ft/s , Horizontal: 0.00 ft/s , Magnitude: 89.56 ft/s (Check launch conditions and launch data)

The weights of the major components of the launch vehicle as predicted by RockSim9 are listed in Table 16 below.

Table 16: Predicted Component Weight	
Component	**Predicted Weight (oz.)**
Nosecone	2.75
Avionics bay	35.0
Booster section (see RockSim Figure 25)	128.15
Mid body section(see RockSim Figure 24)	105.53
Forward section (see RockSim Figure 25)	136.34

Figure 22 shows the velocity of the rocket over time. This data was calculated using the RockSim9 simulations for the rocket using an Aerotech L1170-FJ motor.

Figure 22: Velocity vs. Time Graph

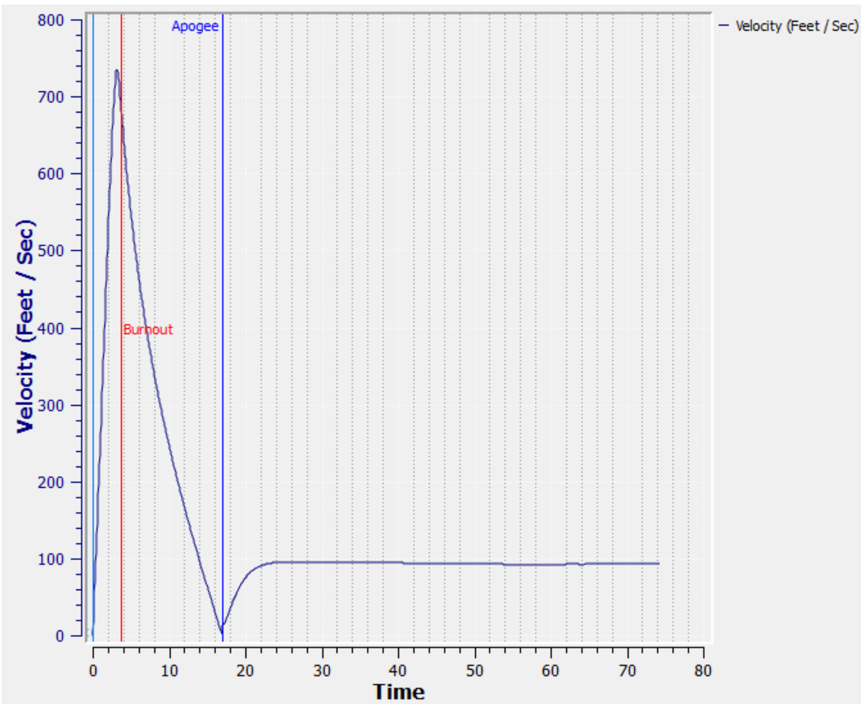


Figure 22: shows the relationship between the launch vehicle's velocity and time for the entire duration of the flight.

As indicated by the graph above after the launch vehicle has reached apogee, it quickly stabilized velocity to about 100ft/s.

Figure 23 illustrates the static stability margin versus flight time of the rocket as indicated by RockSim9.

Figure 23: Static Stability Margin vs. Time Graph

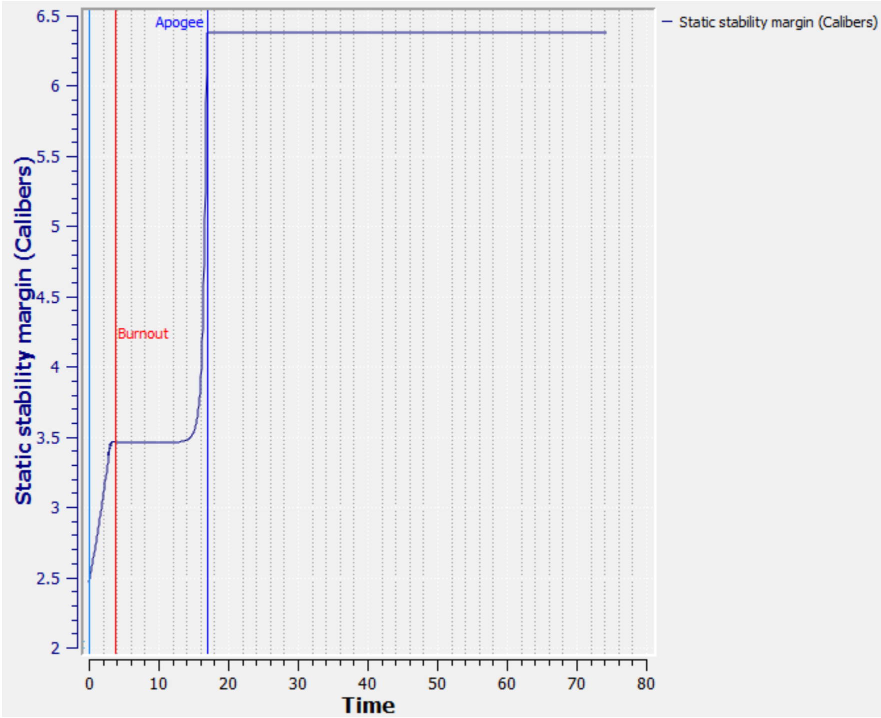


Figure 23: shows how the static stability of the launch vehicle changes over time. The majority of the change occurs within the first 20 seconds of launch.

Selected Motor Characteristics
The average thrust of the Aerotech 1170-FJ motor is 1136.94 N. Figure 24 below illustrates the thrust curve for this motor.
Figure 24: Thrust Curve Graph

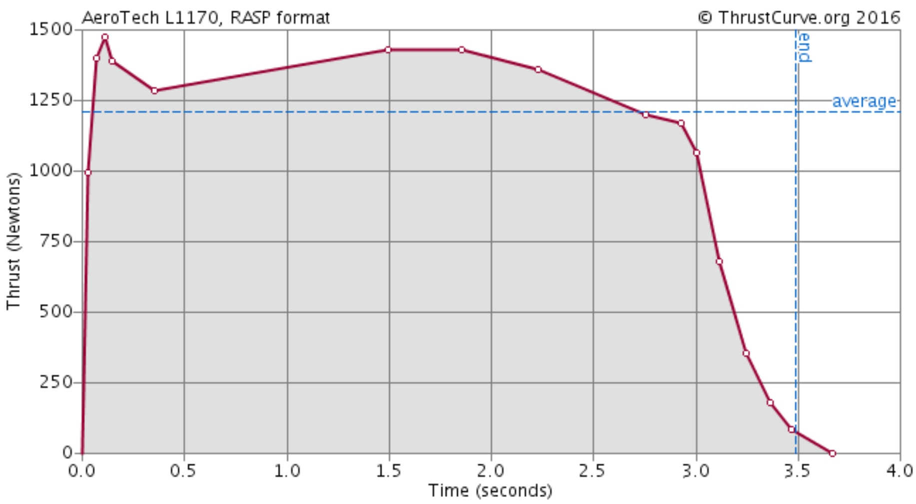


Figure 24 shows the thrust curve for the A 1170-FJ motor

The weight of the launch vehicle on the launch pad is 34.12 lbs. The thrust to weight ratio is 7.5, indicating that the motor is able to overcome the weight of the launch vehicle during takeoff. The thrust curve shows that the L1170-FJ motor reaches its maximum thrust within 0.5 seconds and quickly reduces to slightly above 1250 N. It then increases at a steady rate and slowly begins to decrease again around 2 seconds.

Table 17 below outlines the other properties of the selected motor.

Table 17: Motor properties of Aerotech L1170-FJ	
Properties	**Data**
Diameter (mm.):	75
Length (in.):	26.18
Average thrust (N):	1136.94
Maximum thrust (N):	1489.0
Total impulse (Ns):	4222.60
Burn time (s):	3.71

Vehicle Stability

Figures 25 and 26 show the Center of Pressure (CP) and the Center of Gravity (CG) of the launch vehicle with and without the selected motor.

Figure 25: CP and CG of the Rocket with the Loaded Motor

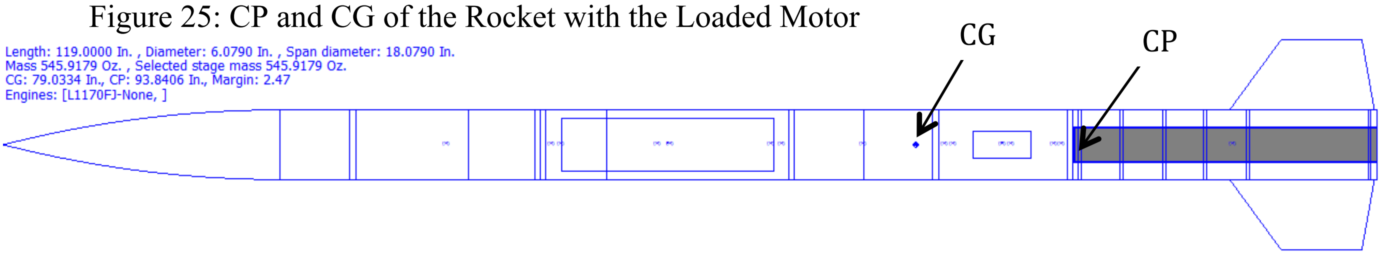


Figure 25: shows the CP and CG of the rocket with the Aerotech L1170-FJ motor. As indicated by the figure, the CG has moved closer to the booster section with the added weight but the CP remains in the same position.

Figure 26: CP and CG of the Rocket without the Motor

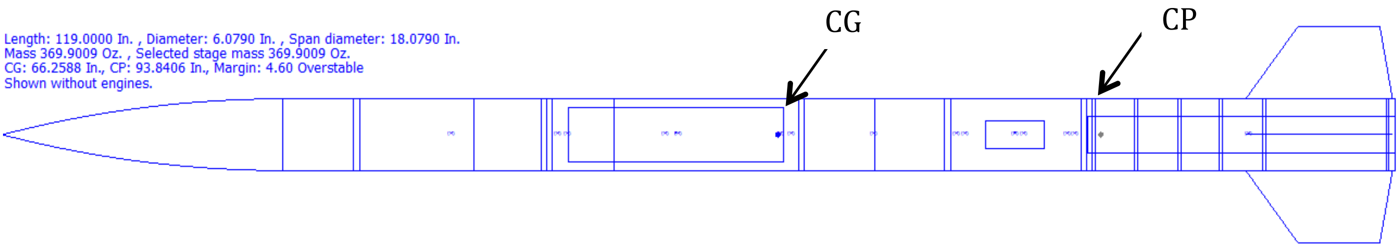


Figure 26: shows the CP and CG of the rocket without the Aerotech L1170-FJ motor.

Table 18 below lists the predicted stability margins of the launch vehicle with and without the selected motor. RockSim9 utilized the Barrowman equation to calculate the location of the CP and the stability of the launch vehicle.

Table 18: Predicted Stability Margins			
Launch vehicle	**CG (inches from top)**	**CP (inches from top)**	**Stability**
With motor	79.03	93.84	2.47
Without motor	66.26	93.84	4.60

As indicated by Table 18, the stability of the launch vehicle increases once the motor is inserted.

Kinetic Energy

Table 19 shows the kinetic energy of each section for several simulations. The kinetic energy was determined using the formula $K=\frac{1}{2}mv^2$ where v is the descent velocity of the rocket. To ensure that each section remains undamaged, the kinetic energy of the each independent section may not exceed 75 ft.-lbft.

Table 19: Kinetic Energy of Rocket Sections			
Launch vehicle section	**Kinetic energy from simulation 1 (ft.-lb.ft.)**	**Kinetic energy from simulation 2 (ft.-lb.ft)**	**Kinetic energy from simulation 3 (ft.-lb.ft)**
Booster	3.32	3.34	3.31
Mid-frame	2.36	2.37	2.37
Forward-frame	4.09	4.12	4.11

RockSim9 predicts that the kinetic energy of these sections is less than 75ft.-lb.ft, indicating that they will be intact upon descent.

Drift from Launch Pad

Table 20 shows the predicted maximum range of the rocket under different wind speed conditions. As indicated by Table 20 below, the launch vehicle's drift increases greatly as wind speed increases. Wind speed on the day of the launch is expected to be no greater than 16 mph, meaning that the launch vehicle predicted to drift no further than 1238.2 ft.[13].

Table 20: Wind Speed and Drift	
Wind speed (mph)	**Max range (ft.)**
0	0
5	406.9
10	792.6
15	1165.2
20	1521.6

IV. Safety

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 with any safety concerns from the previous week.
- 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.
- 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 D).
- 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 B and safety protocols in Appendix C

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 21 shows the qualitative assessment chart.

Table 21: 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. The impact levels are defined in Table 22.

Table 22: 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

The likelihood levels are defined in Table 23.

Table 23: 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 24 List and describe the cause and effects that specific risks pose to the project's completion. A qualitative assessment is give before and after mitigation.

Table 24: Project Risk and Mitigation					
Risk	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**
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 11/22/16 Duplicate parts of the vehicle will be constructed simultaneously, team members responsibilities	1C

				and roles will be define during the team's weekly meetings	
Unable to launch	Unpredictable weather, not all components of the rocket are brought to the launch site. RSO, team mentor or safety officer deems the launch vehicle unsafe to launch	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 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	2C
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
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
Low funds	Too much money used to buy unnecessary material for construction	The team may run out of money to purchases necessary material to	2B	Extra fundraising will be done if necessary	3B

		complete the project			
Low resources	Insufficient funds	Amount of materials purchased might not be enough to complete construction	2B	Extra material will be purchased	2C
Loss of team members	Team member lost interested or become overwhelmed, or lack of work from team member, team member fail to meet the responsibilities 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

Preliminary Checklists

The safety officer is responsible for writing, maintaining and reinforcing the use of the launch procedure checklist during all launches that will occur throughout the entirety of the project. The checklists were created with the intent of ensuring the safety of team members, spectators, equipment, and the environment. Therefore, the usage of the checklist will be heavily enforced by the safety officer. The checklists are broken up into several categories including, but not limited to: launch event operations and final assembly. Each checklist will be reviewed and signed off by the safety officer and two additional team members to ensure compliance of all checklist requirements. Table 25 shows the checklist that will be utilized prior to launch days to ensure all required equipment is taken on site.

Table 25: 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 26 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 26: 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					

Safety Checklist: Drogue Bay Setup

Required Equipment/Supplies:

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

Required PPE:

- Safety glasses
- Gloves

Table 27 shows the preliminary checklist that will be used by the team for final assembly of the drogue parachute bay to prepare it for launch.

Table 27: Preliminary Checklist for Drogue Parachute Bay						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
1	Ensure that the harnesses are secured with quick links to the drogue and avionics bay.					
2	Visually and manually verify the absence of snags inside of the drogue bay.					
3	Ensure the drogue parachute is properly packaged.					
4	Properly loop shock cords and secure the loops with masking tape.					
5	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 28 shows the preliminary checklist that will be used by the team for final assembly of the avionics bay to prepare it for launch.

Table 28: Preliminary Checklist for the Avionics Bay						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
1	Ensure the batteries have a 9-V charge.					
2	Ensure wires are properly attached.					
3	Verify that the electrical components are secured and properly fastened.					
4	Verify that the arming switches engage all subsystems.					
5	Grease and secure bulkheads.					
6	Insert black powder into ejection canisters and seal with duct tape.					

Safety Checklist: Main Bay Setup

Require Equipment:
- Clamp
- Drogue parachute
- Shock chords
- Masking tape
- Duct tape
- Quick links
- Nylon cable tie
- 24” Nomex parachute protector
- Shock cord protector

Required PPE:
- Safety glasses
- Gloves

Table 29 shows the preliminary checklist that will be used by the team for final assembly of the main parachute bay to prepare it for launch.

