NASA Student Launch
2016-2017

Flight Readiness Review

1000 W. Foothill Blvd.
Glendora, CA 91741

Project Aegis

Fragile Material Protection

March 06, 2017

Table of Contents

References....253

List of Tables....1

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

lriderer@citruscollege.edu
(626) 914-8763

Rick Maschek
- Team Mentor
- Director, Sugar Shot to Space

rickmaschek@rocketmail.com
(760) 953-001

3. Safety Officer
Janet
alonsojanet21@gmail.com
(626) 608-8584

4. Team Leader
Yvonne
y.villapudua@gmail.com
(909) 244-2662

5. Team Members and Proposed Duties

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

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

Figure 1 below shows the hierarchy based on the Citrus College Rocket Owls team is structured.

Figure 1: Team Organization Chart

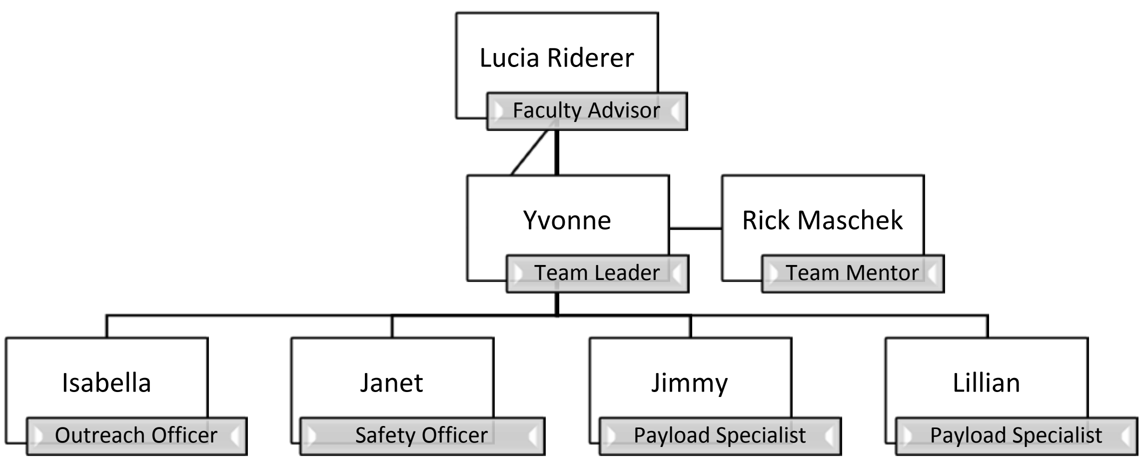


Figure 1 outlines the Rocket Owls team organization chart.

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 FRR Report

1.1 Team Summary

Team Name: Citrus College Rocket Owls

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

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

1.2 Launch Vehicle Summary

Vehicle Dimensions

Length: 119”
Diameter: 6.08”
Mass (without motor): 35.55 lbs
Mass (with motor): 45.61 lbs

Rail Size

12ft in length and fits size 1515 launch rail buttons

Motor Choice

Aerotech L1420R

Recovery System

Missile Works RRC2+ altimeters will initiate all flight events. A black powder charge will separate the rocket and deploy a 24” drogue parachute at apogee. The rocket will fall as two tethered sections with a descent rate of 78.18 fps. A second black powder charge will eject the 120” main parachute at 800 ft AGL. The rocket will descend as three tethered sections at a rate of 12.92 fps. The drogue parachute deployment will utilize redundant black powder charge with a 1sec delay while the main parachute deployment will utilize a redundant black powder charge at 500 ft AGL.

Milestone Review Flysheet

The milestone review flysheet will be available as a separate document

1.3 Payload Summary

Payload Title

“Fragile Material Protection”

Payload Materials

- Polycarbonate

- Silicone rubber
- Steel nuts and rods
- Springs
- Aircraft grade plywood
- Aerogel
- PVC
- Weld-on adhesive

Payload Experiment Overview
The team will has designed and constructed a container capable of protecting an unknown fragile material(s) before, during, and after a high-powered rocket launch. The container is able to safely hold a maximum amount of eight separate samples. The main components of the team's container are: radiation shield, outer shell, inner chamber, and inner chamber rack. The team's container focuses on protecting the sample(s) from impact, shock, contamination, temperature change, pressure change, and radiation. The main objective of the payload is to be able to safely retrieve an unknown sample from the surface of Mars.

II. Changes Made Since CDR

2.1 Changes to Vehicle Criteria
1. No changes were made to the Vehicle Criteria since the CDR.

2.2 Changes to Payload Criteria
1. Error in container calculations.

During the process of constructing the payload the team noticed that the dimensions for the inside spacing of the container were incorrect. The original calculations for the container were done with the inner chamber being pressed against the outer shell, but the calculations were assumed to have been done with the inner chamber being centered. To compensate for the missing space inside of the container the team reduced the size of the radiation and aerogel layers as well as the liquid compartment by 2/3. The team feels confident that both layers will still be able to fulfill their purpose given the size reduction.

2.3 Changes to Project Plan
1. No changes were made to the Project Plan since the CDR.

III. Vehicle Criteria

3.1 Design and Construction of Vehicle
This section describes the features that enable the launch vehicle to be recovered safelly as well as the flight reliability and the construction process of project Aegis.

The launch vehicle is composed of the following three main sections:
1. Aft Section (Booster section and drogue parachute compartment)

2. Middle Section (Avionics bay and main parachute compartment)
3. Forward Section (Nose cone and fragile material protection payload)

The construction of each section of the launch vehicle is detailed in the following list:

3.1.1 Aft Section (Booster):

1. The 75-mm motor mount and 6” Blue Tube airframe were cut using a miter saw, 20 in and 44.5 in in length, respectively. Due to the size of the blade being used, multiple cuts were necessary to cut through the entire airframe. The tubes were held in place manually by two team members and an initial cut was made. The tubes were then rotated and cut through the remaining section attached.
2. The cut airframe was fiberglassed using epoxy based resin and hardener and 3oz weaved fiberglass cloth.
3. After the fiberglass cured, the airframe was lightly sanded using an orbital sander and 320 grit sand paper.
4. Using an adjustable circle cutter perpendicular to the 10-ply aircraft grade plywood (Figure 5) the four 0.25” thick centering rings were cut manually to have a 6” outer diameter and a 3.1” inner diameter
5. Using an adjustable circle cutter perpendicular to the 5-ply birch plywood (Figure 5) the two 0.50” thick centering rings were cut manually to have a 6” outer diameter and a 3.1” inner diameter
6. The centering rings’ inner and outer edges had to be sanded so that they could slide onto the motor mount and into the airframe smoothly.
7. G5000 rocket epoxy was used to bond the forward 0.50” thick centering ring onto the motor mount.
8. Four equally spaced fin slots, measuring 0.25” by 9.5”, with 90° between each of them were cut out of the airframe using a rotary tool with a cutting wheel attachment.
9. Epoxy was added to the inner airframe where the installed 0.50” thick centering ring was to be positioned.
10. The motor mount was inserted until the aft section laid flushed with the most aft section of the booster section.
11. Epoxy was added to the inner airframe and the outer motor mount section where the following 0.25” thick centering ring was to be positioned, aft of the 0.50” thick centering ring.
12. The centering rings was inserted manually and pushed down with two meter sticks on opposing side, applying light forcer with a mallet until the marked position was reached.
13. Epoxy fillets were incorporated around the outer and inner centering ring diameters to
14. Steps 9-11 were repeated two more times for the remaining 0.25” forward centering rings.
15. The fin tabs were sanded until the fin root chords were flushed with the airframe while the tabs kept contact with the motor mount.
16. Epoxy was inserted through the fin slots and placed onto the motor mount using popsicle sticks.
17. Epoxy was placed on the fin tabs and root chords.
18. The fins were inserted through the fin slots.
19. Epoxy fillets were incorporated along both sides of the fin tabs at the motor mount and airframe interphases.

20. The fins were held normal to the airframe surface using clamps and string and allowed to cure for 24 hrs.
21. The string and clamps were removed and the excess external epoxy was sanded to minimize drag.
22. A layer of fiberglass was added to all four fins and fin joints and allowed to cure for 24 hrs.
23. The fiberglassed fins and airframe were lightly sanded with 320 grit sand paper on an orbital hand sander.
24. One 1515 rail button was epoxied near the bottom of the booster section, in between the last two centering rings
25. Steps 9-11 were repeated for the last two centering rings, the 0.50" thick centering ring with the motor retainer was placed in last and flushed with the bottom of the booster section.
26. The inside of the booster section was measured 5" forward of the motor mount and epoxy was placed above and over this line around the inside of the airframe.
27. One 5.97" bulkhead was pushed through the top of the booster section until reaching the pre-marked line, u-bolt hook facing the forward opening.

Figure 2: Aft Section

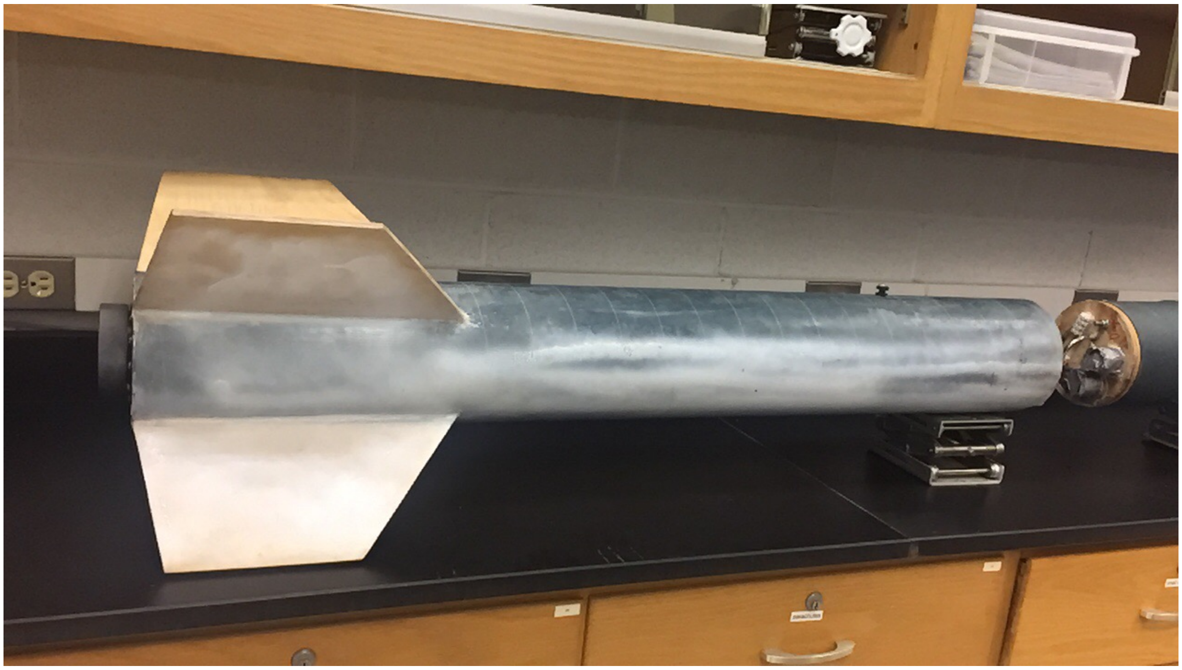


Figure 2 shows the fully assembled booster section of the launch vehicle

Detailed descriptions of the construction of the fins and motor retainer are given below.

3.1.2 Fins:

1. The 12.5" root chord length was drawn 2" above the edge of the 10-ply aircraft grade plywood.
2. A protractor was used to draw a line extending from the leading edge 10" in length 34° from

the vertical.

3. A line perpendicular to the root chord 6” in length was shifted along the root chord line until it intercepted with the 34° line.
4. At the point of intersection a line 7” long (tip chord) was drawn perpendicular to the root chord line.
5. The end of the tip chord line was then used as the starting point for a connecting line between this point and the trailing end of the root chord line.
6. A dash was drawn 2” from the leading end of the root chord line, and 2” from the trailing end of root chord line.
7. These dashes were then extended toward the endge of the 10-ply aircraft grade plywood, perpendicular to the root chord line.
8. The 10-ply plywood with the frin outline was then clamped into place using c-clamps.
9. The solid outline was then cut using a jigsaw and a wood cutting blade
10. Steps 1-9 were repeated for the remaining three fins
11. The four fins were clamped together and sanded together using 80 grit and 220 grit sand paper.
12. Each side of the fins were fiberglassed using epoxy based resin and hardener as well as 3oz weaved fiberglass cloth.

3.1.3 Motor Retainer (AP 75):

1. The motor mount was placed through one of the 0.50” 5-ply birch centering ring, 3” from the edge.
2. The threaded portion of the retainer was then slid over the motor mount tube.
3. The 0.50” centering ring was slid to touch the threaded portion od the retainer.
4. The holes in the retainer were then traced over the centering ring.
5. Holes were then drilled through the marked centering ring.
6. Then retainer was then secured with screws, nylon lock nuts, and epoxy.

3.1.4 Bulkheads:

1. The 0.50” 5-ply birch plywood was clamped onto a lab table using c-clamps.
2. The 6” blue tube airframe inner and outer diameters were traced concentrically in three different locations on the 5-ply plywood.
3. The 6” coupler tube inner and outer diameters were traced concentrically in one different location on the 5-ply plywood
4. A jigsaw was used to cut three bulkheads with 5.97” diameters and one with a 5.86”diameter using a wood cutting blade.
5. The bulkheads were sanded using 80 grit sandpaper until the 5.97” diameters ones fit inside of the 6” airframe and the 5.86” diameter fit in the coupler tube.
6. A 0.3125” u-bolt was placed near the center of the bulkheads and marked where the two ends of the u-bolts touched. A 0.3125” drill bit was used to drill through the bulkhead markings.
7. The u-bolt was secured into these drilled holes with nuts and epoxy.

3.1.5 Middle Section:

1. The airframe for the main parachute compartment was cut using a miter saw to a length of 27.5”.

2. The cut airframe was fiberglassed using epoxy based resin and hardener and 3oz weaved fiberglass cloth.
3. After the fiberglass cured, the airframe was lightly sanded using an orbital sander and 320 grit sand paper.
4. The pre-cut avionics coupler tube was marked halfway, 6.0” from either end.
5. A 1.0” section of airframe (switch panel) was epoxied to the middle of the avionics coupler at the previously 6” marked location.
6. A pre-cut bulkhead with a 5.86” diameter was centered and epoxied over a team constructed 5.97” diameter bulkhead.
7. The stacked bulkheads were sanded using 80 grit sand paper so they could slide into the avionics bay.
8. Two opposing 0.25” holes were drilled onto the stacked bulkheads, the distance was determined based on avionics threaded rod distance. Three small strips of airframe were added to the inner airframe of the avionics coupler tube. They prevented the bulkheads from moving forward or aft and provided additional sealing from the ejection charges.
9. Two 0.25” threaded rods were inserted through the bulkheads and secured with flat washers, lock washers and nuts.
10. A stainless steel u-bolt was epoxied to the forward and aft stacked bulkheads of the avionics bay.
11. The main parachute airframe was secured to the avionics bay using 5, 0.50” metal screws.
12. The drogue parachute airframe was temporarily fixed using three 2-56 black nylon shear pins.
13. Two holes were drilled for the key switches on the switch panel. Three 0.25” equidistant vent holes were drilled into the switch panel as well. The key switches were epoxied into the switch panel after the wiring for the electronics was completed.
14. The forward rail button was added to the drogue parachute compartment, just below the avionics bay, using a straight edge and a level to align it with the aft rail button.

Figure 3: Middle Section

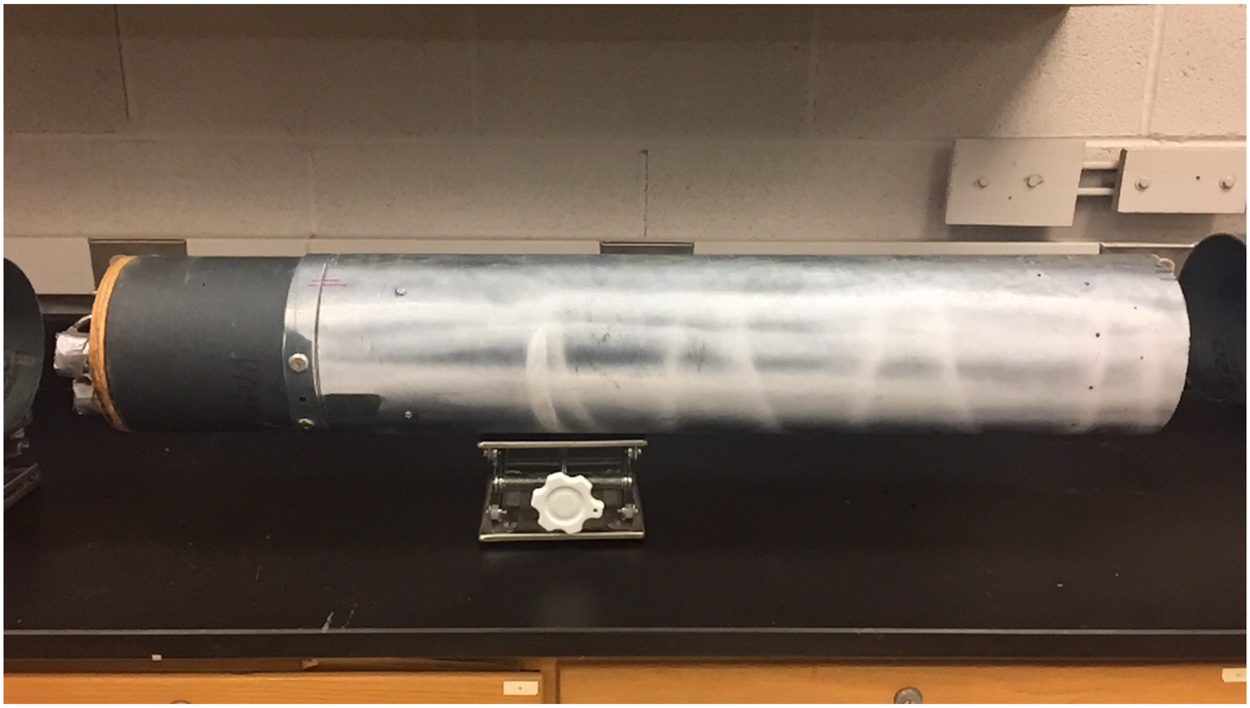


Figure 3 shows the fully assembled middle section of the launch vehicle

3.1.6 Forward Section:

1. The airframe was cut to a length of 23” using a miter saw.
2. The cut airframe was fiber glassed using epoxy based resin and hardener and 3oz weaved fiberglass cloth.
3. After the fiberglass cured, the airframe was lightly sanded using an orbital sander and 320 grit sand paper.
4. 1” of the nose cone shoulder was cut off using a rotary cutting tool. (Figure 13)
5. The pre-cut 12” coupler tube was marked halfway, 6.0” from either end.
6. Epoxy was spread over one side of the center mark and inserted into the 23” airframe.
7. A 5.86” bulkhead was epoxied inside of the coupler tube, u-bolt hook facing out.
8. The nose cone was placed inside of the airframe, opposite of the coupler, and secured with 5 0.50” metal screws.
9. The forward section is attached to the main parachute compartment using 11 nylon shear pins. The design and construction of the fragile material protection payload is detailed in section 4.1.

Figure 4: Forward Section

Figure 4 shows the fully assembled forward section of the launch vehicle.

3.1.7 Structural Elements
3.1.7.1 Booster Section:

Table 2 outlines the structural components of the booster section along with their corresponding functional requirements.

Table 2: Booster Section Structural Elements	
Components	**Functional Requirements**
Blue tube airframe	• Houses the fully assembled motor mount
Motor mount	• Houses the fully assembled motor/motor casing
Centering rings	• Stabilizes and secures the motor mount • Withstand the thrust of the motor when launched
Fins	• Provide aerodynamic stability • Do not experience aeroelastic flutter
Motor retainer	• Prevents motor ejection during launch
Nylon shear pins, #2-56	• Prevent premature separation from the avionics bay

The structural elements of the fragile material protection payload are detailed in section 4.1.

3.1.7.2 Middle Section:

Table 3 outlines the structural components of the middle section along with their corresponding functional requirements.

Table 3: Middle Section Structural Elements	
Component	**Functional Requirements**
Airframe	• Houses the main parachute compartment • Houses the avionics bay's coupler tube
Coupler tube	• Houses the two RRC2+ altimeters • Connects the main parachute compartment to the drogue parachute compartment
Switch panel	• Houses the key switches • Prevents the coupler tube from sliding forward or aft
Electronics' sled	• Secures the electronics with zip ties and nylon standoffs •
U-bolts, 0.3125"	• Tethers the middle section of the launch vehicle to the aft section • Ensures all parts of the launch vehicle descend under a parachute
Threaded rods, 0.25"	• Secures the bulkheads and electronics' sled in place
Bulkheads, 0.50"	• Provides a place for the U-bolts • Able to withstand the force of the parachutes' deployments
Main parachute	• Deploys at 800 ft AGL • Allows each independent section of the launch vehicle to land with a kinetic energy less than 75 ft-lbf
Metal screws, 0.50"	• Ensures secure main parachute compartment connection to the forward section
Nylon shear pins, #2-56	• Prevent premature separation from the avionics bay

3.1.7.3 Forward Section:

Table 4 outlines the structural components of the forward section along with their corresponding functional requirements.

Table 4: Forward Section Structural Elements	
Component	**Functional Requirements**
Airframe	• Houses fragile material protection payload
Couple tube	• Fixes forward section to middle section
U-bolts, 0.3125”	• Tethers the forward section of the launch vehicle to the middle section • Ensures all parts of the launch vehicle descend under a parachute
Nose cone	• Provides in flight stability
Metal screws 0.50”	• Ensures secure payload compartment connection to the middle section

Table 5 below lists the materials that were used in the construction of each section of the launch vehicle.

Table 5: Launch Vehicle Materials	
Component	**Material**
Airframe	• Blue tube 2.0 • 3oz weaved fiberglass cloth • Epoxy based fiberglass resin and hardener
Coupler tube	• Blue tube 2.0
Centering rings, 0.25” thick (4)	• 10-ply aircraft grade plywood
Centering rings, 0.50” thick (2)	• 5-ply birch plywood
Threaded rods, 0.25”	• Zinc plated steel
U-bolts, 0.3152”	• Stainless steel
Metal screws, 0.50”	• Steel
Flanged motor retainer, AP 75	• Aircraft grade aluminum
Fins, 0.25” thick (4)	• 10-ply aircraft grade plywood • 4oz weaved fiberglass cloth • Epoxy based fiberglass resin and hardener

A detailed list of the materials used for fragile material protection can be found section 4.1.

3.1.7.4 Electrical Elements

No electronics are used in the booster section, although a 9-V firing system is required to fire the igniter. The electronics used in the middle section of the launch vehicle can be found in section 3.6.2.2.

Assembly of Vehicle (Drawings and Schematics)

Figure 5: Centering Ring Set-up

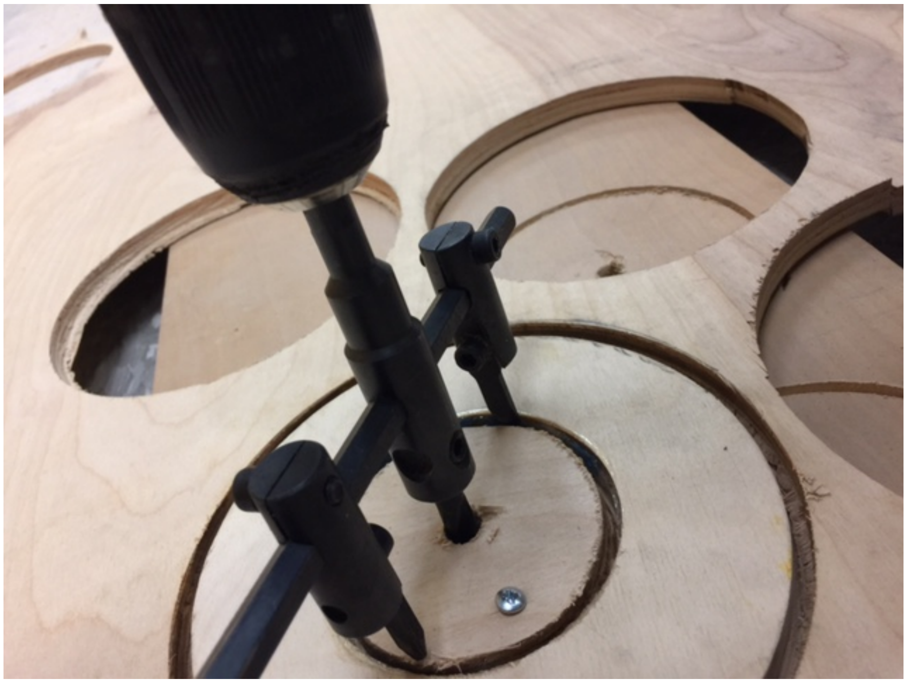


Figure 5 shows the centering rings being cut using an adjustable circle cutter.

Figure 6: Centering Ring Construction

Figure 6 shows how the 0.50" centering rings were constructed out of 5-ply birch wood.

Figure 7: Epoxy Fillets

Figure 7 shows the method used to fillet the inner and outer diameters of the centering rings to adhere them to the motor mount and airframe.

Figure 8: Fin Installation

Figure 8 displays the installation method for the fins.

Figure 9: U-bolt Installation

Figure 9 shows how the bulkheads were drilled in preparation for bulkhead installation.

Figure 10: Attached Bulkhead

Figure 10 displays the U-bolt secured onto the bulkhead using epoxy.

Figure 11 - 12 display how the bulkheads that seal the avionics bay are epoxied together.

Figure 11: Stacked Avionics Bulkhead Preparation

Figure 11 shows the epoxy being applied to the top bulkhead of the avionic bay.

Figure 12: Stacked Avionics Bay Bulkheads

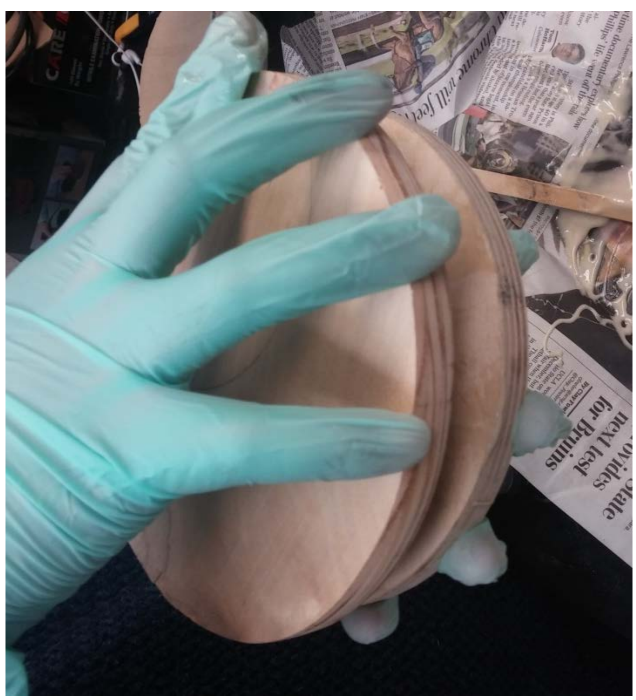


Figure 12 displays the two avionics bulkheads being epoxied together.

Figure 13: Trimmed Nose Cone Shoulder

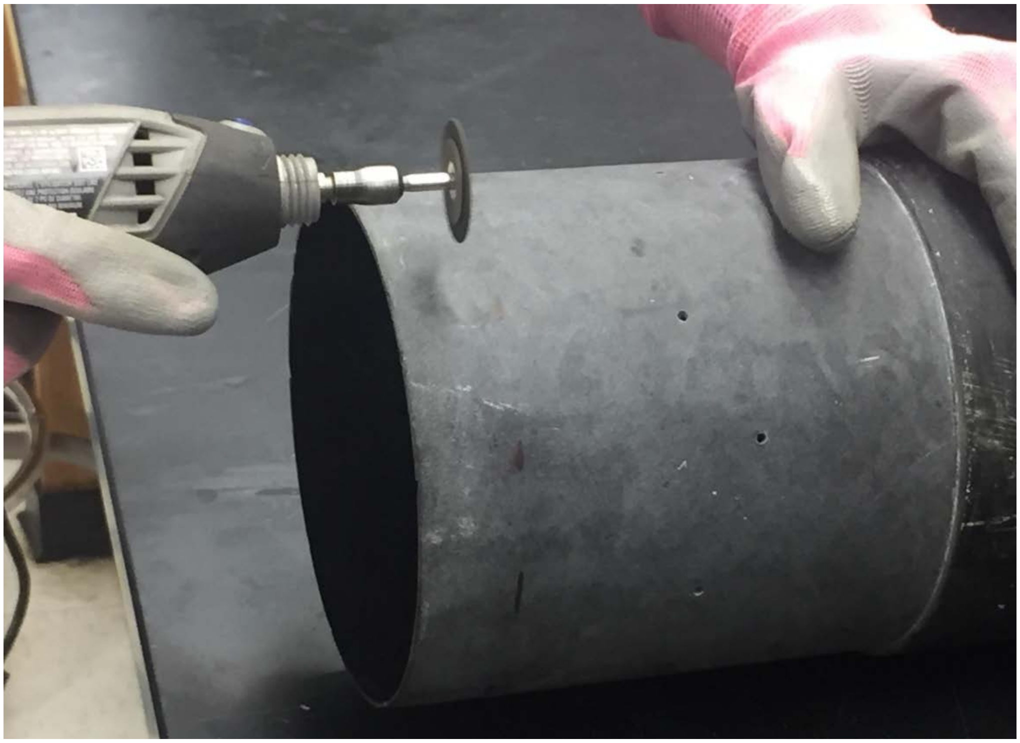


Figure 13 displays the nose cone shoulder being cut with a rotary tool.

3.2 Flight Reliability Confidence

Table 6 outlines the tests utilized to prove the launch vehicle design will meet the mission success criteria.

Table 6: Flight Reliability	
Mission Performance Criteria	**Test**
The launch vehicle has a stable flight	• Full scale test launch • Center of gravity determination
The launch vehicle reaches target apogee (5,280 ft) ± 200 ft AGL	• Full scale test launch
The drogue parachute deploys within 10 ft of apogee	• Full scale test launch • Ground ejection tests
The main parachute deploys within 15ft of 800 ft AGL	• Full scale test launch • Ground ejection tests
Each independent section of the launch vehicle lands with less than 75 ft-lbf of kinetic energy	• Full scale test launch • Kinetic energy calculations
The launch vehicle is recoverable and reusable	• Full scale test launch

The drift of the launch vehicle does not exceed 2,500 ft from the launch pad	• Full scale test launch

3.2.1. Stability
The stability of the launch vehicle design was demonstrated during the team's test launch. This launch was conducted on February 04, 2017 at the FAR launch site where the wind had a speed of approximately 10 mph, and the vehicle flew straight. The launch vehicle design stability is further shown through the center of gravity calculations and test.

3.2.2 Altitude
The onboard altimeters recorded an altitude of 5,191 ft and 5,181 ft. These values were less than the 5,257 ft altitude predicted using of RockSim.

3.2.3 Parachute Deployment
Ground ejection tests were performed were performed on January 27, 2017 and February 1, 2017. The test was not successful on the first date however, after incorporating more black powder the main parachute and drogue parachute were both deployed successfully during the second test. Drop tests were conducted on 1/27 with Rick, and 2/1, 2/3 by the team. The main parachute stayed within its compartment, this ensures that the main parachute will not prematurely eject along with the drogue parachute deployment. During the full-scale test launch, both parachutes were deployed successfully. The redundant altimeter recovery system further increases the team's confidence in successful parachute deployment. Each altimeter is independently wired and is connected to its own battery, igniter, key switch, and black powder charge.

3.2.4 Safe Landing
Calculations indicate that all sections of the launch vehicle will land with a kinetic energy less than 75 ft-lb after main parachute deployment. This ensures that the launch vehicle will not be damaged upon landing. The chance of fin splintering due to impact with the ground was decreased by the fiberglass lamination of the fins. The launch vehicle was recovered intact and reusable after the test launch.

3.2.5 Drift
Calculations indicate the drift of the launch vehicle will remain within 2,500 ft during high wind speeds. After the test launch the launch vehicle landed slightly over 1,000 away during 10 mph wind, supporting our calculations.

3.3 Test Data and Analysis
Tests concerned with the recovery subsystem of the launch vehicle or payload are found in their respective sections.

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

A weighted shear modulus was calculated based off of the thickness of the fin components. The total thickness of the fin increased to 0.2775" with the addition of a single layer of fiberglass (0.25" of wood and 0.0275" of fiberglass). The calculation for the weighted shear modulus is shown below:

$$G_{total} = \frac{G_{wood}T_{wood} + G_{fiberglass}T_{fiberglass}}{T_{total}}$$
$$= \frac{(102000\text{ psi})(0.25\text{ in}) + (4278613\text{ psi})(0.0275\text{ in})}{0.2775\text{ in}} = 515{,}899\text{ psi}$$

Where,
G is shear modulus and T is the thickness of the material.

The variables used in the succeeding equations are defined below:

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

$$a\left(\frac{ft}{s}\right) = \sqrt{1.4 \times 1716.59 \times (T(°F) + 460)}$$
$$= \sqrt{1.4 \times 1716.59 \times (60°F + 460)}$$
$$= 1117.9\ \frac{ft}{s}$$
$$\beta = \frac{S^2}{A_f} = \frac{(6\text{ in})^2}{58.5\text{ in}^2} = 0.615$$
$$\lambda = \frac{C_T}{C_R} = \frac{7\text{ in}}{12.5\text{ in}} = 0.56$$
$$P\left(\frac{lbs}{ft^2}\right) = 2116 \times \left(\frac{60 - 0.00356h + 459.7}{518.6}\right)^{5.256}$$
$$= 2116 \times \left(\frac{60 - 0.00356(1748\text{ ft}) + 459.7}{518.6}\right)^{5.256}$$
$$= 1767.7\ \frac{lbs}{ft^2}$$

$$V_f = a\sqrt{\frac{G}{\frac{1.337\beta^2 P(\lambda+1)}{2(\beta+2)(\frac{t}{C_R})^3}}}$$

$$= (1117.9\frac{ft}{s})\sqrt{\frac{515{,}899\frac{lbs}{in^2}}{\frac{1.337(0.615)^2(12.28\frac{lbs}{in^2})(0.56+1)}{2(0.615+2)(\frac{0.25\ in}{12.5\ in})^3}}}$$

$$= 1{,}668\ \frac{ft}{s}$$

$$\text{Safety Factore (SF)} = \frac{\text{Calculated flutter speed}}{\text{Predicted maximum speed}} = \frac{1{,}668\ \frac{ft}{s}}{704\frac{ft}{s}} = 2.36$$

3.3.2.Airframe Compression Test

The airframe must be capable of withstanding 407.86 lbs of force (the maximum motor thrust, 1814 N). The length of the Blue Tube airframe measured 21.5" in length prior to testing. 409 lbs were added to the top of the airframe, no observable strain or damage were witnessed on the airframe, and the length of the tube remained at 21.5".

$$SF = \frac{\text{Force on airframe}}{\text{Maximum motor thrust}} = \frac{409\ \text{lbs}}{407.86\ \text{lbs}} = 1.0$$

Figures 14 – 17 display how the test was conducted.

Figure 14: Compression Test Set-up

Figure 14 displays the fiberglassed Blue Tube set up prior to adding mass for testing.

Figure 15: Compression Test Mass Configuration

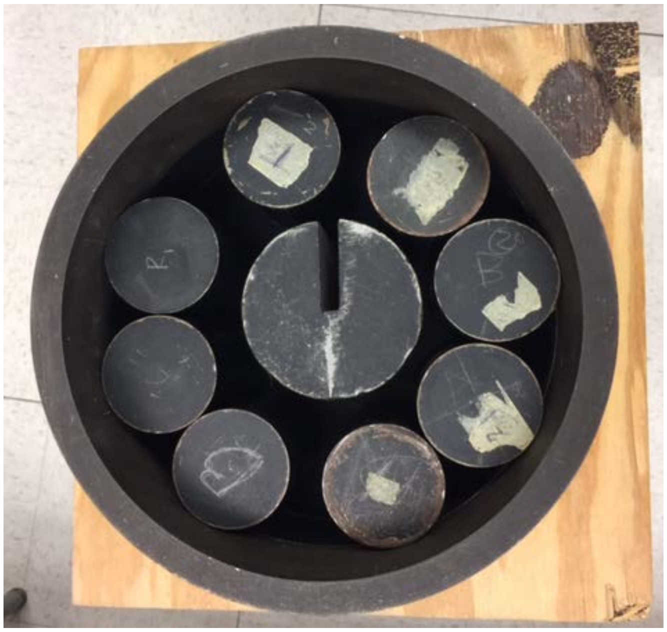


Figure 15 shows how the weights were arranged in the bottom layer to keep the force evenly distributed on the Blue Tube.

Figure 16: Compression Test (Half Complete)

Figure 16 shows the configuration half way through the compression test.

Figure 17: Compression Test (Complete)

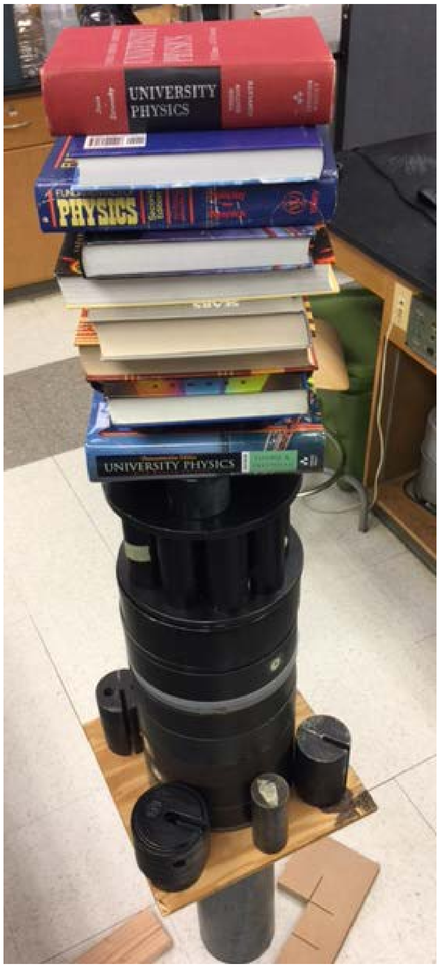


Figure 17 displays the final set up of the compression test with a total mass of 409 lbs.

