Northeastern

University
Student
Launch
Initiative

University

2016 - 2017
Flight Readiness Review

NUHOPE

Northeastern
University
High altitude
Object
Protection
Experiment

Northeastern University
267 Snell Engineering
Boston, MA 02115

March 6th, 2017

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1. Summary of FRR Report

1.1. Team Summary

The Northeastern chapter of AIAA project's name is the **Northeastern University High-altitude Object Protection Experiment (NU HOPE)**. The mailing address for the team is Northeastern University, 267 Snell Engineering Boston, MA 02115. The team mentor is Robert DeHate for this competition. The certification level of the team is L2 and this certification is held by launch vehicle Leader Evan Kuritzkes. The NAR/TRA number is 97460.

1.2. Launch Vehicle Summary

The launch vehicle has been designed to propel itself and the payload contained inside to a simulated apogee of 5380 feet, and safely descend after separating into four subsections. The length of the launch vehicle is 140 inches and its diameter is 6.14 inches. This vehicle will have a mass of 48.9 pounds mass, and will be propelled by an AeroTech L2200G-18 motor. The rocket will be compatible with both a 10-10 or a 15-15 aluminum rail.

At apogee, the launch vehicle will split into two sections, a booster section and a payload section, with the payload section deploying a 15 inch drogue parachute and the booster section deploying an 18 inch drogue parachute. These two sections will be separately falling bodies to reduce the forces acting on the payload and its section. At an altitude of 500 feet the booster will deploy its main parachute and at 500 feet the sustainer section will deploy a main parachute. The booster section will deploy the 72 inch annular Iris parachute, and the payload section will deploy a 60 inch annular Iris parachute.

The Northeastern University Milestone Review Flysheet can be reviewed in Appendix A.

1.3. Payload Summary

Our payload system is known as the Payload Protection System (PPS). We began the design process with the goal of creating a passive system which could be adapted to protect an object of any size or shape. To accomplish this goal we designed a system composed of a canister surrounded by horizontal and vertical dampeners made out of foam. These systems should adequately reduce the force experienced on the payload.

The canister itself is made of 3D printed PLA and is threaded. The threading allows for multiple discs within the canister to be moved to any height, such as two locking screw caps that will secure a single object we receive. Foam discs are also present throughout the canister and will help separate a potential payload consisting of multiple objects into compartments. Finally, a strapping system is present, which can secure any long, skinny object. The band is woven through holes on the outside of the canister, and the payload would be strapped between these said bands and a hollow threaded foam disc inside the canister. Two of these discs are present in the canister. We believe these described systems will be successful in meeting our team derived goals as well ensuring the overall safety of any potential payload.

2. Changes Made Since CDR

2.1. Changes Made to Vehicle Criteria

An in-depth analysis of the changes made to the vehicle criteria can be found in Section 3.1.1, below is a list of the main changes.

1. All shock cords were upgraded to ½ inch tubular kevlar.
2. The size of the eye bolts connected to the two drogues have been changed from ¼ inch to ⅜ inch.
3. All the structural bulkheads were changed from a thickness of ¼ inch to ½ inch.
4. Blast caps were added to assure two are dedicated to each separation event. Black powder charges were increased to 2 grams for each main deployment, and 1.5 grams and 1.75 grams for the drogue deployment of the Payload Section and Booster Stage respectively.
5. The Payload Section main parachute now deploys at 500 feet like the Booster Stage rather than at 300 feet.
6. The main parachute for the Booster Stage was changed from 66 inches to 72 inches.
7. The drogue parachute for the Payload Section was changed from 18 inches to 15 inches.
8. The aft-parachute subsection and the nose cone subsection were both lengthened by 5 inches.
9. The length of the nose cone will be changed from a length of 30 inches to a length of 24 inches due to availability to purchase component.
10. The material composing the nose cone will be changed from carbon fiber to fiberglass to provide radio frequency transparency.
11. The gps on the motor section electronics bay was changed from a Big Red Bee to a TeleGPS due to size concerns.
12. Due to availability concerns and safety reasons we switched from our Cesaroni L1395 Bluestreak motor to our alternative AeroTech L2200G-18 motor.