Table 29: Preliminary Checklist for Main Parachute Bay						
Step		Verified by	Verified by	Date	Time of Verification	Final Verification by Safety Officer
1	Confirm that the harnesses are secured with quick links to the main and avionics bay.					
2	Visually and manually verify the absence of snags inside of the main bay.					
3	Confirm that the main parachute is properly packaged.					
4	Properly loop shock cords and secure the loops with masking tape.					
5	Insert prepared shock cords along with main parachute into the main bay.					

Safety Checklist: Fins

- N/A

Table 30 shows the preliminary checklist that will be used by the team for final assembly of the fins to prepare it for launch.

Table 30: Preliminary Checklist for the Fins						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
1	Manually confirm that fins are properly bonded to the launch vehicle.					
2	Visually confirm that fins are not damaged or cracked.					

Safety Checklist: Launch Pad
Required Equipment

- E-matches
- Electrical tape
- Scissors
- Writing equipment
- Certification card

Required PPE

- Safety glasses
- Gloves

Table 31 shows the preliminary checklist that will be used by the team for launch preparation at the launch pad.

Table 31: Preliminary Checklist for the Launch Pad						
Step		**Verified by**	**Verified by**	**Date**	**Time of Verification**	**Final Verification by Safety Officer**
1	Carry rocket to the launch pad.					
2	Align rail buttons with guide rails and position launch vehicle into place.					
3	Lift launch vehicle into vertical position.					
4	Arm launch vehicle electronics.					

5	Properly install and secure igniters into motor.					
6	Connect igniters to launch system equipment.					
7	Confirm electrical continuity.					
8	Move to, and remain, at a safe distance from launch pad for the duration of the launch process.					

Preliminary Personal Hazard Analysis

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 preliminary risk levels with the goal of controlling and/or eliminating the risk. Table 32 shows the risk matrix used to analyze the severity and probability of a hazard for the entire duration of the NASA SL.

Table 32 : 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 33 lists and defines the severity of a hazard ranging from negligible (4) to catastrophic (1).

Table 33: 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.
	2	Severe injury; major damages to facilities, system or

Critical		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 34 lists and defines risks based on their likelihood. Each hazard is assigned a probability of occurrence ranging from improbable (1) to frequent (5).

Table 34: 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 35 lists the facility hazards potentially present in the construction of the rocket that pose sufficient risk to require mitigation procedures.

Table 35: Facility Hazard Analysis and Mitigation				
Facility	**Hazard**	**Pre-RAC**	**Mitigation**	**Post-RAC**
Citrus College Computer Lab	Lost or corrupted data	**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**
	Damaged facilities			
Launch Sites 1. Rocketry Organization of California (ROC) 2. Friends of Amateur Rocketry (FAR) 3. Mojave Desert Advanced Rocketry Society (MDARS)	Bodily harm	**2D**	NAR High Powered Rocket Safety Code will be followed at every launch. Before launches, a certified team member 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	**2E**
	Damaged facilities	**4E**		**4E**

			safe for launch and the team will comply with their assessment.	
Cal Poly Pomona Wind Tunnel	Physical injury or damage to the rocket	**4D**	Trained personnel will operate the wind tunnel. All activities will be supervised by Cal Poly personnel.	**4E**
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**

MSDS is used to understand the potential hazards of the materials mentioned in Table 36 below. In addition, the preliminary risk levels are also provided in Table 36.

Table 36: Material Hazards Analysis and Mitigations

Materials	Hazard	Cause	Effect	Pre-RAC	Mitigation	Post-RAC
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**
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 least 15 minutes.	**4E**
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**

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**
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**
Solder	Burns, respiratory irritation	Failure to wear goggles, masks, and protective clothing	Mild discomfort, redness, and dryness	**2B**	Appropriate goggles, masks, and protective clothing will be worn. Soldering equipment will be used only in well-ventilated areas.	**3C**
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**
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**
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**

Table 37 below lists the equipment required in the construction of the launch vehicle that poses sufficient risk to require mitigation.

Table 37 : Equipment Hazards Analysis and Mitigation						
Equipment	**Hazards**	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**
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**
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**
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**

Table 38 lists hazards that may occur during launch preparation and flight of the launch vehicle.

Table 38 : Launch Vehicle Hazard Analysis and Mitigation					
Hazards	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**
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. Verify the altimeters are preset to the correct altitude.	**2E**
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**
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

Failure to recover rocket	Ballistic descent could cause destruction of rocket. Premature deployment of the main parachute will cause the launch vehicle to drift further than expected	Loss of launch vehicle	**1D**	Rocket simulation software will be used to ensure rocket stability. Ground ejection tests will be conducted 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.	**1E**
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**

The safety guidelines listed below will be followed to ensure the safety of the participants in all team facilitated outreach events:

- Mechanical operations such as drilling and/or hammering will be done beforehand by the team members
- Minors will be under the direct supervision of adults to ensure the safety of the children
- Potentially hazardous materials and equipment will be locked at all times to prevent unauthorized access
- Written permission will be obtained from the parent or guardian before publishing photographs of the minors
- Proper authorities will be notified should a minor share information that could pose a threat to others or themselves

Table 39 lists the potential hazards posed from the construction of the payload and their corresponding mitigations.

Table 39: Payload Hazards and Mitigation			
Hazard	**Pre-RAC**	**Mitigation**	**Post-RAC**
Cuts and/or burns	**2D**	Protective clothing, gloves, masks, and goggles will be worn while constructing the payload.	**3E**
Skin and eye irritation	**3B**	Protective clothing, gloves, masks, and goggles will be worn while constructing the payload.	**3D**
Fumes and/or particle inhalation	**3C**	Protective masks will be worn while constructing the payload.	**4C**

Preliminary Failure Modes

The systems of the proposed launch vehicle and their components have been analyzed in order to identify the cause and effect of their possible failures and malfunctions. Mitigations were then developed to understand and reduce the risk of these failures.

Table 40 shows the possible failure modes of the launch vehicle with their corresponding mitigations.

Table 40: Launch Vehicle Hazard Failure Modes					
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**
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**
Fin failure	**1B**	Fins are not properly attached to the	Unstable flight, potential rocket damage	Fins slots in the airframe and epoxy will be	**1D**

		motor mount and/or they do not have equal radial spacing		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.	
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 port holes will be correctly sized to ensure proper altimeter readings.	**1E**
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**
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**
Bulkhead failure	**2D**	Bulkheads detach from the airframe	Recovery system failure, damages to	0.50” thick Birch plywood will be bonded to the	**2E**

			rocket	airframe. Tests will be conducted to ensure that the bulkheads are secured.	
Airframe shredding	**1D**	Miscalculation tensile strength of the airframe	Damages to rocket	High shearing strength Blue Tube will be used.	**1E**

Table 41 shows the possible failure modes of the payload and the mitigation of those failures.

Table # 41: Payload Failure Modes					
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**
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	**3E**
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**
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**
Peeling of radiation shield	**1D**	Radiation shield is not properly adhered to the container	Radiation shield is not effective	Properly install the radiation shielding	**3D**
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**

Table 42 shows the failure mode of the propulsion system and the mitigation for such failures.

Table 42: Propulsion Failure Modes					
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**
Motor ignition failure	**3D**	Faulty motor, disconnected e-matches	Failure to launch	Only commercially available E-matches will be used	**3E**
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**
Exploding of the motor during ignition	**1D**	Faulty motor	Loss of rocket and/or motor	Commercially available motors will be used	**1E**
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**
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**
Premature burnout	**3C**	Faulty motor	Failure to reach target altitude	Commercially available motors will be used	**3E**

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 team mentor according to guidelines outlined in the motor handling and storage section	**1E**

Table 43 shows recovery failure modes and mitigations for such failures.

Table 43:Recovery Failure Modes					
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**
Rapid decent	**1C**	Parachute is the incorrect size	Damage to airframe and payload, loss of rocket	RockSim along with various other calculations will be used to determines and estimate the decent rate .	**1D**
Parachute deployment failure	**1C**	Parachute gets 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**
Parachute separation	**1C**	Parachute disconnects from the U-bolt	Damage to rocket and all components	Parachute will be properly secure to the bulk plates with quick links and welded eye bolts, various test will be conducted to ensure parachute remains attached	**1E**

Tear in parachute	**2D**	Poor quality of parachute , parachute was mishandle	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**
Parachute burns	**1C**	Parachute was improperly setup	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**
Slow decent	**2C**	Parachute is the incorrect size	Rocket drifts out of intended lading zone resulting in loss of rocket	RockSim along with various other calculations will be used to determines and estimate the decent rate	**2D**

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

Table 44: 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 feet 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 N-sec (9208 pound-seconds) 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 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	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.
11	**Launcher Location**: My launcher will be 1500 feet from any occupied building or from any	All launches will occur at the launch site(s) listed in Table

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

Table 45 : 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 C 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 feet 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. See section 1.4, for details in the handling and storage of other energetics.

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 the contract in order to engage in any construction or participate in launches. The safety contract can be found in Appendix D.

Environmental Concerns

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

While working on site, the team will create some waste, including but not 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 cause harm to the surrounding environment. In order to prevent possible harm caused by the unknown material the team has constructed a container that will protect the material, as well as anything surrounding it. Details of this container are provided in next section of the document.

There are several environmental hazards that may occur during and after launch. At take-off, the rocket's motor will create a strong flame and thrust. This flame has the power to create a wildfire. To avoid any wildfire, the rocket launches will occur in designated areas, away from any dry brush or grass. The motor's 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 conducting only the minimum amount of launches, as required by the NSL rules. 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 events while there are low clouds or aircraft in launch area. Additionally, the rocket will not exceed the permitted maximum altitude, to avoid collisions with aircraft that may not be visible from the ground. Furthermore, the area where the team has scheduled all rocket launches is located in a field located at 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, as shown in the Safety section of the document. Additionally, the team will ensure that 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 malfunctioning, causing the rocket to come down in free fall motion, possibly 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, as discussed in the Recovery section of the document.

It is also important to consider how the environment might affect the rocket. Actions will be taken to reduce the negative effects that the environment could have 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. The weather concerns are: wind speeds greater than 20 mph, heavy rain, lightning, and severe storms. In addition, the rocket will be launched in an open area where it cannot be damaged by the surroundings.

Table 46 below shows the possible environmental hazards and mitigations.

Table 46: Environmental Hazards and Mitigations

Hazards	Cause	Effect	Pre-RAC	Mitigation	Post-RAC
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. The team will keep rocket	3E

				electronics and parts in the shade, when not in use.	
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
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
Humidity	N/A	Inability to light motor or black powder	3D	The team will keep the e-matches, motors, and black powder stored in a safe location away from the humidity.	4E
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
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
UV damage	Sun	Inability to launch rocket, damage to electronics, and possible explosions	2A	The team will work in shaded area and keep all components from being exposed to the sun for too long.	2E
Sunburn	Sun	Skin Irritation and pain	3D	The Team will apply Sunscreen when necessary	4E

				and work will be conducted in the shade whenever possible	
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
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 rocket will be launched in an unpopulated area away from trees, telephone/power lines, highways or moving vehicles to ensure its safe retrieval.	4D
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
Motor overheating or exploding	Sun	Injury to team member(s) and/or surrounds	1E	The team will keep the motor in a cool area before launch.	4E

Table 47 below list 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 47: 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 before inserting it into the rocket	No significant impact results from this mitigation.

			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 such a way that if a team member were to leave the work load could be	If the team must increase their individual work load there is a slight chase the project may fall behind schedule, but new timelines

			easily distributed amongst the remaining team members.	will be made to accommodate changes to redirect the project back on schedule.

V. Payload Criteria

Selection, Design, and Rationale of Payload
This section outlines the selection process and design justification of the primary payload design and its alternatives.

Objective of the Payload
The goal of the proposed payload is to accomplish the task of providing a protective storage space for fragile Martian sample(s) of unknown characteristics. This storage space must be capable of ensuring the sample(s)'s safe return to Earth.

Experiment Performance
To secure the original quality of the collected material, along with the performance of fragile material protection system, several key elements were selected as shown in table 49. Table 48 defines the abbreviation for the dimension used in table 49. The fragile protection system will achieve the objective of the payload by meeting the container features listed in table 50. The proposed container features and their protective purpose, along with the components interface are shown in table 51.

Table 48 defines the abbreviation for the dimension used.

Table 48: Dimension Abbreviation	
Abbreviation	**Definition**
OD	Outer diameter
ID	Inner diameter
D	Diameter
THK	Thickness
W	Width
L	Length

Table 49 outlines the materials and dimensions of the key elements that will be used for constructing the proposed container designed to perform the fragile material protection task.

Table 49: Materials and Dimension of Key Elements		
Key Element	**Material**	**Dimension**
Outer shell	Polycarbonate	5"OD x 4.75"ID x 12"THK
Inner chamber	Polycarbonate	4.25"OD x 4"ID x 12"THK
Borated flexi-panel	Boron	6.5"W x 11.8"L x 0.275"THK
Aerogel Insulator	Silicon dioxide	6.5"W x 11.8"L x 0.197"THK
Silicon disks	Silicon	3.75"D x 0.25"THK
Pressure sensitive laminating film	Polycarbonate	0.197"THK

Compression springs	Metal	0.25"D x 0.5"L
Threaded rods	Metal	0.25"D x 12"L
Nuts	Metal	0.25"ID
Flat washer	Metal	0.625"OD x 0.281"ID x 0.025"THK
Lock washer	Metal	0.25"ID
Threaded adaptor	Polycarbonate	5.5"D
Threaded cap	Polycarbonate	5.5"D

Table 50 shows the features of the container as a sample protection system and the sample type to which that those features apply.

Table 50: Container Feature and Sample Types that Applies	
Container Features	**Sample Type that Applies**
Impact resistance	Solid/Liquid
Shock absorption	Solid
Heat resistance	Solid/Liquid
Isolation	Solid/Liquid
Containment resistance	Solid/Liquid
Radiation resistance	Solid/Liquid
Pressure change accommodation	Solid/Liquid
Liquid containment	Liquid

Table 51 outlines the experiment performance with respect to the main sample protection features of the container, the key elements related to those features, their component interface and their expected performance as related to preventing sample damage due to potential threats posed by the flight.