3.3.3 Motor Mount and Centering Strength

The centering rings and motor mount must be capable of withstanding the 1420 N average thrust of the motor. This force is divided among the six centering rings installed on the motor mount, meaning each centering must be able to withstand 237 N (53.24 lbs). The experimental setup used to test the motor mount and centering ring strength is shown in Figure 18.

Figure 18: Motor Mount and Centering Ring Strength Test

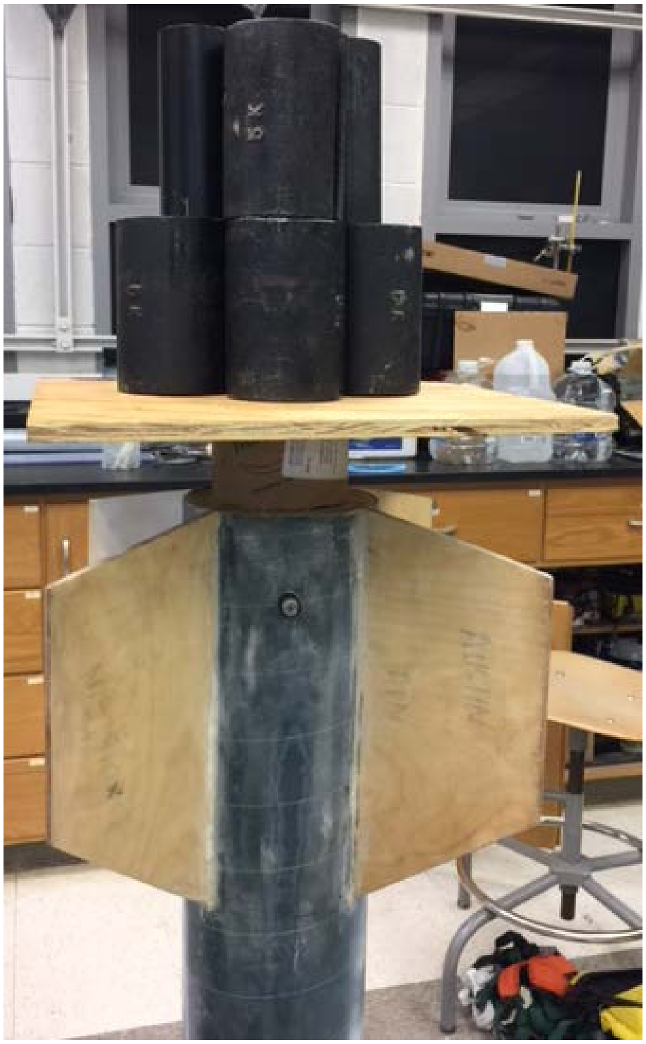


Figure 18 shows the final configuration for the motor mount and centering ring strength test with a total of 81.57 lbs on the after centering ring.

22.05 lbs were added to the board applying force to the aft centering ring via a 4” tube. After verifying that the centering ring remained intact the mass was increased to 48.5 lbs, then 81.57 lbs. The final mass corresponds to a gravitational force of approximately 2175.6 N. The centering ring showed no signs of strain at any of the applied weights. This procedure was successfully completed for the forward centering ring.

$$\mathrm{SF} = \frac{6(\mathrm{Weight})}{\mathrm{Average\ motor\ thrust}} = \frac{2175.6\ \mathrm{N}}{1420\ \mathrm{N}} = 1.53$$

After the full-scale test flight, the aft centering ring was slightly blackened (Figure 18) during motor burn. This test was repeated to test the integrity of the centering ring after flight, no superficial damage was seen.

3.3.4 Center of Gravity Test

The fully assembled launch vehicle and payload, in launch ready configuration, were utilized to determine the center of gravity. Figure 19 shows the configuration used to determine the center of gravity.

After ballast was added, the test was conducted a second time to verify the precise location of the center of gravity and stability of the rocket (Figure 19).

Figure 19: Center of Gravity Test

Figure 19 shows the configuration for the completed center of gravity test.

The center of gravity was located 63.2” from the nose cone.

3.3.5 Full-Scale Test Flights

The full-scale test flight results are presented in section 7.1.1.4.

3.4 Workmanship

Careful attention to workmanship is critical to mission success, especially with regard to:

- Structural integrity of the launch vehicle
- Proper functioning of the recovery electronics

Structural integrity requires proper bonding of structural elements. This was accomplished using the following:

- Epoxy resin and hardener were carefully measured to attain the proper ratio (1:1 by volume)
- Surfaces that were bonded were cleaned with alcohol and lightly sanded prior to bonding
- Rocket Epoxy with a 60-minute set time was used for bonding critical joints for structural integrity of the launch vehicle, such as the fins, centering rings, and bulkheads.
- Joints were immobilized throughout the duration of epoxy cure time
- High temperature epoxy was used to bond the motor retainer to the motor mount
- All bonds were inspected by a second team member

Proper functioning of the recovery electronics requires proper wiring and secure mounting. This was accomplished using the following

- Electronics were handled carefully by the edges and stored in ESD bags to avoid damage from static discharge
- Altimeters were secured to electronics sleds with nylon standoffs
- Wiring connections are secured by soldering, or with screw terminals, or with snap-together JST connectors
- Only 1-2 wires were used per connector (i.e. the redundant altimeter wires did not use the same JST connector as wires from the other altimeter)
- JST-connectors were taped prior to flight
- Soldering was inspected for 'cold joints'
- Stranded wire was twisted and made a 180-degree hook, in a clockwise direction, when connected to a screw terminal.
- Connections between wire and screw terminals were tested for a strong connection
- Batteries were secured with zip ties
- Wiring is bundled and routed in such a way that it does not flop around excessively during flight
- Wires are not tight
- Stranded, 22-gauge wire, was used wherever possible
- Heat shrink tubing was used to cover bare wire
- Continuity of circuits was tested with a multi-meter
- Wire was stripped with the proper wire stripper; wires were checked for damage afterwards

All electronics and wiring were inspected by a second team member.
In addition, the team paid careful attention to the following during the construction of the launch vehicle:

- The length of the Blue Tube was carefully measured and marked with a pencil
- The proper tools were used for each section
- Super glue was applied to the walls of any non-threaded holes in the side of the airframe
- A metal file was used to sand down the rounded bolts on the rail button

3.5 Mass Statement

After construction and assembly each independent section was weighed with a digital scale. Table 7 lists the complete mass statement of the launch vehicle with the payload.

Table 7: Mass Statement			
Section	**Mass (lbs)**	**Original Mass Estimate (lbs)**	**Percent Error (%)**
Aft (booster. motor hardware, drogue parachute and components)	14.40	13.27	7.85
Middle (avionics, main parachute and components)	8.92	6.78	23.99
Forward (nosecone, fragile material protection payload)	12.23	14.22	16.27
Aerotech L1420R	10.06	10.06	0
Total without motor	35.55	34.28	3.57
Total with motor	45.61	44.34	2.78
Total with empty motor mass	39.96	38.69	3.18

A 1.27 lbs mass increase was noticed for the fully assembled launch vehicle after the independent sections were weighed manually. The biggest percent error in mass is visible in the middle section. Despite the 1.27 lbs mass increase, the launch vehicle still possesses an 18.28 lbs mass margin to ensure the required 5:1 thrust to weight ratio. The launch vehicle has yet to be painted, however, the paint is not expected to add more than a 1lb to the total launch vehicle mass.

3.6 Recovery Subsystem

This section describes and defends the robustness of the recovery subsystem used in Project Aegis.

3.6.1 Design Overview

In project Aegis, the recovery subsystem consists of two parachutes, recovery harnesses, parachute attachment hardware, and parachute deployment electronics. The recovery subsystem performs the following operations:

- Detects when the launch vehicle reaches apogee and 800 ft AGL
- Deploys the drogue and the main parachutes at the above altitudes
- Reduces the kinetic energy of the tethered sections (forward, middle, and aft) to less than 75 ft-lbf upon landing for each independent section

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

Table 8 summarizes the recovery subsystem components along with their specifications.

Table 8: Recovery Materials			
Recovery System Component	**Material**	**Justification**	**Strength**
Drogue parachute	24” elliptical ripstop nylon	-Light weight, 0.136 lbs -Low packing volume (12.2in^3) , -Cd of 1.5	3.3 lbs@20 fps
Main parachute	120” toroidal ripstop nylon	-Light weight, 1.375 lbs -Low packing volume (128.2in^3) -Cd of 2.2	64 lbs@15 fps
Shroud lines	Spectra fiber	Strong and duarble	1400 lbs
Drogue parachute recovery harness, 45’	1” tubular ripstop nylon	High breaking strength	9 kN
Main parachute recovery harness, 35’	1” tubular ripstop nylon	High breaking strength	9 kN
Shock cord protectors	High temperature nomex sleeves	Able to withstand the high temeratures of the ejection gases	700°F
Drogue parachute protector	18” square nomex	Able to withstand high temperatures	700°F
Main Parachute Protector	24” square nomex	Able to withstand high temperatures	700°F
Bulkheads, 0.50” (2)	5-ply birch plywood	Robust and does not break easily	N/A
Bulkheads, 1.0” (2)	Double stacked 5-ply plywood	Robust and does not break easily	N/A
Recovery harness interface	0.3125” quicklink	Easy connection and removal of recovery harness from launch vehicle	5280 lbs
Bulkhead and quicklink interface	0.3125” metal u-bolt	Strong	10,571 lbs
Shock cords and shroud lines nterface	Stainless steel swivel	Strong and prevents tangling between shock cord and shroud lines	3000 lbs

3.6.2 Robustness of the As-Built and As-Tested Recovery System

3.6.2.1 Structural Elements

*Parachutes***,** *Harnessses, Bulkheads, and Attatchement Hardware*

The recovery subsystem consists of a 24" diameter drogue parachute and a 120" diameter main parachute capable of withstanding a force of 3.3 lbs@20 fps and 64 lbs@15 fps, respectively, as shown in Figure 20 and Figure 21. All 1.15" diameter shroudlines attached to the parachutes converge and are held together by a strong metal eye swivel. The shroudlines are made out of spectra fiber and are durable with a strength of 1400lbs. The metal eye swivel is connected to the quicklink and is made of stainless steel; it is able to withstand a total strenth of 3000lbs.

Suitable diametesr of the drogue and main parachute were determined by the following equation [2]:

$$D = \sqrt{\frac{8mg}{\rho C_d v^2 \pi}}$$

where,
D is the diamter of the parachute
g is the acceleration due to gravity
ρ is the air density
C_d is the coefficient of drag of the parachute
v is the terminal velocity.

Figure 20: Drogue Parachute

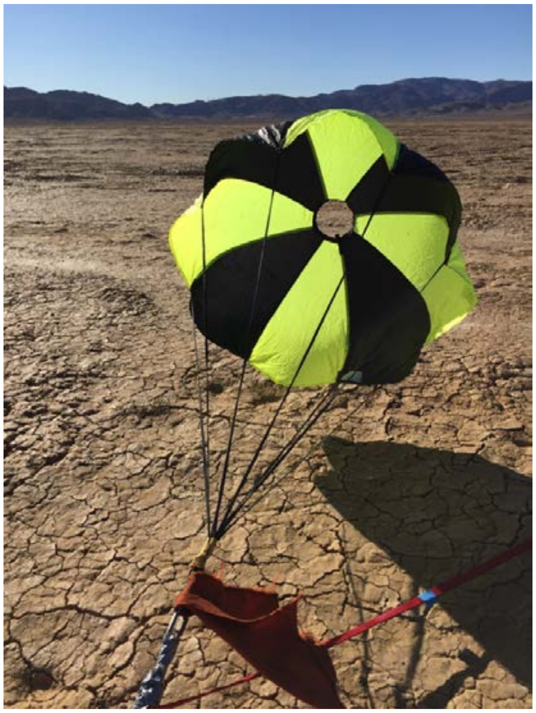


Figure 20 shows the 24" diameter elliptical ripstop nylon drogue parachute used in Project Aegis.

Figure 21: Main Parachute

Figure 21 shows the 120" diameter toroidal ripstop nylon main parachute used in Project Aegis.

Figure 22: Eyeswivel

Figure 22 shows the interface between the shroud lines, eyeswivel, quicklink and shock cord.

The drogue and main parachutes will be attached to the launch vehicle via two high strength 1” wide tubular nylon shock cords. The shock cord features a high breaking strength of 9kN. The drogue parachute is attached to the booster section and the middle airframe with a 45’ long shock cord and the main parachute is attached to the middle and forward airframes with a 35’ shock cord. Each shock cord will be attached to the airframe and the parachute using three 0.3125” quicklinks. Each quicklink has a safe working load of 3000lbs of force. The first quick link connects to a knot at the end of the shock cord and a 0.3125” heavy duty u-bolt as seen in Figure 23. One of the quicklinks is secured onto the epoxied 0.50” thick 5-ply wood bulkhead via a 0.3125” u-bolt as demonstrated in Figure 24. The second quick link attaches to a knot near the center of the shock cord with the the parachute eye swivel and the nomex parachute protector. The last quicklink is attached to the 0.3125” u-bolt secured onto the 1” double stacked avionics bulkhead.

Figure 23: Quicklink and U-bolt Connection

Figure 23 shows the 0.3125” quicklink attached to the 0.3125” u-bolt secured into the bulkhead of the avionics bay.

Figure 24: U-Bolt and Bulkhead

Figure 24 shows the 0.3125” u-bolt that will be secured into a 0.50” thick 5-ply wood bulkhead to be attached to the 6” diameter airframe.

The 18” nomex drogue parachute protector (blanket) and the 24” main parachute protector are used to shield the parachutes from high temperature ejection gases. Within the airframe, the nomex blankets cover the properly folded parachutes as shown in Figure 25. The shock cords are also covered in nomex sleeves to prevent burning and loss of integrity. The nomex sleeves can be seen in Figure 26.

Figure 25: Nomex Blanket

Figure 25 shows the main parachute wrapped in the 24" nomex blanket.

Figure 26: Nomex Sleeves

Figure 26 shows the nomex sleeves that protect the shock cords.

The launch vehicle descends as two tethered sections after drogue parachute deployment. To prevent premature ejection of the main parachute during drogue parachute deployment, two sets of 1” elastic cords are each looped through two knots on the drogue parachute shock cord. This system allows the elastic to absord some of the shock created by drogue parachute deployment and thus decrease the force experienced by the 11 shear pins on the main parachute compartment.The distance between the two knots is two times longer than the looped elastic cord diameter. Figure 27 shows the elastic cord connection.

Figure 27: Elastic Cord

Figure 27 shows the attachment of the elastic cord to the two knots tied on the shock cord.

Drop tests were conducted to verify the robustness of the elastic cord and ensure that the proper amount of shear pins are utilized to temporarily secure the main parachute compartment. Figure 28 shows the team dropping the connected forward and middle section without an elastic cord to simulate the shock from drogue parachute deployment. The figure below shows that the main parachute compartment separated. This indicates that force experienced by the shear pins was greated than they could withstand.

Figure 28: First Drop Test

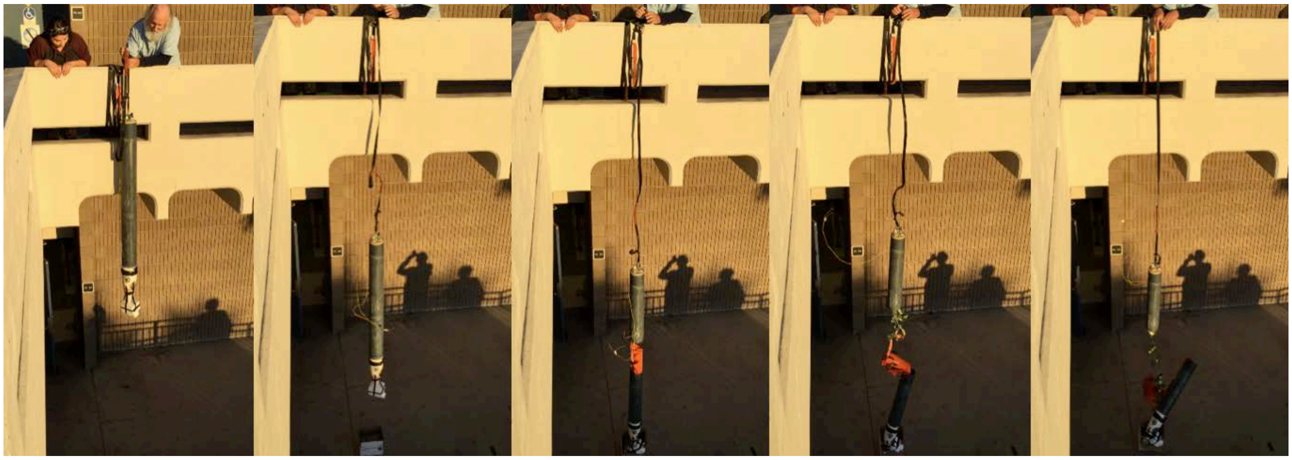


Figure 28 shows the team dropping the forward section of the launch vehicle to simulate the force created by the drogue parachute deployment.

After the first trial, the team's metor, Rick, suggested using an elastic cord to absorb some of the forced experienced by the 11 shear pins. Figure 29 shows the second trial of the drop test conducted after attaching elastic cord to the shock cord. The elastic cord stretched out as the shock cord extended to its maximum length. This reduced the shock that the shear pins experienced. As a result the main parachute compartment did not separate. The second drop test demostrated that the elastic cord succesfully absorded enough shock, generated from the deployment of the drogue, to keep the shear pins intact detered the seperation of the main compartment.

Figure 29: Second Drop Test

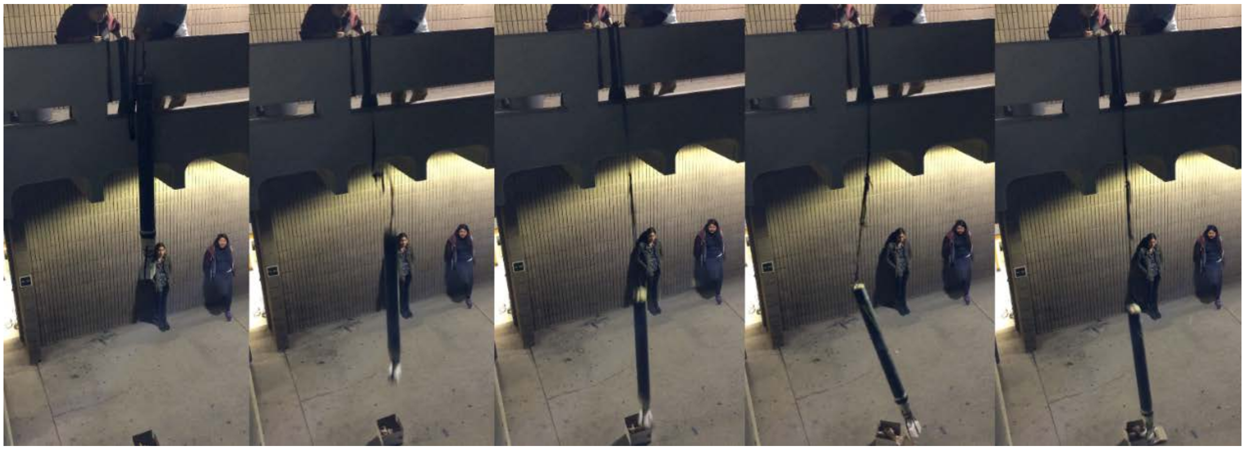


Figure 29 shows the second drop test with the elastic cord attached to the shock cord knots.

Order of Deployment:

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

Figure 30 displays an exploded view diagram for the launch vehicle before construction and Figure 31 shows an exploded view of the actual launch vehicle after completing the full scale test launch. The team paid careful attention to detail throughout the constructing of the launch vehicle to ensure that it would match the initial design. Figures 32 - 33 show the drogue parachute deployment configuration and main parchute deployment configuration.

Figure 30: Launch Vehicle (Internal/Exploded View)

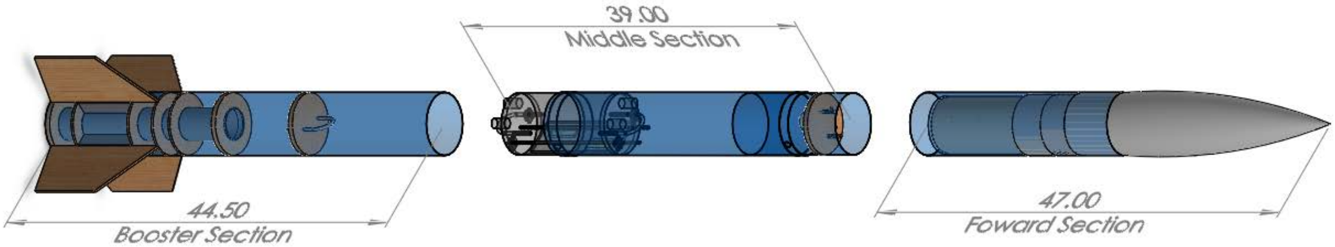


Figure 30: shows an exploded isometric view of the launch vehicle diagram with transparent subsections.

Figure 31: Parachute Deployment Airframe Seperations

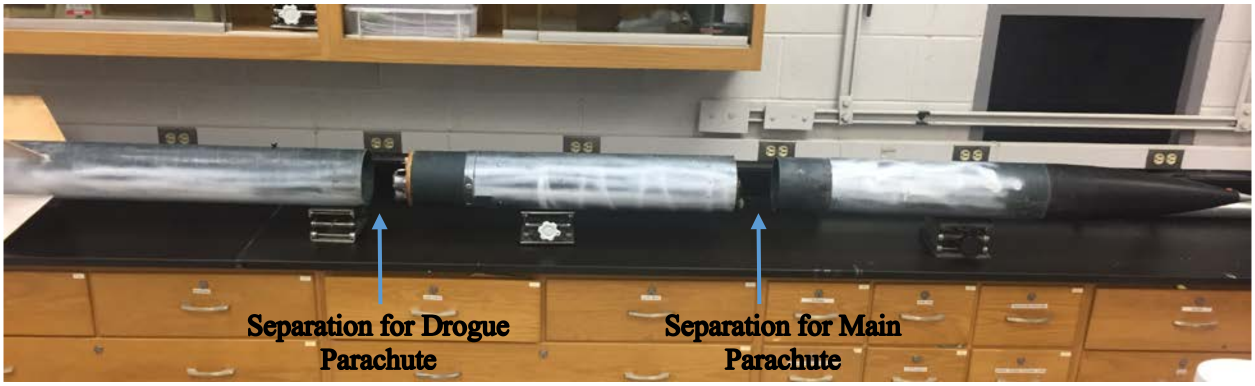


Figure 31 shows the locations where the airframe seperates during drogue and main parachute deployment.

Figure 32: Drogue Parahute Deployment

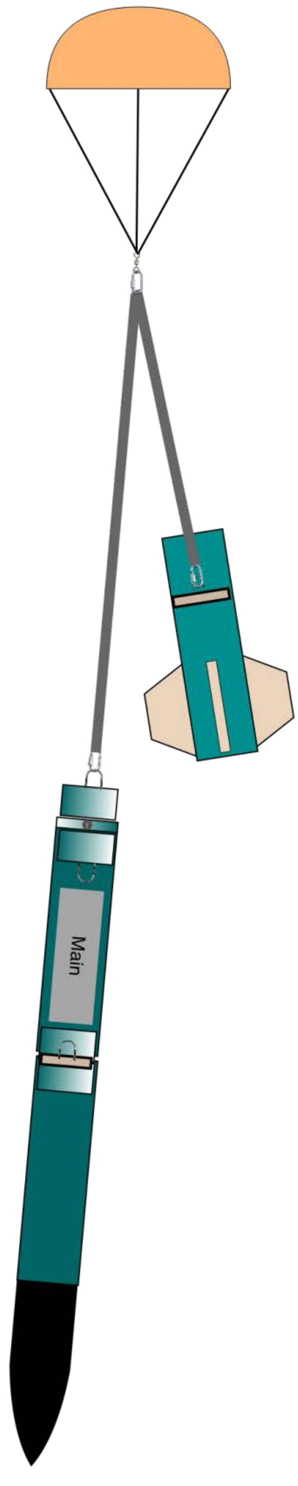


Figure 32 shows the launch vehicle configuration after the deployment of the drogue parachute.

Figure 33: Main Parachute Deployment

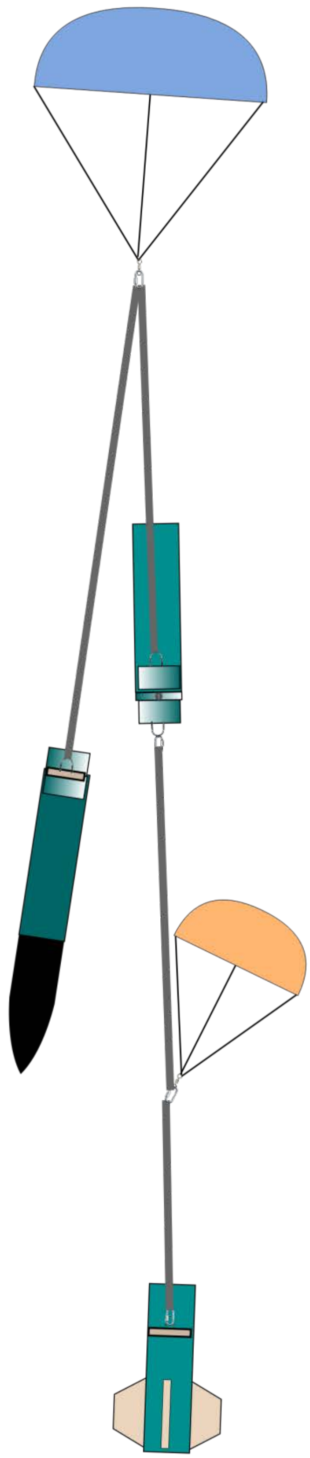


Figure 33 shows the launch vehicle configuration after the deployment of the main parachute.

3.6.2.2 Electrical Elements
The parachute deployment electronics consist of the following elements:

- Missile Works RRC2+ Altimeters
- 9-V Batteries
- Battery Clips
- 22-gauge Wires
- JST Connector
- E-matches
- Terminal Blocks
- Key Switches

The Missle Works RRC2+ dual deployment altimeters, are attatched to a 12” long, 5” wide wood sled inside of the avionics bay. Figure 34 shows the altimeters in use. 9-V batteries,shown in Figure 35, will be secured on the wood sled with zipties. The voltage of the batteries are checked with a multimeter prior to launch to ensure that all on-board batteries are fully charged. 22-gauge wires connect the altimeters to the batteries and key switches. Figure 36 shows the JST connectors utilized for wire connections. The drogue and main parachute wiring starts at the altimeters and goes to the externally attached terminal blocks on the bulkheads enclosing the avionics bay. Opposite of this connection the stripped end of the e-matches are connected to the terminal blocks, as shown in Figure 37, while the pyrogent end is inserted into the loaded black powder ejection canisters . Figure 38 shows the key switches for the launch vehicle. The on-board altimeters are independently controlled by Uxcell electric metal keylock switches installed on the switch panel of the avionics bay. Keys are required to activate the switches which provide arming and disarming control.

Figure 34: Missile Works RRC2+ Altimeter

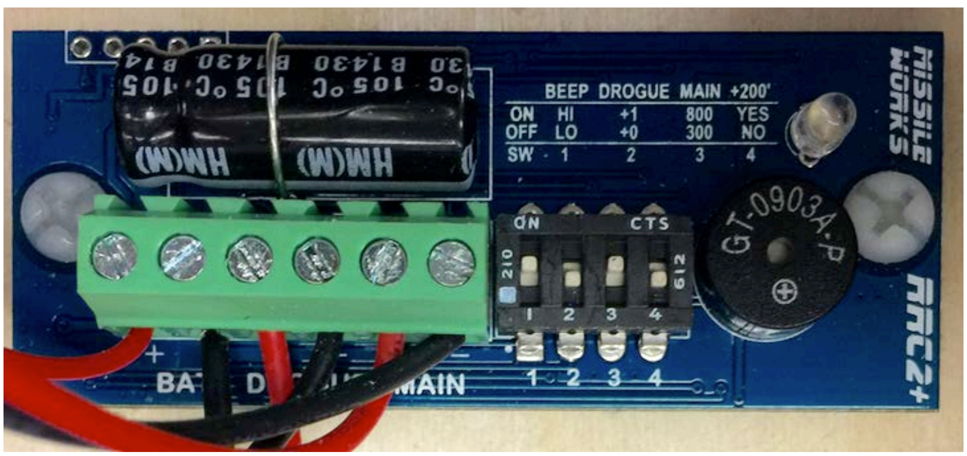


Figure 34 show the barometric altimeter secured on the wooden sled of the avionics bay.

Figure 35: 9-V Battery

Figure 35 shows the 9-V battery utilized for the electronic deployment system.

Figure 36: JST Connector

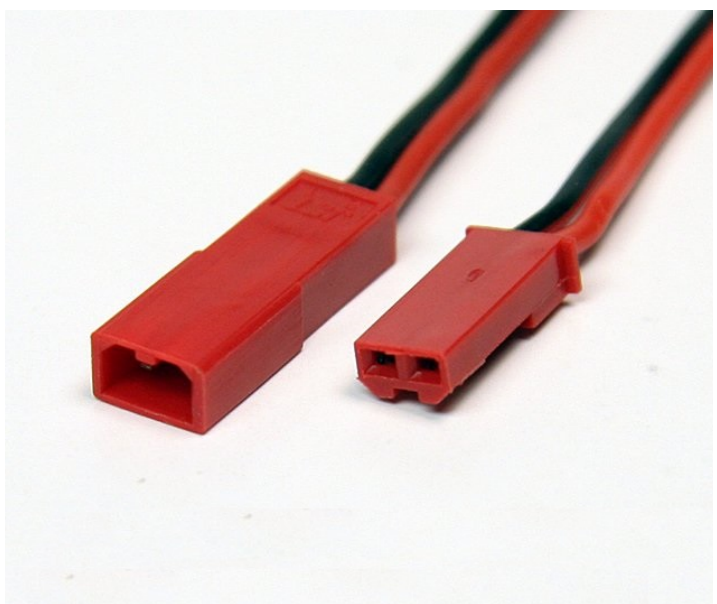


Figure 36 show the JST connectors that connect the 22-gauge wires to the batteries.

Figure 37: Terminal Blocks

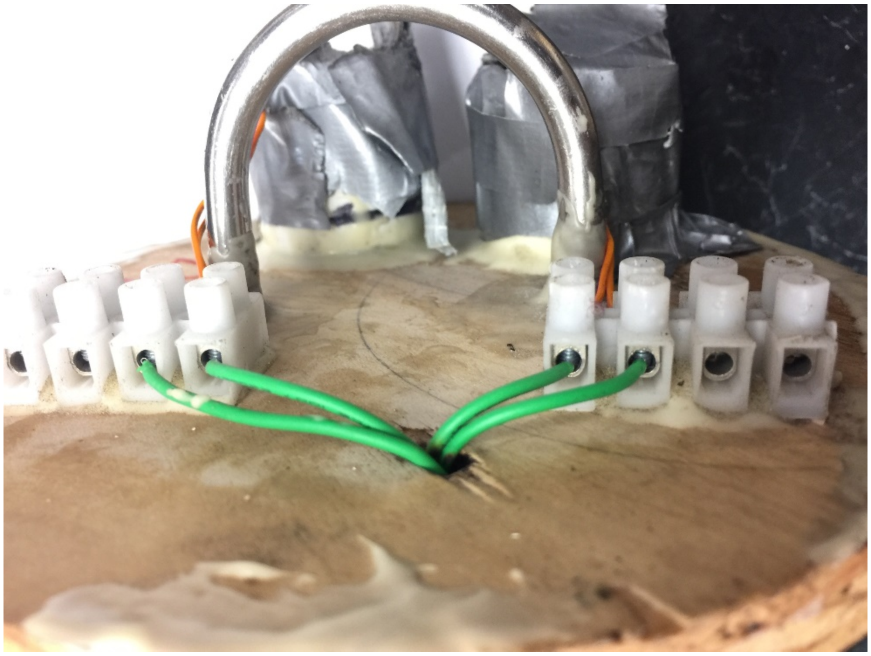


Figure 37 shows the terminal blocks that are attached to the bulkheads that enclose the avionics bay.

Figure 38: Key Switches

Figure 38 shows the key switches that arm and disarm the electronics in the avionics bay.

The accelometer consists of the following:

- SparkFun 9DoF IMU Breakout - LSM9DS1 Altimeter
- 3-axis accelerometer
- 3-axis gyroscope
- 3-axis magnetometer
- SD shield
- Arduino Uno

A SparkFun 9DoF IMU Breakout - LSM9DS1 accelerometer (Figure 39) is used in the avionics bay and is equipped with a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer. The accelerometer is connected to an Arduino Uno using an SD shield as shown in Figure 40 and 41. The SD card is inserted in the SD shield before flight to collect data. Algorithms are programmed to calculate the Accel, Mag, Gyro, Pitch, and Roll of the launch vehicle throughout its flight.

Figure 39: LSM9DS1 Altimeter

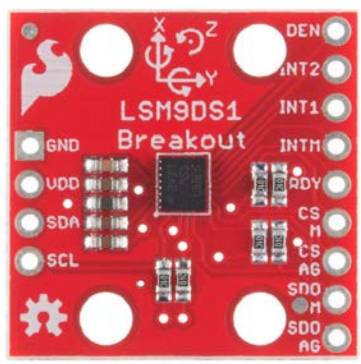


Figure 39 shows the unsoldered LSM9DS1.

Figure 40: Arduino Uno

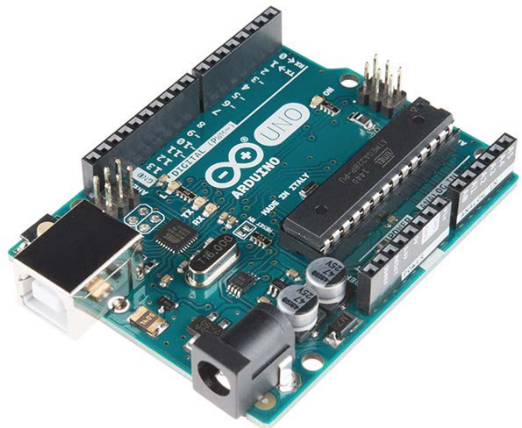


Figure 40 shows the Arduino Uno that is used in the launch vehicle.

Figure 41: SD Shield

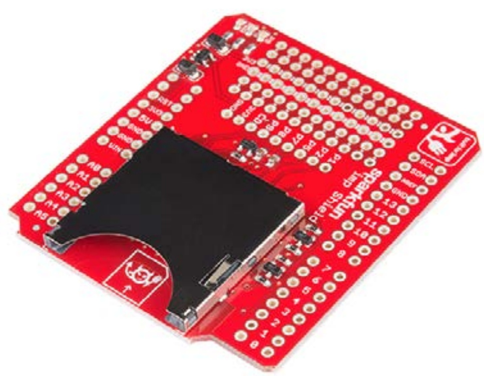


Figure 41 shows the unsoldered SD shield.

Figure 42 shows the ground ejection test conducted verifying the electrical elements were fully secured on the wood sled. The shear pins that connect the parachute compartments sheared as the black powder ignited and created ejection gases within the compartments. For more detail on the ground ejection test see Section VII. *Testing.*

Figure 42: Ground Ejection Test

Figure 42 shows snapshots of the ground ejection test.

3.6.2.3 Redundancy Features

The primary and redundant altimters are programmed with flight logic that enables the barometer in the alitmeter to detect the flight altitude based on barometric pressure. A current is sent to the e-match as the launch vehicle reaches apogee and 800 ft AGL. Each altimeters is connected to independent batteries to ensure that the redundant electrical system is separate from the primary system.

The redundancy features of the recovery system include backup black powder deployment charges for both the drogue and main parachutes connected to the redundant altimeters. The black powder is placed in the ejection canisters constructed out of 1.25" diameter 1" long PVC pipes. The ejection canisters are epoxied to the bulkheads that enclose the avionics bay. There are four ejection canisters total. Two drogue ejection canisters are epoxied to the bottom bulkhead of the avionics bay that are inserted into the booster section of tha launch vehilce and two main ejection canisters are epoxied to the top bulkhead inserted into the middle section of the launch vehicle. One drogue and main ejection canister is assigned for the primary deployment system while the other set is responsible for the redundant deployment system.

4F black powder is used to deploy the drogue and main parachute. Black powder ignition creates ejection charges that build pressure within the parachute compartments of the airframe in order to shear the nylon screws and deploy the parachutes at their programed altitudes. The mass of the black powder is calculated by using the following equation [3]:

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

where,

m_b is the mass of the black powder in grams

d_c is the length of the inner diameter of the parachute compartment in inches

L_c is the length of the compartment in inches

Table 9 shows the calculated mass of the black powder required for proper parachute deployement.

Table 9: Calculated Black Powder	
Parachute	**Black Powder Mass (g)**
24” Drogue	2.86
120” Main	5.37

To ensure that the proper amount of black powder is used, ground ejection tests were conducted starting with 0.5 g less than the calculated amount of black powder. Black powder mass was increased in increments of 0.5 g until the correct amount was determined.

The first black powder charge deploys the 24” elliptical drogue parachute at apogee. Once the rocket descends to 800 ft AGL, a second black powder charge ejects the 120” toroidal main parachute. The drogue parachute deployment system incorporates a redundant black powder charge with a 1-second delay, while the main parachute has a redundant black powder charge at 500’ AGL.

Figure 43: Redundant Missile Works RRC2+ Altimeter

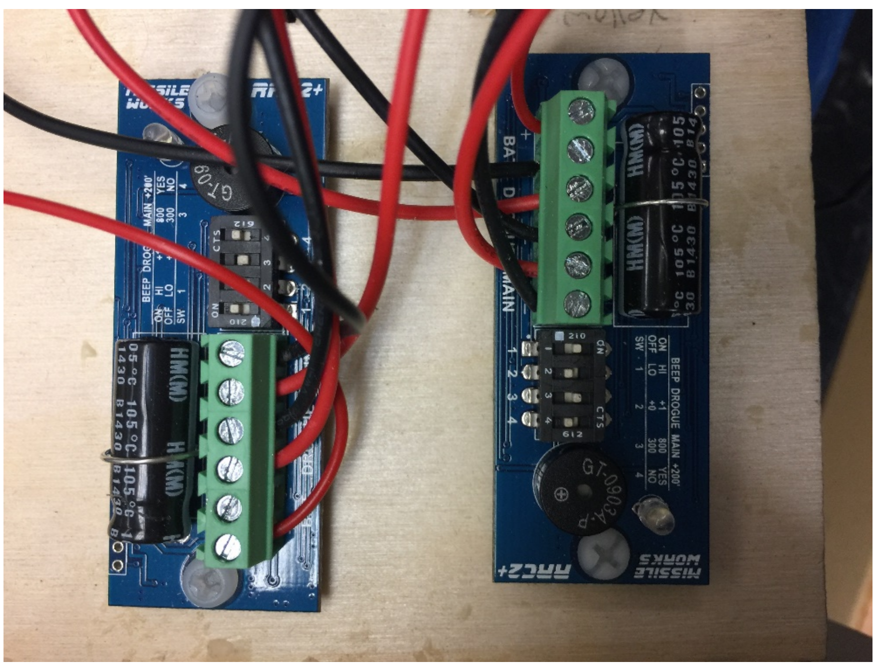


Figure 43 shows the two altimeters secured to the avionics wood sled with nylon standoffs.