2.2. Changes Made to Payload Criteria

Since our Preliminary Design Review the changes to the PPS include, a change to the canister height, a redesign of our strapping system to secure long and skinny objects, and the finalization of certain aspects dealing with our acceleration sensor. First, the canister, which the payload will be inserted into, was changed to a height of 11.5 inches from its previous 8 inches. This was due to a recalculation concerning the foam above and below the canister.

The strapping system now utilizes two hollow threaded discs, with foam along the inner circumference. Breaks in the foam are evenly spaced and allow for the straps to pass through. This new system is intended to provide something other than the hard wall of the canister for our potential payload to rest against when strapped in. Additionally, the amount of openings around the circumference of the canister for the straps to weave through was changed from 10 to 6. The openings in this were moved down 1 inch from center.

Finally, we decided on the use of the LIS 331 accelerometer, which will allow us to measure up to 24 Gs and pull data at 1000 Hz. The sensor will be mounted to the bottom of the canister, and the canister will therefore be inserted into the launch vehicle upside down.

2.3. Changes Made to Project Plan

The timeline includes the addition of a second full scale launch before April. The budget was updated with more realistic estimate on travel and lodging costs, incorporating accommodations for the team at different campsites on the trip to Huntsville, Alabama. In addition, the funding plan changed slightly as the request for Provost funding was denied. Fortunately, the application for the Richard J Scranton fund was accepted and we were given $167 more than expected. With these, the funding plan and budgets were updated accordingly.

2.4. CDR Action Items

The majority of the CDR action items conveyed in the Q&A portion of our CDR presentation were focused on improving the safety of the launch vehicle. Items 1 - 5 listed in Section 2.1 above are the direct result of action items from CDR. Further elaboration on the launch vehicle changes made directly because of CDR action items related to 1) shock cord diameter, 2) eye bolt diameter, 3) bulkhead thickness, 4) black powder calculations, and 5) main parachute deployment height can be found in Section 3.1.1.

3. Vehicle Criteria

3.1. Design and Construction

3.1.1. Launch Vehicle Design Changes from CDR

1. NASA expressed concern over our previous shock cord, ¼ inch and ½ inch kevlar, and suggested we use 1 kevlar inch thick kevlar shock cords. After doing multiple analyses on the strength of the cord, strength of bulkheads and eyebolts, added weight from this cord and its effects on apogee, descent rates, and impact velocities, and increased volume of this cord, it was determined that this cord would not be suitable for our rocket. We have decided to upgrade all shock cords to the ½ inch diameter tubular kevlar and to use this on all test launches and the final launch. The strength of this shock cord has been validated in our first full scale launch. However, we will still bring a ¾ inch nylon shock cord in the case that NASA insists our ½ inch shock cord is insufficient and requires us to use the larger cord to launch.
2. The two eye bolts on the Booster Stage and Payload Section were changed from a thickness of ¼ inch to ⅜ inch. These eye bolts connect to the two drogues that deploy around apogee. It was NASA's concern that if they do not end up leaving their housing until a few seconds after apogee, the rocket sections would quickly pick up speed and the sudden deceleration from the drogue parachutes combined with the large mass of the rocket sections would impart a very large force on the eye bolts. There was a chance that they would break under the force, which would result in the rocket sections separating from the drogue parachutes and being ballistic until the main parachutes deploy. With the change to ⅜ inch, the eyebolts will be able to withstand the force imparted upon deceleration and keep the drogue connected to the rocket sections.
3. The wooden bulkheads that house either a swivel bolt or an eye bolt connected to a parachute were changed from a thickness of ¼ inch to ½ inch. This change was made after NASA brought up the concern that ¼ inch wood was too thin and could possibly break upon deceleration due to the drogue and main parachutes.
4. NASA expressed concern that there was not enough black powder to properly pressurize the chamber and that we were running the risk of not having the parachute separate. This will be remedied by including more black powder in the blast caps. Additionally, there are now there are two blast caps for each separation, so if one fails to go off there will be more than enough pressure to break the shear pins and release the parachute. After performing ejection tests, it was determined that there will be 2 grams of black powder in each blast cap for main parachutes, 1.75 grams for the Interstage separation, and 1.5 grams for the motor section drogue parachute. For more information on this test, see test L11 in section 7.1.1.
5. To assure safety of launch bystanders the main parachute deployment height for the Payload Section was changed from 300 feet to 500 feet like the Booster Stage to assure there is enough time to clear the area if a parachute malfunction occurred.
6. The main parachute for the Booster Stage was changed from 66 inches to 72 inches. The mass of the rocket since the last report was increased due to new and heavier shock cord and eye bolts which increased the kinetic energy of the rocket parts upon descent. With