Table 51: Experiment Performance			
Container Features	**Key Elements**	**Components Interface**	**Effect on Sample**
Impact resistance	- Polycarbonate cylinder - Line-X - Borated flexi-panel	- Line-X will be sprayed on the external wall of the outer polycarbonate cylinder as a protective coating. - Borated flexi-panel will be wrapped around the outer polycarbonate cylinder with a sprayed Line-X coating.	A firm outer shell with high impact resistance is the fundamental protection of the entire sample storage system that safeguards the sample(s).
Shock absorption	- Threaded rods - Silicon disks - Nuts - Flat washers - Compression springs	- Each sample will be sealed between two silicon disks. - Three equidistantly placed threaded rods will run	Shock absorption for the layers of silicon disks that sandwich the sample(s) is highly important for the duration of the

		through all the silicon disks. - Washers and nuts will be fastened on each rod to hold the layers of silicon plates in place. - The three rods will also run through segments of compression springs playing the role of shock absorbers for each sample laminated with silicon disks. - Segments of compression springs will be coiled around the rods below each set of laminated samples.	rocket's flight. The slight relative motion between the silicon disks as the suspension travels up and down will ensure flexibility of the protective system.
Heat resistance	- Aerogel insulator - Outer shell - Borated flexi-panel	- Aerogel will be installed in between the borated flexi-panel sheet and the container.	Protection against changes in temperature is significant during the rocket's flight. Samples are sheltered from changes in temperature with aerogel insulator.
Isolation	- Silicon disks - Treaded metal rods - Flat washers - Nuts	- Each solid sample will have two silicon disks laminating it from the top and the bottom. - Each silicon disk will have holes drilled on its outer circular ring for allowing three rods to run through. - Nuts will be tightening on the rod, and thus compressing the silicon disks.	Isolation of samples in order to avoid their collision during transportation is an important aspect of protection, should more than one sample needed to be stored in the container. This is accomplished by sandwiching each collected sample between two silicon disks. The restricted space created by the silicon disks ensures that the samples are safe from colliding with each other during

			the rocket's flight.
Contamination resistance	- Outer shell - Inner chamber - Threaded adaptor - Threaded cap	- A threaded adaptor will seal the inner chamber that contains a rack to store solid sample(s). - The threaded adaptor will also be able to seal on the threaded cap as the threaded cap encloses the container.	Safeguarding against contamination of samples that might lead to possible chemical change of the samples is of high importance. The chamber incorporated within the threaded cap that is able to separate solid and liquid samples will ensure the absence of contamination.
Radiation resistance	- Borated flexi-panel - Outer shell	- A sheet of borated flexi-panel will be wrapped around the external wall of the outer shell.	Shielding from radiation is extremely important for sample protection. The collected samples are protected from ionizing radiation by the borated flexi-panel.
Pressure change accommodation	- Outer shell - Inner chamber - Line-X	- Line-X will be sprayed on the external wall of the outer polycarbonate cylinder as a protective coating. - Borated flexi-panel will be wrapped around the outer polycarbonate cylinder with a sprayed Line-X coating.	Sample protection against pressure changes is of high significance during the rocket's flight. The rigid container is capable of providing a stable a storage space for the collected sample(s), preventing it (them) from any possible crushing due to container expansion or shrinkage under unbalanced pressure changes.
Liquid containment	- Outer shell - Inner chamber - Threaded adaptor - Threaded cap	- The inner chamber will be sealed with a threaded adaptor as it is for storage and transportation of solid samples. - The liquid sample will be placed in the spacing between the external space of	Liquid containment with complete sealed function provides a storage space for collected sample in form of liquid.

		the inner chamber and the internal area of the outer shell. - The outer shell that contains liquid will be sealed with a threaded cap.	

Successful Payload Evaluation
In order to observe the performance of the sample(s) under the designed payload protection system, a testing of the proposed payload features will be conducted. The samples of unknown characteristics will be substituted with raw eggs to simulate the fragility of the collected solid samples; the liquid sample will be substituted by water to investigate the effectiveness of the payload protection system for a possible liquid sample. The testing procedures and methods of evaluating the success of the results are outlined in table 52 (solid sample) and table 53 (liquid sample) below.

Table 52 shows the tests that will be conducted to assess the effectiveness of the designed container in protecting solid sample(s) successfully along with what constitute successful results.

Table 52: Successful Payload Evaluation (Solid Sample)

Test	Setup and Procedures	Successful Results
Impact resistance	Set up: - A coating of Line-X will be sprayed on the outer shell. - A sheet of borated flexi-panel will be wrapped around the external wall of the outer shell. Procedure: - The container will be dropped from 4th floor in order to assess its impact resistance.	- Cracks are not found on the surface of the outer shell that protects the inner chamber.
Shock absorption/ Isolation/Containment resistance	Setup: - Each egg will be laminated between two silicon plates. - Three rods will run through all the silicon disks. - Washers and nuts will be fastened on the rod to hold layers of silicon plates in place. - Rods will run through segments of compression springs acting as shock absorbers for each set of sample laminated with	- Eggs are fully secured without any cracks on surface. - Eggs stayed in between the silicon disks, with possible minor position shifts.

	silicon disks. - Segments of compression springs will be coil around the rods below each set of laminated samples. - The rack will be loaded in the inner chamber sealed with a threaded cap. Procedure: - The container will be dropped from 4th floor to assess its shock absorption capability.	
Heat resistance	Setup: - Aerogel will be installed in between the borated flexi-panel and the outer shell. - (Assumed the container is under high temperature)	- No chemical changes are found on the collected sample. - Outer shell remains in the original condition.
Radiation resistance	Setup: - Borated flexi-panel will be wrapped around the external wall of the outer shell. - (Assumed the container is under radiation exposure)	- The collected sample does not change under ionizing radiation.
Pressure change accommodation	Setup: - The solid sample chamber will be sealed with a threaded adaptor. - The outer shell will be sealed with a threaded cap. - (Assumed the container is under unstable pressure change)	- The cylinder does not explode due to pressure change in high altitude.

Table 53 outlines the tests that to assess the effectiveness of the designed container in protecting a liquid sample successfully along with what constitute successful results.

Table 53: Successful Payload Evaluation (Liquid Sample)		
Test	**Setup and Procedures**	**Successful Results**
Impact resistance	Setup: - The cylinder is sprayed with a coating of Line-X and wrapped up with borated flexi-panel sheet. - Threaded adaptor will seal the solid sample chamber. - The liquid sample will be placed in the spacing between the external space of the inner chamber and the internal area of the outer shell. - The outer shell that contains liquid will be sealed with a threaded cap. Procedure: - The container will be dropped from 4th floor to test for impact resistance.	- The surface of the cylinder remains dry without any leakage. - No cracks are found on the surface of the outer shell.
Heat resistance	Setup: - The aerogel will be installed between the borated flexi-panel and the outer shell. Procedure: - (Assume the container is under high temperature)	- The sample does not undergo any chemical changes. - The outer shell remains in the original condition.
Isolation/Liquid containment/ Contamination resistance	Setup: - The solid sample chamber will be sealed with a threaded adaptor. - Water will be placed in the outer shell. - Outer shell will be sealed with a threaded cap. Procedures: - A simulation of rocket vibration during flight will be performed by shaking the container containing water. - A simulation of container position before parachute deployment will be conducted by holding the container	- Water did not leak under rapid fluid motion. - Solid sample chamber remains dry without any leakage from the outer shell.

	upside down to assess its isolation with respect to other sections of the container.	
Radiation resistance	Setup: - Flexi-panel will be wrapped around the external wall of the outer shell. - (Assume the container is under radiation exposure)	- Collected sample remains originality.
Pressure change accommodation	Setup: - Solid sample chamber will be sealed with a threaded adaptor. - Water will be placed in the outer shell. - Outer shell will be sealed with a threaded cap. - (Assume the container is under unstable pressure change)	- The cylinder does not explode or crack due to unstable pressure changes. - Leakage is not found due to expansion of air within the container.

Payload Systems
The payload consists of five different systems. Each system is designed to protect the collected sample(s) with unknown characteristics from a different hazard. The current payload systems and their alternative designs are described in this section. Evaluations of the pros and cons for each alternative design are also provided.

Containment and Impact System
Current Leading Alternative
The containment and impact system of the payload is designed to hold the sample rack and house any liquid samples that may be present. The container will be constructed from polycarbonate, a high impact resistant polymer [14]. Polycarbonate has a tensile strength of 10152.6 psi which is more than necessary to protect the sample(s) from impact [15].
Alternative Designs

1. The first alternative design consists of a box-shaped container that opens from the side to house the samples. This container has adjustable chambers to allow for samples of different shapes and sizes to be inserted. The chambers are adjusted using a rail system and Sorbothane dividers. Sorbothane is impact and shock resistant and provides the sample(s) with additional protection [16]. The dividers move up or down via the rail system. Any spare dividers are stored at the bottom of the container. This design had ample space for sample(s) but resulted in a large bulky container. The small components of this design also made the container difficult to construct.
2. The second alternative has a similar structure to the current leading alternative, but it also utilizes a lining of Kevlar or oobleck to further cushion the sample(s). The sample disks are made of Sorbothane instead of silicone. This material is firmer than silicone and more resistant to tears or punctures [17]. Sorbothane has a tear strength of 16lb/in and silicone has a tear strength of 9lb/in [18]. However, this material is less flexible than silicone, and would not seal the samples as well as the silicone disks used in the current leading alternative.

Isolation System

Current Leading Alternative

The isolation system is designed to securely hold each sample and prevent motion or interaction with the rest of the container or other samples. It will consist of three threaded rods running through several silicone disks. Everbilt zinc nuts will be placed above and below each pair of disks and will be tightened on the rod to compress them. In addition, there will be a spring coiled on each rod between the pair of silicone disks. In order to hold the sample(s) in place (between two disks) the two disks will be pinched around the sample, compressing the spring.

Alternative Designs

1. The first alternative was designed to have adjustable chambers to allow for samples of different shapes and sizes to be inserted. The chambers are adjusted using a rail system and Sorbothane dividers. The dividers move up or down via a rail system that is controlled by an Arduino Uno. Any spare dividers are connected to the rail, but stored at the bottom of the container to be used when needed. The dividers adhere to the rail system using Loctite Epoxy Plastic Bonder. This design was not desirable because of the complexity of the rail/platform design. The outer container would have been simpler to construct than a cylinder but the inner components would have been difficult to manufacture and install. This design also did not consider the possibility of housing a liquid sample. The wiring of the rail system would have been in the bottom of the container and would run outside the container and be connected to a power source. If a liquid sample had been chosen it would have had to go in the main compartment were it could possibly cause damage to the rail system.
2. The second alternative system has the same design as the primary container but instead uses Sorbothane disks instead of silicone.

Radiation Protection System

Current Leading Alternative

The radiation protection system of the primary design consists of a borated flexi panel. This layer will be used to protect the inner samples from gamma radiation and penetrating neutrons that could otherwise affect the sample(s). The panel will be adhered to the outside of the container using Loctite Plastic Epoxy Bonder.

Alternative Designs

1. An alternative design is to cover the outside of the box-shaped container (see Figure 27) with a sheet of polyethylene using Loctite Epoxy Plastic Bonder to prevent radiation from damaging the sample(s). It is lightweight sheeting that provides protection from fast neutrons and reduces the impact of hydrogen captured gammas [19]. Although it is effective protection against radiation, it is a thick shielding that would increase the container's size by about 0.5", making it too large to fit in the payload bay of the designed launch vehicle.
2. Another alternative design would be to use Polyethylene pellets in combination with the cylindrical container (see Figure 31). The pellets would fill a second outer wall and be contained when the cap seals the entire structure. These pellets would be effective in shielding against gamma radiation and neutron beams [20]. However, this design increases the size of the container and requires a second outer chamber to be constructed.

Thermal Protection System

Current Leading Alternative

The thermal protection system consists of a layer of aerogel insulation. This will prevent heat from entering the sample and from escaping the container, thus ensuring that the temperature of the sample(s) remains stable.

Alternative Designs

1. The first alternative design utilizes a layer of polyurethane foam. It is an effective thermal insulator but requires a thick layer to stabilize temperature [21]. This increase in the container's size could prevent it from fitting in the rocket.
2. The second alternative to this design would be to coat the container in Icynene insulation spray. This would reduce the size of the container allowing for additional thermal protection layers. However, it is preferred that Icynene is not used because it is more expensive and not a recyclable material.

Flammability System

Current Leading Alternative

The flammability system of the primary design works by restricting the oxygen supply to the sample. This prevents a possible fire from growing and spreading in the container. To achieve this, the sample container will be sealed preventing air from entering or leaving the container.

Alternative Designs

1. The first alternative relies solely on the high heat resistance of polycarbonate to reduce the risk of fire [22]. While the likelihood of the sample(s) combusting is low, additional steps should be taken to reduce the risk of fire. This design was originally considered because it does not require any extra layers of fire protection which would make the container larger, but not provide a more effective protection.
2. The second alternative design adds a layer of Kevlar on the wall of the inner chamber for additional fire protection. This design provides the sample with protection should an external fire take place. The layer of Kevlar lines the inside of the container and adheres to the wall using Loctite Plastic Epoxy. In addition to providing fire protection, this would offer extra impact protection for the samples should they come in contact with the inner wall of the container.

Alternative Payload Designs

The alternative payload designs, including research based facts about why those alternatives were or were not chosen, followed by a summary of pros and cons for each alternative are introduced in this section.

Alternative 1: Box-shaped Container (see Figures 27 and 28)

This alternative is designed as a 5.5" by 5.5"by 13" box with a door on one side to allow for the sample(s) to be inserted into the container. A box-shaped design is simple to construct but this shape is not ideal for being stored inside a rocket. A cylindrical container is preferred for this purpose. This is because the corners of the box are weak structural points and could possibly cause damage to the interior of the rocket [23].

Figure 27: Alternative Container Design (Internal View)

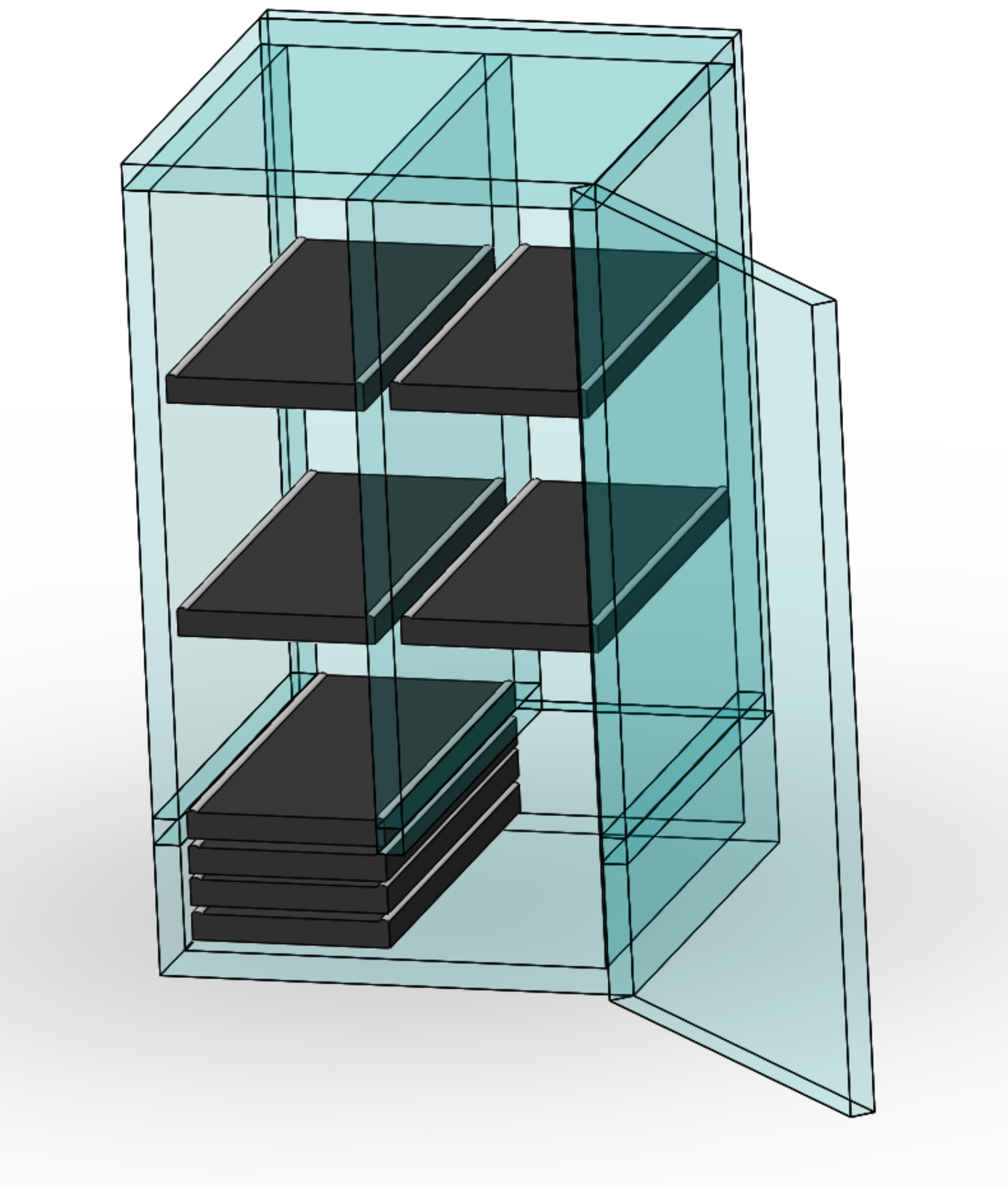


Figure 27: shows an internal view of previous design for the team's container.