Figure 44: Redundant Key Switches

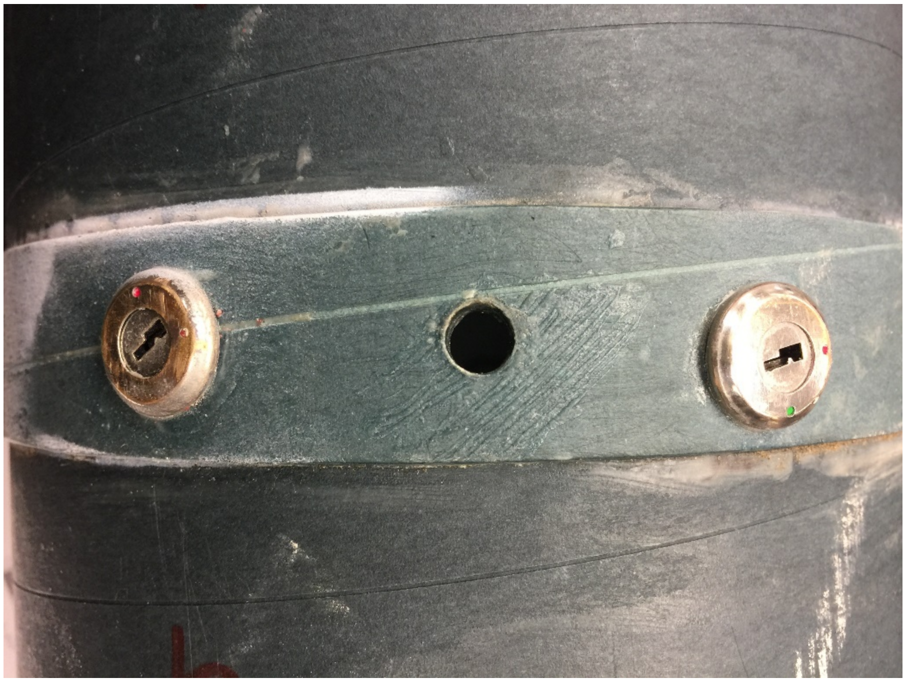


Figure 44 shows the two key switches on the avionics switch panel.

3.6.2.4 Parachute Sizes and Descent Rates
Terminal Velocity, Kintic Energy, and Drifting Distance
Project Aegis incorporates a 24” elliptical ripstop nylon drogue parachute and a 120” toroidal ripstop nylon main parachute. With a 24” drogue parachute and a 120” main parachute, the launch vehicle descends at 78.18 ft/s after the deployment of the drogue parachute. At 800’ AGL the launch vehicle descends at 12.92 ft/s after the deployment of the main parachute. Both desent ratesindicate that the landing kinetic energy of each tethered section will remain under 75ft-lbf as the sections collide with the ground upon landing. The detailed calculation for the terminal velocity, landing kinetic energy of each tethered section, and the drifting distance are depicted below.

Table 10 shows the parachute specification including parachute type, parachute diamter size, coefficient of drag, deployment altitude, and the stregth of the parachute.

Table 10: Parachute Specification				
Parachute Type	**Size**	**Coefficient of Drag**	**Deployment Location**	**Strength**
Drogue parachute	24” elliptical ripstop nylon	1.5	Apogee	3.3 lbs@20 fps
Main parachute	120” toroidal ripstop nylon	2.2	800’ AGL	64 lbs@15 fps

The forward, middle, and aft section of the launch vehichle have a kinetic energy no greater than 75 ft-lbf to ensure that the sections remain undamaged. To determine the kinetic energy, the terminal velocity for each section was calculated using the equation below[4]:

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

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

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

The kinetic energy was then calculated using the following equation[5]:

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

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

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

The kinetic energy from this formula gives the results in Joules which were then converted to ft-lbf using the conversion factor of 1J = 0.738 ft-lbf. The calculated results are summarized in Table 10.

Table 11: Terminal Velocity and Kinetic Energy

Launch Vehicle Section	m_s (lbs)	$V_{(drogue)}$ (ft/s)	$V_{(main)}$ (ft/s)	$K_{(drogue)}$ (ft-lbf)	$K_{(main)}$ (ft-lbf)
Forward Section	14.22	78.18	12.92	1350.75	36.92
Middle Section	6.78	78.18	12.92	643.75	17.60
Aft Section	13.27	78.18	12.92	1260.71	34.46

The drifting distance from the launch pad and the apogee of the launch vehicle differs under different wind conditions. RockSim was used to simulate the drifting distance and the apogee of the launch vehicle. The results are summarized in Table 11.

Table 12: Drifting Distance and Apogee		
Wind Speed (mph)	**Drifting Distance (ft)**	**Apogee (ft)**
5	328.10	5283.3
10	738.88	5294.13
15	954.96	5278.05
20	2111.76	5233.86

3.6.2.5 Electrical Schematics and Structual Assemblies

Electrical Schematics

As shown in Figure 45, the launch vehicle consists of two Missile Works RRC2+ altimters; one is the official scoring altimeter and the other is a required redundant altimeter. Each altimeter is connected to its own 9-V battery using 22 gauge wire. This is done to ensure that the redundant deployment system is independently powered.

Figure 45: Altimeter Elctrical Schematics

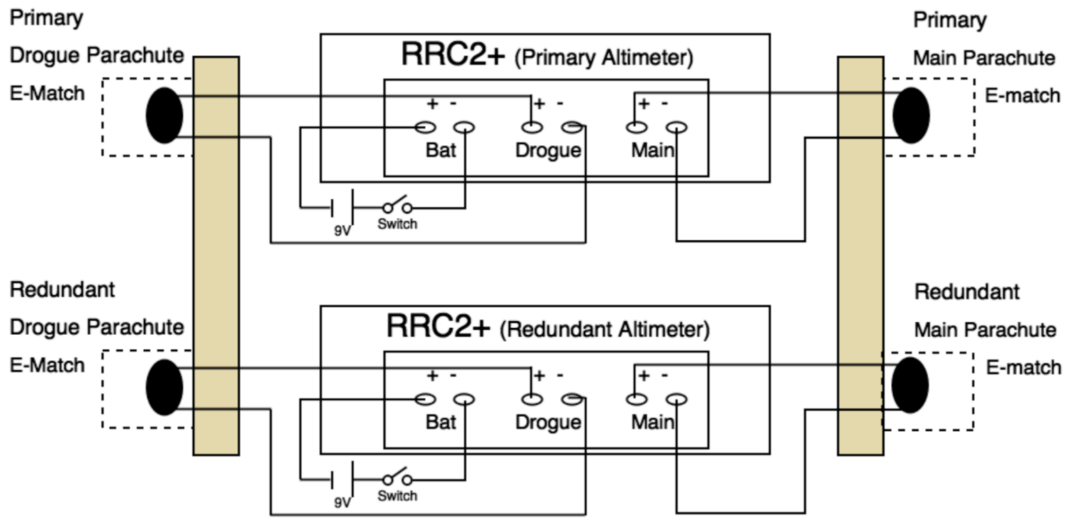


Figure 45 shows the electrical schematic of the primary and redundant altimeters.

The accelerometer setup is located on the wooden sled in the avionics bay and is held in place with four nylon screws. Figure 46 shows the programmed accelerometer used to calculate the Accel, Mag, Gyro, Pitch, and Roll of the launch vehicle throughout its flight. Figure 50 shows the algorithm programmed in the accelerometer. Figure 47 - 49 shows the detailed electrical schematic of the accelerometer elements.

Figure 46: Accelerometer

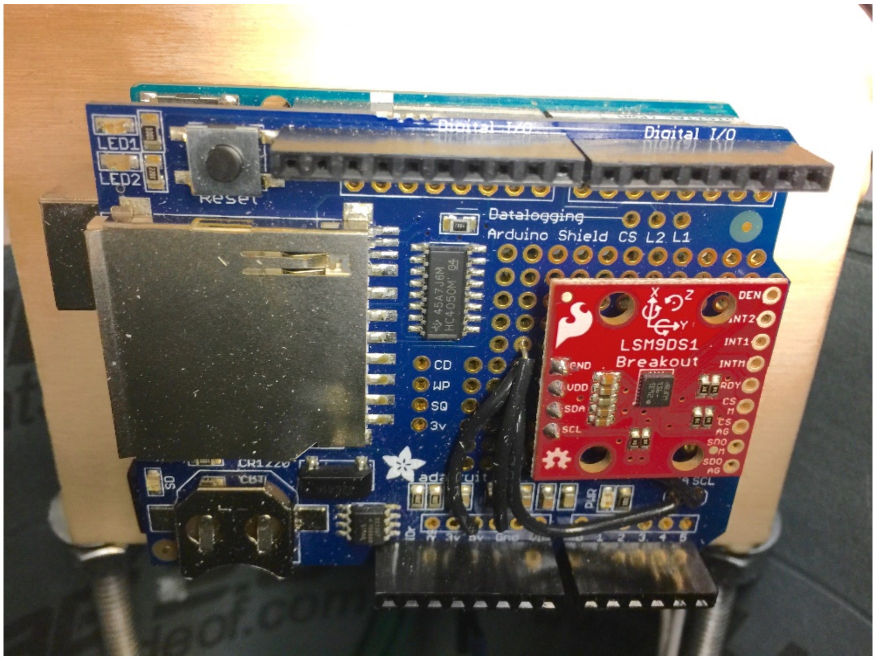


Figure 46 shows the assembled accelerometer.

Figure 47: LSM9DS1 Altimeter Electrical Schematic

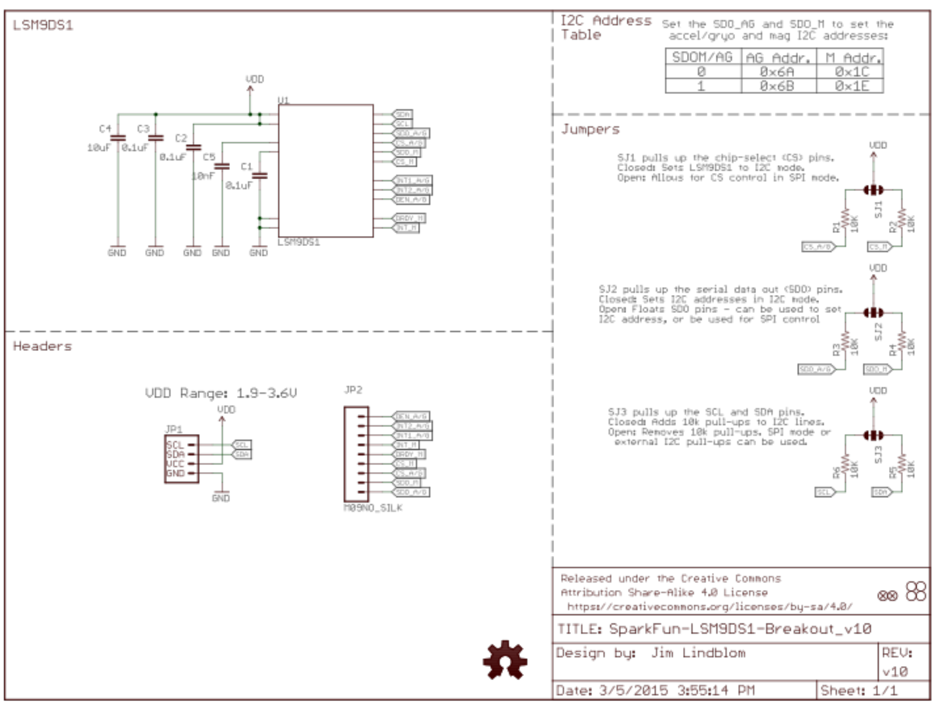


Figure 47 shows a detailed electrical schematic for the LSM9DS1 altimeter.

Figure 48: Arduino Uno Electric Schematic

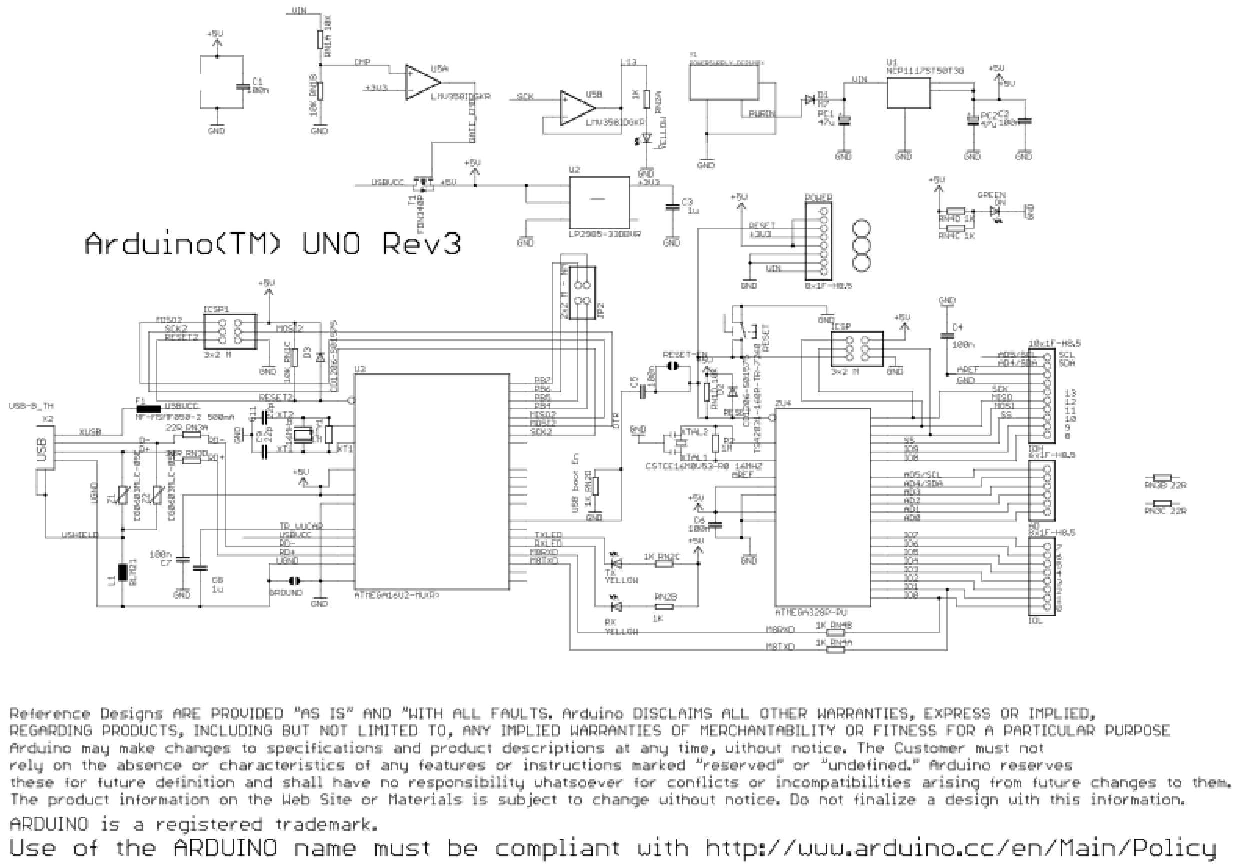


Figure 48 shows a detailed electrical schematic for the Arduino Uno.

Figure 49: SD Shield Electrical Schematic

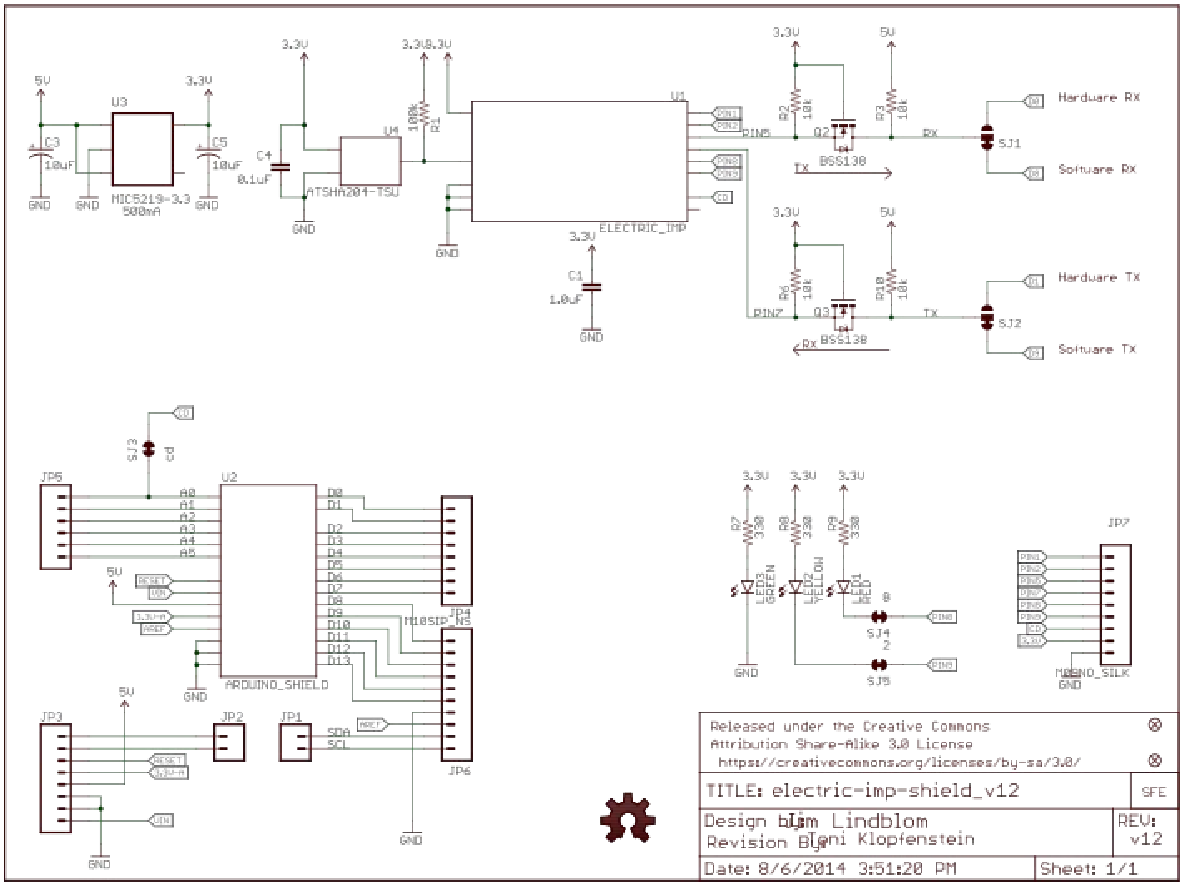


Figure 49 shows a detailed electrical schematic for the SD shield.

Figure 50: Accelerometer Algorithm

```
Accel_LSM9DS1 §
#include <SPI.h> //
#include <Wire.h> //
#include <SparkFunLSM9DS1.h> 1

LSM9DS1 imu;

#define LSM9DS1_M   0x1E
#define LSM9DS1_AG  0x6B
#define PRINT_CALCULATED
#define PRINT_SPEED 1000

void setup() {

  Serial.begin(115200);

imu.settings.device.commInterface = IMU_MODE_I2C;
imu.settings.device.mAddress = LSM9DS1_M;
imu.settings.device.agAddress = LSM9DS1_AG;


if (!imu.begin())
{
    Serial.println("Failed to communicate with LSM9DS1.");

    at cc.arduino.packages.discoverers.network.NetworkChecker.r
    at java.util.TimerThread.mainLoop(Timer.java:555)
    at java.util.TimerThread.run(Timer.java:505)
8                                    Arduino/Genuino Uno on /dev/cu.usbmodem1421
```

```
Accel_LSM9DS1 §
    Serial.println("Looping to infinity.");
    while (1)
      ;
}

}

void loop() {

  imu.readGyro();
  Serial.print("G: ");
#ifdef PRINT_CALCULATED
  Serial.print(imu.calcGyro(imu.gx), 2);
  Serial.print(", ");
  Serial.print(imu.calcGyro(imu.gy), 2);
  Serial.print(", ");
  Serial.print(imu.calcGyro(imu.gz), 2);
  Serial.println(" Deg/sec");
#endif

  imu.readAccel();
  Serial.print("A: ");
#ifdef PRINT_CALCULATED

    at cc.arduino.packages.discoverers.network.NetworkChecker.r
    at java.util.TimerThread.mainLoop(Timer.java:555)
    at java.util.TimerThread.run(Timer.java:505)
8                                    Arduino/Genuino Uno on /dev/cu.usbmodem1421
```

```
Accel_LSM9DS1 §
  imu.readAccel();
  Serial.print("A: ");
#ifdef PRINT_CALCULATED
  Serial.print(imu.calcAccel(imu.ax), 2);
  Serial.print(", ");
  Serial.print(imu.calcAccel(imu.ay), 2);
  Serial.print(", ");
  Serial.print(imu.calcAccel(imu.az), 2);
  Serial.println(" g");
#endif

  imu.readMag();
  Serial.print("M: ");
#ifdef PRINT_CALCULATED
  Serial.print(imu.calcMag(imu.mx), 2);
  Serial.print(", ");
  Serial.print(imu.calcMag(imu.my), 2);
  Serial.print(", ");
  Serial.print(imu.calcMag(imu.mz), 2);
  Serial.println(" Gauss");
#endif

float ax = imu.ax;

    at cc.arduino.packages.discoverers.network.NetworkChecker.r
    at java.util.TimerThread.mainLoop(Timer.java:555)
    at java.util.TimerThread.run(Timer.java:505)
8                                    Arduino/Genuino Uno on /dev/cu.usbmodem1421
```

```
Accel_LSM9DS1 §
  Serial.print(", ");
  Serial.print(imu.calcMag(imu.mz), 2);
  Serial.println(" Gauss");
#endif

float ax = imu.ax;
float ay = imu.ay;
float az = imu.az;
float mx = -imu.my;
float my = -imu.mx;
float mz = imu.mz;

  float roll = atan2(ay, az);
  float pitch = atan2(-ax, sqrt(ay * ay + az * az));

  Serial.print("Pitch, Roll: ");
  Serial.print(pitch, 2);
  Serial.print(", ");
  Serial.println(roll, 2);
  Serial.println();
  Serial.println();
  delay(PRINT_SPEED);
}

    at cc.arduino.packages.discoverers.network.NetworkChecker.r
    at java.util.TimerThread.mainLoop(Timer.java:555)
    at java.util.TimerThread.run(Timer.java:505)
8                                    Arduino/Genuino Uno on /dev/cu.usbmodem1421
```

Figure 50 shows the algorithms used by the accelerometer.

Structural Assembly
Detailed structural assembly of the electrical deployment system are shown in the following figures.

Figure 51: Avionics Bay Bulkhead

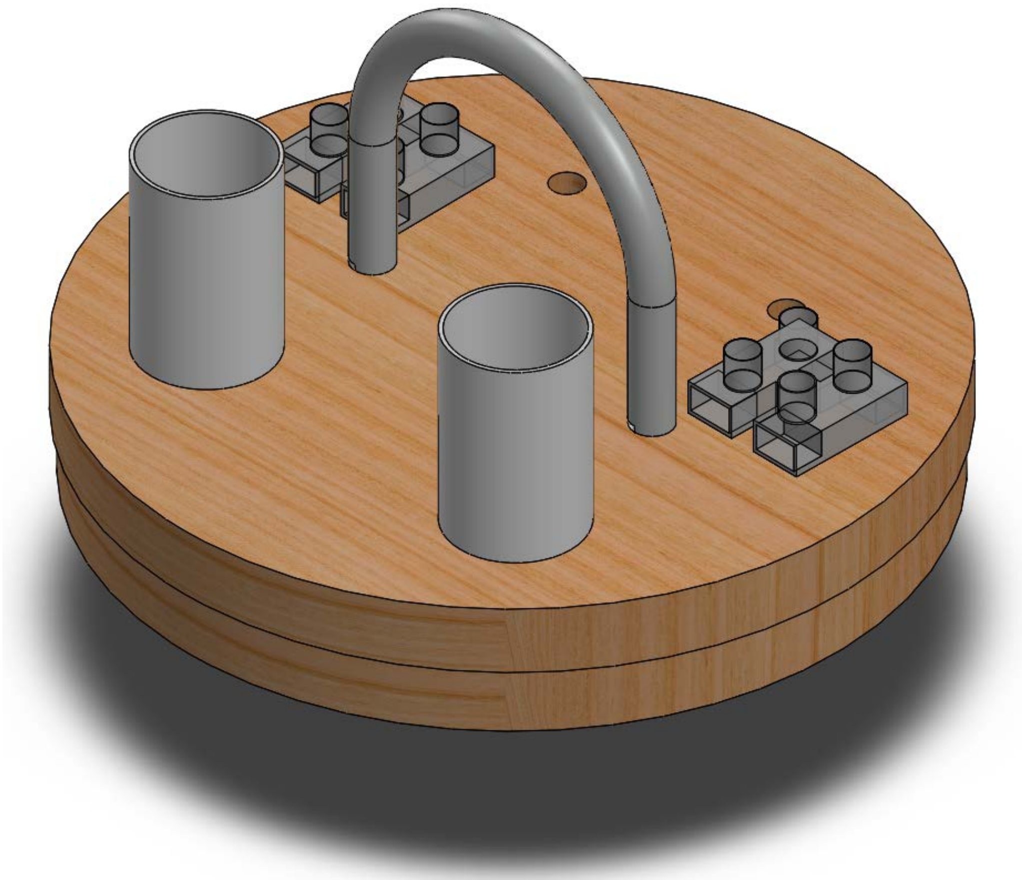


Figure 51 shows a 0.3125" u-bolt secured into a 1" thick 5-ply wood avionics bulkhead with terminal locks and ejection canisters attached.

Figure 52: Avionics Bay

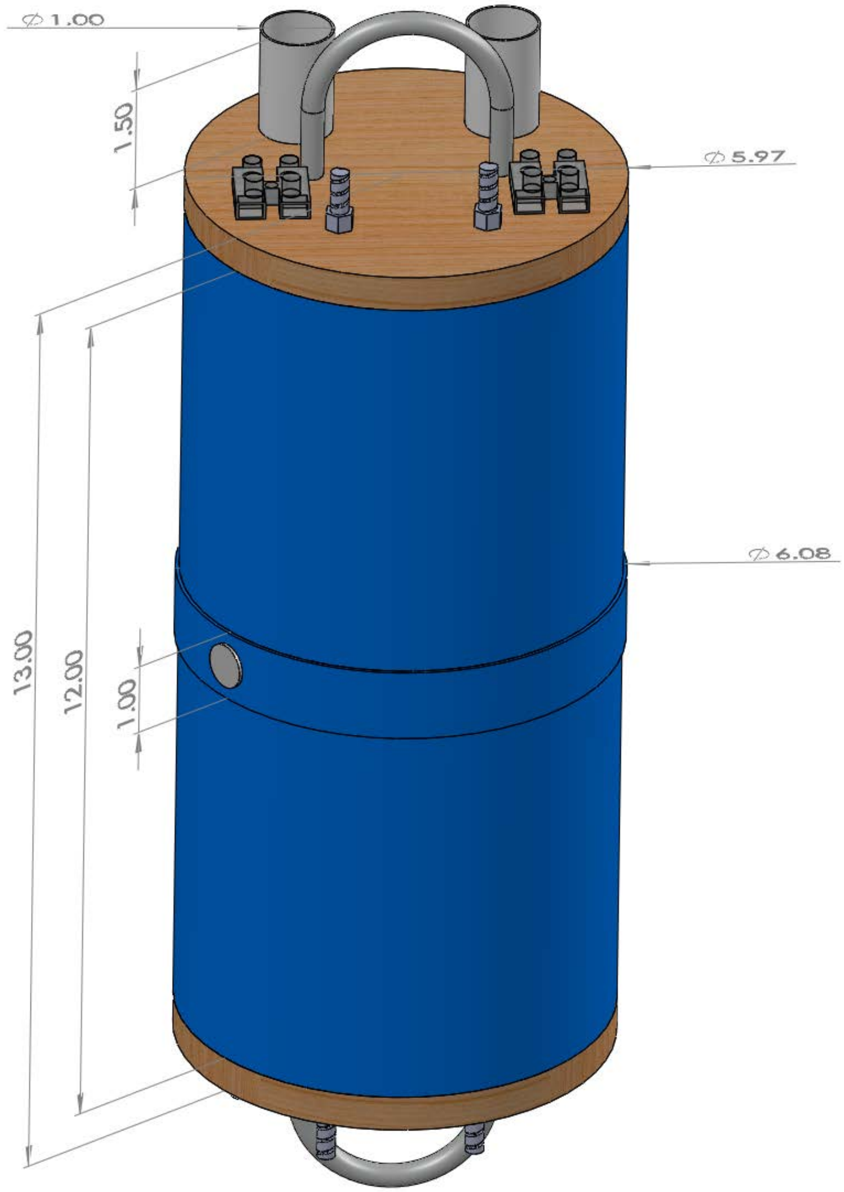


Figure 52 shows an isometric view of the fully assembled avionics bay that stores all electrical components in a 6" wide BlueTube enclosed by two bulkheads.

Figure 53: Avionics Bay (Internal View)

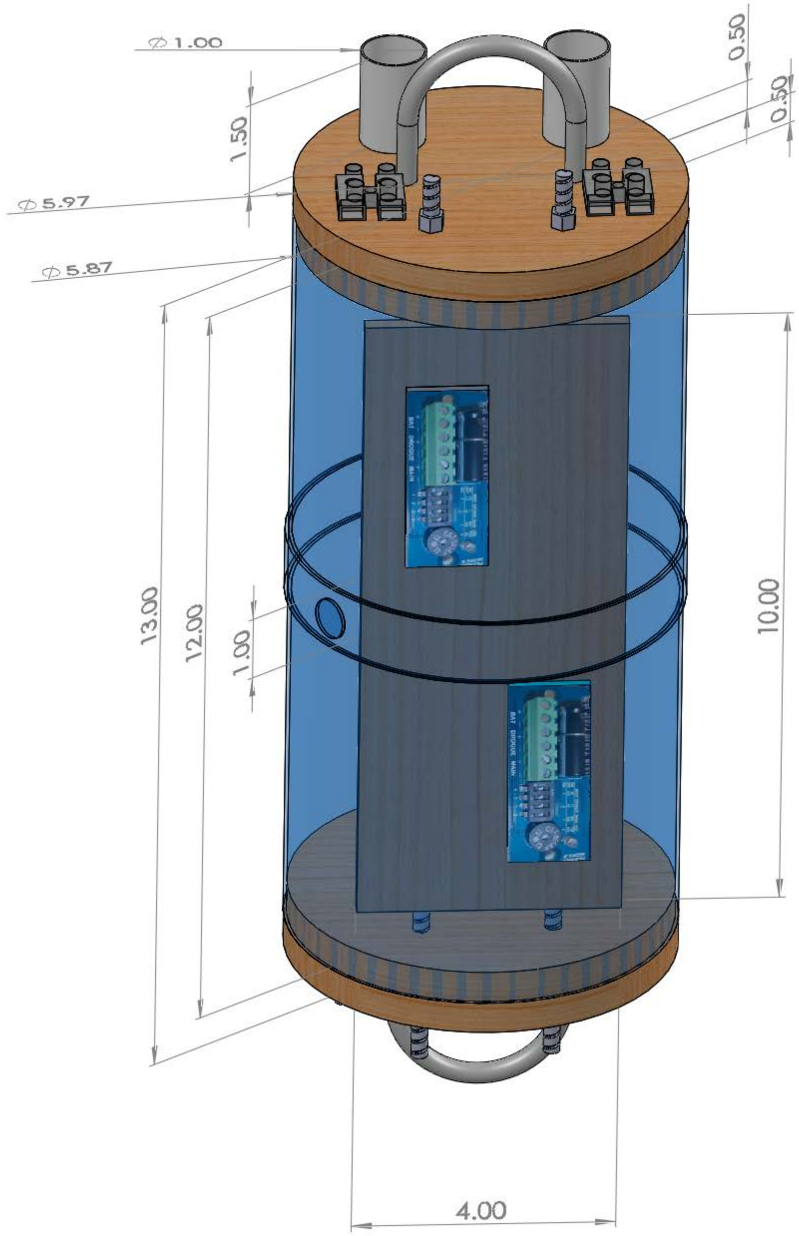


Figure 53 shows a transparent lateral view of the avionics bay.

Figure 54: Avionics Bay (Exploded View)

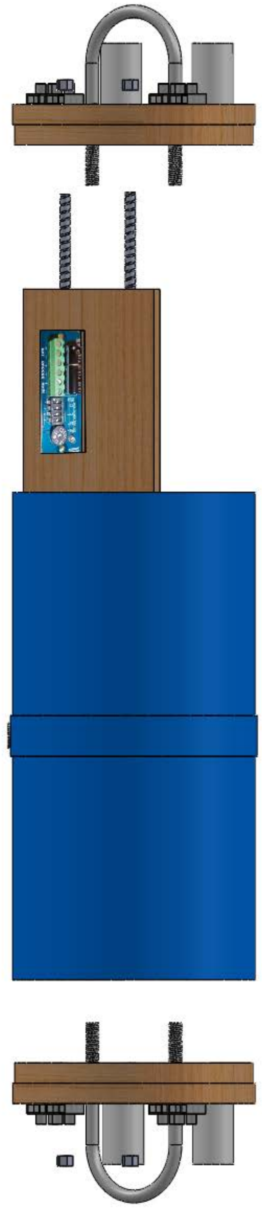


Figure 54 shows a lateral view of the exploded avionics bay with RRC2+ barometric altimeters attached to a 12" long 5" wide wooden sled.

3.6.2.6 Rocket-Locating Transmitters
Frequency, Wattage, and Range
The Altus Metrum TeleGPS shown in Figure 55 is a position tracker and logger. This GPS is utilized in the launch vehicle to track its location and ensure its recovery. The Altus Metrum TeleGPS is placed in the nosecone of the launch vehicle and has an operating frequency of 434.55 MHz, shown in Figure 56. The operating frequency could be adjusted by selecting different channels in order to avoid identical frequency transmissions at launch site. A handheld receiver, the Yagi Atenna (Figure 57) will receive the frequency generated by the GPS transmitter. The transmitter has 16mW of transmitting power and uses a 3.7-V lithium polymer battery. The flight computer functions in an altitude range of ±32767m. The AltOS Fixes version 1.5 allows the transmitter to function correctly above the 32km level which means the updated version of the software allows an increase range from ±32767m to ±214748364m.

Figure 55: Altus Metrum TeleGPS

Figure 55 shows the locating tracker for Project Aegis.

Figure 56: Operating Frequency

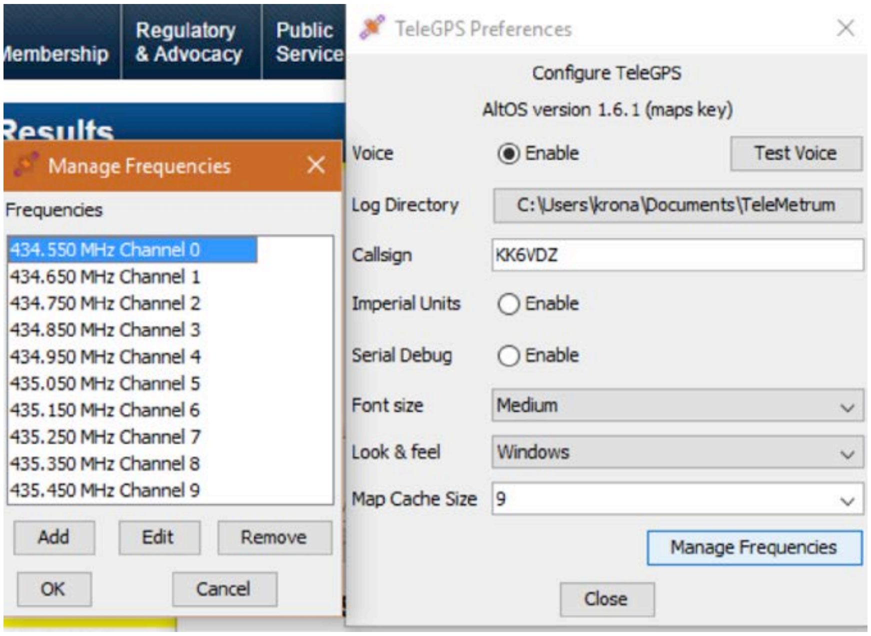


Figure 56 shows a screenshot of the TeleGPS frequency setting.

Figure 57: Yagi Atenna

Figure 57 shows the Yagi Atenna that receives the frequency of the transmitter.

3.6.2.7 Sensitivity of the Recovery System

The recovery system includes a GPS transmitter in the nosecone, two altimeters and an accelerometer located in the avionics bay. Electromagnetic field disturbances of the on-board electronic devices may degrade their functionality and even stop their performance. Signal interference may also increase error rate of the electrical devices or a total loss of data.

To verify that no signal interruption will occur between the GPS transmitter and the independent electronic devices while activated simultaneously, ground tests were conducted. They ensured that the funtionality of the electrical elements are free from disturbance of separate electromagnetic fields that individual eletrical equipment generates. For detailed result and analysis of the GPS ground test, see Section VII. *Testing*.

During the full-scale test launch, both altimeters and the accelerometer performed expected funtionality. The primary altimeter successfully detected the altitude and sent out a current to ignite the black powder. The redundant altimeter repeated the electronic deployment procedure with a 1s delay at apogee for the drogue parachute and at 500' AGL for the main parachute. Data was collected from the accelerometer. There were no visible signal interruptions in the retrieved data collected during the test flight.

Detailed failure modes, causes, effects, and risk mitigations of the recovery system can be found in section *Recovery Failure Mode.*

3.7 Mission Performance Predictions

This section overviews the mission performance criteria of the project, the simulation data, stability of the launch vehicle, kinetic energy of each independent section, and the drift values of the suggested launch vehicle. The launch vehicle was designed and simulated in RockSim 9.