the increase in parachute size the rocket will descend at a slower speed and stay within the kinetic energy cutoff.

7. The drogue parachute of the Payload Section was decreased from 18 inches to 15 inches in diameter to keep maximum drift below the 2500-foot requirement.
8. The Aft-Parachute Subsection and the Nose Cone Subsection were lengthened from 20 to 25 inches and 15 to 20 inches respectively. These sections contain the main parachutes of 72 and 60 inches and their corresponding shock cord which take up 40 feet and 35 feet respectively. With the previous dimensions, there was a risk that the main parachutes would not exit the body tube upon deployment due to it being too tight of a fit. With these changes, the parachutes should now deploy as expected.
9. The original nose cone was composed of carbon fiber which is a conductive material. This meant that it could possibly intercept and distort the signal from our altimeter and gps. With the change to fiberglass, a non-conductive material, we will be able to have RF transparency.
10. The previous design of incorporated a fiberglass ogive nose cone of 30 inches. This unfortunately was sold out, and we are now using a fiberglass ogive nose cone of 24 inches.
11. The gps on the Booster Stage electronics bay was changed from a Big Red Bee to a TeleGPS due to its lower power, which will lower the amount of interference between the gps and the StratoLogger.
12. Lastly, we had to change the motor for the launch vehicle. Initially, we were going to be using a Cesaroni L1395 Bluestreak, however, due to availability concerns and safety reasons, we have elected to switch to an alternate motor, the AeroTech L2200G-18 motor and the rest of this report assumes the use of this motor.

3.1.2. Structural Elements

Body Tube

The airframe of the launch vehicle will be made from 6-inch diameter BlueTube, a high density and high strength vulcanized cardboard laminate, manufactured by Always Ready Rocketry. The body tubes and coupler tubes have a thickness of 0.079 inch and 0.68 inch respectively.

Table 1 BlueTube Material Classifications

Density	1.2 g/cm^3
Material Type	Laminate Composite, Linear Elastic Orthotropic Model
Young’s Modulus (Axial)	12,000,000* PSI
Tensile Strength	16,000 PSI
Compression Strength	35 PSI
Flexural Strength	15 PSI

* Interpretation of data listed on Always Ready Rocketry. Data sheet says 12 x 10 PSI, assumed meant $x10^6$ as is standard when listing Young's Moduli, but could also be 12 x 10^3.

Bulkheads

There are various bulkhead designs throughout the Launch Vehicle, with different arrangements of hoist rings, U-Bolts, or eye-bolts. A constant feature of all the bulkhead designs is the thickness of the pieces, which is ½ inch. In addition, all of the bulkheads are constructed of two ¼ inch five-layer birch plywood epoxied together in order to form a ½ bulkhead. The increase of thickness using this method improves strength to further ensure that the stresses that occur during parachute deployment do not damage the bulkheads. The material properties of the Birch which we are utilizing are found in Table 2.