Figure 28: Alternative Container Design (Side View)

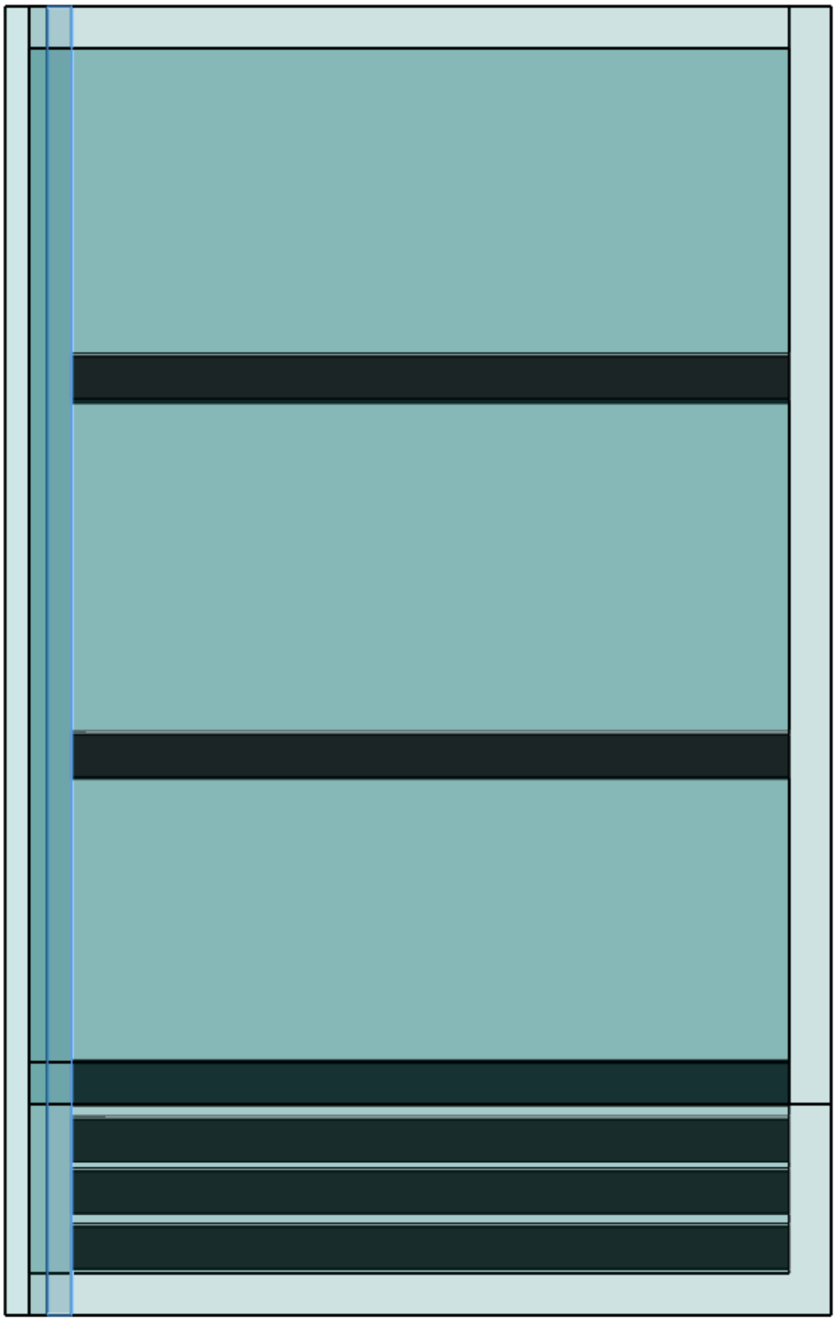


Figure 28: shows the side view of the alternative container design.

Table 54 below summarizes the pros and cons of this alternative.

Table 54: Pros and Cons of Box-shaped Container Alternative	
Pro	**Con**
Ample space for sample(s)	Results in a large bulky container
The outer container is simple to construct	Inner components are difficult to manufacture and install.
The isolation chambers can be adapted to different sizes and shapes	Design does not consider the possibility of housing a liquid sample
Effective protection against radiation	Thick shielding increases the container's size significantly
Effective thermal insulator	Requires a thick layer of thermal insulator to stabilize temperature
Container does not require any extra layers of fire protection which would make the container larger	Flammability protection could be more effective
Simple construction of outside container	Weak points at corners

Alternative 2: Cylinder with Pressure Valve

This alternative design consists of a 5.5"x13"cylinder with an inner chamber for solid sample(s) and two outer chambers. The outermost chamber is designated to house the radiation protection material and the other chamber is to hold a liquid sample if necessary. The cylinder also has a pressure chamber used to stabilize the pressure in the container. This chamber is located on the underside of the cylinder in order to maintain the cylinder's width. It is connected to the main container using a vent controlled by an Arduino. The Arduino is programmed to open or close the vent depending on the readings it receives from the attached pressure sensor. The inside of the cylinder is lined with a bag containing oobleck, a mixture of cornstarch and water, in order to soften any possible impact of the sample with the chamber walls. A different material considered for coating the interior chamber is Kevlar, which would not only cushion the sample in the case of impact, but also provides extra protection against fire [24].

This container design was rejected as a result of the following considerations: (1) the atmospheric pressure on Mars is significantly less than the one on Earth; as such, should the container be designed to withstand the pressure on Earth, it is clear that it would be capable of enduring the atmospheric pressure and any pressure changes on Mars, and (2) oobleck hardens when a force is applied to it [25]. The launch to Mars and back to Earth might provide enough force to harden the oobleck, thus increasing the likelihood that the sample will damage itself in the container. The use of Kevlar to line the inside of the container instead of oobleck could provide effective impact protection and additional fire shielding, as the structures of the Kevlar fiber are not flammable, so a Kevlar layer along with the seal of

the container could provide the fire protection for the sample [26]; however, Kevlar is very expensive.
Table 55 summarizes the pros and cons of the second alternative design.

Table 55: Pros and Cons of Cylinder with Pressure Valve Alternative	
Pro	**Con**
Cylindrical shape of container designed to fit in rocket	Pressure chamber is unnecessary
Thicker material used for sample containment, less likely to tear, compared to silicone	Less flexible than silicone, Sorbothane disks would not seal the samples as well as the silicone disks
Effective shielding against gamma radiation and neutron beams	Increase the size of the container and requires a second outer chamber to be constructed.
Icynene reduces the size of the container allowing for additional thermal protection layers	More expensive and not a recyclable material
Additional fire and impact protection	Oobleck hardens when a force is applied

Primary Payload Design Configuration and Leading Alternative

The chosen payload design configuration and the current leading alternative design are presented in this section. In addition, this section introduces the main differences between the primary design and its leading alternative, along with the rationalization and circumstances under which the leading alternative design configuration would be chosen over the primary design.

Primary Payload Design Configuration

The payload designed to protect Martian samples (solid and liquid) while being transported to Earth is comprised of a polycarbonate cylindrical container (see Figure 31). The polycarbonate was chosen due to its high impact strength [27]. The container was designed considering that the collected samples must be protected from the following main hazards: impact, shock, cross-contamination, radiation, and temperature and pressure changes. In order to address these hazards, the primary payload configuration consists of building blocks designed to optimize sample isolation, impact resistance, radiation resistance, and thermal and fire protection. These main elements of the primary payload configuration are introduced next.

Sample Isolation

The isolation component of the primary payload design is the sample containment system designed to securely hold each sample and prevent their motion or interaction with the rest of the container. It consists of three (3) threaded Everbilt zinc rods placed inside the container and running through eight (8) pairs of silicone disks, as shown in Figure 34. The 16 silicone disks (the eight pairs mentioned above) will form eight (8) compartments designed to hold the samples in place. The sections of the rods located between each pair of disks will be coiled by springs. Each pair of consecutive disks will be pinched together, enclosing the sample, while compressing the springs. The disks will be held in a secure position using two nuts, one thicker than the other to prevent them from loosening [28].

Impact Resistance

The impact protection is performed by designing the containment system to hold the sample rack and house any liquid sample(s) safely. The container is comprised of polycarbonate cylinder 13.25" in length and 5.25" in diameter, as shown in Figure 31. The cylindrical container has an outer wall and thus provides a total of two (2) vertical chambers for sample containment: one larger chamber, divided in eight (8) horizontal sections as described in the section above to house the solid samples and another thinner chamber designed to house the liquid sample. The tensile strength of polycarbonate (8702.26-10500.73 psi) along with its compression shear strength of 1713 psi is sufficient to protect the sample from any damage that may be caused by impact [29]. Additionally, a layer of LineX, a sturdy and enduring protective material, will be sprayed onto the outer surface of the container providing more impact resistance and strength to the container. The LineX coat will increase the container's tensile strength up to 6,600 psi and its tear strength up to 780lbs/in [30].

Radiation Resistance

Protection against radiation is done by adding a layer of 9 % borated flexi panel to the outside of the container using Loctite Plastic Epoxy Bonder. The borated flexi panel is made of a substance commonly used for radiation shielding in fusion test facilities and high energy accelerators due to its high hydrogen and boron density which attenuates the radiation field, in addition to being a hydrogenous additive which reduces the speed of neutrons, also contributing to the cutback of radiation fields [31].

Thermal and Fire Protection

The sample(s) are protected against changes in temperature by using a layer of aerogel insulation added to the container's inner vertical chamber. Aerogel is commonly used as protective insulation due to its exceptionally permeable features [32] and very low thermal conductivity [33].

In order to protect the sample(s) against any possible fire hazard, the container will be sealed with threaded caps, of dimensions shown in Figure # 29. This will restrict the oxygen supply to a potential flame accidentally developed within the container. Limited oxygen supply in combination with the self-extinguishing properties of polycarbonate ensures an effective fire protection of the proposed payload [34].

Leading Alternative Design Configuration

The leading alternative to the primary payload design consists of a cylindrical container of the same dimensions as the primary design. Many aspects of the protective elements of this design are the same as the ones of the primary design, presented in the section above. However, the alternate design configuration has the impact, radiation, thermal and fire protection systems somewhat different, as described below.

Impact and Radiation Protection

The impact protection is carried out by the design of the container, which is an acrylic cylinder with two outer walls; this provides a total of three (3) vertical chambers: one larger vertical space for the solid samples, a thinner chamber for the liquid sample and a final chamber for a radiation shield.

The main differences between the protection system in the alternate design and the one in the primary design consist of the following: (1) the material that the alternately designed container is made of is acrylic, as opposed to polycarbonate, which is the material that the primary design uses, and (2) the cylindrical container of the alternate design consists of an inner compartment and two outer vertical shells, as opposed to the primary design which is comprised of an inner vertical chamber and only one outer vertical space. Acrylic has the same tensile strength as polycarbonate and can protect the sample(s) from any damage that may be caused by impact. However, it is very rigid, more likely to chip than polycarbonate, and much less resistant to flames when compared to polycarbonate [29]. Because acrylic is more durable than polycarbonate and less expensive [35], it will be used to construct the container instead of the polycarbonate should the durability and/or cost be considered as significant factors in the construction of the payload. The alternate design of the container comprised of three (3) vertical chambers as opposed to two (2) as the primary design indicates will be considered, should the extra outer vertical compartment be unproblematic to fabricate and the 5% borated polyethylene pellets used for shielding that will be housed in this extra vertical space will prove to be easier to use than the 9 % borated flexi panel, since the panel's flexibility is low, which makes the use of it to line the cylinder complicated.

Thermal and Fire Protection

The leading alternative design for thermal protection is to coat the container with several layers of Icynene insulation spray. The Icynene coats are placed between the acrylic container and the radiation shielding. Icynene is a mixture of isocyanate and resin that forms expanding foam. It is simple to use and provides another solution for the thermal protection element of the payload [36]. Both aerogel and Icynene are effective thermal insulators; however, since Icynene is more expensive and not recyclable [36], this alternate thermal protection would be used only if the thickness of the container becomes a factor of significance. The use of Icynene coats removes the need for any aerogel insulation layers and reduces the container's thickness.

In addition to keeping the container sealed to restrict oxygen supply as the primary design indicates, an alternate design that would enhance fire protection would be an addition of a Kevlar lining to the interior vertical chamber of the container. Kevlar is a strong and flexible material with an enhanced thermal stability that does not melt or support combustion; however, it is expensive and reacts badly with UV radiation [37]. Kevlar will be used should the need for an enhanced fire protection arise while completing the project.

Payload Diagrams

Figures 29-36 in this section give diagrams of the primary payload's main components. In all diagrams, dimensions are given in inches.

Figure 29: Cap of Proposed Container

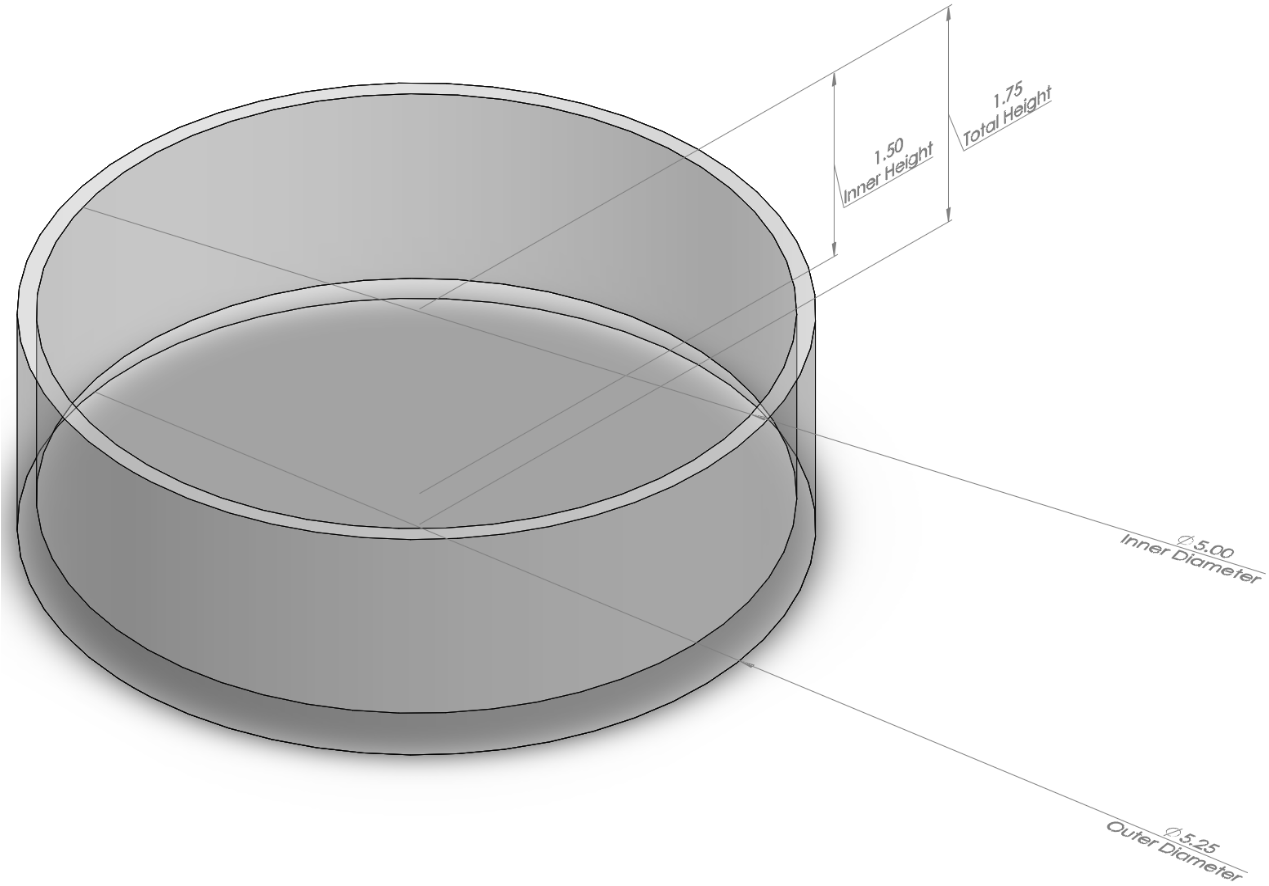


Figure 29 shows the container's cap with inner diameter, outer diameter, inner height, and total height