3.7.1 Mission performance criteria

The following criteria must be reached in order for the mission to be considered successful. This includes launch vehicle criteria and payload criteria:

3.7.1.1 Launch Vehicle Criteria

- The flight of the launch vehicle must be stable.
- The launch vehicle must reach an altitude of 5,280 ±50' above ground level.
- The drogue parachute must deploy within 10' of apogee, while the main parachute must deploy at 800 ± 15' above ground level.
- The launch vehicle sections must experience less than 75 ft-lbf of kinetic energy upon landing.
- The launch vehicle must stay within the 2,500' range limit.
- The launch vehicle must be easily recoverable and reusable.

3.7.1.2 Payload criteria

- The unknown sample(s) must remain intact and undamaged after the flight.
- The unknown sample(s) must be fully accommodated within the container.

- The unknown sample(s) must remain in their designated compartments throughout the entirety of the flight.
- The payload must return undamaged.
- The payload must be reusable.

3.7.2 Flight Profile Simulations

This section describes the results of the launch simulations done by RockSim9 when using an Aerotech L1420R motor and a 12’ launch rail.

Table 13 listed the expected launch conditions in Huntsville Alabama on April 8, 2017, the day of launch. These values were also input into the simulation.

Table 13: Expected Launch Day Conditions

Conditions	Expected values
Temperature (°F)	70
Pressure (psi)	14.24
Elevation (ft.)	600
Humidity (%)	40
Wind speed (mph)	8-14.9
Cloud coverage	Mostly sunny

These estimates were obtained from weather sites online and are expected to slightly vary on the day of the launch [6].

3.8 Final Launch Vehicle Design - Simulation results

3.8.1 Engine selection

[L1420R-None]

3.8.2 Simulation control parameters

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

3.8.3 Launch conditions

- Altitude: 600.00’
- Relative humidity: 40.00 %
- Temperature: 70.00 °F
- Pressure: 29.00 In. Hg.

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

- Low wind speed: 8.00 mph

- High wind speed: 14.90 mph

3.8.5 Wind turbulence: Fairly constant speed (0.01)

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

3.8.6 Launch guide data:

- Launch guide length: 144.00”
- Velocity at launch guide departure: 77.29 fps
- The launch guide was cleared at: 0.34 sec.
- User specified minimum velocity for stable flight: 43.99 fps
- Minimum velocity for stable flight reached at: 48.11”

3.8.7 Max data values:

- Maximum acceleration :Vertical (y): 1167.44 fps/s Horizontal (x): 8.03fps/s Magnitude: 1167.44 fps/s
- Maximum velocity :Vertical (y): 703.77 fps, Horizontal (x): 20.45 fps, Magnitude: 708.01 fps
- Maximum range from launch site: 916.98’
- Maximum altitude: 5226.12’

3.8.8 Recovery system data

- P: Main Parachute Deployed at: 66.19 sec.
- Velocity at deployment: 93.97 fps
- Altitude at deployment: 799.96’
- Range at deployment: 92.11’
- P: Drogue Parachute Deployed at: 17.52 sec.
- Velocity at deployment: 43.00 fps
- Altitude at deployment: 5226.12’
- Range at deployment: -760.16’

3.8.9 Time data

- Time to burnout: 3.24 sec.
- Time to apogee: 17.52 sec.
- Optimal ejection delay: 14.28 sec.

3.8.10 Landing data

- Successful landing
- Time to landing: 108.24 sec.
- Range at landing: 916.98’

- Velocity at landing: Vertical: -18.09 fps, Horizontal: 20.45 fps, Magnitude: 27.30 fps

As indicated by the simulation data the full scale launch vehicle is estimated to fly to an apogee of 5226.12’ which is 53.88’ under the target apogee.

Figures 58-60 display different aspects of the test launch.

Figure 58: Velocity versus Time Graph

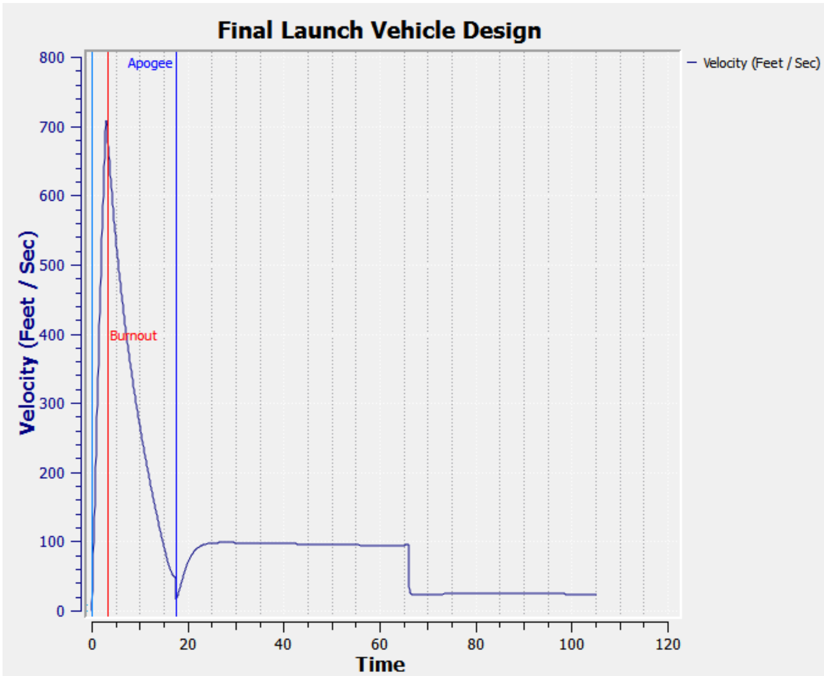


Figure 58 above shows the relationship between the velocity and time of the launch. The launch vehicle reaches apogee at 17.5 seconds into the flight. At this time, the drogue is deployed and the velocity greatly decreases. At 65 seconds in the launch, the main parachute deploys and the velocity decreases to about 20 fps.

Figure 59 Altitude versus Time Graph

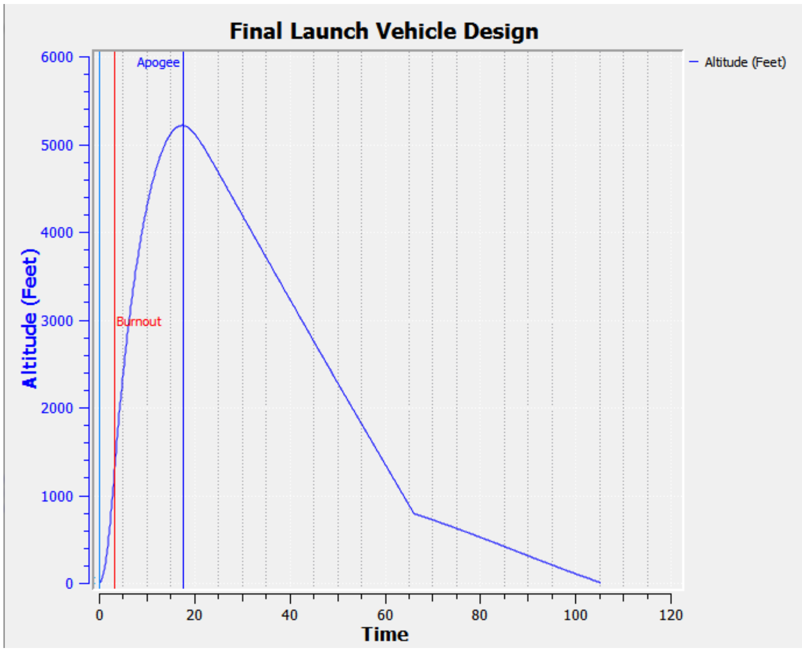


Figure 59 shows the Altitude vs Time graph of the launch vehicle's flight. This graph shows the trajectory of the launch vehicle over time.

Figure 60: Static Stability Margin versus Time Graph

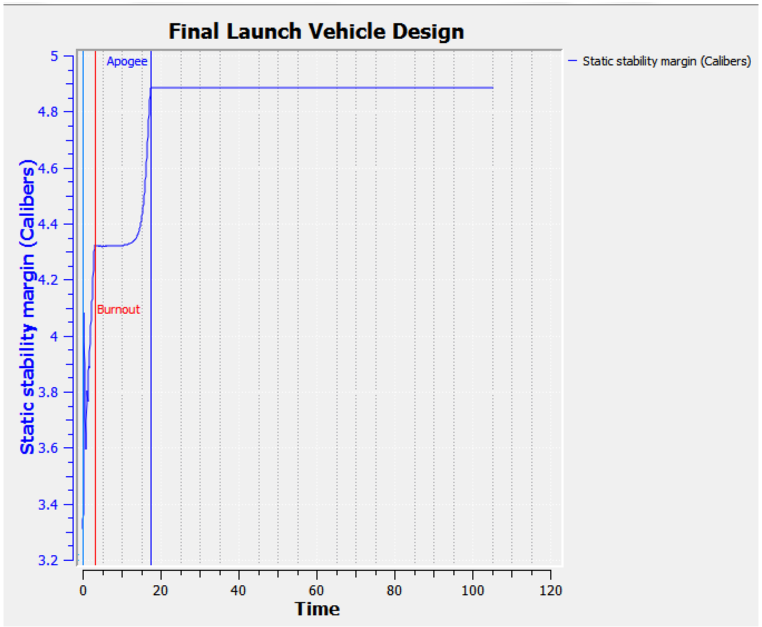


Figure 60 shows how the static stability margin changes over the course of the launch. As shown in the graph the stability increases to about 4.9 calibers within the first 20 second of flight. It then stabilizes at this caliber for the remainder of the flight.

The launch vehicle is estimated to drift to a range of 916.98' which is well within the 2,500' range limit. As the wind speed was changed in the simulation the maximum altitude values also changed.

Table 14 below lists the different apogees at these different wind speeds.

Table 14: Maximum Altitudes at Different Wind Speeds	
Wind Speed (mph)	**Max Altitude (ft.)**
0	5175.43
5	5287.63
10	5249.87
15	5186.29
20	5097.90

The average wind speed is expected to be around 9mph with a high of 16 mph on the day of the launch in Huntsville, Alabama [7]. Considering these conditions, along with the design of the launch vehicle, the Aerotech L1420R motor is best suited to launch the vehicle closest to the target apogee. Originally, the Aerotech L1170-FJ was selected but recent simulations were done with more accurate mass values for the launch vehicle. The L1170 motor launched the rocket to a much higher apogee than was needed and was then replaced with the Aerotech L1420R.

3.9 Motor selection

The Aerotech L1420R motor was chosen in part because of its burn time and thrust. It has a burn time of 3.2 sec and max thrust of 1814N. The motor thrust curve for the motor is displayed below. According to this graph, the thrust initially peaks around 1500 N, it then decreases at 0.5 seconds and again increases to its maximum thrust at 1.5 sec. After this time the thrust steadily decreases till about 2.88 sec when the thrust begins to rapidly decrease. This indicates that the launch vehicle will experience steady thrust for the majority of the flight and will not experience any sudden increases or decreases in thrust. This will help ensure the steadiness of the flight.

Figure 61: Aerotech L1420R Motor Thrust Curve

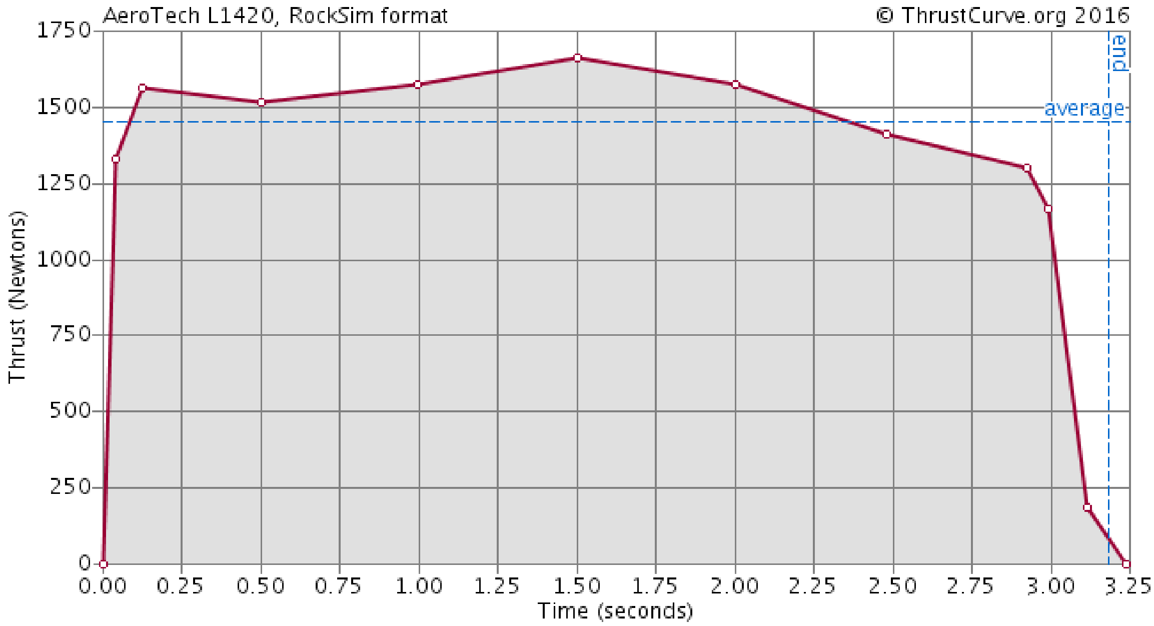


Figure 61 show the amount of thrust the Aerotech L1420R produces overtime. The steady levels of thrust will help the launch vehicle have a more steady flight.

To verify that the selected motor is capable of launching the rocket the thrust to weight ratio was calculated. The thrust to weight ratio indicates the efficiency of the propulsion [8]. The mass of the rocket with the motor is estimated to be 44.34 lbs. Multiplying this by 9.8 m/s^2 gives a weight of 178.16 N.

Table 15 listed the masses of the launch vehicle with and without the motor.

Table 15: Mass of Launch Vehicle	
With the L1420R (lbs.)	**Without the L1420R (lbs.)**
44.34	34.28

The average thrust of the selected motor is 1420 N. When this is divided by the weight of the launch vehicle it results in a thrust to weight ratio of 7.97. The minimum thrust to weight ratio required for a successful launch is 5:1[9]. The value obtained indicates that the motor is more than capable of launching this vehicle.

Table 16 listed the characteristic of the selected motor.

Table 16 : Motor properties of Aerotech L1420R	
Properties	**Data**
Diameter (mm.):	75
Length (in.):	17.44
Average thrust (N):	1420.0
Maximum thrust (N):	1814.0
Total impulse (Ns):	4603.0
Burn time (s):	3.2

3.10 Validity of Analysis

This section discusses the thoroughness and validity of the analysis, drag analysis and the scale modeling results. The simulations used are compared to the measured values from flight and ground test. The manner in which these simulations have been made more accurate by these test is also discussed below.

3.10.1 Validity of Recovery System Analysis

The effectiveness and functionality of the recovery system was analyzed by inspecting the components of the recovery system and by testing the recovery system via such test as the drop test, ground ejection test, and the full scale and sub scale test flights.

3.10.2 Components of Recovery System

The components of the recovery system were theoretically tested using RockSim simulations. The dimensions and materials used in the recovery system resulted in successful flight simulations. This indicates that the recovery system should also function during an actual test launch.

3.10.3 Drop Test

The drop test was done to ensure that the proper length and type of shock cord was selected along with the correct number of sheer pins. Calculations were done to estimate how many sheer pins should be used but testing was done to verify that the correct amount was used. To perform the test the forward and middle section of the launch vehicle were connected via sheer pins. Each sheer pin was checked to ensure that it was fully inserted into the body tube. The shock cord for the main parachute was also attached to its bulkhead but not to the parachute. The launch vehicle was then held over a railing of a second story building and the shock cord was secured in place by being wrapped around the rail several times. The launch vehicle was then released from the second story building imitating the drop it will experience from apogee. The shock cord was measured so that the launch vehicle did not come in contact with the ground. The length of the shock cord was measured so that the launch vehicle fell to a constant height. The aim of the test was to determine how many sheer pins are necessary to prevent the main parachute compartment from opening at apogee. Our initial test revealed that the number of sheer pins used was insufficient to hold the two sections together. We then conducted several trials using different numbers of sheer pins and different amounts of elastic loops tied into the shock cord to absorb shock. To see a detailed description on the test methods and results see section 1.7 *Testing.*

Table 17 listed the independent and dependent variables of the test.

Table 17: Variables of Drop Test	
Independent	**Dependent**
Length of shock cord	Force on mid and forward connection
Number of sheer pins	
Number of elastic bands	
Number of elastic loops	

The test revealed that the optimal number of sheer pins and elastic loops used for the launch vehicle is 11 sheer pins and two sets of two elastic bands, one looped three times and one looped four times. The only variables that were altered that would affect the amount of force that the mid and forward connection experienced are the number of sheer pins used and the elastic used.

3.10.4 Ground Ejection Test

The ground ejection test was done to ensure that the correct amount of black powder is used in the avionics bay to create enough pressure to fully separate the mid and forward section and the mid and aft section of the launch vehicle. To perform this test, calculations were done to estimate the amount of black powder needed in the avionics bay. The black powder was then weighed and placed into plastic bags. The black powder was poured into the main and drogue ejection canisters as well as into the redundant ejection canisters. E-matches were then wired through the avionics bay and into the drogue ejection canisters. Each canister was inspected to ensure that the e-match was covered in black powder. The canisters were then sealed with duct tape and the avionics bay was inserted between the middle and aft section of the launch vehicle. The launch vehicle was taken outside and positioned so that launch vehicle lay horizontally. The wires were than connected to a battery and the drogue charges were fired. The wire and e-matches were then removed and the process was repeated using the main ejection canisters. The launch vehicle was positioned at a 30° angle and ejection canisters were then fired in the same manner previously described. This was done several times using different amounts of sheer pins to ensure that the black powder used was sufficient to eject the parachutes at launch. For a detailed description of the test and results see section 1.7 *Testing*.

Table 18 lists the variables of the test.

Table 18: Variables of Ground Ejection Test	
Independent	**Dependent**
Number of shear pins used	Distance of separated sections
Black powder	
Position of launch vehicle	
Battery voltage	

Several trials were conducted revealing that the most effective shear pin to black powder ratio is 11:5.37 grams of the black powder for the main parachute bay and 4:2.86 grams of black powder for the drogue bay. Factors such as, battery voltage and improper wiring or black powder installation could alter the validity of the test. To ensure that the test was as accurate as possible the batteries used were tested before each use with a multimeter. If the voltage was below 9 volts then another battery was connected in series. The voltage of the circuit was also checked using a multimeter. The wiring and black powder installation was done by our team mentor Rick and was inspected by several different team members to confirm that this was done properly. New shear pins were also used after each test in case some were weakened or partially sheered from the previous test.

3.10.5 Test Flights

Test flights were done to ensure that recovery system was operating properly. This was done with the sub scale and full scale launch vehicle. Each test flight resulted in successfully deployed main and drogue parachutes. The drogue deployed at apogee during the sub-scale test flight and the main at 800'. During the full scale test flight the drogue parachute deployed at apogee and the main at 500'. The redundant charges also fired when they were programmed to. The shear pins were able to hold the main parachute compartment together until the launch vehicle reached the specified altitude for the main deployment and the main ejection charge fired. The elastic used with the shock cords tore from the shock it absorbed but the shock cords were undamaged. These test further show that the recovery system is functional for this launch vehicle design.

3.10.6 Validity of Ignition System Analysis

The ignition system was tested by the sub scale and full scale test flights. The sub scale utilized a different motor but the motor mount structure was consistent with that of the full scale design. Inspection of the sub scale and full scale launch vehicle after the test flights revealed that the motor mount received no damage from the thrust of the motor. This ensures that the structure is strong enough to endure the thrust of the selected motor.

3.10.7 Validity of Flight Analysis

RockSim Analysis

RockSim was used to analyze the flight of the launch vehicle and to verify that the proper design and motor are used. Factors that could affect the validity of the RockSim simulations include inaccurate mass values, mass distribution or inaccurate dimensions. Each component was weighed or the mass value was obtained from the manufacturer. Mass values were input into the RockSim simulation to account for the mass from the epoxy, fiberglass, and miscellaneous hardware. Any inaccuracies in the mass value are likely from imprecise estimates of these elements. The differences between the actual and estimated values are likely no more than 10 oz. The dimension of the components was obtained from measuring the components of the launch vehicle and inputting these values into the RockSim simulation. Any inaccuracies in dimensions would be due to human error and/ or the accuracy of the tools used to measure the components. Cuts from the tools used were also not completely precise and altering materials by sanding or applying fiberglass cloth and resin also changed dimensions.

3.10.8 Test Flights Analysis

Test flights were also conducted to test the launch vehicle design and motor selection. The subscale and full scale launch vehicle were tested using a K550 and an L1420R Aerotech motor. The launch vehicle was successfully launched and recovered both times. Factors that could affect the results include the structure of the launch vehicle and the conditions of the day. The launch vehicle was constructed using the design from the RockSim simulation. The dimensions were carefully measured but the resulting components did differ from the precise dimensions in the RockSim simulation. The differences from the RockSim apogee and the recorded apogee from the Missile Works RRC2+ altimeter could be due to these accumulated differences in dimensions and mass values.

Table 19 shows the percent error of the predicted altitudes.

Table 19: Percent Error of Predicted Altitudes (%)		
Sub scale test flight	**Full scale test result 1**	**Full scale test result 2**
4.27	1.25	1.44

As indicated in the table above the percent error of each flights altitude measurement is below 5%. This indicates that any differences in dimensions or mass values do not greatly affect the validity of the flight analysis.

3.10.9 Drag Analysis

The drag force of the full scale rocket was estimated in RockSim9 using the apogee recorded at the full scale test launch. The coefficient of drag was altered in the simulation until the apogee produced in the simulation matched the apogee recorded from the test launch. This revealed a Cd value of 0.772 when matching the 5191’ apogee and a Cd value of 0.78 when matching the apogee of 5181’ that was recorded from the full scale test flight. Several factors could have affected the drag analysis. This includes the accuracy of the apogee recorded from the test flight, the accuracy of the mass value of the launch vehicle in the simulation, and the launch day conditions that were input into the simulation. The apogee from the full scale test launch was recorded using Missile Works RRC2+ altimeters. This was used for the sub scale and full scale launches and has been tested for reliability. It is unlikely that the mass value of the launch vehicle is inaccurate because of the method used to obtain the mass values of each component. An increase of 10 oz. results in an apogee difference of 50.52’ and a decreased in the mass values by 10 oz. resulted in an apogee difference of 78.58’.

Table 20 shows the resulting percent difference.

Table 20: Percent Difference (%)	
+10 oz. mass change	**-10 oz. mass change**
0.96	1.48

As indicated in the above table, this difference in mass does not result in a significant altitude difference.

The launch day conditions were obtained from a weather site online several days after the launch. This ensures that the values used in the simulation are accurate. However, there may be small inaccuracies resulting from the level of precision of the tools used to obtain these measurements.

3.10.10 Scale Modeling Results

The scale model was accurately designed and constructed to be a 2/3 scale model of the full scale launch vehicle. The fins, body tube, couplers and shock cords are among the scaled components from the full scale design modeled in RockSim. Several components were not scaled for the subscale design. They were either kept at their same dimensions or were made smaller but not by a 2/3 scaling ratio. This is because the manufacturer did not offer products in the scaled sizes.

Tables 21 and 22 below list each component of the subscale, whether it was scaled or not and the justification.

Table 21: Scaled Components

Component	Justification
Nose cone	Scaled to ensure the stability of the launch vehicle design and to maintain proper weight distribution
Payload	To accommodate payload bay dimensions and maintain the correct weight distribution
Airframe	Scaled to ensure the stability of the launch vehicle and to maintain proper weight distribution
Coupler	Scaled to accommodate airframe dimensions and to maintain weight distribution
Fin set	Scaled to verify the stability of the launch vehicle and to maintain proper weight distribution
Motor mount	To accommodate motor dimensions and maintain weight distribution
Shock cords	Accommodate parachute bay and maintain weight distribution
Centering Rings	Scaled to accommodate motor mount dimensions
Quick links	Scaled to maximize space and maintain weight distribution
U-bolts	Maximize space and maintain weight distribution
Avionics bay sleigh	Done to accommodate avionics bay dimensions
Avionics bay bulkhead	Done to accommodate avionics bay dimensions
Bulkheads	Scaled to accommodate inner frame dimensions
Avionics bay metal rods	Done to accommodate avionics bay dimensions

Table 22 lists the un-scaled components as well as the justification for not scaling them.

Table 22: Non Scaled Components	
Components	**Justification**
Altimeters	Fixed manufacturer dimensions
Batteries	Fixed manufacturer dimensions
Battery clips	Fixed manufacturer dimensions
Centering ring thickness	Avoid compromising component strength
Bulkhead thickness	Avoid compromising component strength
Main parachute diameter	Fixed manufacturer dimensions
Drogue parachute diameter	Fixed manufacturer dimensions

3.10.11 Center of Gravity and Center of Pressure of the Full Scale Launch Vehicle

The center of gravity and the center of pressure are important in determining the stability of the flight and were estimated with RockSim. These values can be seen in the figures below.

Figure 62: Center of Gravity and the Center of Pressure (without motor)

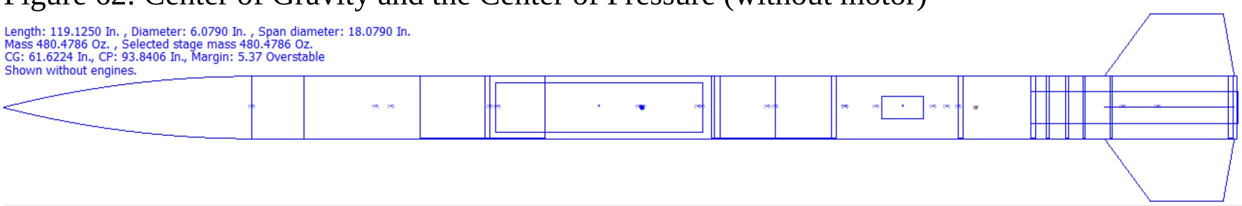


Figure 62 shows the center of gravity and the center of pressure without the motor

Figure 63: Center of Gravity and the Center of Pressure (with L1420R motor)

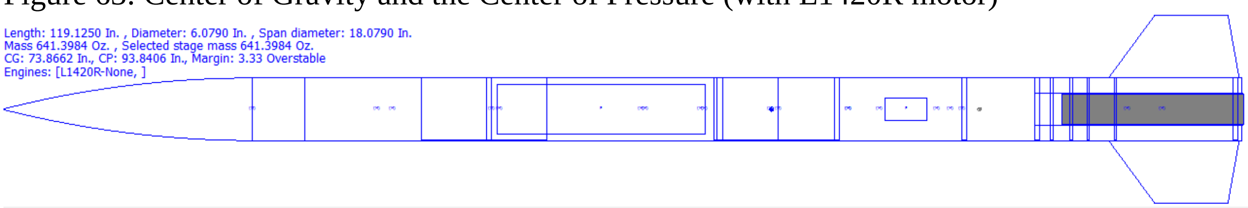


Figure 63 shows the center of gravity and center of pressure with the L1420R motor

As indicated by the figures above, the center of pressure remains at a constant position on the rocket regardless of whether or not the motor is installed. The center of gravity changes position from 61.62” from the front of the launch vehicle to 73.87” after the motor is installed. The center of gravity, stability margin, and center of pressure with and without the motor are listed in the table below. The center of gravity was measured when the launch vehicle is not loaded with the motor. The details of this test are in section 1.7 *Testing.* The measured distance of the center of gravity from the tip of the nose cone is 63.5” revealing a difference from the predicted value of 1.88”. The percent error of the CG calculations was found to be 3.05% this small percent reveals that there were some inaccuracies when estimating mass values and the RockSim simulation has a slightly different weight distribution than the actual launch vehicle.

Table 23: Predicted Stability Margins			
Launch vehicle	**CG from top (in.)**	**CP from top (in.)**	**Stability**
With motor	73.87	93.84	3.33
Without motor	61.62	93.84	5.37

3.12 Kinetic energy

The kinetic energy of each section was also calculated to ensure that it does not exceed the 75 ft.-lbs. limit and the sections don't experience damage upon landing. In order to calculate the kinetic energy of the sections the terminal velocity of each section was calculated using the formula:

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

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

The C_d of the parachute was calculated by the manufacturer to be 2.2 [10]. The air density was estimated to be 1.225 $\frac{kg.}{m^3}$ [11].

The predicted weight of each section of the rocket is listed in the table below. These estimates were achieved using RockSim 9. The simulation incorporated masses for epoxy, protective foam, fiberglass, resin, and miscellaneous hardware. Multiple components were either weighed or the mass value was found online and input into RockSim to increase the accuracy of the simulation.

Table 24 shows the masses of each component of the launch vehicle.

Table 24: Launch Vehicle Component Mass Estimates	
Components	**Estimated Mass Values (oz.)**
Nose cone	51.12
Forward body tube	12.79
Payload	136.00
Bulkhead	5.51
Tube coupler	6.37
Mega foam	4.00
Mid body tube	15.29
Avionics bay	21.30
Avionics bay coupler	6.37
Main parachute	22.00
Shock cord	19.88

Quick link	2.65
U-bolt	4.16
Aft body tube	24.79
Fin set	12.11
Shock cord	15.72
Centering ring (0.25 in thick)	1.39
Centering ring (0.50 in thick)	5.51
Engine casing	35.63
Motor mount	5.31
Drogue parachute	2.20

Table 25 listed the total mass of each section of the launch vehicle.

Table 25: Weight of Launch Vehicle Components	
Sections	**Weight (lb.)**
Forward	14.22
Middle	6.78
Aft	13.27

For the purpose of these calculations the weight of the aft section of the rocket was calculated with only the empty weight of the motor. This is due to the fact that the parachutes are deployed after the motor propellant has burned out and only the empty weight of the motor remains. This terminal velocity was then used in the equation below to calculate the kinetic energy:

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

where m_s is the mass of the independent section. The kinetic energy of each independent section at different stages of the launch are listed in Table 26.

Table 26: Kinetic Energy of Each Section (ft.-lbf)			
Section	**Kinetic Energy at Take-Off**	**Kinetic Energy at Apogee**	**Kinetic Energy at Landing**
Forward	1320.09	1350.75	36.92
Middle	628.32	643.75	17.60
Aft	1232.09	1260.71	34.46

The calculations reveal that no independent section of the rocket will be experiencing kinetic energy values over 40 ft.-lb. upon landing. This ensures that no section will be damaged from the force of landing.

3.13 Drift from Launch Pad

Table 27 lists the different wind speed values input into the simulation and their corresponding predicted maximum range values due to drift.

Table 27: Wind Speed and Drift	
Wind Speed (mph)	**Maximum Drift (ft)**
0	0.0
5	328.10
10	738.88
15	954.96
20	2111.76

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

3.14 Launch Day Conditions and Full Scale Flight Analysis

The full scale launch vehicle was test flown on February 4, 2017 at FAR launch site in Randsburg, California.

Table 28 shows the launch day condition.

Table 28: Launch Day Conditions	
Conditions	**Recorded values**
Elevation (ft.)	2530
Temperature (°F)	61
Time of launch (pm)	1:00
Precipitation (%)	0
Mean wind speed (mph)	10.01
Pressure (psi)	14.71

A RockSim flight simulation was done using the above launch conditions.

3.15 Final Launch Vehicle Design - Simulation results

3.15.1 Engine selection

[L1420R-None]

3.15.2Simulation control parameters

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

3.15.3 Launch conditions

- Altitude: 2530.00’
- Relative humidity: 20.00 %
- Temperature: 61.00°F
- Pressure: 29.88 In. Hg

3.15.4 Wind speed model: Custom speed range

- Low wind speed: 8.00 MPH
- High wind speed: 10.01 MPH

3.15.5 Wind turbulence: Fairly constant speed (0.01)

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

3.15.6 Launch guide data:

- Launch guide length: 144.00”
- Velocity at launch guide departure: 77.29 fps
- The launch guide was cleared at : 0.34 sec
- User specified minimum velocity for stable flight: 43.99 fps
- Minimum velocity for stable flight reached at: 48.11”

3.15.7 Max data values:

- Maximum acceleration: Vertical (y): 1168.72 fps/s Horizontal (x): 6.52 fps/s Magnitude: 1168.72 fps/s
- Maximum velocity: Vertical (y): 705.92fps, Horizontal (x): 14.11 fps, Magnitude: 708.75 fps
- Maximum range from launch site: 635.05’
- Maximum altitude: 5266.53’

3.15.8 Recovery system data

- P: Main Parachute Deployed at : 68.53 sec
- Velocity at deployment: 93.11 fps
- Altitude at deployment: 499.94’
- Range at deployment: 43.28’
- P: Drogue Parachute Deployed at : 17.60 sec
- Velocity at deployment: 35.36 fps
- Altitude at deployment: 5266.53’
- Range at deployment: -635.05’

3.15.9 Time data

- Time to burnout: 3.24 sec

- Time to apogee: 17.60 sec
- Optimal ejection delay: 14.36 sec

3.15.10 Landing data

- Successful landing
- Time to landing: 101.27 sec
- Range at landing: 498.63’

Velocity at landing: Vertical: -14.94 fps, Horizontal: 14.11fps, Magnitude: 20.55 fps

This simulation estimated that the launch vehicle would reach an apogee of 5266.53’and drift to a range of 498.63’. However, the recorded data from the test flight revealed that the launch vehicle reached a lower apogee and drifted to a range of 1,320’. The two altimeters used in the test flight recorded different max altitudes. One altimeter recorded a maximum altitude of 5181’ and the other recorded a maximum altitude of 5191’. The full scale flight test was successful. The launch vehicle exited the launch rail without tilting or showing signs of instability. At apogee, the drogue parachute deployed and opened and the main parachute deployed at 500’ Originally, the main parachute was set to deploy at 800’ but was reprogrammed to deploy at a lower altitude because of the wind speed. The redundant charges were also fired at their designated altitudes and the main parachute opened successfully. The launch vehicle landed a quarter of a mile away and was successfully recovered. There were no damages to the launch vehicle. All fins were intact and without damage and all shock cords, shroud lines and parachutes were without tears or burns. The launch vehicle drifted several feet once on the ground because of the loose parachute and wind but only minimal scratches were found on the body tube. The lower apogee of the simulated flight could be due to an inaccurate approximation of the launch vehicle’s mass. Mass values were added to the simulation to account for weight from fiberglass resin and cloth, epoxy, and miscellaneous hardware. The team may have under estimated the mass of these components resulting in a lighter launch vehicle. This would account for the lower apogee of the actual launch vehicle, 5191’ or 5181’. The smaller drift value could be a result of inaccurate wind speed values in the simulation. The average wind speed on the day of the launch was 10.01 mph but the wind speed at the time of the launch vehicle’s descent could have been much lower, thus reducing drift. To estimate the drag coefficient of the launch vehicle, the Cd was altered in the simulation until the estimated maximum altitude matched that of the recorded maximum altitude. This revealed a Cd value of 0.772 when matching the 5191’ apogee and a Cd value of 0.78 when matching the apogee of 5181’. The data from the sub-scale test flight was used to estimate the Cd for the full scale launch vehicle. The sub-scale was estimated to be 0.67 the full scale was therefore estimated to be the same value of 0.67. The Cd values differ by about 0.1 points. This significant difference could be due to the increased area of the full scale launch vehicle which would result in the launch vehicle experiencing more drag.

IV. Payload Criteria

4.1 Design of Payload Equipment

4.1.1 Payload Body

The following steps were taken to construct the payload body.

1. The outer shell was created by Cutting a 13" section out of the 5.5"OD - 5.25"ID polycarbonate tubing using a miter saw.
2. A 0.25” polycarbonate sheet was secured to a lab table using clamps (shown in figure 64)
3. A jigsaw was then used to cut out a 5.25” disk out of the polycarbonate sheet (shown in figure 78)
4. The 5.25” polycarbonate disk was then sanded until it fit inside of the 13” polycarbonate tube without resistance.
5. The base of the outer shell was created by cementing the 5.25” polycarbonate disk onto the bottom of the inside of the 13” polycarbonate tubing using Weld-on adhesive.
6. The team let the adhesive set for 48 hours
7. Two silicone rubber sheets were thinned from a 0.25” thickness to a thickness of 1/6” by cutting the silicone sheet horizontally using a razor blade.
8. The silicone rubber sheet was then fitted inside of the outer shell, additional silicone rubber was applied as needed.
9. The silicone rubber sheets were then attached to the walls of the outer shell using the adhesive preinstalled on the backs of the silicone sheets.
10. A tape weave was constructed using standard tape to hold the aerogel insulator.
11. Small bunches of aerogel were attached to the tape weave.
12. A second tape weave was constructed and applied to the top of the first tape weave to enclose the aerogel in between both tape weaves.
13. Then the aerogel was fitted inside of the outer shell removing any excess.
14. The bottom of the aerogel was secured to the base of the outer shell using super glue.
15. The top of the aerogel was secured to the upper inside rim of the superglue, clamps were used to hold the aerogel in place while the superglue dried.
16. The 4.5”OD - 4.25ID was cut into a 12.75” section using a miter saw.
17. A disk was cut with a 4.25” diameter out off a 0.25” polycarbonate sheet using a jigsaw.
18. The 4.25” polycarbonate disk was then sanded until it fit inside of the 12.75” polycarbonate tube without resistance
19. The base of the inner chamber was created by cementing the 4.25” polycarbonate disk onto the bottom of the inside of the 12.75” polycarbonate tubing using Weld-on adhesive.
20. The team let the adhesive set for 48 hours
21. The inner chamber was cemented onto the base of outer shell using Weld-on adhesive.
22. The team let the adhesive set for 48 hours
23. The lid and adaptor were sanded until they could both fit inside the main airframe with no resistance.
24. The lid adapter was then cemented onto the top of the outer shell using Weld-on

adhesive.

4.1.2 Inner Rack

The following steps were taken to construct the inner rack.