Table 2 Birch (Betula verrucosa) Material Properties

Material Type	Wood (hardwood)
Young's Modulus (Longitudinal)	2.13 - 2.6 x 10^6 psi
Young's Modulus (Transverse)	.115 - 1.41 x 10^6 psi
Tensile Strength (Longitudinal)	17.6 - 21.5 ksi
Tensile Strength (Transverse)	.899 - 1.1 ksi
Shear Strength (Longitudinal)	1.7 - 2.07 ksi
Shear Strength (Transverse)	5.09 - 6.22 ksi
Flexural Strength (Longitudinal)	17.2 - 21.1 ksi
Flexural Strength (Transverse)	.899 - 1.1 ksi

The Birch was used instead of MIL-P-6070 Aircraft Mahogany Plywood due to cost concerns and the availability of the hardwood compared to the mahogany plywood. Both materials had similar strengths, and therefore it was economically and logistically sensible to utilize this alternative in the bulkheads.

Figure 1 Fin Centering Ring

Figure 2 Centering Ring

Electronics Bay Main Parachute Bulkheads

There are two electronics bays situated within the launch vehicle, and they will each utilize electronics bay main parachute bulkhead(s). There is one of these bulkheads attached to the motor electronics bay, and one attached to the payload electronics bay, towards the aft of the launch vehicle and towards the front of the launch vehicle respectively. The payload electronics bay has a ½ inch bulkhead with only holes for the threaded rod and the motor electronics bay has a ½ inch bulkhead which connects it to the Interstage component referenced later in this section. The bulkheads referenced here are distinguished by their ½ inch hoist rings, which will be discussed more below. Figure 3 displays a fully constructed electronics bay main parachute bulkhead.

Figure 3 Electronics Bay Main Parachute Bulkhead

This bulkhead configuration contains two terminal blocks and two Thick-Wall Clear Unthreaded PVC Pipe Fittings, which are used to store the gunpowder that will be used to separate sections of the rocket and release the main parachutes. The terminal blocks and pipe fittings are organized as pairs, one terminal block with one pipe fitting, and are situated on opposite sides of the bulkhead. In addition, there is a ½ inch -13 forged steel hoist ring in the center of the bulkhead. The hoist ring will be attached to the main parachute by a length of ½ inch tubular kevlar. The properties of the hoist ring are displayed in Table **Properties of ½ Inch-13 Black-Oxide Steel Hoist Ring** below.

Table 3 Properties of ½ Inch-13 Black-Oxide Steel Hoist Ring

Fabrication	Forged
Material	Steel
Finish	Black Oxide
Thread Length	1 1/16 “
Inside Width	1 ¼ ”
Overall Height	4 ⅜”
Vertical Capacity	2,250 lbs.
Movement	180 Pivot and 360Swivel

This hoist ring was chosen as it was designed for angular lifting with the pivot and swivel motion of the ring, and thus can withstand angular stresses that would destroy a regular eye bolt.

Fins

The materials chosen for the rocket is G10 Garolite. This is due to its incredible durability, and high strength-to-weight ratio. Unlike wood, which was another possible choice for fin material, Garolite is resistant to corrosion and moisture. The properties of this material are shown in Table 4. Carbon fiber was considered as another alternative. It was ruled out because, due to the woven nature of carbon fiber, very specific machining would have been required to fully maximize its strength. The fins are ⅛ inch thick and have a root chord of 10 inches, a tip chord of 5 inches and a semi-span of 6 inches. 1.5-inch-long tabs directly beneath the fin are included as a means of mounting the fins onto the bottom two centering rings and through the body tube. The fins are in the shape of isosceles trapezoids so that they angle into the body and do not easily collide with the ground upon impact like triangle shaped fins tend to do. Furthermore, forces imparted on these fins due to the angling of the fins, will be directed towards the body tube, keeping the fins structurally sound.