Figure 30: Outer Shell of Proposed Container

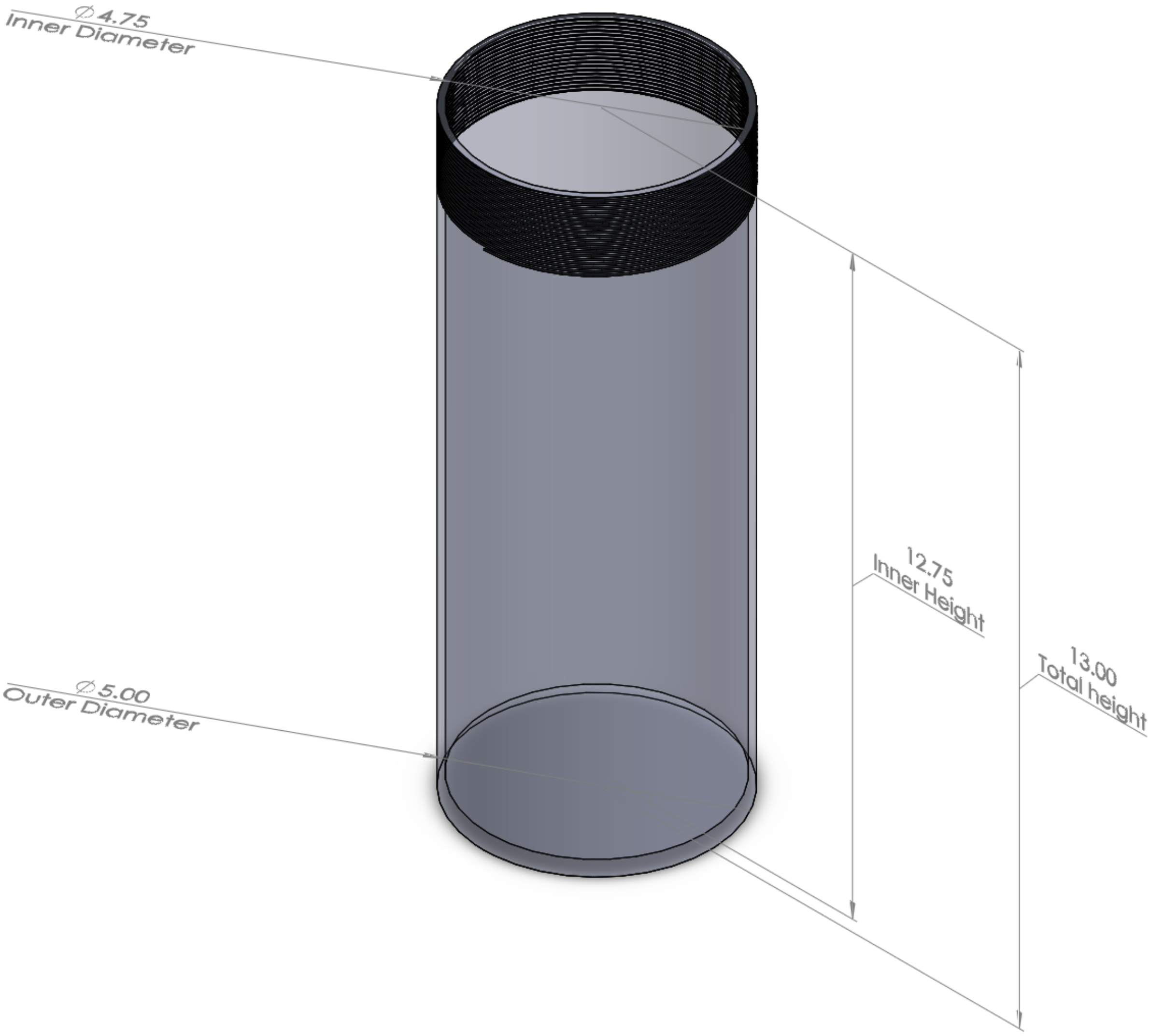


Figure 30 shows the outer shell of the proposed container with outer diameter, inner diameter inner height, and total height

Figure 31: Fully Assembled Proposed Container (External View)

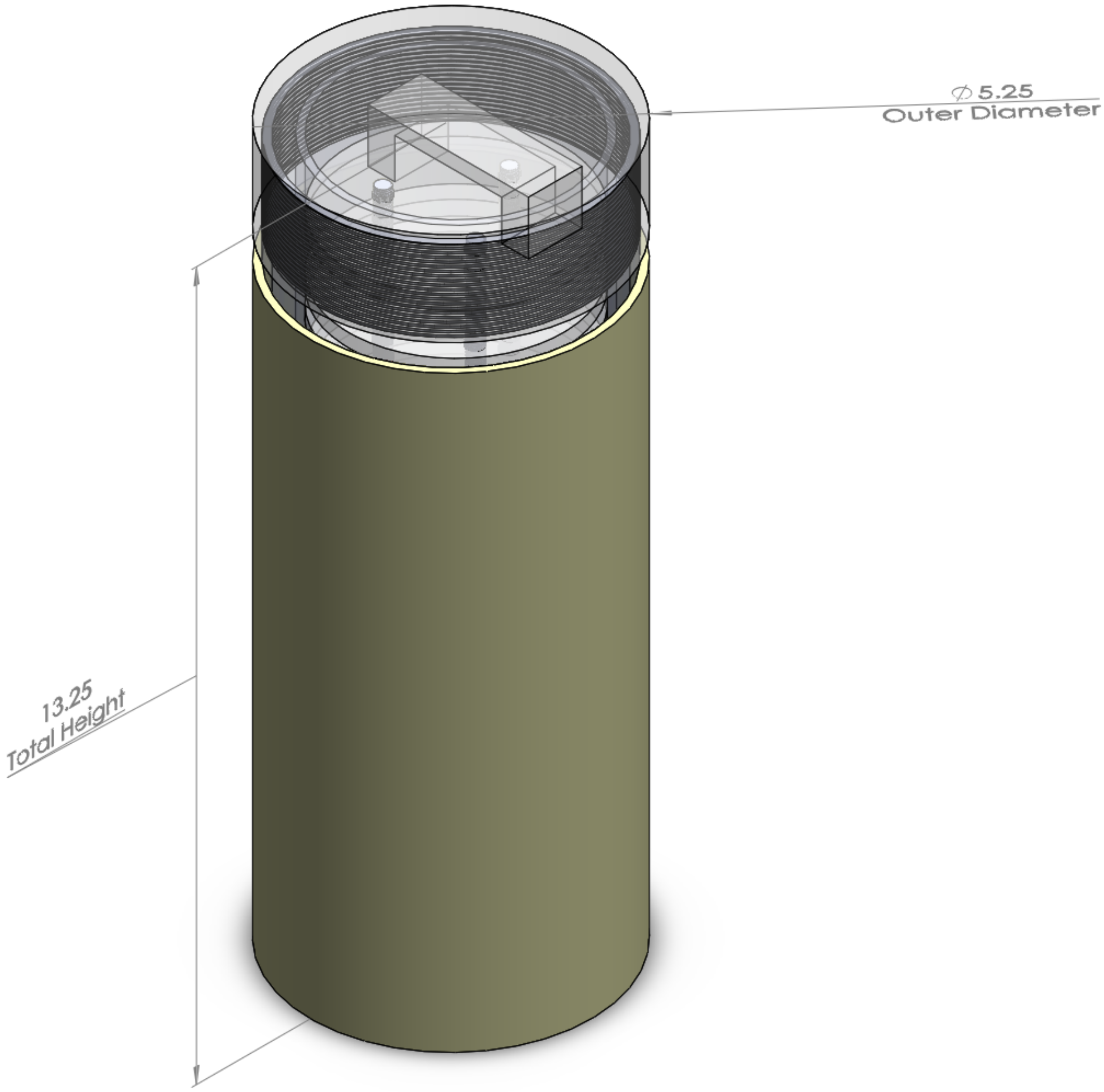


Figure 31 shows the complete proposed container with total diameter and height

Figure 32: Spring of the Inner Rack

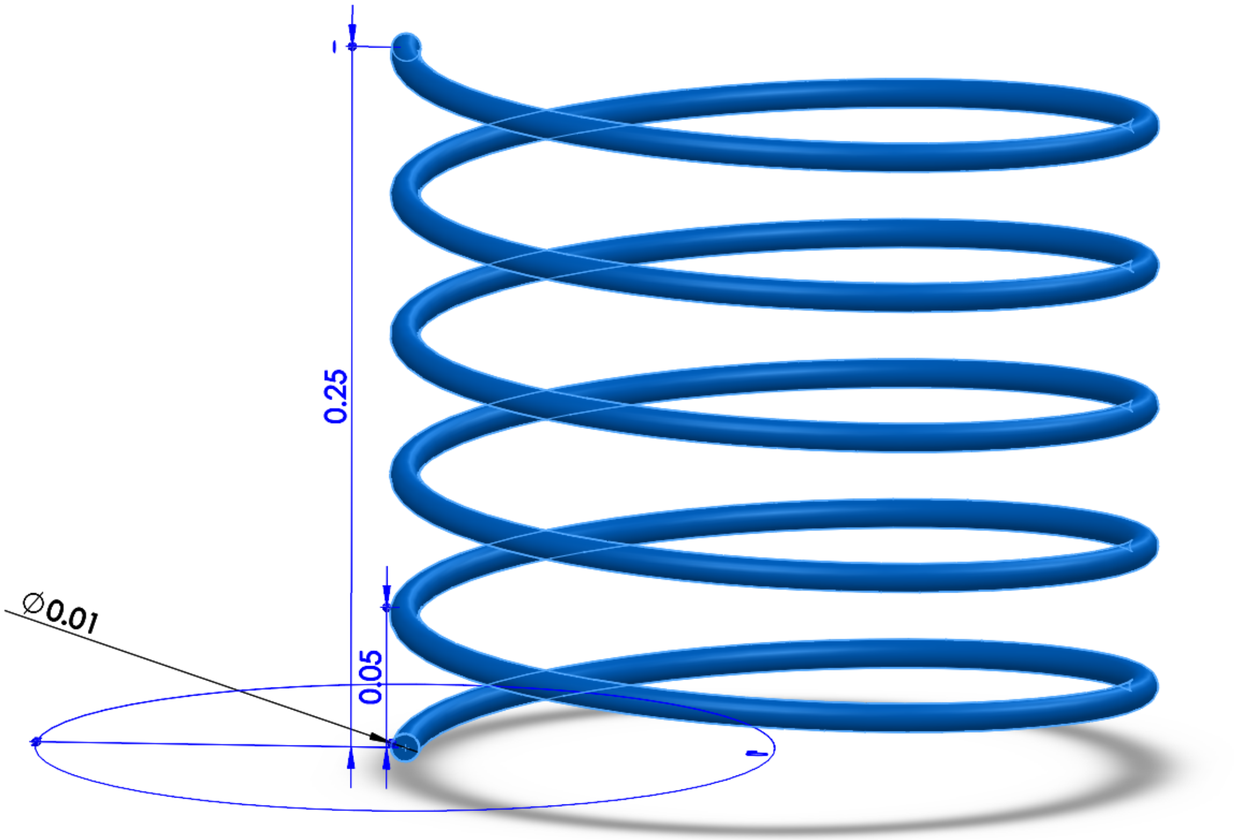


Figure 32 shows the spring with total height, coil separation, and coil diameter.

Figure 33: Inner Chamber of the Proposed Container

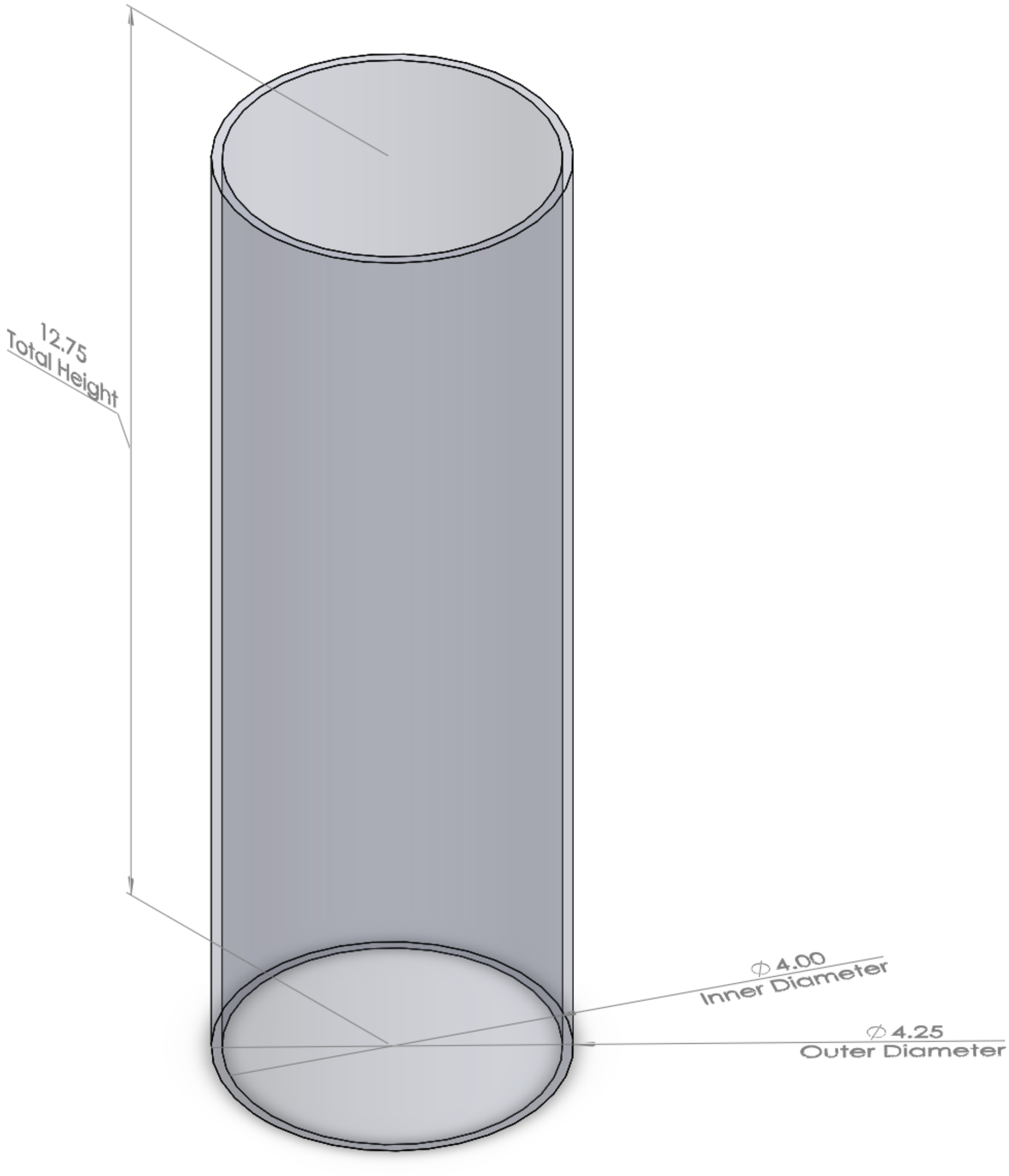


Figure 33 shows the inner chamber of the proposed container with total height, outer diameter, and inner diameter