1. Two 4.25” disks were cut out of aircraft ply wood using a jigsaw.
2. The two wooden disks were sanded until they fit inside of the inner chamber without resistance.
3. A circle with a 3.5” diameter was drawn on the wooden disks.
4. The circle was used to mark the optimal position of the three rods.
5. A drill was used to make holes for the steel rods at the marked locations.
6. One 1” x 3” piece was cut out of aircraft ply wood using a jigsaw.
7. Two 1” x 1” pieces of wood were cut out of aircraft ply wood using a jigsaw.
8. The three pieces were cemented together to form a handle using rocket epoxy.
9. The handle was then cemented onto top wooden disk using rocket epoxy.
10. The team let the epoxy set for 48 hours.
11. A silicone disk was used to make the sealing disk.
12. A section in the middle of the sealing disk was cutout to allow the handle to go through it.
13. The sealing disk was then fitted onto the top disk.
14. After the best position for the sealing disk was found it was cemented onto the top disk using rocket epoxy.
15. The team let the epoxy set for 48 hours
16. Three 12.75” sections of steel rod were cut from a 1/8” steel rod using a dremel.
17. The steel rods were secured to the bottom wooden disk using three nuts on the bottom of the disk and three nuts on the top of the disk.
18. Rocket epoxy was then applied to the nuts located at the bottom of the wooden disk.
19. The team let the epoxy set for 48 hours.
20. Three silicone rubber sheets were used to make the disks for the inner rack compartments.
21. Six 4.25” circles were drawn onto each silicone sheet.
22. Scissors were then used to cut out each of the circles on the silicone sheets.
23. The location of the steel rods was marked on each individual silicone disk.
24. A drill was then used to make the holes on the silicone disks.
25. The holes on the silicone disks were fortified using duck-tape.
26. The inner rack compartments were assembled using the silicone disk, springs, and nuts.
27. Three nuts were screwed onto the steel rods, then a single silicone disk was slid onto the steel rods, followed by three metal spring, then another silicone disk was slid into place, and the final step was securing the top silicone disk using three nuts.
28. The process described in step 17 was used to construct the eight separate compartments of the inner rack.
29. The completed inner rack was then inserted into the inner chamber of the payload

4.1.3 Foam Cavity

The following steps were taken to form the payload foam cavity.

1. The bottom section of the fully assembled payload was wrapped in wax paper (shown in figure 74)

2. The Mega-Foam (urethane, closed-cell expandable foam) was prepared in a Styrofoam cup.
3. The Mega-Foam was slowly poured into the forward section of the launch vehicle.
4. The wrapped payload was then quickly inserted into the forward section.
5. A 10kg weight was placed onto of the payload.
6. The team let the foam set for 1 hour.
7. The payload was removed and the foam cavity was inspected.
8. After the team approved the cavity the forward section was stored until launch day.

Figure 64: Silicone Rubber

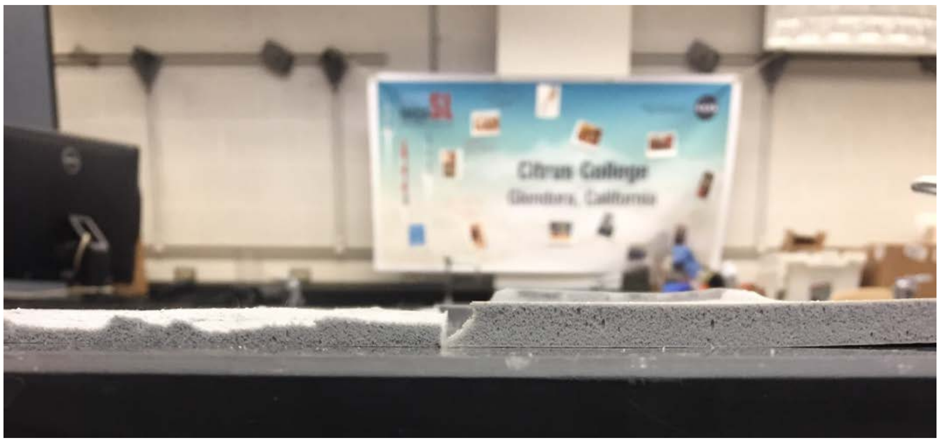


Figure 64 shows the thinned layer of silicone rubber used in the payload.

Figure 65: Silicone Disk

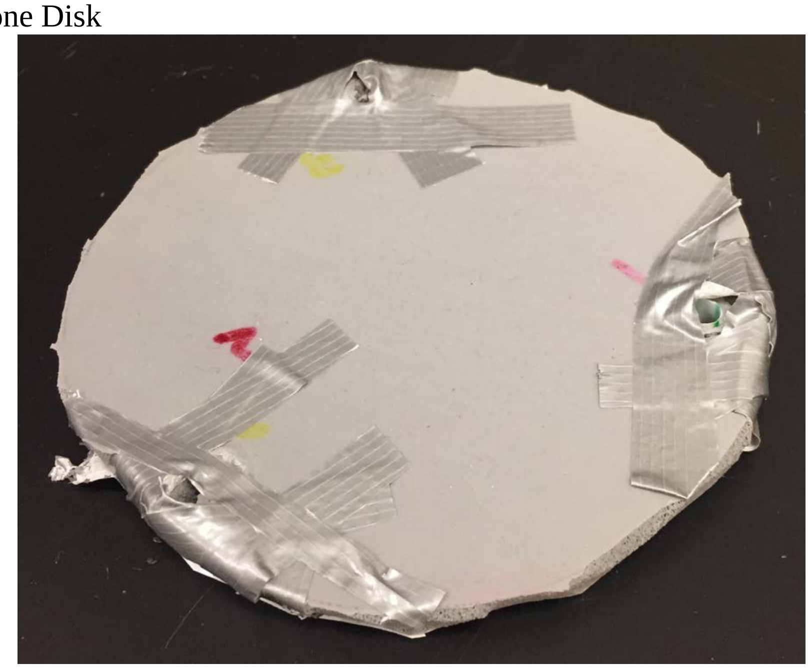


Figure 65 shows one of the silicone disk used for the payload compartments.

Figure 66: Inner Rack

Figure 66 shows the team's inner rack.

Figure 67: Inner Rack (Close-up)

Figure 67 shows a close up view of the team's inner rack.

Figure 68: Lid and Adapter

Figure 68 shows the lid and adapter before and after sanding.

Figure 69: Complete container (External)

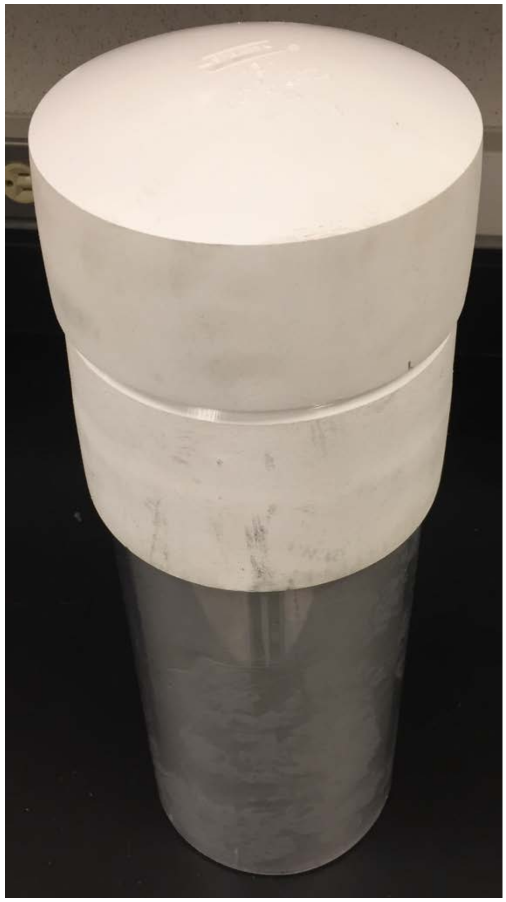


Figure 69 shows the fully assembled container.

Figure 70: Payload body (Internal)

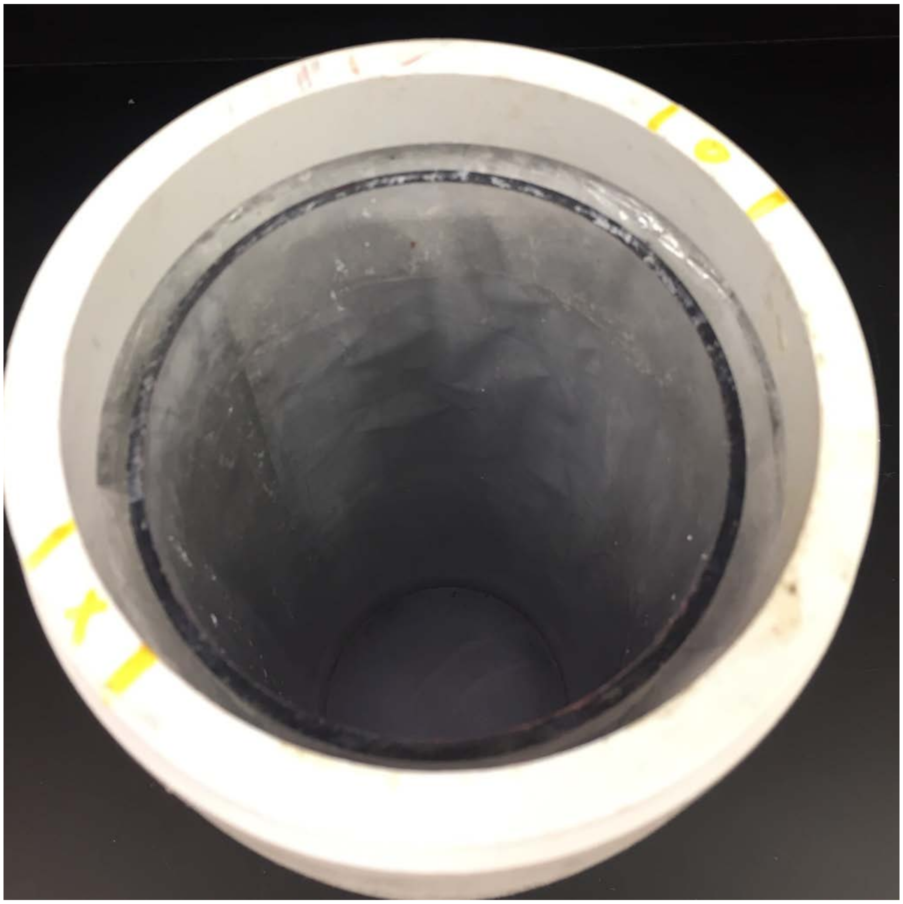


Figure 70 shows the inside of the fully assembled container.

Figure 71 Payload Body with Inner Rack (Internal)

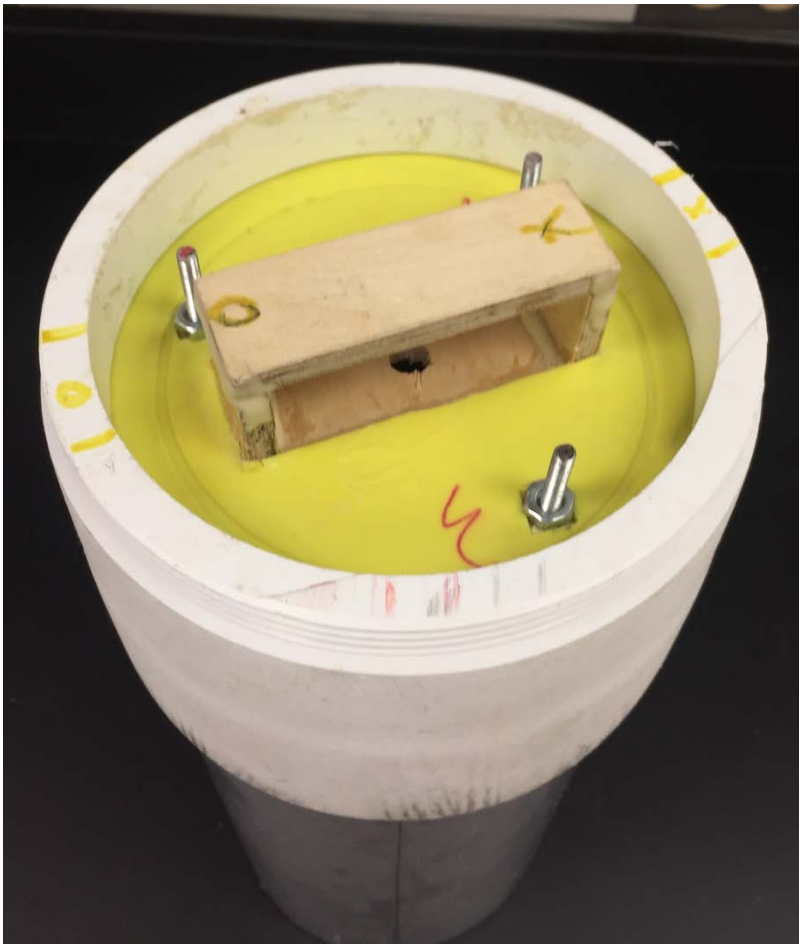


Figure 71 shows the inside of the fully assembled container with the inner rack installed.

Figure 72: Inner Rack Bottom Plate

Figure 72 shows the bottom plate of the inner rack.

Figure 73: Inner Rack Handle

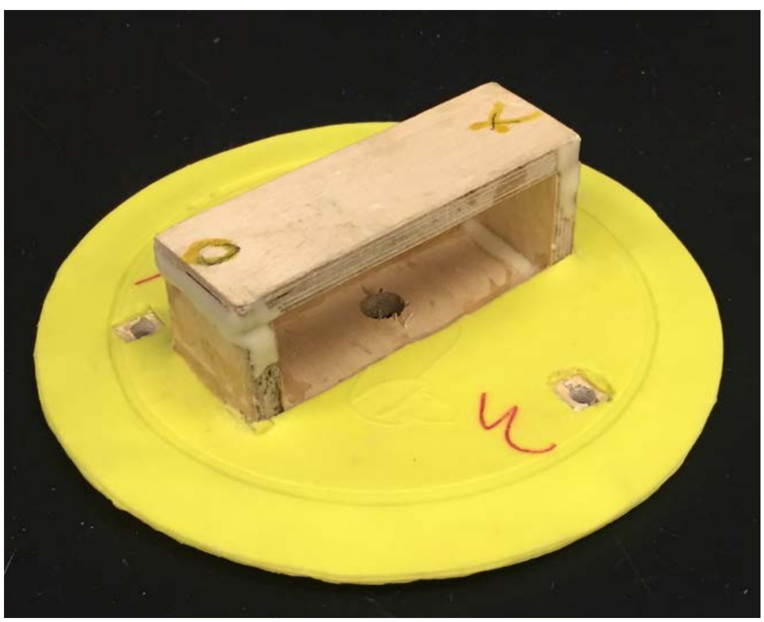


Figure 73 shows inner rack's fully assembled handle

Figure 74: Payload Body Wrapped in Wax Paper

Figure 74 shows the complete container raped in wax paper.

Figure 75: Max-Foam

Figure 75 shows the Max-Foam being made.

Figure 76: Payload Body and Forward Section

Figure 76 shows the payload body inside the forward section as the foam mold is being made

Figure 77: Cutting of Outer Shell

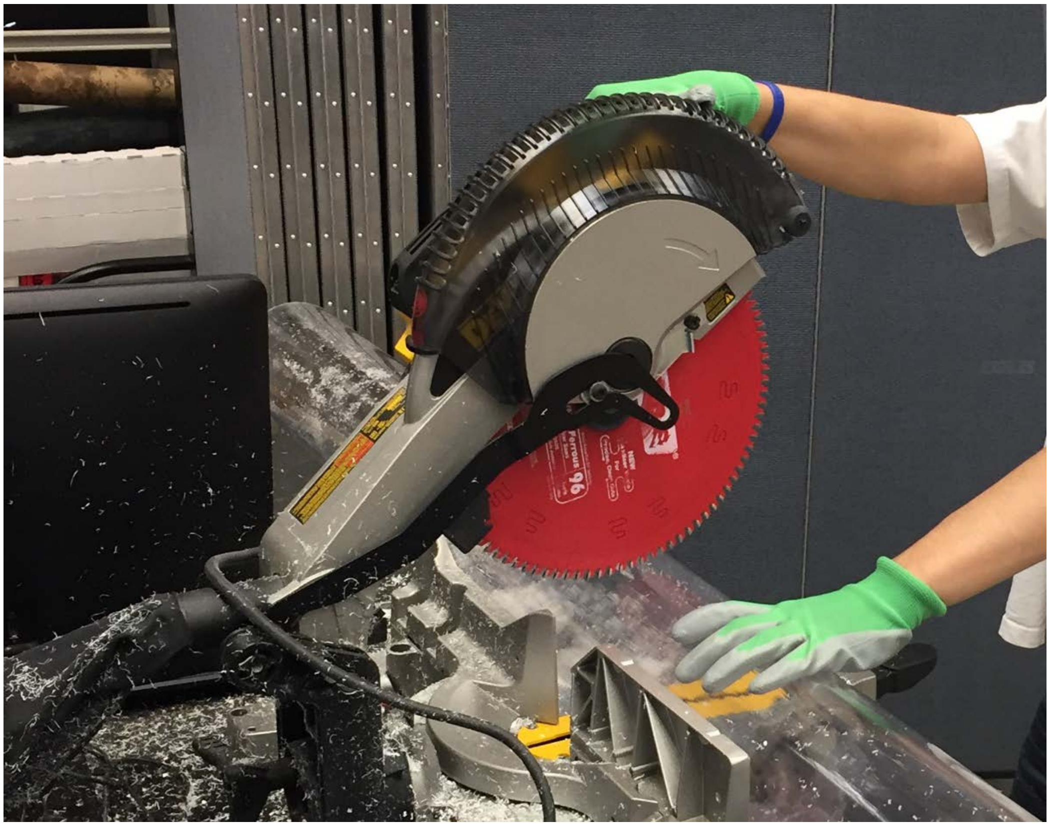


Figure 77 shows how the outer shell cut.

Figure 78: Cutting of the Outer Shell Base

Figure 78 shows how the base of the outer shell was cut.

Figure 79: Team Container (Exploded)

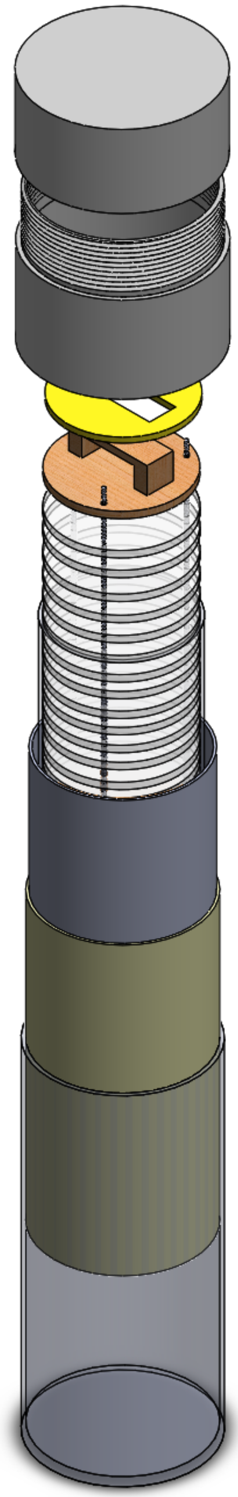


Figure 79 shows and exploded view of the team's container.

4.1.4 Inner Rack Functionality

The inner rack of the container (shown in figure 66-67) starts outside of its corresponding inner chamber compartment. Solid samples are inserted into the inner rack compartment using the following method. First, the correct number of compartments needed is determined. Then, the silicone disks of the inner rack are adjusted manually by sliding the metal nuts holding the silicone disks in place, up or down over the threaded metal rods. This process is repeated until the correct number of compartments have been made. Using separate compartments isolates each sample. The silicone disk compartments can be manually adjusted to fit 1-8 objects. The objects are placed into their individual compartments one at a time, the team then manually screw the metal nuts on the threaded rods, both above and below the silicone disks, until the silicone disks are taut over and under the sample(s). This process is repeated until all of the objects are secured between the silicone disks of the inner rack. After the inner rack is full and secured, it is inserted into the inner chamber of the container and sealed closed with threaded fitted cap. Liquid samples are carefully poured into the liquid compartment, then the cover is secured, and lastly the entire container is sealed. Upon receiving the unknown fragile material on launch day the proper method will be chosen to secure the material within the container.

4.1.5 Payload Incorporation

The container is manually inserted into the payload bay of the rocket between a single bulk heads and the nosecone shoulder. The bulk heads were constructed from 0.50" thick birch plywood using a jigsaw. The bulk plate is located forward of the main parachute. The nosecone shoulder and bulk plate aid in the stability of the team's container within the body of the rocket. To further increase the stability of the payload during flight a thin layer of mega foam was added to the payload bay.

4.2 Precision of Instrumentation

The outer shell and inner chamber were cut to the desired sizes of 13" and 12.75" respectively, out of polycarbonate tubing. Polycarbonate was the most favorable material choice because "It has high strength, toughness, heat resistance, and excellent dimensional and color stability [and] One of the biggest advantages of polycarbonate is its impact strength." [11] The 9% borated flexi panel was chosen because it "is a flexible light-weight sheet material with relatively high boron content of 9% (natural isotope distribution) that produces an attenuation factor of 22 for thermal neutrons. [The borated flexi panel] also includes a hydrogenous additive that helps slow the fast neutrons and can reduce the overall radiation field." [12] The flexi panel is also easily cut and can be wrapped around a small circumference which gave the team the opportunity to place the flexi panel wherever it may be needed. Due to budget limitations the team used a substitute material for the borated flexi panel (silicone rubber). The silicone rubber has the same density and physical properties as the original flexi panel to insure the integrity of the design is held. The substitute material was manually attached to the inside wall of the outer shell using the adhesive that is on the back of the material. The aerogel insulator was chosen because according to NASA it is the best and lightest insulator on the planet with a thermal conductivity of 0.016 – 0.03 (W/mK) at 25 degrees C. [13] The flexi panel and aerogel layer were placed inside the outer shell wall to increase the protection of these layers while also decreasing the total diameter of the container. The 0.17" gap in between the aerogel and inner chamber is utilized as a liquid compartment. A maximum volume of 8.58in^3 can be held inside the liquid compartment. To keep the liquid from getting contaminated by the aerogel, the aerogel was placed inside a tape weave. The top of the liquid compartment is sealed with a cover made from a o.25" silicone disk. Figure 66 -67 shows the final design of the team's inner rack. The silicone disks are stationed by three 0.125"x12.25" steel rods. The team chose to use three rods because it held the compartment disks in place while still leaving enough room inside each compartment for the maximum possible sample size. Silicone was chosen as the material for the compartment disks because of its flexibility, high heat resistance, and strength. 16 separate silicone disks were used to make the eight separate compartments. To secure the compartments (6) 0.125" hex nuts were placed on the opposing exterior surfaces of the disks, 3 nuts per rod. Three metal springs were placed in between the silicone disks within each compartment over the metal rods to increase the overall tension and grip of the disks on the desired material, this process is explained in detail in the payload integration section of this document. A handle (shown in figure 73) was made out of 0.25" plywood and will be attached to the top of the inner chamber rack using rocket epoxy to allow the rack to be inserted and removed from the container quickly and easily.

4.3 Payload Electronics

There are no electronic components in the design payload.

4.4 Payload Success Criteria

The criteria that the payload must meet in order to be considered successful is as follows:

1. The unknown sample(s) must remain undamaged and intact throughout the entirety of the flight
2. The unknown sample(s) must remain in their designated compartment(s) during the entirety of the flight
3. The unknown sample(s) must be fully accommodated within the payload
4. The payload must remain undamaged
5. The payload must be reusable

Several tests were conducted to demonstrate that the payload meets all listed requirements and are described in detail in Section VII *Testing*. To test the ability of the payload to properly contain and protect the sample the payload underwent the drop test, impact test, compartment weight test, compartment adjustment test. The results from these test show that the payload is capable of withstanding a force of 1088.18 Newtons. According to the calculations done in the *Mission Performance* section the launch vehicle is estimated to land well below the 75 ft. –lb. kinetic energy limit

V. Safety

Safety and Environment (Vehicle and Payload)

5.1 Safety Officer Responsibilities

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

- Certify that the safety plan corresponds with federal, state, and local laws.
- Address the team members about any safety concerns.
- Inform the team members of expected safety concerns for the upcoming week at the team's weekly meeting.
- Request that the team member express any safety concerns during weekly meetings, or as they arise.
- Train the team on proper use of Personal Protective Equipment (PPE).
- Ensure that all team members understand and sign the team safety contract (see Appendix B).
- Be aware of all hazardous chemicals and machinery accessed by team members and ascertains 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 D and safety protocols in Appendix E.

A hazard is a potential threat to life, health, property or environment. Assessment of a hazard is made by combining the severity of the consequence with the likelihood of its occurrence in a matrix. Hazard analysis is the first step to assessing risk levels with the goal of controlling and/or eliminating the risk. Table 29 shows the risk matrix used to analyze the severity and probability of a hazard for the entire duration of the NASA SL. From this analysis, various tables related to personnel hazards have been constructed. The team members will come into contact with various materials, facilities and equipment that may present hazards to personnel. In order to understand and reduce the risks of hazards that may occur during the duration NASA SL MSDS, operator's manuals and NAR regulations were utilized in order to develop various mitigations. MSDS safety overviews, operation instructions and review of safety protocols will be covered during briefing conducted before construction, test and launches. These briefing will lead by the safety officer in order to reduce the probability of hazards and accidents occurrences.

Table 29 shows the qualitative assessment chart. There are several risks that pose a danger to the success of the project. The risks are evaluated based on their likelihood and impact.

Table 29: 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 in red but should still be monitored. Items in green pose very little threat to the project overall success.

Table 30 defines the impact levels.

Table 30: Impact Level Definitions

Rating	**Definition**
1-High	High impact risk is define as having a severe effect on the overall continuation of the

	project and would require substantial effort, time and/or money to resolve.
2-Medium	Medium impact risk is define as having a moderate effect on the overall continuation of the project but would be reversible with modest effort, time and/or money.
3-Low	Low impact risk is define as having a minor effect on the overall continuation of the project but would be easily resolve with minimal effort, time and/or money

Table 31 describes the definition of likelihood.

Table 31: 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 32 lists and describes the cause and effects that specific risks pose to the project's success . A qualitative assessment is give before and after mitigation.

Table 32: Project Risk and Mitigation						
Risk	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification**
Insufficient building time	Overruns of schedule and cost, poor time management, lack of clear roles and responsibilities among team members	Launch vehicle will be constructed in a rush therefore decreasing the quality of the launch vehicle	1A	Duplicate parts of the vehicle will be constructed simultaneously, team members responsibilities and roles will be define during the team's weekly meetings	1C	**Complete** The team remained on the designated construction schedule for the full scale launch vehicle and payload. The team followed launch operation procedures to ensure the quality of the launch vehicle.
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 time line will get pushed back, team will be behind schedule	2A	Back-up launches has been schedule for the full scale rocket if unpredictable weather where to occur, a checklist has been created for all supplies needed for a launch, careful attention to all safety concerns will be give	2C	**Complete** The team has utilized the pre-launch day checklist that has been created to ensure all components of the rocket are packed and brought to the launch site.

				before, during and after construction		
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	**Complete** The team has followed all requirements listed on Table 73 General Requirements to ensure there was sufficient writing time for the design review.
Low funds	Too much money used to buy unnecessary material for construction	Low funds can result in inadequate recourses	2B	Extra fundraising will be done if necessary	3B	**Complete** The team has not deviated from the previously created budget plan listed on table 75.
Low resources	Insufficient funds	Amount of materials purchased may be insufficient in order to complete construction	2B	Team will only purchase essential items	2C	**Complete** The team budget found on Table 75 has been followed carefully to avoid small discretionary expenses and insufficient funds. The team followed the procedures founded in Section 3.1 Designed and Construction of Vehicle to ensure proper construction of launch vehicle in order to avoid repurchasing materials.
Loss of team members	Team member lost interested or become overwhelmed,	Increase the work load of remaining	2B	The lost team members responsibilities will be	2C	**Complete** Team has followed the general team derived requirements to avoid loss of team member.

	or lack of work from team member, team member fail to meet the responsibilities given to them	time members, increase the amount of time for an assignment to be completed		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		

5.2 Hazards Analysis

5.2.1 Personal Hazard Analysis and Mitigations

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

Table 33 shows the qualitative assessment chart.

Table 33: 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 34 lists and defines the severity of a hazard ranging from negligible (4) to catastrophic (1).

Table 34: Severity Definitions

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

Table 35 lists and defines risks based on their likelihood. Each hazard is assigned a probability of occurrence ranging from improbable (1) to frequent (5).

Table 35: 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 36 has been expanded to included verification as hazards are encountered.

Table 36: Facility Hazard Analysis and Mitigation

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

2. Friends of Amateur Rocketry (FAR) 3. Mojave Desert Advanced Rocketry Society (MDARS)			will use a team created checklist to confirm that the rocket is safe for launch. The Range Safety Officer (RSO) will determine if the rocket is safe for launch and the team will comply with their assessment.		
Citrus College Machine Shop	Physical injury, skin or eye irritation	**2D**	Gloves, masks, goggles, and closed toe shoes will be worn at all times. Team members will be trained to properly handle and operate the machinery and tools.	**2E**	No injuries have occurred

Table 37 provides the preliminary risk levels. MSDS are used to understand the potential hazards of the materials mentioned in the table below.

Table 37: Material Hazards Analysis and Mitigations

Materials	**Hazard**	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification Status**

Fiberglass	Skin and eye irritation; hazardous fume inhalation	Failure to wear gloves, masks, and safety 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**	**Complete** The sections listed below, located in MSDS under product name E-761/E-761LT Epoxy Fiberglass have been used to verify the mitigations listed. • **Section 4: First Aid Measure** The team has followed the first aid procedures outline in this section if direct skin and eye contact with the material occurred in order to prevent negative symptoms • **Section 6: Accidental Release Measure** The team has followed the personal precaution listed in this section to prevent unnecessary skin contact with the material. • **Section 7: Handling and Storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section. • **Section 8: Exposure Control/ Personal Protection** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring.

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. In case of direct contact with the material the team will follow the fort aid measures found in the MSDS Under product name Acetone section 4.	**3D**	**Complete** The sections listed below, located in MSDS under product name Acetone have been used to verify the mitigations listed.

							• **Section 4: First Aid Measures** The team has followed the first aid procedures outline in this section if direct bodily contact with the material occurred in order to prevent negative symptoms such as lung, eye or throat irritation • **Section 6: Accidental Release Measures** The team has followed the maintenance procedure detailed in this section to prevent this flammable chemical from becoming a source of ignition • **Section 7: Handling and Storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section. • **Section 8: Exposure Controls/Personal Protection** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring.

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**	**Complete** The sections listed below, located in MSDS under product name WEST SYSTEM 105 Epoxy Resin have been used to verify the mitigations listed. • **Section 4: First Aid Measures** The team has followed the first aid procedures outline in this section if they come into direct bodily contact with the material to prevent negative symptoms such as lung, eye or respiratory irritation and skin rashes. • **Section 6: Accidental Release Measures** The team has followed the maintenance procedure detailed in this section to prevent unnecessary skin contact with epoxy. • **Section 7: Handling and Storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section • **Section 8: Exposure Controls/Personal Protection** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring.

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**	**Complete** The sections listed below, located in MSDS under product name black powder have been used to verify the mitigations listed. Section 4: Emergency First Aid The team has followed the first aid procedures outline in this section if any direct bodily contact with material occurred
Solder	Damage to equipment while soldering	Soldering iron is too hot, prolonged contact with heated iron	The equipment become damage and unusable	**2B**	The temperature of the soldering iron will be controlled and set to an appropriate level that will not damage equipment	**3C**	**Complete** The sections listed below, located in MSDS under product name Rosin-Core Solder have been used to verify the mitigations listed. • **Section 4: Emergency First Aid** The team has followed the first aid procedures outline in this section if they come into direct bodily contact with the material to prevent negative symptoms such as lung, eye or throat irritation • **Section 6: Procedures if material is spilled or released** The team has followed the maintenance procedure detailed in this section to prevent unnecessary contact with the material

	Dangerous fumes while soldering	Toxic fumes that are produce because of leaded solder can cause eye irritation, headache and irritation of the repository system	Sickness or irritation of the lungs due to inhalation of toxic fumes		Team member will use appropriate soldering techniques and solder in well ventilated areas		• **Section 7: Precautions to be taken in handling and storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section • **Section 8: Protective measure against exposure** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring.
	Burns while soldering	Team members do not pay attention while soldering	Minor to severe burns may occur		Team member will use appropriate soldering techniques		

Paint	Respiratory irritation	Failure to wear protective masks	Wheezing, coughing, and shortness of breath	**3C**	Protective masks will be worn. Painting will be done in well-ventilated areas.	**4C**	**Complete** The sections listed below, located in MSDS under product name Paint have been used to verify the mitigations listed • **Section 4: First Aid Measures** The team has followed the first aid procedures outline in this section if they come into direct bodily contact with the material to prevent negative symptoms such as lung, eye or throat irritation • **Section 6: Accidental Release Measures** The team has followed the maintenance procedure detailed in this section to prevent unnecessary contact with the material • **Section 7: Handling and Storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section • **Section 8: Exposure Controls/ Personal Protection** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring

Batteries	Chemical burns and skin irritation Source of fire and explosion	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. Batteries will be kept away from fire situation to prevent burst and release of hazardous decomposition products	**3D**	**Complete** The sections listed below, located in MSDS under product name Duracell Alkaline Batteries have been used to verify the mitigations listed. • **Section 4: First Aid Measures** The team has followed the first aid procedures outline in this section if they come into direct bodily contact with the material to prevent injuries such as chemical burns, skin peeling and lung irritation. • **Section 5: Fire Fighting Measure** The team has followed extinguishing methods outline in this section of batteries come in contact with fire situations. • **Section 6: Accidental Release Measures** The team has followed the maintenance procedure detailed in this section to prevent any unnecessary skin contact with potassium hydroxide that is released from a leaking battery. • **Section 7: Handling and Storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section. • **Section 8: Exposure Controls/ Personal Protection** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring.

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**	**Complete** The sections listed below, located in MSDS under product name Super Glue have been used to verify the mitigations listed • **Section 4: Emergency First Aid** The team has followed the first aid procedures outline in this section if they come into direct bodily contact with the material to prevent negative symptoms such as lung or eye irritation • **Section 6: Accidental Release Measures** The team has followed the maintenance procedure detailed in this section to prevent unnecessary skin contact with super glue • **Section 7: Handling and Storage** The team maintained proper storage condition and practice proper waste disposal as outline in this section • **Section 8: Exposure Controls/ Personal Protection** The team utilized all safety equipment identify in this section to prevent and reduces any hazards from occurring.

Table 38 below lists the equipment required in the construction of the launch vehicle that poses sufficient risk to require mitigation.

Table 38: Equipment Hazards Analysis and Mitigation							
Equipment	**Hazards**	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification**
Drill Press	Physical injury or damaged to facility	Failure to use the Drill Press correctly and/or improper training of tool and improper use of PPE	Mild to severs skin penetration	**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**	**Complete** The team has closely followed the procedures outlined in the Rocket Owls Protocol for Drill Press to prevent bodily harm and/or damages to the facilities. The team has also followed the safety protocols found in the Environmental Health and Safety section of the document mentioned above to reduce the probability of a hazardous situation occurring.
Hand Drill	Physical injury damage to equipment	Improper use of PPE	Team members may experience mild to severe cuts	**3B**	Proper safety attire such as protective clothing, safety goggles, and glove will be worn	**3E**	**Complete** The team has closely followed the procedures outlined in the Rocket Owls Protocol for Hand Drill to prevent bodily harm and/or damages to the facilities. The team has also followed the safety protocols found in the Environmental Health and Safety section of the document

	Damage to rocket or rocket components	Improper usage of tool due to inadequate training	The team will fall behind schedule due to rebuilding the damage component of the rocket		Team members will be trained on the tool being used		mentioned above to reduce the probability of a hazardous situation occurring.
Soldering Iron	Bodily harm	Failure to correctly use the soldering iron 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**	**Complete** The team has closely followed the procedures outlined in the Rocket Owls Protocol for Soldering Iron to prevent bodily harm and/or damages to the facilities. The team has also followed the safety protocols found in the Environmental Health and Safety section of the document mentioned above to reduce the probability of a hazardous situation occurring.
Jigsaw	Bodily harm, property damage	Improper use of PPE , Improper usage of tool due to inadequate training	Mild to severe skin penetration, damage to equipment	**2D**	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**	**Complete** The team has closely followed the procedures outlined in the Rocket Owls Protocol for Jig Saw to prevent bodily harm and/or damages to the facilities. The team has also followed the safety protocols found in the Environmental Health and Safety section of the document mentioned above to reduce the probability of a hazardous situation occurring.

Table Saw	Bodily harm, property damage	Improper usage of tool due to inadequate training	Mild to severe skin penetration, damage to equipment		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.		**Complete** The team has closely followed the procedures outlined in the Rocket Owls Protocol for Table Saw to prevent bodily harm and/or damages to the facilities. The team has also followed the safety protocols found in the Environmental Health and Safety section of the document mentioned above to reduce the probability of a hazardous situation occurring.
Hot glue gun	Bodily harm	Improper usage of equipment	Mild to sever burns		Team members will only use the hot glue gun for quick repairs		**Complete** The team has closely followed the procedures outlined in the Rocket Owls Protocol for Hot Glue Gun to prevent bodily harm and/or damages to the facilities. The team has also followed the safety protocols found in the Environmental Health and Safety section of the document mentioned above to reduce the probability of a hazardous situation occurring.

Table 39 lists hazards that may occur during launch preparation and flight of the launch vehicle.

Table 39: Launch Vehicle Hazard Analysis and Mitigation						
Hazards	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verification Status**
Absence of deployment, premature or delayed deployment	Malfunction of altimeters which results in inaccurate deployment	Launch vehicle will descend rapidly to the ground resulting in significant damage to the rocket, in the case of premature deployment the launch vehicle will drift to great a distance	**1D**	Redundant altimeters and black powder charges will be used to ensure deployment. A safety checklist will be made to confirm that the proper electronics are installed and activated. Verify the altimeters are preset to the correct altitude.	**2E**	**Complete**. The tests listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations, • **Parachute Packing and Running Test** The team successfully conducted parachute packing and running tests which ensure that parachute will open fully during flight preventing delayed deployment • **Altimeter Test** The team has successfully conducted altimeter pressure test which ensures the altitudes will relayed • **Ground Ejection Test** The team has successfully conducted several ground ejection to determine the correct amount of black powder used for the ejection charges to prevent an absence of deployment
Unstable flight	Crooked, forward, asymmetrical, and/or loose fin, CG shift	Launch vehicle will not achieve highest altitude	**1D**	Rocket simulation software will be used to determine the CP before launch.	**2E**	**Complete** The test listed below, located in *Section VII Project Plan* was used as a method of verifying the mitigations • **Center of Gravity**

	during flight			Fins will be cut using a CNC machine to ensure precision of cuts.		The team has successfully conducted a center of gravity test to verify a center of gravity within a 3 unit range of the CG recorded in RockSim. The test will ensure the launch vehicle has a stable flight.
Injury during ground or launch testing	Black powder charges go off prematurely when expose to open flames and heat sources	Minor to serious injuries to personal near the launch vehicle	2C	Team members will be at a required safety distance from the launch vehicle when conducting ground or launch testing.	2D	**Complete**. The team member utilize Table 47: Minimum Distance for Launch Safety to ensure they were at safe distance from the launch vehicle when conducting ground or launch testing
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**	**Complete** The tests listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations, • **Parachute Packing and Running Test** The team successfully conducted parachute packing and running tests which ensure that parachute will open fully during flight preventing delayed deployment • **GPS Testing** The team successfully conducted GPS testing in order to prevent lost of launch vehicle • **Ground Ejection Test** The team has successfully conducted several ground ejection to determine

						the correct amount of black powder used for the ejection charges to prevent an absence of deployment
Catastrophic takeoff (CATO)	Failure to properly assemble and install the motor retainer. 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	The motor retainer will be properly installed. The mentor will oversee the installation of the motor.	3E	**Complete** The construction procedures listed below, located in *Section II Vehicle Criteria* are used as a method of verifying the mitigation • **Motor Retainer** The team has properly installed the motor retainer as outlined in the procedure.