Table 4 G10 Fiberglass Material Properties

Density	0.0650 lb/in^3
Tensile Strength at Break	38000 psi Crosswise
	45000 psi Lengthwise
Flexural Strength	65000 psi Crosswise
	75000 psi Lengthwise

Figure 4 G10 Fiberglass Fins

3.1.3. Electrical Elements

The vehicle contains two electronics bays, the following is the electronics components for the recovery system:

The lower motor electronics bay controls two drogue parachutes and a main parachute. It contains two double pole double throw keylock switches that each control two StratoLoggers. This creates redundancy because if one switch were to fail the other switch would still close the circuit and the StratoLoggers in that circuit would function. When the switches are turned the two circuits are open. This prevents accidental ejection charge activation. When the switches are turned and taken out, the two circuits are closed. There is redundancy on each charge; there are two StratoLoggers per parachute each leading to their own electronic match and black powder charge. This ensures that separation will occur even if one of the StratoLoggers fail. There are four 9-volt batteries; one to power each StratoLogger. The batteries are connected with snap on battery connectors so they will not become dislodged in flight. They are also taped to the connectors as a backup safety precaution. The batteries are secured in wooden battery boxes that are screwed into the electronics bay with tap inserts to keep them in place.

The upper payload electronics bay controls one main parachute and contains two keylock switches that are each connected to one StratoLogger, giving the upper electronics bay two StratoLoggers in total. There are two 9-volt batteries to power the StratoLoggers which are attached the same way in which they are in the lower electronics bay.
The wiring conventions for the recovery systems are as follows:

Table 5 Wire Color Code

Component	Wire Color
Batteries/Power	Red/Black
Keylock Switches	Orange/Green
Drogue Parachutes	Purple/Grey
Main Parachutes	Blue/White

The bulkheads that hold the black powder charges are connected to the electronics bay wiring with four pin connectors. The two charge outputs for each parachute are soldered to a four pin connector that connects to a connector on the bulkhead. The bulkhead that contains two drogue parachutes have connectors that are attached in opposite direction so that the different drogue charges cannot be plugged incorrectly. This ensures the drogue parachutes go off in the correct order.

The connectors are soldered to the wires with leaded solder and heatshrink was used to prevent the wires from short circuiting. The connectors were used to allow the bulkheads to be detachable from the electronics bay. The switches are soldered to wires that run to the StratoLoggers to complete the circuit. The battery connectors are soldered to wires that run to the StratoLoggers for power.

3.1.4. Drawing and Schematics

Drawings and schematics of the as built launch vehicle are depicted below in the form of SolidWorks drawings, several with a bill of materials (BOM) that lists the parts that compose each section of the launch vehicle.

The sections will be described starting with the motor section and will end in the nose cone, and will thus move in ascending order in reference to the motor section.