Figure 34: Inner Rack of the Proposed Container

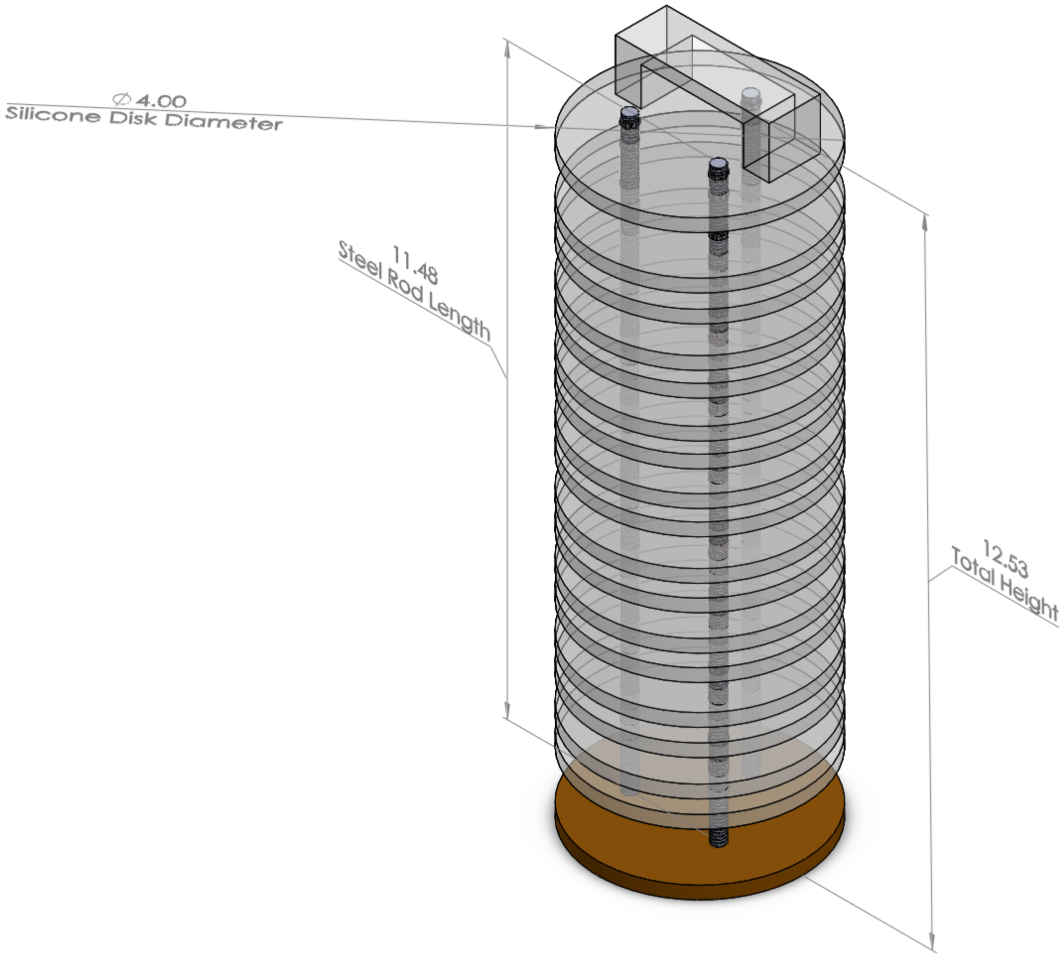


Figure 34 shows the inner rack of the proposed container with total height, rod height, and silicone disk diameter.

Figure 35: Radiation Shielding of Proposed Container

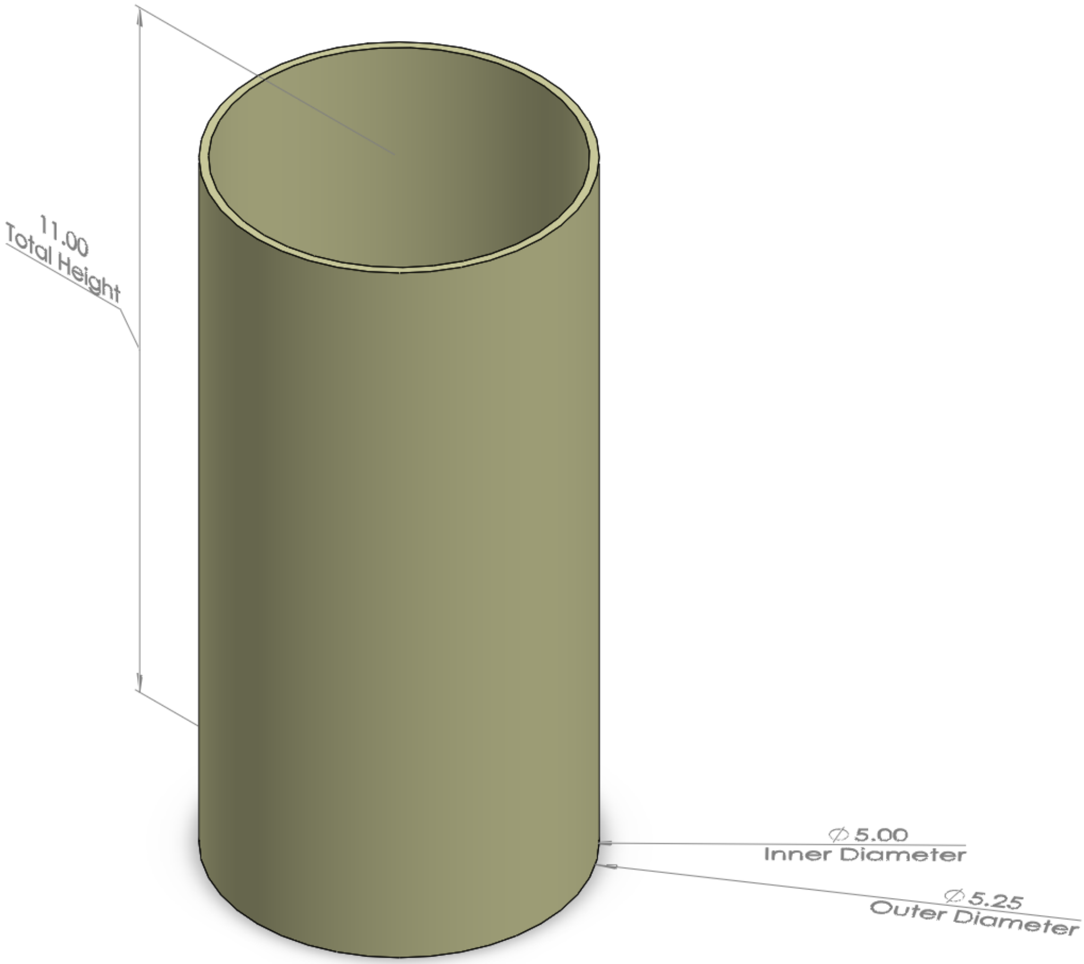


Figure 35 shows the radiation shielding of the proposed container with inner diameter and total height

Figure 36: Proposed Container (Cross Section View)

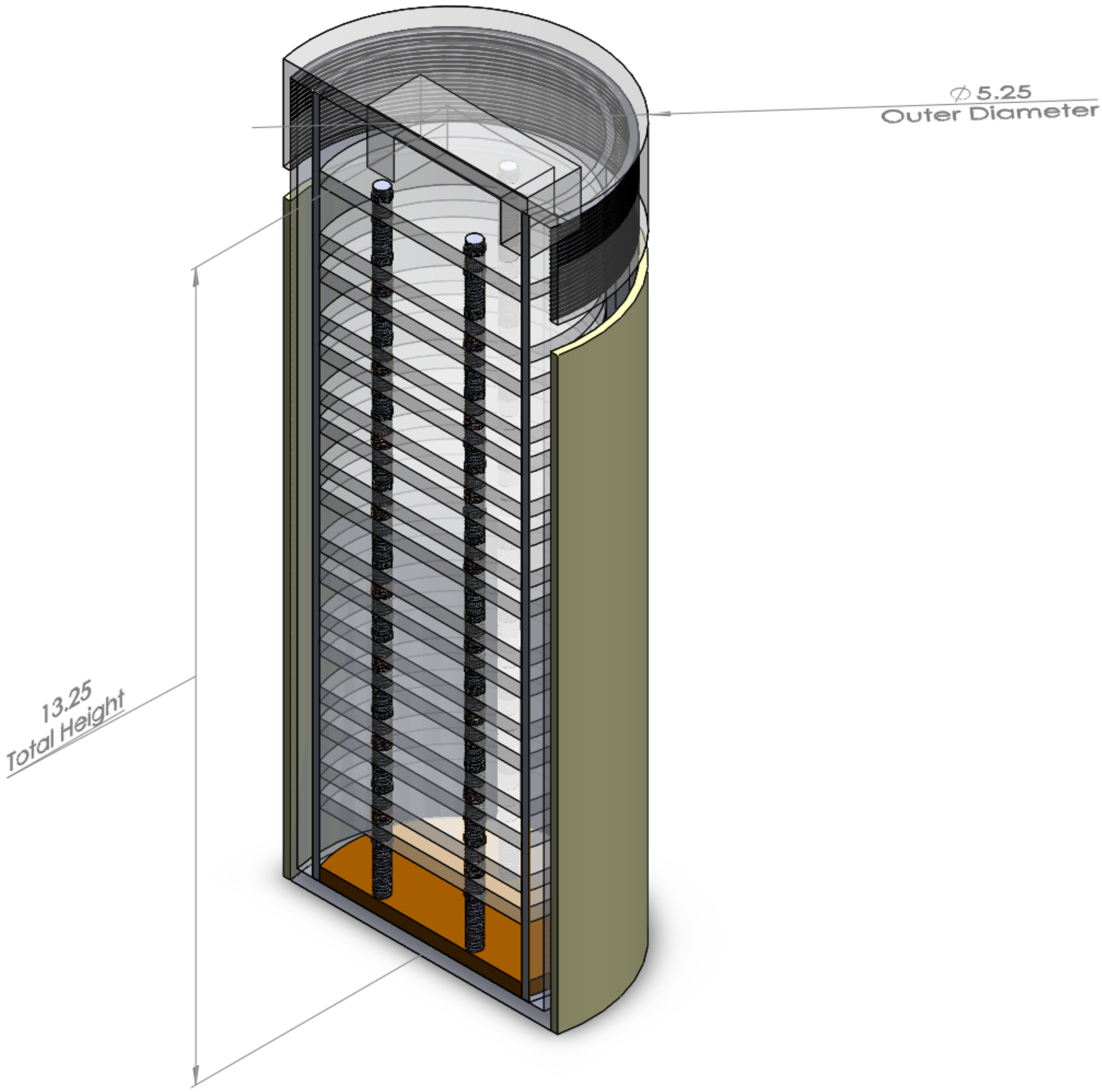


Figure 36 shows a cross section view of the proposed container with total height and outer diameter

Preliminary Integration Plan

The proposed container will be located aft of the main parachute avionics compartment and forward of the drogue parachute avionics compartment as shown in Figure 8 and Figure 9. The payload bay will accommodate for 424.12 in^3 in volume, while the proposed container will occupy 286.18 in^3 in volume of the payload bay. The integration plan presented below outlines the process of including the sample(s) into the payload followed by the method of incorporating the payload securely into the launch vehicle.

Figure 37: Payload Bay

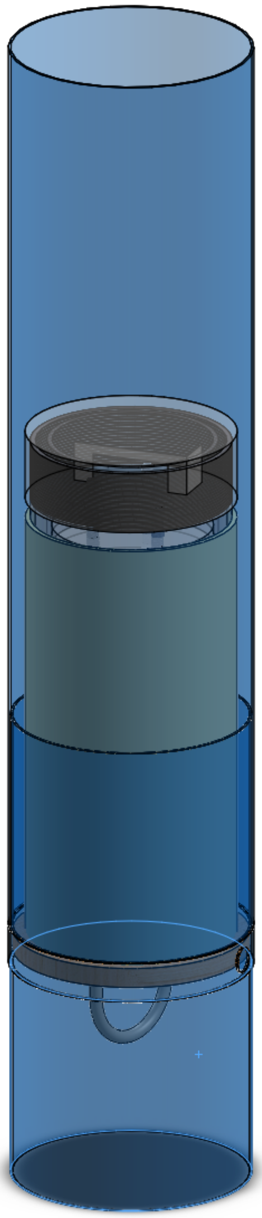


Figure 37 shows an isometric, transparent view of the payload bay

Figure 38: Booster Section and Mid Frame

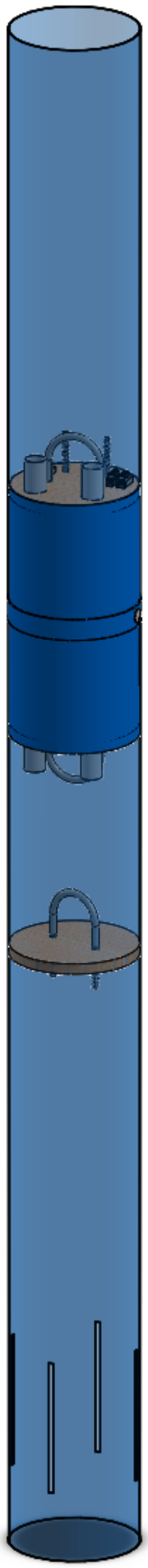


Figure 38 shows an isometric, transparent view of the booster section and mid frame

Sample Incorporation
The process of incorporating the sample(s) begins with the inner rack, as indicated in Figure 39. The inner rack of the proposed container will begin outside of its corresponding inner chamber container compartment. Upon retrieval of the unknown sample(s), the silicone disks of the inner rack will be adjusted manually by sliding up or down over the threaded metal rods, to have the correct number of compartments for each object to be placed into, isolated from the rest. The silicone disk compartments may be manually adjusted to fit 1-8 objects. The objects will be taken one at a time and placed into its individual compartment, the team will the manually screw metal nuts onto 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 proposed container and sealed closed with threaded fitted caps.

Payload Incorporation
The container assembled as outlined above is inserted securely into the payload bay of the rocket between two bulk plates (see Figure 40). The bulk plates are located aft of the nose cone and forward of the main parachute avionics bay. Each bulk plate will be constructed from 0.50" thick birch plywood, and will be cut using a CNC router. These two bulk plates will aid in the stability of the proposed container within the body of the rocket.

Mold and Cavity Incorporation (see Figure 41)
In order to ensure that the proposed container is properly secured within the body of the rocket and bulk plates, closed cell polyurethane expandable foam will be utilized to fill the remaining 137.94 in^3 volume gap between the middle frame of the rocket and the outside of container. Since the proposed container must protect fragile material, the polyurethane foam is utilized to add stability as well as rigidity to the proposed container [38]. Prior to any sample(s) retrieval, the proposed container will initially be plastic wrapped as half of the amount of polyurethane foam is dispensed into the payload bay of the launch vehicle. The plastic wrapped container will then be inserted into the payload bay and centered while the remainder of the expandable foam is dispensed to fill the volume gaps between the Blue Tube of the rocket and the outside of the container. The forward frame of the rocket, housing the payload bay, will then be assembled by placing the nose cone over the wrapped container and securing both ends of the Blue Tube with metal screws. The foam will be allowed to cure for 1-2 hours until it has expanded 20 to 30 times its original size. The proposed container will be removed from the molded foam cavity and plastic wrap after the foam has cured and this molding process will not be repeated. Upon retrieval of the sample(s) the assembled container will just need to be placed into position within the payload bay foam cavity and have the Blue Tube secured with metal screws upon assembly of the middle section of the rocket.