Table 40 lists the potential hazards posed from the construction of the payload and their corresponding mitigations.

Table 40: Payload Hazards and Mitigation

Risk	Pre-RAC	Cause	Effect	Mitigation	Post-RAC	Verification Status
Bodily harm	2D	Misuse of equipment, not wearing proper safety equipment when constructing the payload	Cuts and/or burns	Protective clothing, gloves, masks, and goggles will be worn while constructing the payload.	**2D**	Complete: Masks, lab coats, gloves and goggles were worn when constructing the payload to prevent bodily harm.
Skin and	3B	Not wearing	Redness,	Protective	4C	Complete:

eye irritation		the proper safety equipment when constructing the payload	itching and irritation.	clothing, gloves, masks, and goggles will be worn while constructing the payload.		Gloves and goggles were worn when constructing the payload. This was done to prevent skin or eye irritation from adhesives, particles, or insulation.
Fumes and/or particle inhalation	3C	Not wearing the proper safety equipment when constructing the payload.	Coughing, trouble breathing, and lightheadedness	Protective masks will be worn while constructing the payload. Construction will take place in a well ventilated area	4C	Complete: Masks where worn during construction which was done in a well ventilated area. This was done to prevent the inhalation of fumes from adhesives or particles from polycarbonate, insulation, plywood, or silicone.
Adverse reactions to chemical substances		Not wearing the proper safety equipment or mishandling construction materials	Redness, skin irritation, trouble breathing, vomiting, cancer, death	Protective clothing, working in a well ventilated area, not ingesting or inhaling construction materials, properly handling all construction materials		Complete: All construction materials were handled according to their specific safety guidelines. Masks, gloves, goggles, and lab coats were worn when constructing the payload. Construction was done in a well ventilated area under the supervision of the team safety officer.
Damage to facilities		Misuse of construction tools and equipment	Cuts or scratches, layers or droplets of	All construction equipment will be properly		Complete: All tools used in construction were properly used and stored after use. The miter saw was stored in its container and placed under the cabinet in the lab room after every use. All

			adhesives	handled and stored after use. Protective surfaces will be worked on to prevent damage to the facilities.		adhesive substances were used over a plastic cover or a sheet of old wood or cardboard. When using the jigsaw the material was always clamped to a surface leaving a safe distance for the jigsaw to cut without coming in contact with the table. Palm sanders all stopped rotating completely before placing them onto tabletops or counters. All power tools were unplugged when not in use.

5.3 Failure Modes and Effects Analysis

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

Table 41 shows the possible failure modes of the launch vehicle with their corresponding mitigations and verification status.

Table 41: Launch Vehicle Hazard Failure Modes

Risk	Pre-RAC	Cause	Effect	Mitigation	Post-RAC	Verification Status
Center of gravity is too far aft	**2B**	Mass distribution is greater in the aft section of the rocket	Unstable flight	RockSim simulations will confirm that the center of gravity is at least 1.5 calibers above the center of pressure. Test	**2D**	**Complete** The test listed below, located in *Section VII Project Plan* was used as a method of verifying the mitigations • **Center of Gravity** The team has successfully conducted a center of gravity test to verify a center of gravity within a 3

				flights will also be used to verify the stability of the rocket.		unit range of the CG recorded in RockSim. The test will ensure the launch vehicle has a stable flight.
Fin failure	**1B**	Fins are not properly attached to the motor mount and/or they do not have equal radial spacing	Unstable flight, potential rocket damage	Fins slots in the airframe and epoxy will be used to secure the fins onto the wall of the motor mount. The grain of the wood will be perpendicular to the body of the rocket.	**1D**	**Complete** The construction procedures listed below, located in *Section II Vehicle Criteria* are used as a method of verifying the mitigation • **Aft Section (Booster)** The team has successfully attached the fins to the launch vehicle as describe in the booster construction section. The section describes the design features that enable the launch vehicle to be recover safely and prevent unstable flight. • **Aft Section (Fins**) The team has successfully attached the fins to the launch vehicle as outline in this section. The section describes in further detailed the construction of the fins and precautions taken to ensure proper alignment.
Premature separation of rocket components	**1D**	Insufficient amount of shear pins or faulty altimeters	Failure to reach target altitude, damage to rocket and	Calculations and ground ejection tests will be used to determine and	**1E**	**Complete**. The tests listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations

			various other components	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.		• **Altimeter Test** The team has successfully conducted altimeter pressure test which ensures the accurate altitudes were relayed • **Ground Ejection Test** The team has successfully conducted several ground ejections to determine the correct amount of black powder used for the ejection charges to prevent an absence of deployment • **Sheer Pin/Shock Cord Drop Test** Successful sheer pin/shock cord test were conducted which ensured that the amount of sheer pins used in the forward section was enough to prevent the forward section being detached at apogee. • **Full Scale Launch** The team has successfully conducted a full scale launch which verified that was no premature separation of rocket components.
Lack of separation of	**1D**	Nonessential	Absence of	Calculations	**1E**	**Complete**.

the rocket components		amount of shear pins or insufficient pressure in parachute bay	parachute deployment and ballistic descent of the launch vehicle	and ground ejection tests will be used to determine and verify the necessary amount of shear pins and black powder.		The tests listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations • **Ground Ejection Test** The team has successfully conducted several ground ejections to determine the correct amount of black powder used for the ejection charges to prevent an absence of deployment • **Sheer Pin/Shock Cord Drop Test** Successful sheer pin/shock cord test were conducted which ensured that the amount of sheer pins used in the forward section was enough to prevent the forward section being detached at apogee. • **Full Scale Launch** The team has successfully conducted a full scale launch which verified that was not a lack of separations of the rocket components.
Centering rings failure	**2D**	Centering ring(s) detach from the motor mount and/or airframe	Damage to rocket, possible motor ejection, or	6 centering rings will be attached to the motor mount. Tests will be	**2E**	**Complete** The construction procedure listed below, located in *Section II Vehicle Criteria* are used as a method of verifying the mitigation

			unstable flight	conducted to ensure the centering rings are properly secured to the airframe and motor mount.		• **Aft Section (Booster)** The team has carefully attached the centering to the motor mount as describe in construction procedures for the booster section.
Bulkhead failure	**2D**	Bulkheads detach from the airframe	Recovery system failure, damages to rocket	0.50 in thick Birch plywood will be bonded to the airframe. Tests will be conducted to ensure that the bulkheads are secured.	**2E**	**Complete**. The test listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations • **Full Scale Launch** The team has successfully conducted a full scale launch that verified that the bulkheads did not detach from the airframe.
Airframe shredding	**1D**	Miscalculation tensile strength of the airframe	Damages to rocket	High shearing strength Blue Tube will be used. The test launch will demonstrate that airframe shredding does or does not occur.	**1E**	**Complete**. The test listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations • **Full Scale Launch** The team has successfully conducted a full scale launch that verified that the bulkheads did not detach from the airframe.

Table 42 shows the possible failure modes of the payload and the mitigation of those failures.

Table 42: Payload Failure Modes						
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**	**Verification Status**
Nuts and/or washers become loose and move on the metal rods	**1D**	Nuts and/or washers have not been tightened correctly	Platforms will move around in the container causing the sample(s) to become unsecured	Correct sizing of nuts and washers will be used. The nuts and washers will be tightened manually	**3C**	Complete: This was verified by tightening the nuts and washers above and below the silicone platforms. The inner rack was then shaken vigorously to simulate the force that the payload would experience in flight. The nuts and washers remained in place showing that they will not move up or down on the rod during flight.
Silicone platforms tear	**1D**	Silicone platforms were to thin and tore because of the weight of the sample(s)	Platforms tear under the weight of the sample and cause the sample to become loose in the container.	The thickness of the silicone platforms was measured to ensure that they will not tear under the weight of the sample	**3D**	Complete: The thickness of the platforms was tested by placing different shaped objects of various masses between the platforms and checking the platforms for damages. The maximum weight tested was 11 lbs. No damage was observed on the platform verifying that the platforms are capable of containing the unknown sample(s) mass. See section 7.1 *Testing* to see a detailed description of this test.
Stiff springs	**1D**	The coil separation distance is too	Platforms will move around in the	Different coil sizes were tested	**3D**	Complete: The coils were tested in the inner rack by placing them on the rods between the platforms and tightening the platforms with the

		small	container causing the sample to become unsecured	to determine which provides the proper resistance		nuts and washers. Springs with a coil distance of 0.1 in provided to much resistance when the platforms were secured together. Springs with a coil diameter of 0.25 in, wire thickness of 0.026 in and a coil distance of 0.08 in were found to be the ideal size for spring resistance.
Peeling of the radiation shield	**1D**	Radiation shield is not properly adhered to the container	Radiation shield is not effective	Properly install the radiation shielding	**3D**	Complete: A silicone sheet was used as a substitute for the radiation sheeting. On the back is an adhesive which was used to stick the sheet to the polycarbonate tube.
Cap not properly sealed	**1D**	The cap is not the proper size for the container and does not fully close	The liquid sample will leak out of the container	Hermetically seal the lid to the payload	**3D**	Complete: A rubber sealing disk was placed on top of the inner rack and under the lip of the lid adapter. This was done to help seal the liquid compartment and prevent leakage. The cap is then screwed on top and pushes down the edges of the seal further ensuring that no liquid will spill out.

Table 43 shows the failure mode of the propulsion system and the mitigation for such failures.

Table 43: Propulsion Failure Modes

Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**	**Verification Status**
Motor ignition failure	**3D**	Faulty motor, disconnected e-matches	Failure to launch. Rocket fires at an unexpected time	Team will follow proper directions when installing the igniter. In case launch	**3E**	**Complete** The checklist listed below, located in *safety section* under the title Launch Procedures are used as a method of verifying the mitigations • **Igniter Installation Checklist**

				vehicle fails to launch the team will follow NAR safety code and will wait a minimum of one minute before attempting to approach the launch vehicle		The team utilized the igniter installation checklist before every test launch to ensure the igniter is properly installed.
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**	**Complete** The team selected a commercially available Aerotech L1420R.(further details about the motor is located in **Motor selections** section) The **Full Scale launch**, located in *Section VII Project Plan* was used as a method of verifying that the motor function as predicted.
Exploding of the motor during ignition	**1D**	Faulty motor	Loss of rocket and/or motor	Commercially available motors will be used	**1E**	**Complete** The team selected a commercially available Aerotech L1420R.(further details about the motor is located in **Motor selections** section) The **Full Scale launch**, located in *Section VII Project Plan* was used as a method of verifying that the motor function as predicted.
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	**2E**	**Complete** The checklist listed below, located in *safety section* under the title Launch Procedures are used as a method of verifying the mitigations

				outside of the rocket to ensure proper length and placement of igniter		• **Igniter Installation Checklist** The team utilized the igniter installation checklist before every test launch to ensure the igniter is properly installed.
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**	**Complete** The construction procedure listed below, located in *Section II Vehicle Criteria* are used as a method of verifying the mitigation • **Aft Section (Booster)** The team has carefully attached the centering to the motor mount as describe in construction procedures for the booster section.
Premature burnout	**3C**	Faulty motor	Failure to reach target altitude	Commercially available motors will be used	**3E**	**Complete** The team selected a commercially available Aerotech L1420R.(further details about the motor is located in **Motor selections** section) The **Full Scale launch**, located in *Section VII Project Plan* was used as a method of verifying that the motor function as predicted.
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	**1E**	**Complete** The following subsection, located **6.8 NAR/TRA Procedures** were used as a method of verifying the mitigation: • *Rocket Motor Usage Plan* • *Storage* • *Transport*

				certified members and/or the team mentor according to guidelines outlined in the motor handling and storage section		• *Use of Rocket Motor* The team has followed all procedures outline in the subsection mention above to ensure only team members with the appropriate qualifications handle the motor.

Table 44 shows recovery failure modes and mitigations for such failures.

Table 44: Recovery Failure Modes

Risk	Pre-RAC	Cause	Effect	Mitigation	Post-RAC	Verification Status
Rapid decent	1C	Parachute is the incorrect size	Damage to airframe and payload, loss of rocket	RockSim9 along with various other calculations will be used to determines and estimate the decent rate.	1D	**Complete** Section 3.2.1.4 Parachute sizes and descent rates describes in further details the calculation that were uses to determine and estimate the descent rate.
Parachute deployment failure	1C	Parachute gets stuck in the coupler, parachute lines become	Loss of rocket, extreme damage to airframe, fins and other components	Parachute will be packed properly, RRC2+ altimeters will be tested before	1E	**Complete** The tests listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations, • **Parachute Packing and Running Test** The team successfully conducted parachute

		tangle		any launch to ensure they properly deploy the parachute		packing and running tests which ensure that parachute will open fully during flight preventing delayed deployment • **Ground Ejection Test** The team has successfully conducted several ground ejections to determine the correct amount of black powder used for the ejection charges to prevent an absence of deployment
Parachute separation	**1C**	Parachute disconnects from the U-bolt	Damage to rocket and all components	Parachute will be properly secure to the bulkheads with quick links and welded eye bolts, various test will be conducted to ensure parachute remains attached	**1E**	**Complete**. The test listed below, located in *Section VII Project Plan* are used as a method of verifying the mitigations • **Full Scale Launch** The team has successfully conducted a full scale launch that verified that the bulkheads did not detach from the airframe and parachutes stayed property secure to the bulkheads.
Tear in parachute	**2D**	Poor quality of parachute	Damage to rocket, rapid decent resulting in an increase of kinetic energy	Parachute will be inspected before each launch Only commercially available parachutes will be used	**2E**	**Complete** The test listed below, located in *Section VII Project Plan* was used as a method of verifying the mitigations • **Parachute Packing and Running Test** The team successfully conducted parachute packing and running tests which ensure that parachute will open fully during flight preventing delayed deployment. Both parachutes were inspected prior to each test.

Parachute becomes burn	**1C**	Parachute was improperly setup. Parachute is less effective or completely ineffective base on the severity of the damage inflicted on the parachute.	Damage to rocket due to increase of kinetic energy resulting in a rapid decent, loss of parachute	Nomex will be used to protect the parachute form burning	**2D**	**Complete** The checklist listed below, located in *safety section* under the title Launch Procedures are used as a method of verifying the mitigations • **Drogue Parachute Bay Checklist** The team utilized this checklist before any test launch in order to ensure that a Nomex blank will be wrap around the parachute
Slow decent	**2C**	Parachute is the incorrect size	Rocket drifts out of intended lading zone resulting in loss of rocket	RockSim9 along with various other calculations will be used to determines and estimate the decent rate	**2D**	**Complete** Section 3.2.1.4 Parachute sizes and descent rates describes in further details the calculation that were uses to determine and estimate the descent rate.
Gases from drogue deployment pressurize avionics bay and	**2B**	Hole made to run wires are not sealed	Early deployment of main parachute will cause rocket to drift far	All holes made to run wires will be sealed with epoxy. Flat washers and silicone grease will seal the spaces around all threads.	**3C**	The checklist listed below, located in *safety section* under the title Launch Procedures are used as a method of verifying the mitigations • **Final Assembly of the Avionics Bay** The team utilized the final assembly of the avionics bay checklist before every test launch to ensure that all holes were sealed

deploy main parachu te						
Avionic s electron ics unarme d	1A	Parachutes will not deployed	Destruction of launch vehicle injury to team or bystanders	Recovery launch checklist will be used to ensure that the recovery electronics are armed before the igniter is installed in the motor.	1D	The checklist listed below, located in *safety section* under the title Launch Procedures are used as a method of verifying the mitigations • **Final Assembly of the Avionics Bay** The team utilized the final assembly of the avionics bay checklist before every test launch to ensure that altimeters are armed.
Parachu te shroud line become tangled during deploy ment.	2B	Parachute was not correctly packed.	Destruction of launch vehicle upon impact due to the potential of the rocket becoming ballistic.	Parachute packing tests will be conducted in order to determine the best method of packing the parachutes.	1D	**Complete** The test listed below, located in *Section VII Project Plan* was used as a method of verifying the mitigations, • **Parachute Packing and Running Test** The team successfully conducted parachute packing and running tests which ensure the best method of packing the parachutes has been selected in order to prevent shroud line from becoming tangled during flight.
Altimet er or e-match failure	2C	Manufacture error	Parachute will not deploy. Rocket follows ballistic path.	Redundant altimeters and e-matches are incorporated into the recovery system to reduce this failure mode.	1E	**Complete** The checklist listed below, located in *safety section* under the title Launch Procedures Checklist are used as a method of verifying the mitigations • **Final Assembly of the Avionics Bay** The team utilized the final assembly of the

						avionics bay checklist before every test launch to ensure that altimeters are functional.
Parachute does not inflate	**2C**	Incorrect sized parachute was used.	Parachute does not generate enough drag	The parachute has been carefully selected based on multiple calculation and simulation via RockSims9.	**1E**	**Complete** Section 3.2.1.4 Parachute sizes and descent rates describes in further details the calculation that were uses to determine and estimate the descent rate.

Table 45 lists the operations failure modes.

Table 45: Operations Failure Modes						
Risk	**Pre-RAC**	**Cause**	**Effect**	**Mitigation**	**Post-RAC**	**Verification Status**
Laptop is non functional	**3D**	Laptop batteries does or not charge	GPS locator cannot be used, code cannot be modified	The batteries will be charged the night before, and the laptop will be powered down until the required day.	4E	**Complete** The checklist listed below, located in *safety section* have been used as a method of verifying the mitigation • **Safety Checklist: Pre-launch day** The team has utilized the check list before every test launch to ensure every item needed for launch day are packed .
Battery used to ignite motor does not provide sufficient charge	**3C**	Insufficient firing voltage	Launch vehicle does not launch	Redundant power sources will be used	4D	**Complete** The checklist listed below, located in *safety section* have been used as a method of verifying the mitigation • **Safety Checklist: Pre-launch**

						day The team has utilized this checklist before every test launch to ensure every item needed for launch day are packed .

5.3.1 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 46 introduces a description of the team's compliances with the NAR Safety Code.

Table 46: NAR/TRA Safety Code and Compliance		
	NAR Code	**Compliance**
1	**Certification**: I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only team members with the appropriate level of certification and the team mentor, Rick, who has a Level 2 TRA certification, will be allowed to handle rocket motors.
2	**Materials**: I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	All team members are responsible for using appropriate material on the rocket.

3	**Motors**: I will use only certified, commercially-made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, or heat sources within 25 ft of these motors.	Only rocket motors certified by TRA/NAR will be purchased and be handled by TRA certificated members of the team. Rocket motors will be stored in appropriate locations.
4	**Ignition System**: I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The team leader and safety officer are responsible for ensuring that the integration at the launch site is performed following the TRA safety code.
5	**Misfires**: If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket in question.	The Range Safety Officer (RSO) will have final say over all misfires that may occur at the launch site. The team members will follow all final ruling of the RSO.

6	**Launch Safety**: I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket, I will observe the additional requirements of NFPA 1127.	The rocket will be presented to the RSO, who will determine if the rocket is safe to launch.
7	**Launcher**: I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour, I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5, clearing that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	All launches will occur at the launch site(s) listed in Table 5 and under appropriate launch conditions. Launches at other launch sites beside those listed in the proposal will not be allowed The RSO will determine if the rocket is safe to launch.
8	**Size**: My rocket will not contain any combination of motors that total more than 40,960 Ns (9208 lb-sec) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	The team leader will be responsible to ensure the rocket follows these constraints.

9	**Flight Safety**: I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	The RSO will have final say regarding the rocket being allowed to be launched.
10	**Launch Site**: I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 ft, whichever is greater, or 1000 ft for rockets with a combined total impulse of less than 160 Ns, a total liftoff weight of less than 1500 g, and a maximum expected altitude of less than 610 m (2000 ft).	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 ft from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	All launches will occur at the launch site(s) listed in Table 5, Launches at other launch sites beside those listed in the proposal will not be allowed. The RSO will determine if the rocket is safe to launch.
12	**Recovery System**: I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The team leader and safety officer will ensure that the recovery system adhere to all of these requirements.
13	**Recovery Safety**: I will not attempt to recover my rocket	The safety officer will ensure that the team members

	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.	follow this requirement.

Table 47 shows the minimum distance required to ensure the safety of participants and spectators during a rocket launch.

Table 47: 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

5.3.2 Hazard Recognition and Pre-Launch Briefing

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

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

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

5.3.2.1 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.

5.3.2.2 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.

5.3.3 Rocketry Laws and Regulations

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

- No person may operate an unmanned rocket:
- In a manner that creates a collision hazard with other aircraft
- In controlled airspace
- At an altitude where the horizontal visibility is less than five miles
- Into clouds
- Within five miles of the boundary of any airport
- Within 1.500 ft of any person or property that is not associated with the operations
- Between sunset and sunrise (Sec.6(c). Department of Transportation Act (49 U.S.C. 1655(c)) [Doc.No. 1580, 28 FR 6722, June 29, 1963, as amended by Amdt. 101-4, 39 FR 22252, June 21, 1974]

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

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

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

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

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

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

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

5.3.3.1 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.

5.3.3.2 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.

5.3.3.3 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.

5.4 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.

5.4.1 Safety Contract

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

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

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

5.5 Environmental Concerns

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

While working on site the team will create some waste. Examples of waste the team may create include but are 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 ematches. Negative outcomes due to waste include but are not limited to: soil and water contamination, damage to wildlife. To prevent contamination and wildlife endangerment the team will adequately dispose of the waste in a designated container.

The team will be handling an unknown material. This material may be able to cause severe harm to anything it comes in contact with. In order to prevent possible harm to, or caused by the unknown material the team has constructed a container that will protect the material, as well as anything surrounding the unknown material (container discussed in section 7.1.1)

During and after launch there are several environmental hazards that may occur. When the rocket it taking off the motor will create a strong flame and thrust. This flame has the power to create a wildfire. To avoid this the team has launched in designated areas away from dry brush. The motors thrust will cause damage to the ground below it. The team will minimize the overall effect of the motors thrust to the ground below the launch rail by only launching the necessary amount of times to meet the requirements of the NASA student launch competition. After the rocket has launched, there is a slight possibility that it may collide with an aircraft or a surrounding building(s). The team will steer clear of launching while there are low clouds or aircraft in launch area. Additionally, the rocket will not exceed the permitted max altitude to avoid collisions with aircraft that may not be visible from the ground. Furthermore, the launch area is located in a field that is a safe distance from any buildings. After launching, the rocket could possibly fly directly into an object in the near vicinity. The team has constructed the rocket using a great amount of test and simulations to assure that this will not happen (rocket construction discussed in section 3.1 of this document). Additionally, the team will make sure the launch rail is in the correct position and is secured before launching the rocket. Equally important, after the rocket reaches apogee the parachutes have a small chance of failing, causing the rocket to come down ballistic which may result in harm to the environment and/or wildlife. The team is using a redundant altimeter system in the avionics bay to ensure deployment of the parachutes (discussed in section 3.6.2.3 of this document).

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

Table 48 lists the hazards and mitigations relating to the environment and the dangers it poses both to the team members and a successful launch.

Table 48: Environmental Hazards and Mitigations

Hazards	Cause	Effect	Pre-RAC	Mitigation	Post-RAC	Verification

Aircraft overhead (helicopters, planes, drones)	N/A	Inability to launch	1A	The team Checks the skies for any overhead aircraft and waits until they pass if one is present.	4A	Prelaunch procedures
Wild animal encounters	N/A	Injury to team member(s), possibly death	1C	The team always pays close attention to the dangers of the surrounding environment including any poisonous or threatening wildlife that may be in the surrounding area. The team is instructed to wear close-toed shoes and long pants at all times when working in such an environment.	3C	N/A
UV damage	Sun	Inability to launch rocket, damage to electronics, and possible explosions	2A	The team has worked in shaded area and has kept all components from being exposed to the sun for too long.	2E	Safety procedures
Harmful substances contaminating the ground and or water	Improper disposal of hazardous materials (batteries, aerogel, silicone	Harm to the surrounding wildlife which can result in human injury	2A	The team has properly dispose of all hazardous materials in marked containers.	2E	Safety procedures
Dangerous weather conditions (wind, rain, extreme heat, extreme cold)	N/A	Inability to launch, damage to electronics and rocket	2C	The team has planned ahead and checked weather conditions for the launch day. As well as keeping rocket electronics and parts in the shade when not in use.	3E	Prelaunch procedures

Heavy and/or low clouds	N/A	Inability to launch rocket	2C	The team has planned ahead and checked the forecast for set launch days.	4E	Prelaunch procedures
Heat stroke	Sun	Unconsciousness and possible bodily harm	1D	The team's work has been conducted in a shaded area if possible and water has been available when exposed to extreme weather conditions.	4D	Safety procedures
Hazard to successful rocket retrieval (trees, telephone/power lines, highways or moving vehicles)	N/A	Damage to rocket and/or loss of rocket	1D	The team's rocket was launched in an unpopulated area away from trees, telephone/power lines, highways or moving vehicles to ensure its safe retrieval.	4D	Prelaunch procedures
Sunburn	Sun	Skin Irritation and pain	3D	The Team has applied Sunscreen when necessary and work has been conducted in the shade whenever possible.	4E	Safety Procedures
Humidity	N/A	Inability to light motor or black powder	3D	The team has kept the ematches, motors, and black powder stored in a safe location away from the humidity.	4E	Prelaunch procedures
Muddy ground	Rain	Inability to launch, possible injury to team members due to failing or getting stuck in mud	3D	The team has checked the forecast for heavy rains before each launch, if the rain was too strong on or near the designated launch day the team rescheduled the launch date.	4E	Prelaunch procedures
Bodies of water (lakes, ponds, rivers)	N/A	Loss of rocket, and damage to electronics	1E	The team has checked the landscape to make sure that there were no large bodies of water near the launch site.	4E	Prelaunch procedures

Motor overheating or exploding	Sun	Injury to team member(s) and/or surrounds	1E	The team has kept the motor in a cool area at all times before launch.	4E	Safety procedures
Spray paint	The rocket will be spray painted	Contaminate surround water and/or ground	1E	The team will spray paint the rocket in secure ventilated area	4E	Safety procedures
Polycarbonate waste	Payload is lost during launch	Contaminate surround water and/or ground	1E	The team has performed multiple test to ensure that the payload will be recovered safely	4E	Prelaunch procedures

Table 49 below list the team's possible risks to the project, likelihood of those risks, impact of those risks, mitigations, and impact of those mitigations

Table 49: 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.

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.
Unsuccessful recovery	Low	High	The team has built two rockets simultaneously in case the one of the rockets was destroyed or lost.	If the team must build more than the two planned rockets, 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 easily distributed amongst the remaining team members.	If the team must increase their individual work load there is a slight chase the project may fall behind schedule, but new timelines will be made to accommodate changes to redirect the project back on schedule.
Failure to launch	Medium	High	The team has set multiple launch dates to ensure that a successful launch could be recorded in time for each competition checkpoint.	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.
Equipment malfunction	Medium	Low-High	The team has tested the equipment multiple times before inserting it into the rocket to ensure that the equipment's performance is at the desired level.	No significant impact results from this mitigation.

Loss of equipment	Medium	High	The team has several copies of each piece of equipment that will be used throughout the project.	If too many pieces of equipment are broken or loose the budget will increase, but the team is prepared to fundraise any additional fund that may be necessary to complete the project.

VI. Launch Operations Procedures

6.1 Launch Operation Procedures

Tables 50-56 outline the preliminary procedures required for all launch vehicle systems along with the corresponding potential hazards caused by disregarding a step. The safety gear and personnel required to complete and verify the steps are listed in the tables below.

6.2 Recovery Preparation

6.2.1 Main Parachute Bay Checklist

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

  and secure with zip ties
- Roll the shock cords into loops and secure them with masking tape.
- Insert prepared shock cords along with main parachute into the main bay.

6.2.2 Drogue Parachute Bay Checklist

- Ensure that the harnesses are secured with quick-links to the drogue and avionics bay.
- Verify the absence of snags and obstructions inside of the drogue bay visually and manually.
- Inspect drogue parachute for any cuts, burns, lose stitching and any other damage
- Note: If damaged is identified, the team lead and safety officer will be immediately informed.
- Lay parachute flat out
- Inspect shroud line and endure lines are taut and not tangled
- Fold drogue parachute
- Attach shroud line to the quick-link
- Wrap the Nomex blanket around the parachute
- Secure the shock cords to their respective U-bolts in the drogue bay
- Cover the knots on the shock cords where the quick-links are attached with masking tap
  and secure with zip ties
- Roll the shock cords into loops and secure them with masking tape.
- Insert prepared shock cords along with drogue parachute into the drogue bay.
-

6.2.3 Avionics Bay Checklist

- Ensure the batteries have a 9-V charge with a multi-meter
- Verify wires are properly attached.
- Tug on wires to ensure they are properly secure.
- Verify that the altimeters are mounted above the sled with a minimum of 0.125 in on standoffs and fastened on the electronics sled properly.
- barometric sensor is mounted on the bottom of the altimeter to ensure the tiny holes use to sample the air are not blocked by mounting the altimeter too tight on the sled a credit card will be slip.
- Connect the wire terminal for switches.
- Attach batteries to battery clips
- Verify that the arming switches engage all subsystems.
- Slide the electronics sled into the avionics bay

- Attach bulkhead at both ends with threaded rods, washers and wing nuts ensure that the hardware is properly assembled and secure
- Connect the wire terminal for the drogue and the main ejection charge
- Turn switches to on positon in order to verify continuity and battery voltage
- Return switches to off position
- Grease and secure bulkheads.
- Unwind the E-matches, and place the pyrotechnic end of the e-match into the ejection canisters
- Secure the e-match with duct tape
- Place pre-measure black powder into the ejection canisters
- Ensure the pyrotechnic end is submerged in the black powder
- Place wadding paper inside the ejection charges to eliminate excess space
- Seal with duct tape

Connect e-matches to the terminal located on the bulkhead

Table 50 lists procedures for the recovery preparation as well as the hazards that can result from not properly following them. The required PPE and personnel required to complete and verify each step are also listed.

Table 50: Recovery Preparation			
Main Parachute			
PPE	**Procedure**	**Hazards**	**Verified By**
-N/A	Attach 40 ft. 1" thick harness to the bulkheads in the main parachute bay and avionics bay using a quick-link	Not attaching the harnesses to the airframe or the parachute will results in severe damage to the launch vehicle	One team member
-N/A	Inspect parachute bay for obstructions or damages	Unobserved obstructions or damages in the airframe may result in	One team member
-N/A	Attach a 24 in Nomex blanket to the quick-link that is 42 in from the	The parachute and shock cords may burn from the ejection gases or	One team member

	avionics bay	catch fire at deployment resulting in possible damage to the launch vehicle	
-N/A	Attach parachute	Not attaching the parachute will result in a ballistic descent of the launch vehicle and damage to the launch vehicle	One team member
-N/A	Inspect shroud lines for tangles or damages	Tangles in the shroud lines may result in the parachute not fully opening after deployment. This would result in damage to the launch vehicle.	Two team members
-N/A	Check parachute for damages	Any damage to the parachute weakens it and may result in the parachute tearing during the launch vehicle's descent. This would reduce the ability of the parachute to decrease the descent velocity resulting in damage to the launch vehicle	Two team members
-N/A	Fold main parachute as described section7.1 *Testing* in the Parachute Packing and Running Test	Improperly folding the parachute may result in it not fully opening at descent	Two team members
-N/A	Cover in Nomex	The parachute and shock cords may burn from the ejection gases or catch fire at deployment resulting in possible damage to the launch vehicle	One team member
-N/A	Cover knots where quick-links are	Not covering the knots in tape and zip	Two team members

	attached with masking tape and zip ties	ties may result in damage to the knots from ejection gases or the knots coming undone. This would result in the shock cord detaching from the launch vehicle.	
-N/A	Make several bundles of 3 or 4 loops from the shock cord and secure with masking tape	Failure to loop the shock cord may result in it tangling with itself. This could lead to the parachute becoming tangled in the shock cord and not fully opening.	One team member
-N/A	Check all connections and insert parachute and shock cords into main parachute bay	Failure to do so could result problems in the recovery system going unnoticed.	Safety officer and team mentor
Drogue Parachute			
-N/A	Tie two 0.5 in thick 1 ft long elastic together and loops 4 times through two knots in the shock cord spaced 22 in apart and 32 in from the booster section	Not attaching the elastic cords may result in the main parachute bay opening when the drogue parachute is deployed. The force of this deployment is too great for only the sheer pins to hold the main parachute bay together.	One team member
-N/A	Loop another set of elastic cords 3 times through two knots in the shock cord 7 in from the first elastic loop set and spaced 21 in apart.	Not attaching the elastic cords may result in the main parachute bay opening when the drogue parachute is deployed. The force of this deployment is too great for only the sheer pins to hold the main parachute bay together.	One team member
-N/A	Attach the 35 ft.	Not attaching the	One team member

	long 1” thick harness to the bulkheads in the drogue parachute bay and avionics bay using a quick-link	harnesses to the airframe or the parachute will results in severe damage to the launch vehicle	
-N/A	Inspect parachute bay for obstructions or damages	Unobserved obstructions or damages in the airframe may result in	One team member
-N/A	Attach a 24” Nomex blanket to the quick-link	The parachute and shock cords may burn from the ejection gases or catch fire at deployment resulting in possible damage to the launch vehicle	Two team members
-N/A	Attach parachute	Not attaching the parachute will result in a ballistic descent of the launch vehicle and damage to the launch vehicle	Two team members
-N/A	Inspect shroud lines for tangles or damages	Tangles in the shroud lines may result in the parachute not fully opening after deployment. This would result in damage to the launch vehicle.	Two team members
-N/A	Check parachute for damages	Any damage to the parachute weakens it and may result in the parachute tearing during the launch vehicle’s descent. This would reduce the ability of the parachute to decrease the descent velocity resulting in damage to the launch vehicle	One team member
-N/A	Fold drogue	Improperly folding	Two team

	parachute as described in section7.1 *Testing* in the Parachute Packing and Running Test	the parachute may result in it not fully opening after deployment.	members
-N/A	Cover in Nomex blanket	The parachute and shock cords may burn from the ejection gases or catch fire at deployment resulting in possible damage to the launch vehicle	One team member
-N/A	Cover knots where quick-links are attached with masking tape and zip ties	Not covering the knots in tape and zip ties may result in damage to the knots from ejection gases or the knots coming undone. This would result in the shock cord detaching from the launch vehicle.	One team member
-N/A	Make several bundles of 3 or 4 loops from the shock cord and secure with masking tape	Failure to loop the shock cord may result in it tangling with itself. This could lead to the parachute becoming tangled in the shock cord and not fully opening.	One team member
-N/A	Check all connections and insert parachute and shock cords into drogue parachute bay	Failure to do so could result problems in the recovery system going unnoticed.	Safety officer and team mentor
Avionics Bay			
-N/A	Check all wiring and connections	Failure to do so may result in improper wiring and soldering going unnoticed. This could result in the parachute deployments not occurring or occurring at	One team member

		incorrect altitudes.	
-N/A	Check battery voltages using a multi meter	Not checking the battery voltage may result in the altimeters not receiving appropriate voltage to deploy the parachutes.	One team member
-N/A	Connect JST connectors to electrical components	Failure to do so would result in the circuit not being closed and the parachutes not deploying.	One team member
-N/A	Tape female and male JST connectors to each other.	Failure to do so could result in the JST connections becoming detached.	One team member
-N/A	Insert new batteries and secure with zipties	Using old batteries could result in the altimeters not having enough power to operate. Batteries that are not properly secure could become disconnected from the altimeters resulting in a failure of the recovery system.	One team member
-N/A	Turn on altimeters	Failure to do so would result in the parachutes not being deployed and the launch vehicle being damaged.	One team member
-N/A	Close avionics bay with bulkheads and secure each side with nuts and washers	An improperly closed avionics bay could result in wires disconnecting and lead to a failure of the recovery system.	One team members
Goggles, gloves	Insert an e-matches into the primary and redundant ejection canisters for the main and drogue	Failure to do so would result in the ejection charges not firing at the set altitudes	Safety officer and team mentor
Goggles, gloves	Pour premeasured	Not pouring the	Team mentor

	black powder into redundant and primary ejection canisters. The main parachute ejection canisters contain 5.37 g of black powder and the drogue canisters contain 2.86 g. Make sure the e-match is completely covered.	black powder into the ejection canisters will result in the ejection charges not firing. This would result in a failure of the recovery system and damage to the launch vehicle.	
Goggles, gloves	Place 12 sheet of Estes recovery wadding paper into the ejection canisters, covering the e-match and black powder.	Failure to add the wadding paper may result in the e-match moving around in the ejection canister and not being in contact with the black powder. This would result in the ejection charges not firing.	Safety officer and team mentor
Goggles, gloves	Cover the ejection canisters with duct tape sealing the edges to prevent black powder from spilling out.	Failure to do so would result in the black powder falling out of the canisters. If this were to happen the ejection charges would not fire.	Safety officer and team mentor
-N/A	Connect e-matches to the wires running to the altimeters.	Failure to do so would result in the ejection charges not firing at their set altitudes or at all.	Safety officer and team mentor
Gloves	Apply super lube to the outside of the avionics bay bulkheads and insert in between the middle section and booster section	Not applying super lube to the avionics bay bulkheads could result in the bulkheads burning from the ejection charges.	Safety officer

6.3 Motor Preparation

Motor Preparation Checklist

- Prepare motor as described by the Aerotech user manual
- Verify motor assembly with team mentor
- Find appropriate igniter length and add tape to mark place on igniter
- Loaf motor into launch vehicle
- Install motor retention system

Table 51 lists the detailed procedures for the motor preparation as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 51: Motor Preparation Procedures

PPE	Procedure	Hazards	Verified By
Forward Closure Assembly			
-Safety goggles -Safety gloves	Apply a light coat of Synco Super Lube to all the threads and all O-rings	Failure to add a coat of super lube may result in the O-rings burning or becoming damaged.	One team member
-Safety goggles -Safety gloves	Hold the forward closure in a vertical position, keep the smoke charge cavity facing up.	Improper positioning of the forward closure hinders assembly of the motor.	One team member
-Safety goggles -Safety gloves -Respiratory mask	Place the smoke charge insulator into the smoke cavity.	Improper placement of the smoke charge insulator may result in delay of the motor assembly.	One team member
-Safety goggles -Safety gloves	Verify that the smoke charge insulator is seated against the forward end of the cavity	Improper placement of smoke charge insulator can lead to motor failure.	One team member
-Safety goggles -Safety gloves	Apply Synco Super lube to one end of the smoke charge element	Failure to do so may result in the last grain fully burning through and the motor casing becoming damaged.	One team member
-Safety goggles -Nitrile gloves	Insert the lubed end of the smoke charger into the smoke charge cavity until it is seated against the end of the cavity	Improper placement of smoke charge can lead to motor failure.	One team members

Case Assembly			
-Safety goggles -Safety gloves	Cut both inside edges of the liner tube	Failure to cut both edges of the liner tube can lead to motor failure.	One team member
-Safety goggles -Safety gloves	Insert the larger diameter portion of the single throat nozzle into one end of the liner (nozzle liner flange must be seated against the liner)	Improper insertion of the nozzle can lead to motor failure.	One team member
-Safety goggles -Safety gloves -Respiratory mask	Hold the liner in a horizontal position and place three grain spaces O-rings between each propellant grains	Improper positioning of the linear can lead to incorrect placement of the O-rings, which can lead to motor failure.	One team member
-Safety goggles -Safety gloves	Inspect that the aft grain is seated against the nozzle grain flange	Improper placement of the aft grain can result in motor failure.	One team member
-Safety goggles -Safety gloves	Place the greased seal disk O-ring into the groove of the forward seal disk	Improper placement of O-rings can lead to motor failure.	One team member
-Safety goggles -Safety gloves	Place the smaller end of the seal disk onto the open end of the liner tube	Improper placement of the seal disk can lead to motor failure.	One team member
-Safety goggles -Safety gloves	Place a light coat of grease on the outside surface of the linear	Failure to add a coat of super lube may result in	One team member
-Safety goggles -Safety gloves	Insert the liner into the motor case leaving the nozzle to protrude approximately 1-3/4" from the end of the case	Failure to do so may result in damage to the motor casing.	One team member
-Safety goggles -Safety gloves	Place the greased aft O-ring into the groove in the nozzle	Omitting this O-ring may result in an improperly sealed motor case. This could result in damage to the booster section.	One team member
-Safety goggles -Safety gloves	Manually thread the aft closure into the aft	Failure to do so may result in the motor	One team member

	end of the motor case until it is seated against the case	casing becoming displaced within the booster section.	