Motor Section

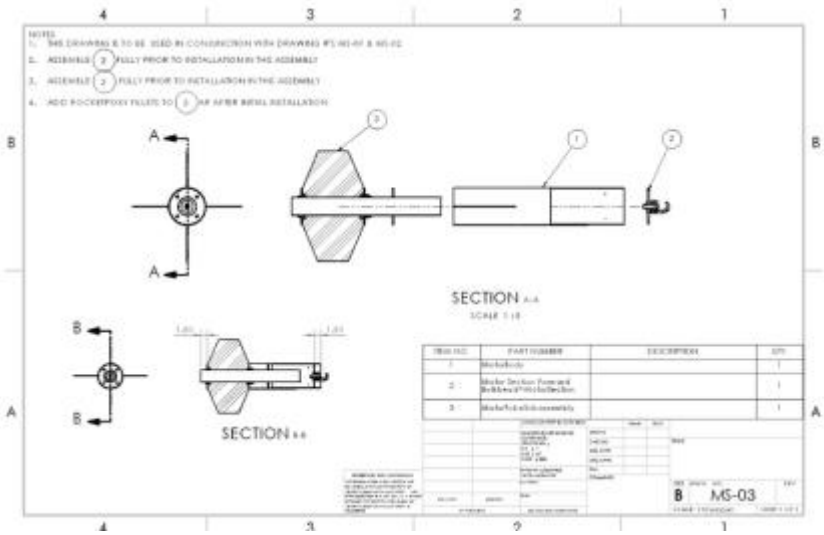


Figure 5 Motor Subsection

The Motor Section, depicted in Figure 5 is comprised of a 6 inch in diameter BlueTube 22 inches in length, a 6 inch in diameter BlueTube coupler tube that is 12 inches in length, a Motor Section bulkhead, and the Motor Section Subassembly. The coupler tube is positioned inside the Motor Body BlueTube towards the forward end of the Launch Vehicle, so that 6 inches of the coupler tube interfaces with the Motor Section BlueTube, and 6 inches of the coupler tube sticks out towards the forward end of the launch vehicle. The coupler tube is secured to the Motor Section Body Tube using epoxy that covers the entirety of the 6-inch interface between the two BlueTube.

The Motor Section bulkhead is epoxied 1.5 inches from the forward end of the 12 inch coupler tube, and it is half an inch in thickness. The bulkhead contains a hoist ring that is connected by a nylon lock nut and an oversized washer. The 72 inch Iris main parachute is tied to this hoist ring. The Motor Body Tube has four fin slots cut into it so that the Motor Subassembly can be slid into the BlueTube.

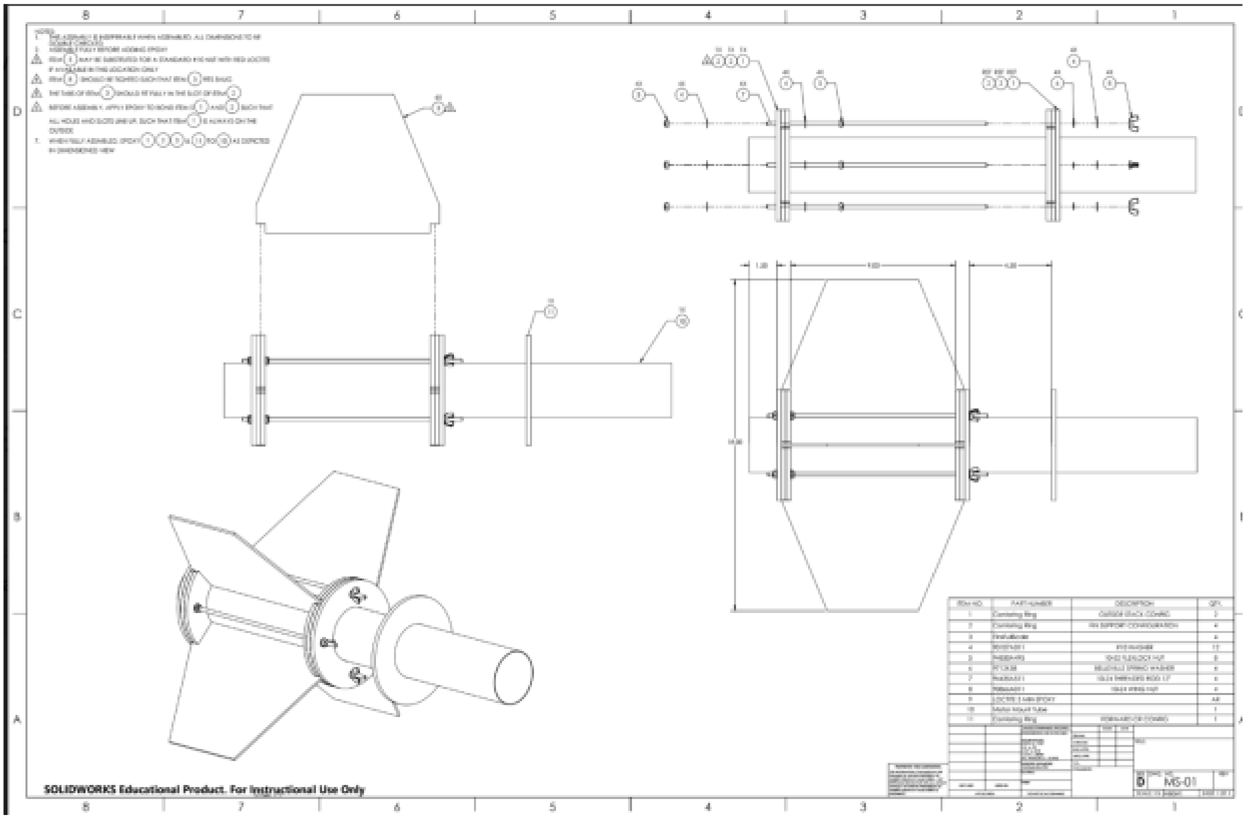
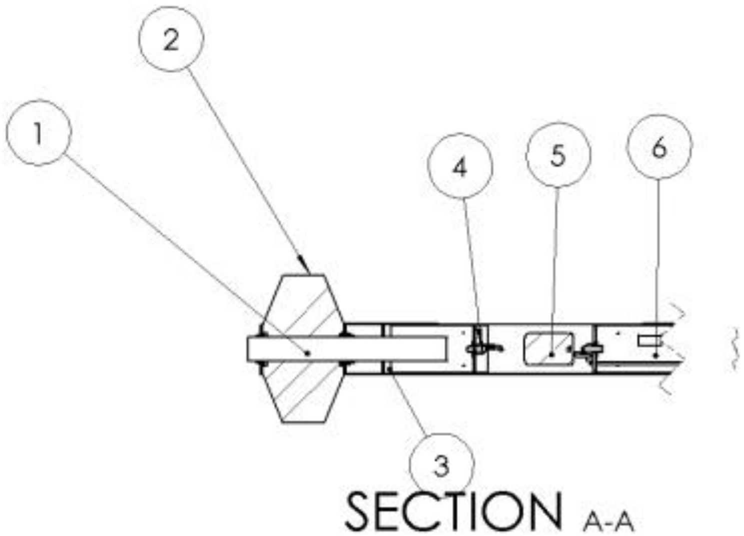