Figures 39 below introduces the sample and container insertion processes, described in the *Sample Insertion* subsection.

Figure 39: Sample Insertion

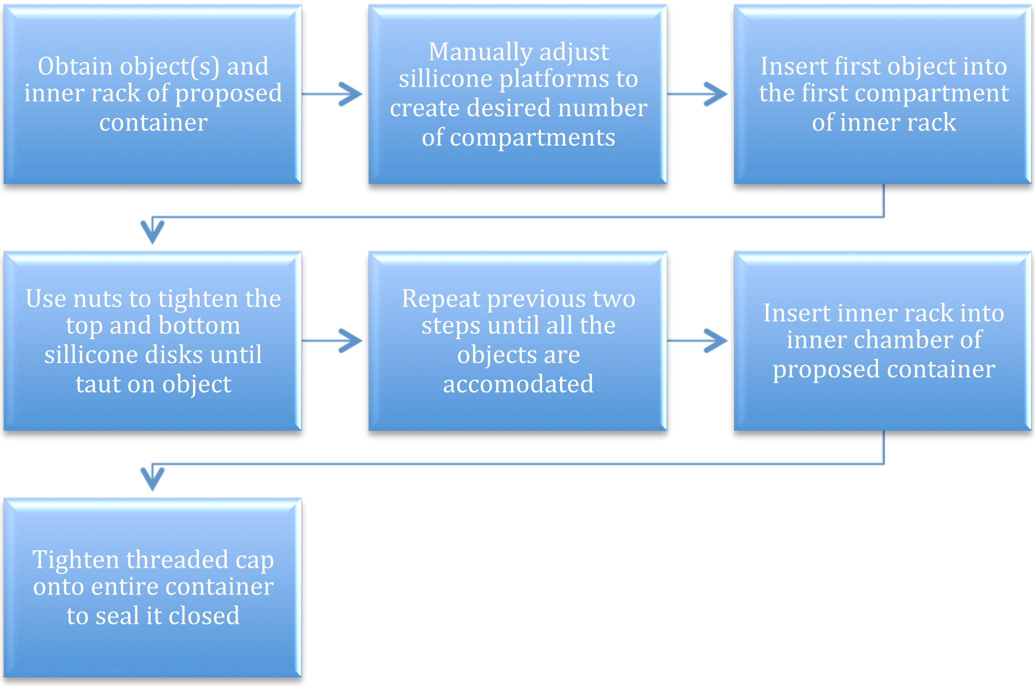


Figure 39 shows the process of inserting the sample(s) into the proposed container.

Figure 40 below introduces the proposed launch vehicle with its main sections: payload bay, main parachute avionics bay and drogue parachute avionics bay. The locations of these sections are helpful to identify where the integration of the payload occurs within the launch vehicle as described in the *Payload Incorporation* subsection above.

Figure 40: Proposed Rocket

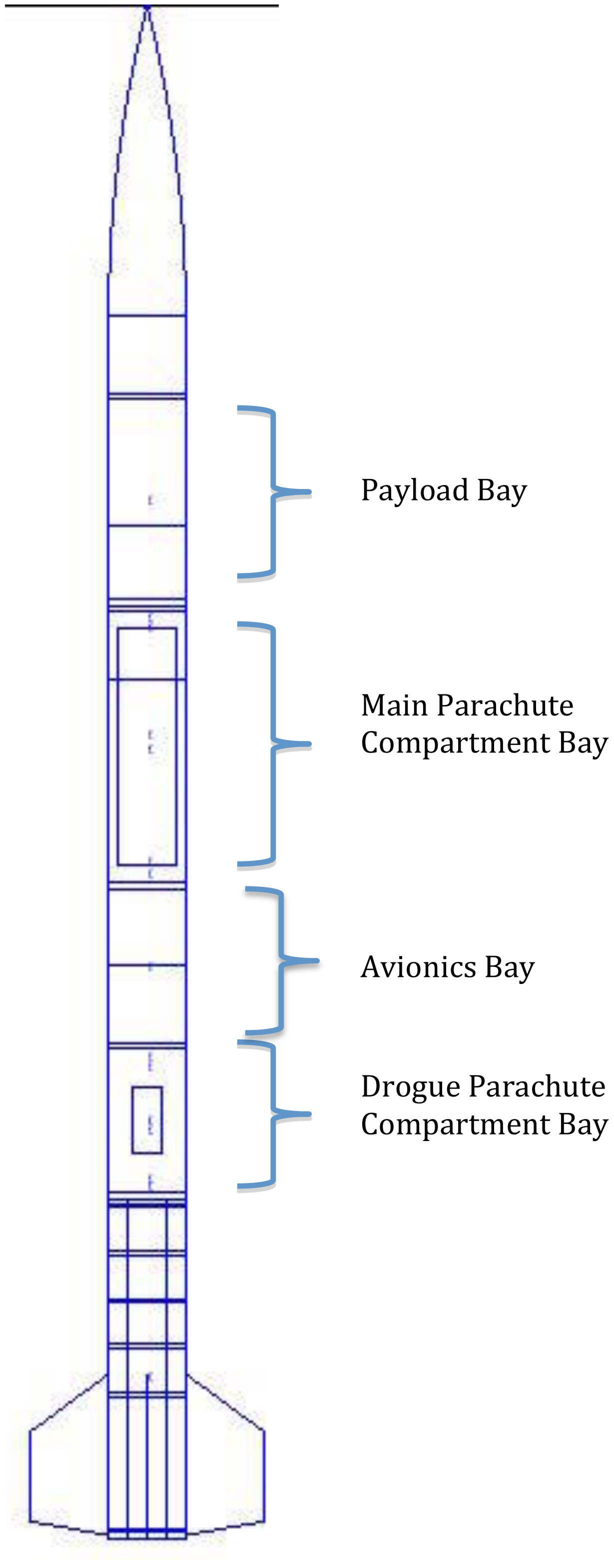


Figure 40 displays the launch vehicle proposed by the team

Figure 41 below introduces the payload bay mold process, described in the *Mold and Cavity Incorporation* subsection.

Figure 41: Payload Bay Mold

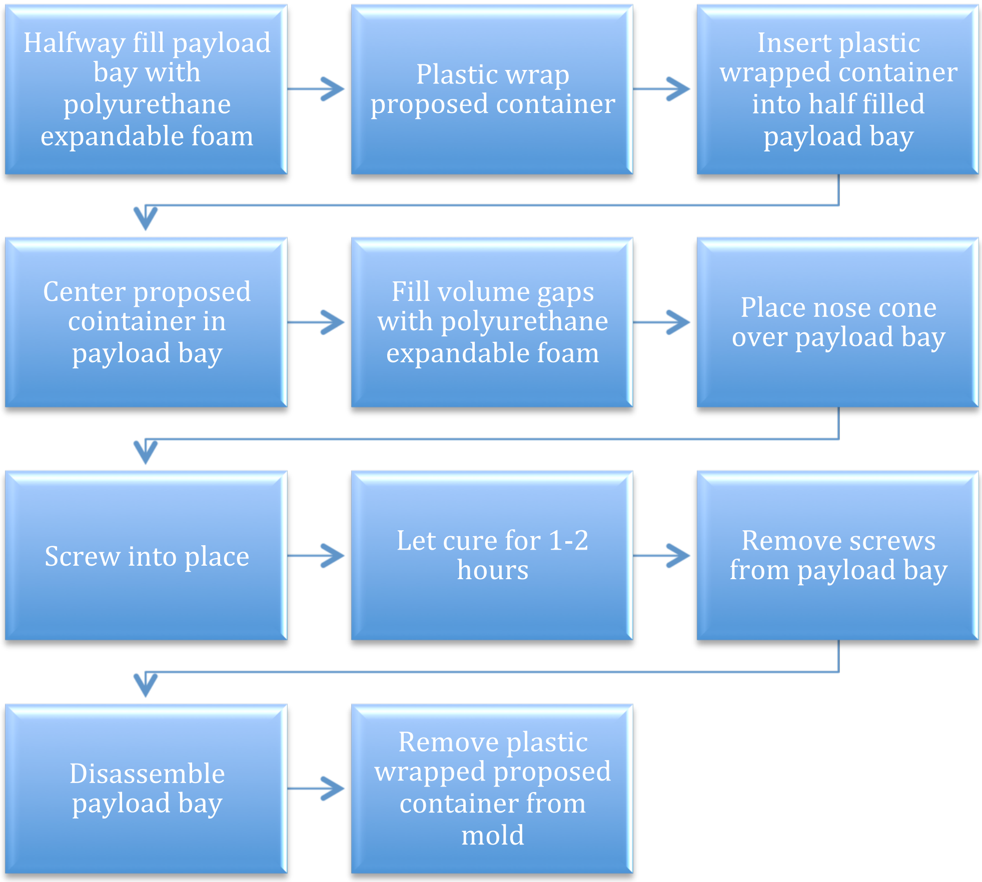


Figure 41 shows the process of creating the container mold inside of the payload bay

Figure 42 below introduces the container insertion processes, described in the *Mold and Cavity Incorporation* subsection.

Figure 42: Container Insertion

Figure 42 shows the process of installing a loaded container onto the rocket.

Precision of Instrumentation and Repeatability
Project Aegis does not have subsystems that utilize instrumentation. Please reference section 6.1.3. for details on what constitutes a successful experiment.

VI. Project Plan

Requirements Compliance

Launch Vehicle Requirements and Verification Plan

Table 56 lists the launch vehicle requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 56: Launch Vehicle Requirements			
Requirement	**Design Feature**	**Verification method**	**Verification plan**
1.1. The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	An Aerotech L1170-FJ 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 flight tests will verify that the Aerotech L1170-FJ is the most efficient motor to deliver the launch vehicle and payload to

			5,280 ft AGL.
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.
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.
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.
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.
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.
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	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.

altimeter shall be capable of being turned off.			
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
1.2.6.1. The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.	The Missile Works RRC2+ will be housed securely inside the avionics bay to prevent damage.	Tests and inspection	The altimeter will 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.
1.2.6.3. The altimeter reports an apogee altitude over 5,600 feet AGL.	An Aerotech L1170-FJ 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 L1170-FJ is the most efficient motor to deliver the launch vehicle and payload to an altitude less than 5,600 ft AGL.
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.
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.
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.
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.
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.
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.

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.
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.
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
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 L1170-FJ or L1420-R motor from Aerotech	Inspection	Inspection of the motor being used will verify that it is a solid fuel commercial motor using APCP.
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

1.11.2. Any motor changes 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.	The team will only make a motor change request if it increases the safety margin significantly.	N/A	N/A
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
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
1.12.2. The low-cycle fatigue life shall be a minimum of 4:1.	Pressure vessels are not utilized.	N/A	N/A
1.12.3. Each pressure vehicle shall include a pressure relief valve that sees the full pressure of the tank.	Pressure vessels are not utilized.	N/A	N/A
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
1.13. The total impulse provided by a Middle and/or High School	An L1170-FJ motor, with 4182.83 Ns total impulse, will be	Inspection	The team will inspect the motor data to ensure its total impulse does

launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	utilized.		not exceed 5,200 Ns.
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 L1170-FJ 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.
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.
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.
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.
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.
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	The team will launch and recover the full-scale (6'' 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.

must be the same rocket to be flown on the launch day.			
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.
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
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
1.17.2.1.1. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.			
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 vehicle, those systems shall be active during the full-scale demonstration flight.	The payload does not alter the external surfaces or manage any energy of the launch vehicle.	N/A	N/A
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	An Aerotech L1170-FJ 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.

used to demonstrate full flight readiness and altitude verification.			
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.
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.
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.
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
1.19. Vehicle prohibitions	See below	See below	See below
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.
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.

1.19.3. The launch vehicle shall not utilize motors that expel titanium sponges.	The Aerotech L1170-FJ motor does not expel titanium sponges.	Inspection	Inspection of the launch vehicle verifies that no motors that expel titanium sponges are utilized.
1.19.4. The launch vehicle shall not utilize hybrid motors.	The Aerotech L1170-FJ motor utilized is a solid fuel APCP motor.	Inspection	Inspection of the launch vehicle 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.
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.
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.
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.

Recovery System Requirements and Verification Plan

Table 57 lists the recovery system requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 57: Recovery System Requirements

Requirement	**Design Feature**	**Verification method**	**Verification plan**
2.1. The launch vehicle shall stage the deployment of its recovery devices,	Missile Works RRC2+ altimeters will eject the drogue parachute at apogee, and the main	Testing	Tests flights will verify that the drogue will deploy at apogee and the main will deploy at a

where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	parachute at 800 ft.		lower altitude of 800 ft.
2.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	Successful ground ejection tests will be conducted prior to all initial subscale and full scale launches.	Inspection	The parachutes and nylon shear pins will be inspected after ground 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.
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.
2.5. The recovery system shall contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight	The recovery system will contain redundant Missile Works RRC2+ altimeters to deploy the parachutes.	Inspection	Inspection of the launch vehicle will verify that commercial altimeters are being used.

computers.			
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.
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.
2.8. Each altimeter shall have a dedicated power supply.	Each altimeter will have a dedicated 9V power supply.	Inspection	Inspection of the altimeters and their wiring verifies that they have a dedicated power supply.
2.9. Each arming switch shall be capable of being locked in the ON position for launch.	The arming switches will require a key to lock them in the ON position.	Inspection	Inspection of the arming switches shows that they require a key to 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" 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.
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.

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
2.11.2. The electronic tracking device shall be fully functional during the official flight on launch day.	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 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.
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.
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.
2.12.3. The recovery system electronics shall be shielded from all onboard devices	Equipment generating magnetic waves will not be utilized.	N/A	N/A

which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.			
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.

Experiment Requirements and Verification Plan

Table 58 lists the experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 58: Experiment Requirements

Requirements	Design Feature	Verification Method	Verification
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
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
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.			

Fragile Material Experiment Requirements and Verification Plan

Table 59 lists the fragile material protection experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 59: Fragile Material Protection			
Requirements	**Design Feature**	**Verification Method**	**Verification**
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.
3.4.1.1. There may be multiple of the object, but all copies shall be exact replicas.			
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.
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 materials.	N/A	N/A
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	Supplemental material for protection will not be added after receiving the object. The container will have a threaded cap closure seal that	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

until after launch.	will remain closed until after launch.		added.
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 diameter, and 6” 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).
3.4.1.6. The object(s) shall have a maximum combined weight of approximately 4 ounces.			

Safety Requirements and Verification Plan

Table 60 lists the safety requirements.

Table 60: Safety Requirements			
Requirement	**Design Feature**	**Verification Method**	**Verification Plan**
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.
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.
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	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.

vehicle and launcher 4.3.1.3. Assembly of 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
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
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.
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	N/A	By inspection	The team will inspection the mentor credential to ensure that he meets the qualifications.

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 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	N/A	By inspection	The safety officer will ensure team members will abide by the rules and guidance of the local RSO

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.			
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

General Requirements and Verification Plan

Table 61 lists the general requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 61: General Requirements

Requirements	Verification Method	Verification
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.
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.

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
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).
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.
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.
5.4.3. No more than two adult educators.	Adult educator identification.	One adult educator will be supporting the team throughout the project year.
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.
5.8. All deliverables must be in PDF format.	Document formatting.	All review documents will be present as a PDF file.
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.
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.
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	Teleconference equipment accessibility.	The team will have accessibility to equipment that are necessary to perform a video teleconference.

refrain from use of cellular phones as a means of 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 8ft 1010 rails, and 8ft 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.
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.

Team Derived Requirements

Table 62 shows a set of team derived requirements for mission success along with their corresponding verification methods.