6.4 Setup on Launcher

Launch Vehicle Final Assembly Checklist

- Slide vehicle onto launch rail
- Ensure vehicle is properly secured to launch rail
- Raise rail to vertical position

Arm recovery electronics

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

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

Safety Officer: ______________ Date: ______________

Launch time: _______________

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

6.5 Igniter Installation

Igniter Installation Checklist

- Tread igniter through plastic cap
- Install igniter, ensuring that the igniter is inserted completely into the motor and apply tape at the bottom
- Secure cap to prevent igniter from falling out
- Check ignition system alligator clips for live wires

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

Table 52 lists the final procedures required to install the igniter into the launch vehicle as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 52: Igniter Installation			
PPE	**Procedures**	**Hazards**	**Verified By**
-N/A	Insert the coated end of the igniter through the nozzle until it stops against the smoke charge element	Improper installation of the igniter can result in an unsuccessful launch.	Team leader
-N/A	Secure the igniter to the nozzle with a piece of making tape	Improper installation of the igniter can result in an unsuccessful launch.	A minimum of two team members

6.6 Launch Procedures

Table 53 lists the launch procedures as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed. All procedures listed will be accomplished within 1.5 hours the day prior to the launch.

Table 53: Launch Procedures			
PPE	**Preliminary Procedure**	**Hazards**	**Verified By**
-Safety glasses -Safety gloves	Weigh and package black powder for: Main1:_____(5.37g) Drogue1:____(2.86g) Main 2:_____(5.37g) Drogue2:____(2.86g)	Failure to properly store the black powder could result in leakage leading to additional black powder being required.	Safety officer
-N/A	Pack all equipment/supplies listed on the launch supply list Note: Launch supply list is located in Safety section	Failure to use the supply list could result in missing tools or materials needed for launch day preparation or last minute repairs.	Team leader and two additional team members
-N/A	Follow the list of preliminary procedures created by the safety officer during each launch	Failure to follow the procedures may result in missed crucial steps, thus compromising project safety and integrity.	Team leader
-N/A	Check and record the voltage of batteries for altimeters (9V min) Battery 1: _______ Battery 2: ________	Failure to inspect battery voltages may result in batteries with insufficient voltages for launch. This could lead to parachute deployment or GPS failure.	Safety officer

6.7 Troubleshooting

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

6.7.1 Recovery System/ Altimeters(s)

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

6.7.2 Igniter Installation

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

6.7.3 Recovery System

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

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

6.7.4 Motor preparation

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

6.7.5 Launch Pad

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

6.8 Post-flight Inspection

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

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

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

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

Table 54 outlines the procedures for inspection.

Table 54: Inspection for Damage and Collection of Data	
Steps	**Verified By**
Disarm recovery electronics	

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

Table 55 shows the procedures for launch vehicle re-launch.

Table 55: Prepare Launch Vehicle for Re-launch	
Steps	**Verified by**
Clean motor and motor casing (See Motor Cleaning Checklist for further detailed)	
Remove samples from payload	
Prepare parachutes, repair small tears	
Prepare all other system (refer to launch checklist to ensure proper assembly and preparation)	

6.8.1 Motor Cleaning Checklist

- Wait for the motor to cool down
- Unthread and remove forward and aft closures
- Discard the smoke charge insulator locates in the forward closure
- Remove all smoke charge and propellant reduces from the closure using damp paper towels
- Discard o-rind from the motor case
- Remove the seal disk and nozzle from the casing
- Remove the forward seal disk from the liner

Table 56 lists the procedures required for the post flight inspection of the launch vehicle and payload as well as the hazards that can result from not properly following the procedure. The required PPE and personnel required to complete and verify each step are also listed.

Table 56: Post-flight Inspection			
PPE	**Preliminary Procedures**	**Hazards**	**Verified By**
Launch Vehicle			
-N/A	Inspect surface of the booster section, middle section and forward section	Failure to inspect the surface of the launch vehicle can result in launching an unsafe launch	Two team members

		vehicle.	
-N/A	Inspect altimeters and record altitude	Failure to inspect altimeter will result in absence of data	Team leader and safety officer
-N/A	Inspect all tubes interface connections	Failure to check all tube interfaces may result in premature separation or no separation	Minimum of two team members
-N/A	Verify that the sample(s) is secured within the payload properly	Failure to properly secure the sample(s) may result in payload malfunction and thus a damaged sample.	Payload specialist

VII. Project Plan

7.1 Testing

Required Tests

The following tests were conducted in order to determine the integrity of the launch vehicle and payload design:

- Payload drop test
- Payload compression strength test
- Payload impact test
- Payload heat resistance test
- Payload compartment adjustment test
- Payload compartment weight test
- Parachute packing and running test
- Altimeter test
- Ground ejection test
- Center of gravity test
- Sheer pin/ shock cord drop test
- GPS testing
- Subscale launch

- Full scale test launch
- Full scale set up test

7.1.1 Payload drop test

- ➢ This test was design to simulate the force the payload and its contents will experience during the rocket launch.

Objective

- To determine if the payload will be able to protect various fragile materials from a 8’ drop.

Success Criteria

- The material(s) are recovered in the same condition as they were before being secured in the payload.

Variable

- The testing variable is the functionality of the payload.

Table 57 includes all variables of the payload drop test.

Table 57: Variables of Payload Drop Test	
Independent	**Dependent**
Fragile material	Material survival
Size of fragile material	
Amount of fragile materials used	

Methodology

The steps necessary to complete this test are listed below.

1. Secure the fragile material(s) into an inner rack compartment
2. Insert the inner rack into the payload body
3. Seal the payload
4. Measure a height of 8’ with a tape measure

5. Drop the loaded payload from the measured 8’ location
6. Recover payload
7. Open the payload
8. Remove the inner rack from the payload body
9. Remove the fragile material(s) from the inner rack compartment(s)
10. Inspect the material(s)
11. Repeat steps 1-10

Results

- The test was done with eggs (shown in figure 80) and light bulbs (shown in figure 81-82). The test was a success in both trials.

Figure 80: Egg Drop Test (Before and After)

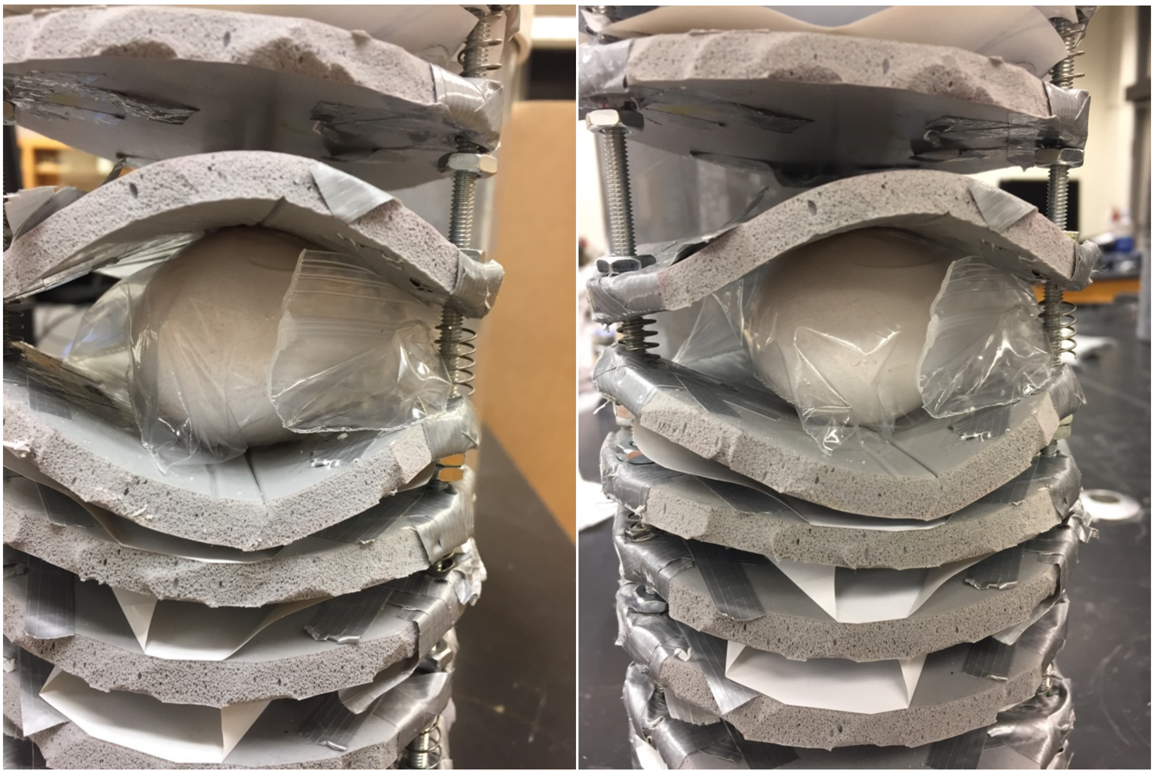


Figure 80 shows the egg inside of the inner rack before(left) and after(right) the drop test was done.

Figure 81: Light Bulb Drop Test (Before and After)

Figure 81 shows the light bulbs inside the inner rack compartment before(left) and after(right) the drop test was done.

Figure 82: Light Bulb Drop Test

Figure 82 shows where the light bulb drop test was performed.

Figure 83: Egg Drop Test

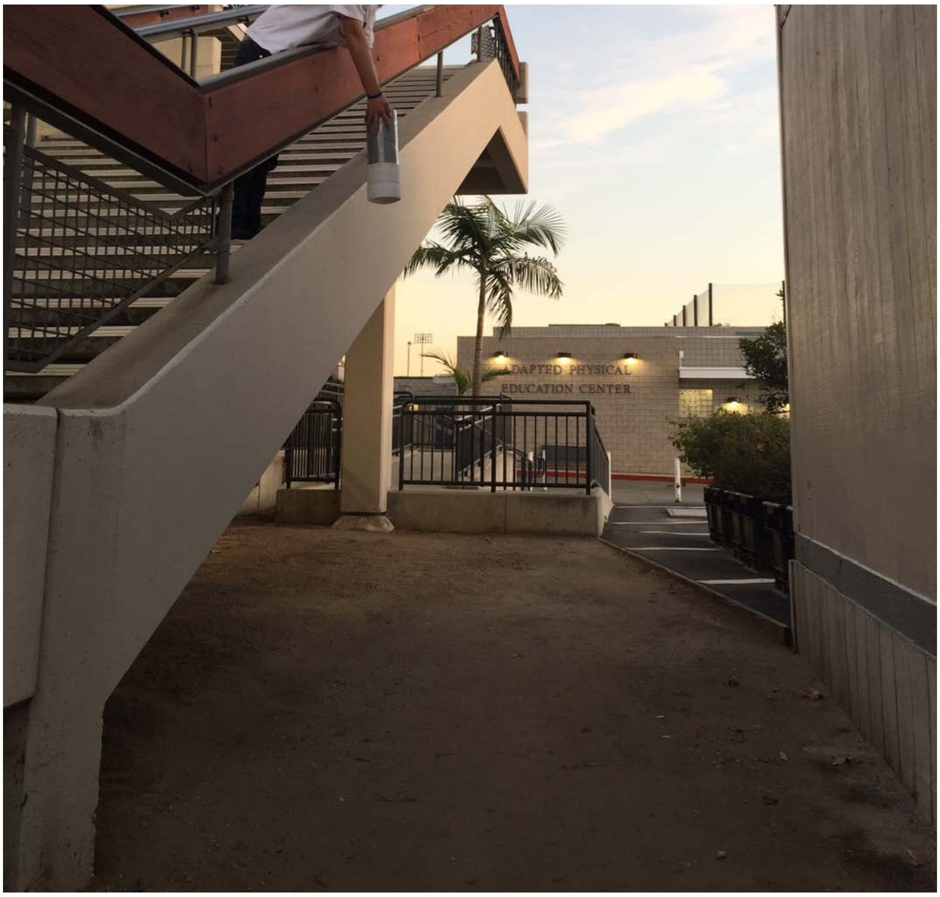


Figure 83 shows where the egg drop test was performed.

7.1.2 Payload Compression Strength Test

- This test was designed to measure the compression strength of the completely assembled payload.

Objective

- To determine whether or not the payload is strong enough to withstand the applied force of the rocket launch.

Success criteria

- No damage to any component of the payload. This includes crack, chips, or components being broken off.

Variables

- The testing variable of this experiment is the strength of the payload.

Table 58 lists all variables of the strength test.

Table 58: Variables of Impact Test	
Independent	**Dependent**
Weights	Applied force
Position of weights	

Methodology

The necessary steps needed to complete this test are listed below. Fully assemble payload and secure lid

1. Lay the payload on its side
2. Surround the payload with wooden blocks
3. Place a 45lb weight onto the side of the payload
4. Increase the amount of weight by 45lb until 325lbs have been placed onto the side of the payload
5. Remove the weight
6. Position the payload upright
7. Place a 45lb weight onto the top of the payload
8. Increase the amount of weight by 45lb until 325lbs have been placed onto the top of the payload
9. Remove the weights
10. Inspect the payload for damage

Results

- The sample container successfully withstood 1420N of force with no visible damage.

7.1.3 Payload Impact Test

- This test was designed to measure the impact strength of the completely assembled payload.

Objective

- To observe if the payload design can withstand the impact from a fall from 4ft, 6ft, and 8ft

Success criteria

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

Variable

- The testing variable of this experiment is the impact strength of the payload.

Table 59 lists all variables of the impact test.

Table 59: Variables of the Payload Impact Test	
Independent	**Dependent**
Drop height	Payload impact strength

Methodology

The necessary steps needed to complete this test are listed below.

1. Manually drop the payload from a measured height of 4ft
2. Inspect the payload for damages
3. Manually drop the payload from a measured height of 6ft
4. Inspect the payload for damages
5. Manually drop the payload from a measured height of 8ft
6. Inspect the payload for damages

Results

- Initially the 4ft drop test failed because the bottom plate and inner chamber disconnected from the outer shell. To improve the design of the payload the team changed how the bottom plate was connected and used Weld-on adhesive instead of plastic epoxy. With the improvements made to the payload all the test results were successful. This ensured that the payload will be able to withstand the impact felt during the flight and landing of the launch vehicle.

7.1.4 Payload Heat Resistance Test

- This test was designed to determine whether the individual components of the payload can withstand a specific temperature for a set time.

Objective

- To determine whether or not the proposed materials are capable of withstanding a max temperature of 1500°F without any damages.

Success criteria

- The materials must be able to withstand a minimum temperature of 1500°F for 60 seconds without damage. This includes severe burns or melting of materials.

Variables

- The testing variable of this experiment is the heat resistance of the materials.

Table 60 lists the all variables of the heat test.

Table 60: Variables of Payload Heat Test	
Independent	**Dependent**
Applied heat	Physical property of material
Heat resistance of material	
Duration that heat is applied	

Methodology

The necessary steps needed to complete this test are listed below.

1. Apply a 1500 °F flame to an individual payload component in 5 seconds intervals
2. Repeat for a total time of 60 seconds, examining the component every 10 seconds
3. Use steps 1 & 2 for every payload component

Results

- No major damages were found on any of the materials. There was no burning or melting of the materials and the test was considered successful.

7.1.5 Payload Compartment Adjustment Test

- This test was designed to observe the time it takes to load the inner rack with samples of different sizes and shapes.

Objective

- To ensure that each compartment is accessible and can be adjusted to different sizes quickly.

Success Criteria

- The inner rack can be filled with samples in each compartment and set in the container under 1 hour.

Variable

- The testing variable of this experiment is the speed of adjusting and loading the inner rack compartments.

Table 61 lists the all variables of the compartment adjustment test.

Table 61: Variables of the Payload Compartment Adjustment Test	
Independent	**Dependent**
Adjusting of compartments	Number of compartments used
	Compartment sizes
	Speed of compartment adjustment

Methodology

The necessary steps needed to complete this test are listed below.

Trial 1: Standard Eggs

1. Use as many raw eggs needed to obtain a max weight of 4oz
2. Start a timer
3. Place an egg inside each inner rack compartment as described in section 3.7.1.1 of this document.
4. Place the loaded inner rack into the container
5. Seal the container
6. Stop the timer and record time

Trial 2: Quail Eggs

1. Use the same steps as Trial 1with Quail eggs

Trial 3: Shot Glasses

1. Use the same steps as Trial 1 with shot glasses

Trial 4: Light Bulbs

1. Use the same steps as Trial 1with light bulbs

Trial 5: Glass Christmas ornaments

1. Use the same steps as Trial 1with Christmas ornaments

Results

- The test was successful in all trials.

7.1.6 Payload Compartment Weight Test

- This test was designed to observe if each individual compartment in the inner rack can hold a specific weight.

Objective

- To determine if each compartment of the inner rack can support a maximum weight of 1lbs

Success Criteria

- Each compartment is able to support a weight of 1lbs with no major damages

Variable

- The testing variable is the compartment's weight capacity.

Table 62 includes all variables of the compartment weight test.

Table 62: Variables of Compartment Weight Test	
Independent	**Dependent**
Weight	Compartment weight capacity
Compartment Material	

Methodology

The steps necessary to complete this test are listed below.

12. Adjust an individual inner rack compartment to fit an 1lb weight
13. Secure the weight inside of the compartment
14. Leave the secured weight inside the compartment for 5 minutes
15. Place inner rack inside the container
16. Seal container
17. Rotate and shake container

18. Remove the weight
19. Inspect the compartment for damages
20. Repeat steps 1-8 for all compartments

Results

- The test was successful for all components.

7.1.7 Parachute Packing and Running Test

- This test was designed to evaluate different parachute packing techniques.

Objective

- To determine if the parachute is packed properly for optimal parachute ejection

Success criteria

- Parachute must open fully and within 5 seconds of running

Variables

- The testing variable is time it takes for the parachute to open.

Table 63 lists the independent and dependent variables of the test

Table 63: Variables of the Parachute Test

Independent	Dependent
Running speed	Opening speed
Distance ran	
Parachute packing technique	

Methodology

The necessary process needed to complete this test is described below.

- The parachute was laid flat on the ground and the shroud lines were detangled. The right edge of the parachute was folded towards the center of the parachute and then the left edge was folded towards the center. The shroud lines were then folded into the parachute and each edge was again folded toward the center. The parachute was rolled vertically and then folded horizontally twice. It was then rolled into a small bundle. A team member held onto a shock cord connected to the shroud lines while another team member held the packaged parachute in the air. The team member holding the shroud lines ran downhill pulling the parachute which then unraveled and opened. Figure 84 - 87 shows the snapshot of four trials of the parachute packing and running test. Figure 88 shows the packing technique that the team has chosen to use.

Results

- The test was successful. No shroud lines were tangled. The parachute opened easily when folded in the manner described above.

Figure 84: Parachute Packing and Running Test (Trial 1)

Figure 84 shows the parachute opens fully.

Figure 85: Parachute Packing and Running Test (Trial 2)

Figure 85 shows the parachute opens fully.

Figure 86: Parachute Packing and Running Test (Trial 3)

Figure 86 shows the parachute opens fully.

Figure 87: Parachute Packing and Running Test (Trial 4)

Figure 87 shows the parachute opens fully.

Figure 88: Parachute Folding (Complete)

Figure 88 shows the process used to fold the parachute before the parachute run test.

7.1.8 Altimeter Test

- ➢ This test was designed to ensure the functionality and consistency of the altimeters used in the rocket.

Objective

- To determine if the altimeters are working properly and recording the correct altitudes

Success criteria

- Altimeters record altitudes that are consistent with the air pressure of

Variable

- The testing variable is the recorded altitude

Methodology

The necessary steps needed to complete this test are listed below.

1. Connect the altimeter to a 9V battery
2. Place the powered altimeter into the custom made pressure chamber
3. Turn the pressure up to 14.43 PSIA
4. Turn the chamber off
5. Remove the altimeter
6. Record the altitude given by the altimeter
7. Wipe the altimeters memory
8. Repeat steps 2-7 using 14.16 PSIA and 12.10 PSIA

Results:

N/A

7.1.9 Ground Ejection Test

- This test was designed to determine the correct amount of black powder for the ejection charges.

Objective

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

Success criteria

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

Variable

- The testing variable is the amount of black powder used for the ejection charges.

Table 64 lists all variables of the Ground Ejection Test.

Table 64: Variables of Ground Ejection Test	
Independent	**Dependent**
Amount of black powder	Ejection thrust
Voltage used	

Methodology

The necessary process needed to complete this test is described below.

- Calculations were done using the equation below to determine the amount of black powder needed to eject the drogue and main parachute. The necessary mass of black powder was then weighed and inserted into small bags. The drogue ejection charge was set up first. Black powder was poured into the drogue ejection canister and the redundant charge ejection canister. An e-match was then placed in the black powder and 5 sheet of wadding paper was placed into each ejection canister. The canisters were then sealed with duct tape and the e-match was wired through the avionics bay. The launch vehicle was placed horizontally on top of a box to simulate conditions it will experience at apogee. Once each team member was a safe distance from the launch vehicle the wires connected to the e-matches were then connected to a 9 volt battery initiating the charge. After the blast the launch vehicle was inspected to ensure that the success criteria was met. The avionics bay was then removed and the ejection charges for the main parachute were then prepared in the same manner previously described. The box was then arranged vertically and the launch vehicle was placed against it at a 60° angle to simulate conditions felt at the deployment of the main parachute. The wires were connected to the 9 volt battery and the charge was initiated. The launch vehicle was then inspected to ensure there were no damages and that all success criteria was met.

Results

➢ The first test was a failure. The team recalculated the amount of black powder needed and repacked the ejection charges. The second test was a success with both sections separating fully and the shock cords being fully exposed as well as all the sheer pins being sheered. Figures 89 – 90 shows the second ground ejection test.

Figure 89: Main Parachute Ground Ejection Test (Complete)

Figure 89 displays the complete ground ejection test of the main parachute.

Figure 90: Drogue Parachute Ground Ejection Test (Complete)

Figure 90: Displays the complete ground ejection test of the drogue parachute.

7.1.10 Center of Gravity Test

➢ This test was designed to find the center of gravity of the launch vehicle.

Objective

- To determine the center of gravity of the launch vehicle

Success criteria

- Determine a center of gravity within a 3 unit range of the CG recorded in RockSim

Variable

- Center of gravity of the launch vehicle

Methodology

The necessary process needed to complete this test is described below.

- A rope was secured to a second story railing and a loop was tied at the hanging end. The launch vehicle was suspended in the air with the rope. It was adjusted along the length of the airframe until the launch vehicle remained in a stable horizontal position. The location of the rope was then marked on the airframe and the launch vehicle was removed from the rope. The distance from the top of the nose cone to the CG was then measured.

Results

- The CG of the launch vehicle was recorded to be 63.2” from the nose cone tip, which is 1.58” different from the CG estimated in RockSim.

7.1.11 Sheer Pin/Shock Cord Drop Test

- This test was designed to determine the amount of sheer pins needed for launch

Objective

- To ensure that the amount of sheer pins in the forward section is enough to prevent the forward section from being detached at apogee.

Success criteria

- The forward section of the launch vehicle does not detach for the middle section.

Variable

- The testing variable was the number of sheer pins used.

Table 65 lists all variables from the Sheer pin/shock cord test.

Table 65: Variables of the Sheer Pin/ Shock Cord Test	
Independent	**Dependent**
Number of sheer pins	Compartment connection strength
Height of drop	
Length of shock cord	
Amount of elastic	

Methodology

The necessary process needed to complete this test is described below.

- Calculations were done to estimate the number of sheer pins required to hold the forward section together using the equation below. It was calculated that 22 sheer pins were needed and this amount was then used to connect the forward section and the middle section of the launch vehicle. A measuring tape was used to measure the distance from the second floor of the Physical Science building and the ground to ensure that the launch vehicle is not damaged once it is released from the second floor. The main parachute shock cord was then marked where it should hang over the railing to prevent the launch vehicle from reaching the ground and being damaged. This shock cord was then attached to its corresponding bulkhead and secured to the railing of the second floor. The launch vehicle was held over the railing and dropped. The team then inspected the launch vehicle to determine whether any sheer pins had sheered. If the forward section detached from the middle section the test was repeated with less sheer pins or with elastic bungie cords tied to the shock cord to absorb some of the shock from the drop.

Results

- The first test was done with 7 sheer pins and was a failure. So the team recalculated the amount and tried again using 22 sheer pins. The result was a success but the team discovered that the amount of black powder need to sheer the 22 pins would cause damage to the rocket. To fix this bungie cords were tied at separate sections of the shock cord shown in figure 27. Two bungie cords were tied together and looped through two slip knots tied from the shock cord. The bungie closest to the airframe was looped four times and the bungie farthest from the airframe was looped three times. The bungie was utilized to absorb most of the force that the airframe would feel, lessening the force felt by the sheer pins (shown in figure 27).With the combination of sheer pins and bungie cords the team successfully performed the drop test with 11 sheer pins. This amount of sheer pins was then successfully used in the ground ejection test. This ensures that the middle section will not detach at apogee and release the main parachute. Figure 91 -92 shows the first and second sheer pin/shock cord drop test results.

Figure 91: First Sheer Pin/Shock Cord Drop Test

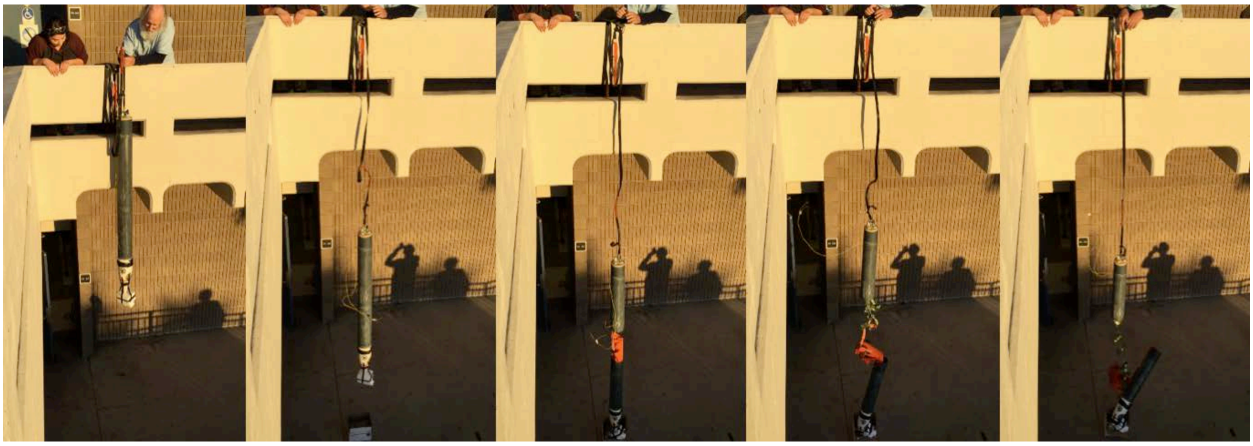


Figure 91 shows the main parachute compartment separate as the simulated shock was applied to the launch vehicle.

Figure 92: Second Sheer Pin/Shock Cord Drop Test

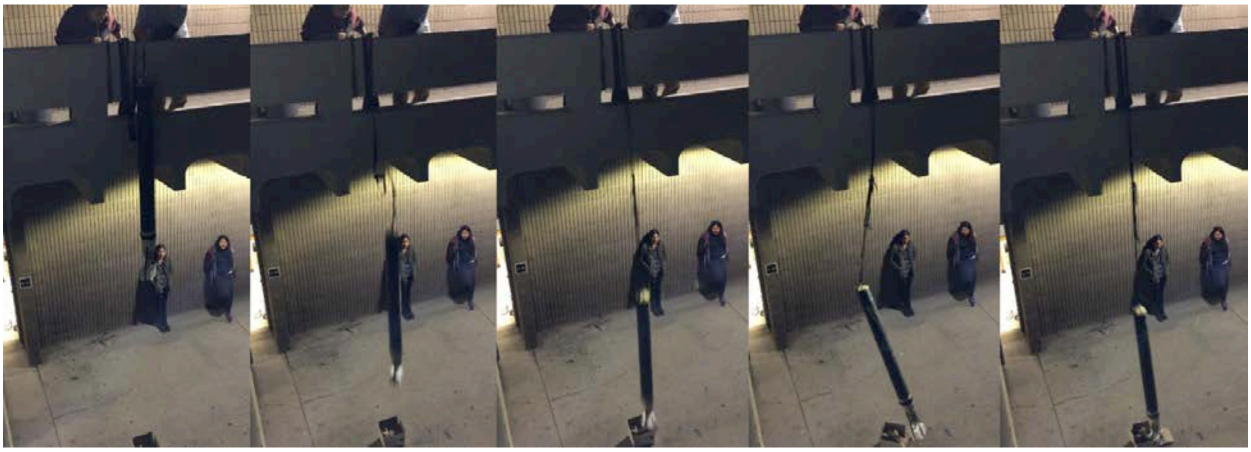


Figure 92 shows the main parachute compartment was still connected without any nylon sheer pin sheering as the simulated force is applied to the launch vehicle.

7.1.12 GPS Testing

- This test was designed to determine the accuracy and precision.

  Objective

  - Test the accuracy and reliability of the GPS

  Success Criteria

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

  Variable

  - GPS accuracy and reliability

  Methodology

  The necessary steps needed to complete this test are listed below.

  1. The GPS will be connected to ground station
  2. One team member will watch the live feed
  3. One team member will walk/drive around with the GPS
  4. Coordinates will be recorded at specific locations
  5. The recorded coordinates will be cross referenced with the actual coordinates provided by Google maps

Results:

- The results were a success. Team members start the testing from a distance shown in figure 93 The team drove around the school stopping at a nearby location. Ground station was able to pinpoint their location using the telegps software as shown in figure 94.

Figure 93: Initial Distance

Figure 93 shows the begging of the GPS test.

Figure 94: TeleGps Map Screenshot

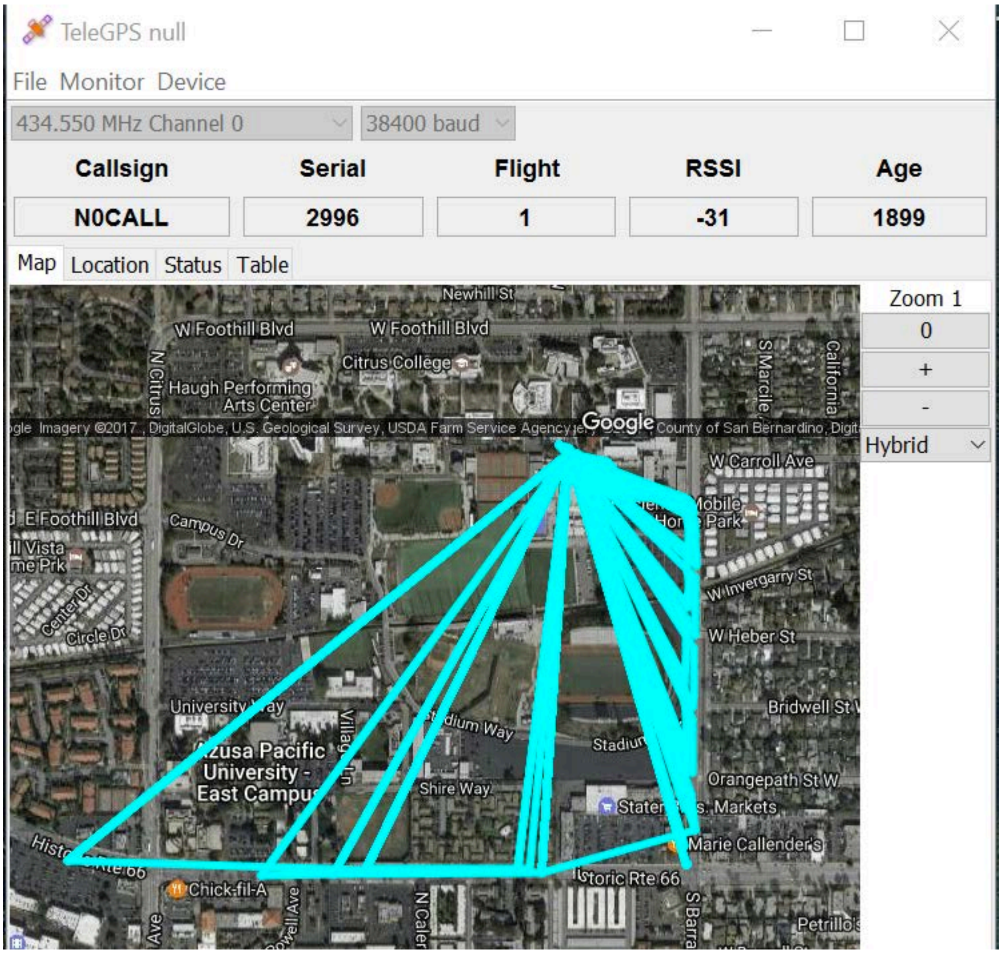


Figure 94 shows a screenshot of the route that was taken during the GPS testing.

7.1.13 Subscale Launch

This test was designed to evaluate the overall design of the launch vehicle.

Objective

- To test the completed subscale launch vehicle and payload

Success criteria

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

Variable

- Overall design of launch vehicle and payload

Methodology

- Launch vehicle at a dry lake bed

Results

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

7.1.14 Full Scale Launch

This test was designed to evaluate the final design of the launch vehicle and payload.

Objective

- Test complete subscale launch vehicle and payload

Success criteria

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

Variable

- Overall design of launch vehicle and payload

Methodology

- o The team went to the Friends of Amatuer Rocketry launch site on February 4, 2017. After proper assembly was complemented by following the safety checklist and assembly procedures the full-scale launch vehicle was launched.

Results

- The test resulted in a success. The motor worked properly and the rocket left the launch rail with no resistance. The flight path of the rocket was straight until it hit apogee. After the rocket reached apogee the drogue parachute was deployed successfully. As the rocket descended to 800ft the main parachute was deployed successfully. The rocket was recovered a quarter mile from the launch site which is will under the required amount. The rocket was recovered with no significant damage to any of the sections or components. These results showed the team the rocket will be able to safely launch in Huntsville for the competition.

7.1.15 Full Scale Set Up Test

Objective

- To determine whether the team is capable of fully assembling the launch vehicle within 4 hours.

Success criteria

- The launch vehicle is fully assembled in the 4-hour time frame

Variable

- The testing variable is the time it takes to set up the launch vehicle.

Methodology

The necessary process needed to complete this test is described below.

- To perform the test all compartments of the launch vehicle and payload were laid out in the physics lab at Citrus College. A timer was set and the team was divided to work on different section of the launch vehicle. Two members began assembling the motor, two members began assembling the recovery system, and one member will ensure that the given sample(s) are secured in the designed payload. Eggs were inserted into the sample container and secured in the compartments. The sample rack container was then inserted into the sample container and the lid secured. Launch set up checklist were referenced and each section of the launch vehicle was connected using screws and sheer pins.

Results

- The team was able to assemble the full-scale launch vehicle within the 4-hour time frame. Nylon sheer pins secured sections of the launch vehicle that are designated to separate and the sections that are not going to separate were all secured by metal screws. The parachutes are properly folded and placed in their compartments. The motor assembly was not included in this testing but the teams have timed the motor assembly time during the preparation of full-scale test launch at Friends of Amateur Rocketry launch site, which is 30 minutes. Considering the assembly time at the Citrus College physics lab and the launch site, the total assembly time was 2 hours. The result shows that the team ensures the launch vehicle will be fully assembled within the 4-hour time frame for flight readiness on launch day.

7.2 Requirements Compliance

7.2.1 Launch Vehicle Requirements and Verification Plan

Table 66 lists the launch vehicle requirements pertaining to the design features that satisfies the requirement, and its corresponding verification method.