Table 62: 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.

Budget 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.

Budget Plan

Table 63 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 63: NSL Budget Items

No.	Item	Qty.	Price/unit	Tax (~9%)	Shipping Cost	Total Cost
1	Shear pin	5	$3.10	$0.00	$4.88	$20.38
2	24" Nomex	2	$13.99	$0.00	$5.85	$33.83
3	6" Blue Tube coupler	1	$19.95	$1.80	$12.10	$34.93
4	Rail button	2	$4.65	$0.00	$4.88	$9.98
5	Fiberglass resin	1	$42.99	$3.87	$10.96	$58.81
6	Fiberglass hardener	1	$21.99	$1.98	$9.92	$34.78
7	Fiberglass laminating cloth 3 oz. satin weave	3 yrds	$9.96	$8.07	$9.12	$42.51

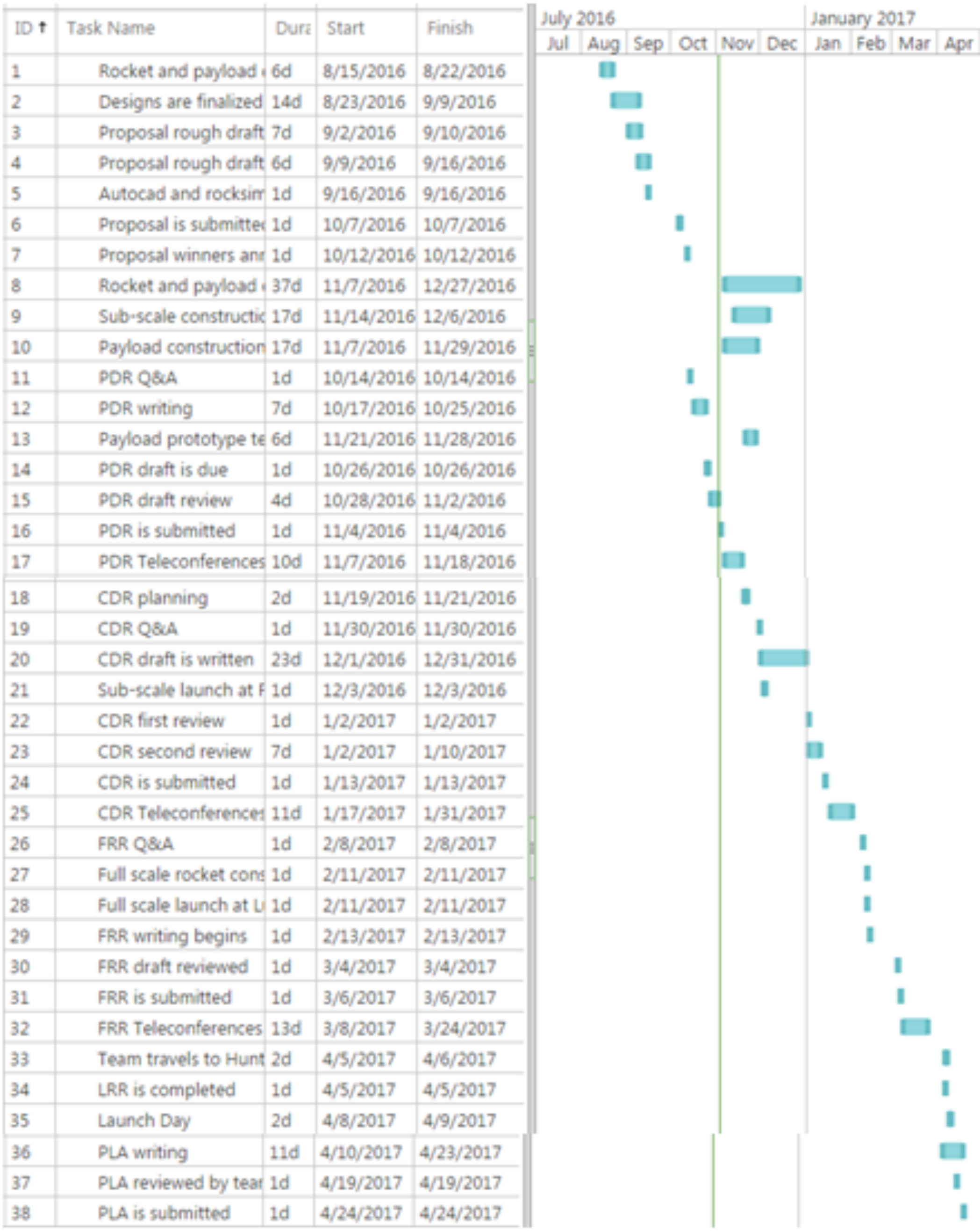
8	Altimeter	4	$44.95	$0.00	$7.00	$186.80
9	Palm sander	1	$29.99	$2.70	$6.99	$40.31
10	Sandpaper 80 grit	1	$15.38	$1.38	$5.99	$22.75
11	Synthetic grease	1	$5.89	$0.53	$5.99	$12.95
12	Sandpaper 5” 120 grit	1	$14.40	$1.30	$5.99	$21.69
13	Dremel(cordless)	1	$89.99	$8.09	$0.00	$98.08
14	Nitrile gloves (box)	1	$8.16	$1.22	$5.48	$14.86
15	Terminal blocks	1	$9.05	$6.03	$0.00	$15.08
16	22-gauge stranded wire pack	1	$19.95	$2.41	$6.83	$29.19
17	Heat shrink tubing	1	$10.99	$0.70	$5.33	$17.02
18	Key switch	4	$4.62	$2.13	$5.14	$25.75
19	6” Blue Tube	4	$66.95	$0.00	$104.27	$372.03
20	4” Blue Tube	2	$38.95	$0.00	$26.89	$104.79
21	98 mm E-bay	2	$42.95	$7.73	$9.13	$103.58
22	6” E-bay	2	$71.95	$12.95	$19.51	$178.12
23	Rocket epoxy (pt)	1	$38.25	$0.00	$11.82	$50.07
24	18” Nomex	2	$10.49	$0.00	$5.09	$26.07
25	6” Ogive 4:1 nose cone	1	$129.00	Included	$12.90	$141.90
26	4” Ogive 4:1 nose cone	1	$65.00	Included	$8.95	$73.95
27	1” Tubular webbing	40	$0.45	$1.62	$5.99	$25.61
28	¼” Aircraft plywood	1	$112.75	$10.15	In store	$122.90
29	Polycarbonate tubing	1	$215.25	$19.37	$12.00	$246.62
30	Silicone sheet	1	$156.55	$12.52	$9.58	$178.65
31	Zinc threaded rails	3	$5.11	$0.46	In store	$16.71
32	Epoxy plastic bonder	2	$4.26	$0.38	In store	$9.28

33	9% Borated flexi-panel	1/2	$75.00	$0.75	$12.00	$92.75
34	Polycarbonate tubing	2	$15.20	$1.37	$10.00	$43.14
35	Airfare	6	$518.00	$46.62	$0.00	$3387.72
36	Hotel expenses	2	$134.00	$12.06	$0.00	$292.12
42	Food expenses	15	$20.00	$0.00	$0.00	$500.00
43	Outreach supplies	12,000.00				
Grand Total for supplies		$18,636.71				

Project Timeline

Figure 43 lists the project main deadlines and milestones as well as the expected date of task completion.

Figure 43: Main Event Timeline



ID	Task Name	Dura	Start	Finish
1	Rocket and payload	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 submitte	1d	10/7/2016	10/7/2016
7	Proposal winners anr	1d	10/12/2016	10/12/2016
8	Rocket and payload	37d	11/7/2016	12/27/2016
9	Sub-scale constructic	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 43 shows the Gantt chart detailing the NASA SL main events and their planned deadlines

Table 64 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 is provided in Table 65.

Table 64: 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	11/7-18/16
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 writing begins	11/19/16

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	1/17-31/17
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	3/8-24/17-
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 44 below provides the timeline of the team's educational engagement events.

Figure 44 Educational Engagement Timeline

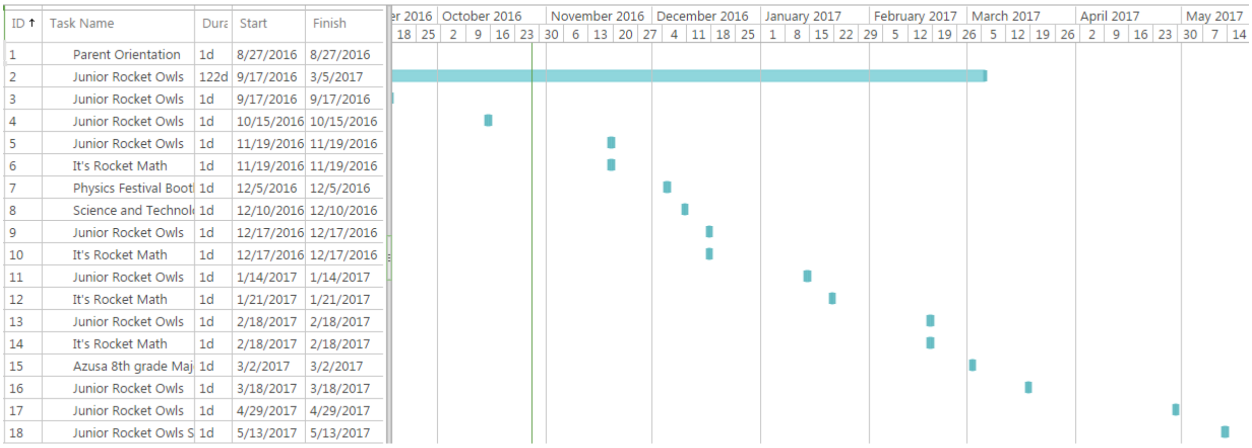


Figure 44 lists all educational engagement events and their corresponding dates.

Table 65 below provides a list of the educational engagement events hosted by the Rocket Owls over the course of the NSL as well as their scheduled date and brief descriptions.

Table 65: 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 5th grade students to basic rocketry concepts
Junior Rocket Owls: Outreach Workshop	11/19/16	Junior Rocket Owls build and launch Estes model rockets

It's Rocket Math Workshop	11/19/16	Rocket Owls introduce the 7th grade students to basic rocketry concepts and mathematical relations
Physics Festival Booth	12/5/16	Rocket Owls present their NASA SL project to Citrus College Physics students
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 7th grade students to relationship between angles and flight altitude
Junior Rocket Owls: Outreach	1/21/17	Junior Rocket Owls build the LoadStar rockets
It's Rocket Math Workshop	1/21/17	Rocket Owls introduce the 7th grade students to more mathematical relationships related to rocketry
Junior Rocket Owls: Outreach Workshop	2/18/17	Junior Rocket Owls launch the LoadStar rockets
It's Rocket Math Workshop	2/18/17	The 7th grade students build and launch Estes rockets
Azusa 8th Grade Majors Fair	3/2/17	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 design and create their professional posters in preparation for the symposium
Junior Rocket Owls: Outreach Workshop	4/22/17	Junior Rocket Owls practice their presentations

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

Funding Plan

Table 66 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 66 presents 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 66: 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 Table 66 indicates, the total funds allocated for the project is $25,850, while Table 66 in the Budget section of this document shows that the cost of the project in its entirety is estimated at $18,636.71. This indicates that the team has an excess of more than $7,000.00 that may be used in case of unexpected expenses, such as increase in material cost or expenditures related to traveling.

References

[1] 75MM Casings. Apogee Components.
https://www.apogeerockets.com/Rocket_Motors/AeroTech_Casings/75mm_Casings
[2] Blue Tube 2.0. Always Ready Rocketry.
http://www.alwaysreadyrocketry.com/about-us/blue- tube-2-0/
[3] http://www.rocketreviews.com/
[4] http://www.animatedknots.com/rope2.php#ScrollPoint
[5] http://www.mrc.uidaho.edu/~atkinson/IPPW/IPPW-3/Parachute%20Course%20Material/14%20Parachute%20Materials%20and%20Stress%20Analysis%20Wolf.pdf
[6] http://www.luremaking.com/catalogue/catalogue-index/catalogue-items/ball_bearing_swivels.htm
[7] http://www.strapworks.com/Tubular_Webbing_s/62.htm
[8] https://www.fastenal.com/products/fasteners/bolts/u-bolts/_/Navigation?r=~%7Ccategoryl1:%22600000%20Fasteners%22%7C~%20~%7Ccategoryl2:%22600001%20Bolts%22%7C~%20~%7Ccategoryl3:%22602313%20U-
[9] http://www.engineeringtoolbox.com/wood-density-d_40.html
Bolts%22%7C~
[10] http://www.missileworks.com/products/
[11] Knight, Randall Dewey. Physics for Scientists and Engineers: A Strategic Approach: with Modern Physics. San Francisco: Pearson Addison Wesley, 2008.
[12] Canepa, Mark, B. *Modern High-Power Rocketry 2.* Victoria, BC:National Library of Canada Cataloguing in Publication, 2005.
[13] http://www.ptsllc.com/intro/polycarb_intro.aspx
[14] http://www.matweb.com/reference/tensilestrength.aspx
[15] http://www.sorbothane.com/Data/Sites/31/pdfs/data-sheets/101-sorbothane-material-properties.pdf
[16] http://www.atlasfdry.com/casting-design3.htm
[17] http://www.shieldwerx.com/assets/swx-201(hd).pdf
[18] http://www.solutionsdirectonline.com/abs-polycarbonate-enclosures-technical-specifications.html

[19] http://www.shieldwerx.com/assets/swx-201%28hd%29.pdf
[20] http://www.shieldwerx.com/poly-based-shielding.html
[21] http://www.excellence-in-insulation.eu/site/
[22] http://www.solutionsdirectonline.com/abs-polycarbonate-enclosures-technical-specifications.html
[23] http://www.atlasfdry.com/casting-design3.htm
[24] http://www.dupont.com/products-and-services/personal-protective-equipment/thermal-protective/articles/flame-resistant-technology.html
[25] http://www.space.com/16903-mars-atmosphere-climate-weather.html
[26] https://mail.google.com/_/scs/mail-static/_/js/k=gmail.main.en.VlyfhbYw8vI.O/m=m_i,pdt,t,it/am=MotjAiBPxvuDODIAyEqfoDD7nvnkUvmxz73anzhAFPIV-H-z_wf4P_aiFgo/rt=h/d=1/rs=AHGWq9CoKztk0zlj-40Lsxb_F2Z2hsF9JQ
[27] http://www.ptsllc.com/intro/polycarb_intro.aspx
[28] http://www.boltscience.com/pages/twonuts.htm
[29] http://www.matweb.com/reference/tensilestrength.aspx
[30] http://www.linex.com/protective-coatings
[31] http://www.shieldwerx.com/assets/swx-227.pdf
[32] http://stardust.jpl.nasa.gov/aerogel_factsheet.pdf
[33] http://www.nasa.gov/missions/shuttle/f_fireprevention.html
[34] http://www.fire.tc.faa.gov/pdf/05-14.pdf
[35] http://www.acplasticsinc.com/informationcenter/r/acrylic-vs-polycarbonate
[36] http://www.planningtiny.com/theas-side-by-side-insulation-comparison/
[37] http://www.technologystudent.com/joints/kevlar2.html
[38] http://giantleaprocketry.com/products/components_composites.aspx

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: MSDS

Appendix is available as a separate document and includes 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 C: Safety Protocols

Appendix is available as a separate document and included the protocols that the team developed. 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 D: 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)
[signature]
Signature
Date: 09/26/16

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

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

Janet Blancas Alonso
Name (Printed)

Signature

Date: 09/26/16

Jimmy Lopez
Name (Printed)

Signature

Date: 09/26/16

Lucia Riderar
Name (Printed)

Signature

Date: 9/26/2016