Table 66: Launch Vehicle Requirements

Requirement	Design Feature	Verification Method	Verification Plan	Status Update
1.1. The vehicle shall deliver the science or engineering payload to an	An Aerotech L1420R motor launched the 40.09 lb rocket and its payload to	Simulations, calculations, and tests	Simulations, calculations (see Mission Performance Criteria), and flight tests	Complete: Simulations, flight test, and calculations discussed in section 3.1

apogee altitude of 5,280’ above ground level (AGL).	5,280’ AGL.		were used to verify that the Aerotech L1420R is the most efficient motor to deliver the launch vehicle and payload to 5,280’ AGL.	Test discussed in section 7.1.14
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 of the full scale test flight was recorded by a Missile Works RRC2+ altimeter to be 15181’ and 15191’.	Inspection	The Missile Works RRC2+ altimeter was inspected after all test launches to ensure that it is functioning and recording the max altitude of the launch.	Complete: Discussed in section 3.6
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 was tested and inspected after test launches. They will also be tested before the main launch to verify that it is operating correctly.	Completed: Discussed in section 3.6
1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiment(s).	Only a redundant altimeter is utilized for recovery.	N/A	No verification plan is needed because additional altimeters are not utilized.	Complete: Discussed in section 3.6
1.2.3. At the	A NASA	Inspection	The altimeter	Planned

Launch Readiness Review, a NASA official will mark the altimeter that will be used for the official scoring.	official will have the official altimeter available at the launch readiness review to be marked.		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.	Planned
1.2.5. At the launch field, to aid in the determination of the vehicle's apogee, all audible electronics, except for the official altitude determining altimeter shall be capable of being turned off.	The official scoring altimeter will remain on at all times. All other audible electronics, if any, may be turned off.	Inspection	All electronic devices except for the altimeter will be inspected prior to the launch to ensure that they are turned off.	Planned
1.2.6. The following circumstances will warrant a score of zero for the altitude portion of the competition.	See below	See below	See below	N/A

1.2.6.1. The 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+ was housed securely inside the avionics bay to prevent damage.	Tests and inspection	The altimeter was tested during the test launches to confirm that it is durable enough for the flight. The launch vehicle's recovery system was also tested and inspected prior to the main launch to ensure that the launch vehicle is not damaged during landing.	Completed: Discussed in section 3.6
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.	Planned
1.2.6.3. The altimeter reports an apogee altitude over 5,600' AGL.	An Aerotech L1420R motor launched the 40.09 lb. launch vehicle and its payload to 5,280' AGL.	Simulations, calculations, and tests	Simulations, calculations (see Mission Performance Criteria), and test flights were used to verify that the Aerotech L1420R is the most efficient motor to	Completed: Discussed in section 3.10.8

			deliver the launch vehicle and payload to an altitude less than 5,600’ AGL.	
1.2.6.4. The launch vehicle is not flown at the competition launch site.	N/A	Tests, inspection, and analysis	The team payed utmost attention when following all specified requirements in constructing and testing the launch vehicle so that the launch vehicle is cleared to launch during the competition.	Completed: Discussed in section 3.1
1.3. All recovery electronics shall be powered by commercially available batteries.	Commercially available 9V batteries power all recovery electronics.	Inspection	All batteries used in the launch vehicle were inspected by the safety officer to establish that they are commercial batteries.	Completed: Discussed in section 3.6
1.4. The launch vehicle shall be designed to be recoverable and reusable.	Current RockSim Pro 9 simulations predicted that all launch vehicle components will be recovered within 2,111’ range from the launch pad. All launch vehicle components are designed	Demonstrations and tests	The launch vehicle’s flight and recovery were tested several times before the main launch. The launch vehicle recoverability and reusability was demonstrated during these test launches.	Complete: Discussed in sections 3.1

	to be reusable.			
1.5. The launch vehicle shall have a maximum of four independent sections.	The launch vehicle has three independent sections.	Analysis and inspection	Analysis of the RockSim9 design and inspection of the launch vehicle were used to verify that it consists of three independent sections.	Complete: Shown in section 3.1
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 were used to verify that it is single stage.	Complete: Discussed in section 3.1
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 was utilized to ensure that flight preparation is efficient, thorough, and completed in less than four hours.	Tests and demonstration	The team measured and recorded the speed at which the launch vehicle was assembled at the full scale test flight. The assembly time was recorded to be 3 hours and 37 minutes. However, the launch vehicle was assembled twice in this time because the altimeter battery had to be replaced.	Complete: Discussed in section 7.1.15
1.8. The launch vehicle	All onboard electronics	Tests and inspection	All electronics were tested	Complete: Discussed in

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.	utilize little power.		and inspected prior to launch to ensure that they are capable of remaining in a launch-ready configuration for several hours.	section 7.1.15
1.9. The launch vehicle shall be capable of being launched by a standard 12-volt firing system.	The launch vehicle utilizes a commercial, APCP motor that ignites with a 12- volt direct current.	Tests	A standard 12-volt firing system was used during test launches confirming that it is capable of launching the launch vehicle.	Complete: Discussed in section 3.1
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	Complete: Discussed in section 3.1
1.11. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium	The team is using a TRA certified L1420R motor from Aerotech to launch the vehicle.	Inspection	Inspection of the motor being used was used to verify that it is a solid fuel commercial motor using APCP.	Complete: Discussed in section 3.9

perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).				
1.11.1. Final motor choices must be made by the Critical Design Review (CDR).	The final motor choice has not changed from what was stated in the CDR	Analysis	Analysis of the RockSim9 design and simulations were used to verify that the Aerotech L1420R motor is still the selected motor.	Complete: Shown in section 3.9
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.	No motor changes have been made.	N/A	N/A	N/A
1.11. Pressure vessels on the vehicle shall	Pressure vessels are not utilized.	N/A	N/A	N/A

be approved by the RSO and shall meet the following criteria:				
1.12.1. The minimum factor of safety (Burst of Ultimate Pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.	Pressure vessels are not utilized.	N/A	N/A	N/A
1.12.2. The low-cycle fatigue life shall be a minimum of 4:1.	Pressure vessels are not utilized.	N/A	N/A	N/A
1.12.3. Each pressure vehicle shall include a pressure relief valve that sees the full pressure of the tank.	Pressure vessels are not utilized.	N/A	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	Pressure vessels are not utilized.	N/A	N/A	N/A

of the tank, including number of pressure cycles put on the tank, by whom, and when.				
1.13. The total impulse provided by a Middle and/or High School launch vehicle shall not exceed 5,120 Ns (L-class).	The Aerotech L1420R motor, has been selected to launch the launch vehicle and has a total impulse of 4182.83 Ns.	Inspection	The team inspected the motor data to ensure its total impulse does not exceed 5,200 Ns.	Complete: Discussed in section 3.9
1.14. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	The launch vehicle has a 3.33 stability margin with the Aerotech L1420R at the point of rail exit.	Analysis and simulations	Analysis of the RockSim9 simulations and vehicle design were used to verify that static stability margin is at least 2.0.	Complete: Discussed in section 3.1
1.15. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The launch vehicle accelerated to a velocity of 77.29 fps at rail exit.	Analysis and simulations	Analysis of the RockSim9 simulations and vehicle design were used to verify that the vehicle has a rail exit velocity greater than 52 fps.	Complete: Discussed in section 3.9
1.16. All teams shall successfully launch and recover a subscale model of their	The team launched and recovered a 2/3-scale model of the full-scale rocket prior to	Analysis	The results of the subscale launch were analyzed prior to the CDR.	Complete: Discussed in section 7.1.13

full-scale rocket prior to CDR.	CDR.			
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 were done to confirm that they are scale models of the full-scale and performed as similarly as possible to the full scale design.	Complete: Discussed in section 7.1.13
1.16.2. The subscale model shall carry an altimeter capable of reporting the model's apogee altitude.	The subscale model had a redundant commercially available altimeter system.	Testing	The altimeter was tested during test launches to determine whether or not it is capable of recording the launch vehicle's altitude.	Complete: Discussed in section 3.10.10
1.17. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on the launch day.	The team successfully launched and recovered the full-scale launch vehicle prior to FRR.	Demonstration	The full-scale launch vehicle was launched and recovered prior FRR	Complete: Discussed in section 7.1.14

1.17.1. The vehicle and recovery system shall function as designed.	The vehicle and recovery systems were constructed according to the designs.	Testing	The vehicle and recovery system were tested during test launches to ensure that they are working as designed.	Complete: Discussed in section 3.1
1.17.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	See below	See below	See below	N/A
1.17.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass.	A mock payload matching the mass of the true payload was launched in the launch vehicle. It was placed in the payload bay of the launch vehicle to accurately simulate the mass distribution of the forward section.	N/A	N/A	Complete: Discussed in section 7.1.14
1.17.2.1.1. The mass simulators shall be located in the same approximate location on the launch vehicle as the missing payload mass.				Complete: Discussed in section 7.1.14
1.17.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or	The payload does not alter the external surfaces or manage any energy of the launch vehicle.	N/A	N/A	N/A

manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.				
1.17.4. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor to be used to demonstrate full flight readiness and altitude verification.	An Aerotech L1420R was flown during the full-scale test launch.	Inspection	The team inspected the launch vehicle during test flights to verify that the L1420R was utilized.	Complete: Discussed in section 3.9
1.17.5. The vehicle shall be flown in its fully ballasted configuration during the full-scale test.	The vehicle was flown in its fully ballasted configuration during the full-scale test.	Inspection	The launch vehicle was inspected before flight to ensure that it is in its full ballasted configuration.	Complete: Discussed in section 3.10.8
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 launch vehicle was not modified after the full-scale demonstration flight.	Inspection	Inspection of the launch vehicle prior to the main launch will verify that there have been no alterations.	Complete: Discussed in section 3.1

the NASA Range Safety Officer.				
1.17.7. Full scale flights must be completed by the start of FRRs (March 6th, 2017).	The full scale launch vehicle was test launched February 4, 2017	Inspection and demonstration	Inspection of the timeline verifies that a full-scale test launch was completed prior to the FRR.	Complete: Discussed in the section 7.1.14
1.18. Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	The launch vehicle does not have structural protuberances.	N/A	N/A	N/A
1.19. Vehicle prohibitions	See below	See below	See below	N/A
1.19.1. The launch vehicle shall not use forward canards.	The fins are only located in the booster section of the launch vehicle.	Inspection	Inspection of the launch vehicle verifies that no forward canards are utilized.	Complete: Shown in section 3.1
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 launch vehicle	Inspection	Inspection of the launch vehicle verifies that no forward firing motors are being utilized.	Complete: Shown in section 3.1
1.19.3. The launch vehicle shall not utilize motors that expel	The Aerotech L1420R motor does not expel titanium sponges.	Inspection	Inspection of the launch vehicle verifies that no motors that	Complete: Shown in section 3.9

titanium sponges.			expel titanium sponges are utilized.	
1.19.4. The launch vehicle shall not utilize hybrid motors.	The Aerotech L1420R motor utilized is a solid fuel APCP motor.	Inspection	Inspection of the launch vehicle verifies that no hybrid motors are utilized.	Complete: Shown in section 3.9
1.19.5. The launch vehicle shall not utilize a cluster of motors.	A single motor is used for the launch vehicle.	Inspection	Inspection of the launch vehicle verifies that no cluster motors are utilized.	Complete: Shown in section 3.9
1.19.6. The launch vehicle shall not utilize friction fitting for motors.	The launch vehicle uses a threaded metallic flange with a fitting threaded cap for motor retention.	Inspection	Inspection of the launch vehicle verifies that the motor does not utilize friction fitting.	Complete: Shown in section 3.9
1.19.7. The launch vehicle shall not exceed Mach 1 at any point during flight.	The launch vehicle reached a maximum velocity of 705.12 fps.	Inspection and analysis	Test flight results verify that the launch vehicle did not exceed Mach 1 at any point during the flight.	Complete: Shown in section 3.10.8
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 was used to verify that it does not exceed 10% of the total weight of the launch vehicle.	Complete: Discussed in section 3.1

Table 67 lists the team derived launch vehicle requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 67: Team Derived Launch Vehicle Requirements			
Requirements	**Design Feature**	**Verification Method**	**Verification**
1.1. The vehicle shall deliver the science or engineering payload to an apogee altitude of 5280’ above ground level (AGL).	An Aerotech L1420R motor launched the 40.09 lb launch vehicle and its payload to the recorded altitudes of 5181’and 5191’.	Simulations, calculations, full scale test launch	Being limited in motor selection the team found this motor to be the best fit to satisfy the requirements. Although the motor does not meet the official target apogee it delivers the launch vehicle closest to the target apogee.

7.2.2 Recovery System Requirements and Verification Plan

Table 68 lists the recovery system requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 68: Recovery System Requirements				
Requirement	**Design Feature**	**Verification method**	**Verification plan**	**Status Update**
2.1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	Missile Works RRC2+ altimeters were used to eject the drogue parachute at apogee, and the main parachute at 500’.	Testing	Tests flights were used to verify that the drogue deployed at apogee and the main deployed at a lower altitude of 500’.	Complete: Discussed in section 7.1.14
2.2. Each team must perform a	Successful ground ejection tests were	Inspection	The parachutes and nylon shear pins were	Complete: Described in section 7.1.9

successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	conducted prior to all initial subscale and full scale launches.		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 calculated the kinetic energy that each independent section will experience upon landing.	Complete: Discussed in section 3.10.8
2.4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Each altimeter is independent of any payload electrical circuits, including other recovery altimeters.	Inspection	Inspection of the recovery system electrical components verifies that they are wired independently of other electrical components.	Complete: Discussed in section 3.6
2.5. The recovery system shall contain redundant, commercially available altimeters. The term "altimeters"	The recovery system will contain redundant Missile Works RRC2+ altimeters to deploy the parachutes.	Inspection	Inspection of the launch vehicle was used to verify that commercial altimeters are being used.	Complete: Discussed in section 3.6.2.3

includes both simple altimeters and more sophisticated flight computers.				
2.6. Motor ejection is not a permissible form of primary or secondary deployment.	Motor ejection was not utilized to deploy the parachutes.	Inspection and analysis	Inspection and analysis of the RockSim designs was used to verify that no motor ejection is utilized.	N/A
2.7. Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the launch vehicle when it is in the launch configuration on the launch pad.	All RRC2+ altimeters have separate external arming switches accessible when the launch vehicle is in the launch position.	Inspection	Inspection of the RRC2+ altimeters was used to verify that they have separate external arming switches accessible when the rocket is in its launch position.	Complete: Discussed in section 3.6
2.8. Each altimeter shall have a dedicated power supply.	Each altimeter has a dedicated 9 V power supply.	Inspection	Inspection of the altimeters and their wiring verifies that they have a dedicated power supply.	Complete: Discussed in section 3.6
2.9. Each arming switch shall be capable of being locked in the ON position for launch.	The arming switches require a key to lock them in the ON position.	Inspection	Inspection of the arming switches shows that they require a key to lock them in the ON position.	Complete: Discussed in section 3.6

2.10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	All parachutes compartments are attached with 2-56 x 0.25 in nylon shear pins.	Inspection	Inspection of the launch vehicle verifies that the main and drogue compartments are attached to the launch vehicle using shear pins.	Complete: Discussed in section 3.1
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 has a GPS tracking device.	Inspection and testing	Inspection of the launch vehicle verifies that a GPS device was used. This device was also used for test flights to test its effectiveness.	Complete: Discussed in section 3.6.2.6
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 were tethered together. All payload components were fixed inside of the launch vehicle.	N/A	N/A	N/A
2.11.2. The electronic tracking device shall be fully functional	The GPS tracking device was tested during the test launch to ensure	Testing and inspection	The GPS was ground tested and inspected prior to the launch day to ensure that it is	Completed: Discussed in Section *7.1.12*

during the official flight on launch day.	its functionality.		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 are independently wired.	Inspection	Inspection of the recovery system electronics verifies that their wiring is independent from all other onboard electronics.	Complete: Discussed in section 3.6
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 are physically separated from the GPS transmitter by being installed in their own avionics bay compartment.	Inspection	The altimeters are separated from the GPS by being installed in their own compartment of the avionics bay. Inspection of the launch vehicle verifies this.	Complete: Discussed in section 3.6
2.12.2. The recovery system electronics shall be shielded from all onboard transmitting devices, to	The recovery system electronics are located in their own avionics bay compartment.	Inspection	Inspection of the electronics verifies that they are properly shielded from the GPS transmission and any other	Completed: Discussed in section 3.6

avoid inadvertent excitation of the recovery system electronics.			devices that may affect their operation.	
2.12.3. The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Equipment generating magnetic waves was not utilized.	N/A	N/A	N/A
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 are secured inside the avionics bay without interference of other electronics.	Inspection and tests	The position of the recovery system electronics were inspected by the team to ensure that they are secured inside the avionics bay. Tests of other onboard electronics ensured no interference occurred.	Completed: Discussed in section 3.6

7.2.3 Experiment Requirements and Verification Plan

Table 69 lists the experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 69: Experiment Requirements				
Requirements	**Design Feature**	**Verification Method**	**Verification**	**Status Update**
3.1.1. Each team shall choose one design experiment option from the following list.	The team has chosen option 3: Fragile Material Protection.	Inspection	Inspection of the experiment verifies that it is from the list of possible experiments.	Complete
3.1.2. Additional experiments (limit of 1) are encouraged, and may be flown, but they will contribute to scoring.	The team does not have any additional experiment.	N/A	N/A	N/A
3.1.3 If the team chooses to fly additional experiments, they shall provide the appropriate documentation in all design reports so experiments may be reviewed for flight safety.				

7.2.4 Fragile Material Experiment Requirements and Verification Plan

Table 70 lists the fragile material protection experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 70: Fragile Material Protection Requirements				
Requirements	**Design Feature**	**Verification Method**	**Verification**	**Status Update**
3.4.1. Teams shall design a container capable of protecting an	The payload is constructed to be adjustable in order to	Tests	Multiple objects of various sizes were placed between the adjustable silicone	Complete: Discussed in section 4.1

object of an unknown material and of unknown size and shape.	accommodate multiple shapes, sizes, and quantities of samples.		disks. The payload was then tested to ensure that it is capable of protecting the samples.	
3.4.1.1. There may be multiple of the object, but all copies shall be exact replicas.				N/A
3.4.1.2. The object(s) shall survive throughout the entirely of the flight.	The team designed and constructed a container that protects an unknown object(s) throughout the entire flight.	Tests	Multiple objects were tested in the payload to test its effectiveness. The container was dropped from 8'to simulate the force that the payload will experience from landing.	Complete: Discussed in section 7.1
3.4.1.3. Teams shall be given the object(s) at the team check in table on launch day.	The team has tested several different samples in anticipation of the object they will be given on launch day.	N/A	N/A	Planned
3.4.1.4. Teams may not add supplemental material to the protection system after receiving the object(s). Once the object(s) have been provided, they must be sealed within their container until after launch.	Supplemental material for protection will not be added after receiving the object. The container will have a threaded cap closure seal that will remain closed until after launch.	Inspection	A solid object will be placed in the inner rack and secured by the component of the protection system that are kept within the proposed container; the container will then be sealed without any supplemental material added.	Planned
3.4.1.5. The provided object can be any size and shape, but will be able to fit inside an imaginary cylinder 3.5 in in diameter, and 6 in in height.	The proposed container will be able to accommodate a volume of 57.70 in^3 and withstand a minimum of 4 ounces for the unknown	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	Planned.

3.4.1.6. The object(s) shall have a maximum combined weight of approximately 4 oz.	object(s).		shell and the inner rack. The container shall be durable for the total weight of the object(s).	Planned

Table 71 lists the team derived fragile material protection experiment requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 71: Team Derived Fragile Material Protection Requirements			
Requirements	**Design Feature**	**Verification Method**	**Verification**
3.4.1. The team shall design a container capable of protecting eight objects of an unknown material and of unknown size and shape.	The proposed container has eight separate compartments. Objects with many different physical characteristics were tested.	Testing	Complete: Discussed in section 4.1
3.4.1.5. The maximum compartment volume will hold an imaginary cylinder with a diameter of 3.6 in, and a height of 6.5 in.	The adjustable compartments are able to accommodate this size.	Testing	Complete: Discussed in section 4.1
3.4.1.6. The separate compartments shall have a maximum weight capacity of 3 lbs.	The nuts hold the silicone disks in place, while the flexibility of the silicone disks enable it to hold the desired max weight.	Testing	Complete: Discussed in section 7.1

7.2.5 Safety Requirements and Verification Plan

Table 72 lists the safety requirements, their respective verification methods and verification plan as well as a status update on their verification.

Table 72: Safety Requirements				
Requirement	**Design Feature**	**Verification Method**	**Verification Plan**	**Status Update**
4.1 Each team shall use a launch and safety checklist.	N/A	Inspection	The safety officer ensures that the safety checklist are used before every launch.	Completed: Discussed in section 5.2
4.2 Each team must identify a student safety officer who shall be responsible for all items in this section.	N/A	Identification	The safety officer is identified in the beginning of this document.	Complete
4.3. The roles and responsibilities of each safety officer shall include, but not be limited to 4.3.1.1. Design of vehicle and launcher 4.3.1.2. Construction of vehicle and launcher 4.3.1.3. Assembly of 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	N/A	Inspection	The safety officer is held accountable for all of these responsibilities, failure to do so will result in demotion of safety officer.	Complete

4.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities	N/A	Inspection	The safety officer ensures that safety procedures developed by the team are followed	Complete
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	Inspection	The safety officer maintains and reviews the following items: hazard analyses, failure mode analyses and procedures and MSDS/chemical inventory data	Complete: Discussed in section 5.2
4.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	N/A	Inspection	The safety officer led the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Complete: Discussed in section 5.3
4.4. Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for	N/A	Inspection	The team inspected the mentor's credential to ensure that he met the qualifications.	Complete

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 for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should	N/A	Inspection	The safety officer ensured that the team members abided by the rules and guidance of the local RSO	Complete

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	Inspection	The safety officer ensured that the team members were familiar with and abided to the rules set by the FAA	Complete

7.2.6 General Requirements and Verification Plan

Table 73 lists the general requirements, the pertaining design feature that satisfies the requirement, and its corresponding verification method.

Table 73: General Requirements

Requirements	**Verification Method**	**Verification**	**Status Update**
5.1. Students on the team shall do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black power or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor)	Inspection	Inspection of all documents and tests reveals that the team is responsible for all aspects of the project. This excludes those aspects that include assembly of the motor or the handling of black powder and ejection charges.	Complete
5.2 The team shall provide and maintain a project plan to include, but not limit to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Inspection	Inspection of the submitted documents verifies that the team has provided and maintained a project plan.	Complete

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	All team members are U.S citizens.	N/A
5.4 The team shall identify all team members attending launch week activities by the Critical Design Review (CDR).	Inspection	Inspection of the CDR verifies that all team members attending launch week activities have been identified.	Complete
5.4.1. Students actively engaged in the project throughout the entire year.	Weekly mandatory meeting	All team members have attended weekly meetings were they discussed work in progress and planned upcoming work.	Complete
5.4.2. One mentor (see requirement 4.4)	Identification	Rick Mascheck has been identified as the team's mentor and his contact information is listed in the beginning of the document.	Complete
5.4.3. No more than two adult educators.	Identification	Lucia Riderer has been identified as the adult educator; her contact information is also listed in the beginning of the document.	Complete
5.5. The team shall engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report shall be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 28 of the handbook.	Documentation	The outreach officer has documented every educational outreach the team has conducted.	Complete

5.8. All deliverables must be in PDF format.	Inspection	Inspection of the review documents verifies that they are presented as PDF files.	Complete
5.9. In every report, teams shall provide a table of contents including major sections and their respective sub-sections.	Inspection	Inspection of the reports verifies that a table of contents is included and lists the major sections and their respective sub-sections.	Complete
5.10. In every report, teams shall include the page number at the bottom of the page.	Inspection	Inspection of the reports verifies that the page numbers are included at the bottom of the page.	Complete
5.11. The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. If possible, the team shall refrain from use of cellular phones as a means of speakerphone capability.	Inspection	The team has accessibility to equipment that is necessary to perform a video teleconference.	Complete
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 field. Launch services will have 8' 1010 rails, and 8' and 12' 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.	Planned
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	Inspection	Inspection of the Safety Contract verifies that the team has complied with the EIT Accessibility Standards.	Complete

intranet and Internet information and applications.			

7.2.7 Team Derived Requirements

Table 74 shows a set of team derived requirements for mission success along with their corresponding verification methods.

Table 74: General Team Derived Requirements			
Requirements	**Verification Method**	**Verification**	**Status Update**
1. All five students remain on the team during the entirety of the competition	Mandatory meetings	All five original members of the team are still actively involved in the project.	Complete
2. All design reviews are passed and the vehicle is launched successfully in Huntsville	NASA score sheet	NASA score sheets 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.	Planned
3. All students have a GPA of 3.0 or greater during the project	Grade Report	Team members have reported their grades to the advisor of the team ensuring that the students have been successful in the project and in academics.	Complete
4. The team has left over budget at the end of the project	Final spending calculation	The final spending of the project will be calculated and compared to the funded budget.	Planned
5. Team members complete the project without injuries	Safety contract	No team member has been injured during the entirety of the project.	Complete
6. All members should be familiar with every aspect of the project.	Mandatory meeting	All members have attended weekly meeting where they discussed the different aspects of the project.	Complete

7.3 Budgeting and Timeline

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

7.3.1 Budget Plan

Table 75 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 75: Budget Plan					
Items	Quantity of items	Unit Price	Tax (~9%)	Shipping	Total price
Full-scale launch vehicle construction expenses					
6" diameter Blue tube	4	$66.95	$0.00	$104.27	$372.03
6" diameter coupler tubes	1	1	$19.95	$1.80	$12.10
6" Ogive 4:1 nose cone	1	$129.00	Included	$12.90	$141.90
1" tubular webbing	40	$0.45	$1.62	$5.99	$25.61
18" Nomex blanket	2	$10.49	$0.00	$5.09	$26.07
24" Nomex blanket	2	$13.99	$0.00	$5.85	$33.83
Altimeter	4	$44.95	$0.00	$7.00	$186.80
Terminal blocks	1	$9.05	$6.03	$0.00	$15.08
22-gauge stranded wire pack	1	$19.95	$2.41	$6.83	$29.19
Heat shrink tubing	1	$10.99	$0.70	$5.33	$17.02
Key switch	4	$4.62	$2.13	$5.14	$25.75
6" E-bay	2	$71.95	$12.95	$19.51	$178.12
¼" Aircraft plywood	1	$112.75	$10.15	In store	$122.90

1515 Rail buttons	2	$4.65	$0.00	$4.88	$9.98
Shear Pins (size)	5	$3.10	$0.00	$4.88	$20.38
Machine screws	1 pack	$1.98	$0.02	$0.00	$2.00
Rocket epoxy (pt)	1	$38.25	$0.00	$11.82	$50.07
Fiberglass cloth 3 oz. satin weave	3 yrds	$9.96	$8.07	$9.12	$42.51
Fiberglass resin	1	$42.99	$3.87	$10.96	$58.81
Fiberglass hardener	1	$21.99	$1.98	$9.92	$34.78
Motor retainer	1	$53.50	$4.82	$5.47	$63.79
Motor	2	$249.99	$2.25	$60.00	$312.24
Engine casing	1	$235.40	$2.12	$10.75	$248.27
Forward closure	1	$101.65	$9.15	$0.00	$110.80
Aft closure	1	$80.25	$7.22	$0.00	$87.47
Forward seal disk	1	$32.00	$2.88	$15.00	$49.88
Sub-scale launch vehicle construction expenses					
4” Blue Tube	2	$38.95	$0.00	$26.89	$104.79
98 mm E-bay	2	$42.95	$7.73	$9.13	$103.58
4” Ogive 4:1 nose cone	1	$65.00	Included	$8.95	$73.95
Tube coupler	1	$10.95	$0.99	$7.36	$19.30
Motor	1	$159.99	$1.44	$60.00	$221.43
Payload expenses					
Polycarbonate tubing	1	$215.25	$19.37	$12.00	$246.62
Silicone sheet	1	$156.55	$12.52	$9.58	$178.65
Zinc threaded rails	3	$5.11	$0.46	In store	$16.71
Epoxy plastic bonder	2	$4.26	$0.38	In store	$9.28
9% Borated flexi-panel	1/2	$75.00	$0.75	$12.00	$92.75
Polycarbonate tubing	2	$15.20	$1.37	$10.00	$43.14
Tools and safety supplies					
Palm sander	1	$29.99	$2.70	$6.99	$40.31
Nitrile gloves	1	$8.16	$1.22	$5.48	$14.86
Sand paper 80 grit	1	$15.38	$1.38	$5.99	$22.75
Sandpaper 5” 120 grit	1	$14.40	$1.30	$5.99	$21.69
Synthetic grease	1	$5.89	$0.53	$5.99	$12.95
Dremel(cordless)	1	$89.99	$8.09	$0.00	$98.08
Outreach expenses					
Outreach supplies	12,000.00				

Food and travel expenses					
Airfare	6	$518.00	$46.62	$0.00	$3387.72
Hotel expenses	2	$134.00	$12.06	$0.00	$292.12
Food expenses	15	$20.00	$0.00	$0.00	$500.00
Total expenses	$19,751.89				

7.3.2 Funding Plan

Table 76 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 75 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 76 : NSL Funding Plan

Funding Source	Amount ($)	Designation
GUSD	8,850.00	Supplies for the Junior Rocket Owls program
Citrus College Foundation Innovation Grant	1,000.00	Sponsor Rocket Owls' activities
Race to STEM Federal Grant	$2,000.00	Rocket supplies
California Space Grant Consortium	$2,000.00	Supplies for rocketry projects
Private donations	$6,000.00	Sponsor Rocket Owls' activities
Mathematical association of America-Tensor Foundation	$6,000.00	Supplies for the It's Rocket Math! program and traveling expenses for the Rocket Owls
Total	$25,850.00	

As indicated by Table 76, the total funds allocated for the project is $25,850, while table 75 in the Budget section of this document shows that the cost of the project in its entirety is estimated to be $19,751.89. This indicates that the team has an excess of over $6,000.00 which may be used in the case of unexpected expenses, such as an increase in material cost or expenditures related to traveling.

7.3.3 Project Timeline

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

Figure 95: 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 submitted	1d	10/7/2016	10/7/2016
7	Proposal winners ann	1d	10/12/2016	10/12/2016
8	Rocket and payload	37d	11/7/2016	12/27/2016
9	Sub-scale constructio	17d	11/14/2016	12/6/2016
10	Payload construction	17d	11/7/2016	11/29/2016
11	PDR Q&A	1d	10/14/2016	10/14/2016
12	PDR writing	7d	10/17/2016	10/25/2016
13	Payload prototype te	6d	11/21/2016	11/28/2016
14	PDR draft is due	1d	10/26/2016	10/26/2016
15	PDR draft review	4d	10/28/2016	11/2/2016
16	PDR is submitted	1d	11/4/2016	11/4/2016
17	PDR Teleconferences	10d	11/7/2016	11/18/2016
18	CDR planning	2d	11/19/2016	11/21/2016
19	CDR Q&A	1d	11/30/2016	11/30/2016
20	CDR draft is written	23d	12/1/2016	12/31/2016
21	Sub-scale launch at F	1d	12/3/2016	12/3/2016
22	CDR first review	1d	1/2/2017	1/2/2017
23	CDR second review	7d	1/2/2017	1/10/2017
24	CDR is submitted	1d	1/13/2017	1/13/2017
25	CDR Teleconferences	11d	1/17/2017	1/31/2017
26	FRR Q&A	1d	2/8/2017	2/8/2017
27	Full scale rocket cons	1d	2/11/2017	2/11/2017
28	Full scale launch at L	1d	2/11/2017	2/11/2017
29	FRR writing begins	1d	2/13/2017	2/13/2017
30	FRR draft reviewed	1d	3/4/2017	3/4/2017
31	FRR is submitted	1d	3/6/2017	3/6/2017
32	FRR Teleconferences	13d	3/8/2017	3/24/2017
33	Team travels to Hunt	2d	4/5/2017	4/6/2017
34	LRR is completed	1d	4/5/2017	4/5/2017
35	Launch Day	2d	4/8/2017	4/9/2017
36	PLA writing	11d	4/10/2017	4/23/2017
37	PLA reviewed by tear	1d	4/19/2017	4/19/2017
38	PLA is submitted	1d	4/24/2017	4/24/2017

Figure 95 shows the Gantt chart detailing the NASA SL main events and their planned deadlines. Included are all project milestones and construction deadlines.

Table 77 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 77.

Table 77: NSL Timeline and Task Description		
Task	**Description**	**Due**
Rocket and payload are designed	Team designs rocket and payload	8/22/16
Designs are finalized	Final decisions are made regarding the designs of the rocket and payload	9/9/16
Proposal rough draft is due	Proposal sections are due for review	9/10/16
Proposal draft is reviewed	The proposal is edited by the team	9/16/16
AutoCAD and RockSim diagrams are due	All diagrams pertinent to the proposal are due	9/16/16
Proposal is submitted	Proposal is submitted to NASA	10/7/16
NSL selected team are announced	NASA announces NSL teams selected to participate in the 2016-2017 competition	10/12
PDR Q&A	Teams ask questions pertaining to the PDR	10/14/16
PDR is planned and writing begins	PDR sections are distributed and writing begins	10/17/16
PDR draft is due	PDR sections are due for revisions	10/26/16
PDR draft is edited by team	PDR draft is edited collectively by the team	10/28/16
PDR is submitted	PDR is submitted	11/4/16
PDR Teleconferences are held	NASA holds teleconferences	11/7/16-11/18/16
Construction begins	Construction of sub-scale rocket and payload prototype starts	11/7/16
Sub-scale construction is completed	Sub-scale rocket construction is completed	11/14/16

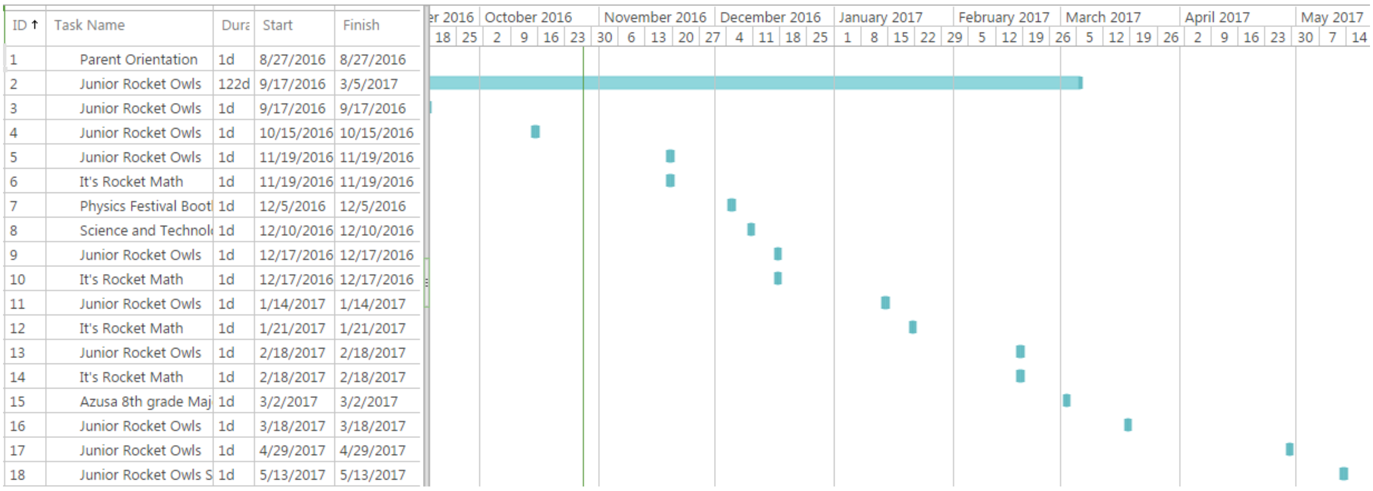
CDR is planned and writing begins	CDR sections are distributed and writing begins	11/19/16
Payload prototype is tested	Payload strength and isolation components are tested	11/21/16
Construction of the full scale rocket begins	Full scale rocket construction begins	11/22/16
CDR Q&A	Teams ask questions 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	1/17/17-1/31/17
FRR Q&A	Teams ask questions pertaining to FRR	2/8/17
Full scale rocket construction is finalized and the rocket is launched	Construction of full scale rocket is completed and rocket is launched, followed by an analysis of the flight	2/11/17
FRR is planned and writing begins	FRR sections are distributed and writing begins	2/13/17
FRR is completed and reviewed by the team	FRR is completed and edited collectively by the team	3/4/17
FRR is submitted	FRR is submitted to NASA	3/6/17
FRR Teleconferences are held	NASA holds teleconferences	3/8/17-3/24/17
The team travels to Huntsville	Team travels to Huntsville	4/5/17
LRR is completed	LRR is completed	4/5/17
NASA SL teams launch the rockets	Launch Day	4/8/17
PLA is planned and writing begins	PLA sections are distributed and writing begins	4/10/17

PLA is completed and reviewed by team	PLA is completed and edited collectively by the team	4/19/17
PLA is submitted	PLA is submitted to NASA	4/24/17

7.3.4 Educational Engagement Timeline

Figure 96 below provides the timeline of the Citrus College Rocket Owl team's educational engagement events. Included are the individual outreaches as well as the entire duration of the Junior Rocket Owls program.

Figure 96: Educational Engagement Timeline:



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

Figure 96 lists all educational engagement events and their corresponding dates.

Table 78 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 78: 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 Workshop	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

References

[1] Howard, Zachary. “How to Calculate Fin Flutter Speed.” Peak of Flight Newsletter, Issue 291. July 2011.

[2] https://www.webpages.uidaho.edu/dl2/on_target/tv.htm

[3] Canepa, Mark, B. *Modern High-Power Rocketry 2*. Victoria, BC:National Library of Canada Cataloguing in Publication, 2005

[4] https://www.grc.nasa.gov/www/k-12/airplane/termv.html

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

[6] https://www.weatherforyou.com/reports/index.php?forecast=zandh&pands=huntsville,alabama
https://www.timeanddate.com/weather/usa/huntsville/historic?month=4&year=2016

[7] https://weatherspark.com/averages/30525/4/Huntsville-Alabama-United-States

[8] https://www.grc.nasa.gov/www/k-12/airplane/fwrat.html

[9] http://metrarocketclub.org/thrust-to-weight-charts

[10] http://www.thrustcurve.org/motorsearch.jsp?id=326

[11] http://adamone.rchomepage.com/index5.htm

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

[13] http://www.shieldwerx.com/assets/swx-227.pdf

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

Appendix A: Citrus College Profile

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

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

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

Appendix B: Safety Contract

Safety Contract

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

1.6. Safety Regulations

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

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

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

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

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

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

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

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

Yvonne Villapudua
Name (Printed)
[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

Appendix C: Launch Day Equipment

The items list below will be pack and brought to every test launch during the duration of the NASA Student Launch.

- 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

Appendix D: 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 E: 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
- Rotary Cutting Tool
- Orbital Hand Held Sander