Figure 6 Motor Tube Subassembly

The motor tube assembly, depicted in Figure 6, houses the four G10 Fiberglass fins that are an eighth inch thick, and the motor that will propel the Launch Vehicle. This subassembly is composed of a 3 inch in diameter inner tube that is 20 inches in length. This inner tube houses the motor casing of the rocket, which contains the motor that will send the Launch Vehicle to its target altitude. To this inner tube, there are three centering rings that are 6 inches in diameter. Two of the centering rings are used to secure the four G10 fiberglass fins to the inner tube, and are each composed of three quarter-inch centering rings that are epoxied together to form one 0.75-inch ring. These two centering rings each have two of their three quarter inch centering rings cut with 4 slots to fit the slots of the fiberglass fins that protrude through the outer Motor Body Tube that houses the entirety of the Motor Tube Subassembly. These two 0.75-inch centering rings are then set 9 inches apart from each other and are connected by four 10-24 12 inch threaded rods, and the fiberglass fins are sandwiched in between the two rings. This configuration is held together by 8 wing nuts attached to both sides of the four threaded rods. The centering ring and fins configuration is positioned so that the one of the 0.75 centering rings is 1.5 inches from the aft end of the inner tube. 4.5 inches from the forward end of the centering rings and fins configuration is one 0.25-inch centering ring. Both the centering ring and fins configuration and the single 0.25 centering ring are epoxied to the inner tube.

The four fins of the launch vehicle are composed of G10 Fiberglass, have a root chord of 10 inches, a tip chord of 5 inches, a height of 6 inches, a sweep length of 2.5 inches, and a sweep angle of 22.6 degrees. The fin tabs which protrude through the Motor Body Tube have a length of 9.25 inches, and a height of 1.5 inches.



Item Number	Item Name	Description
1	Motor	L2200 Motor
2	Fins	10in Root Chord 6in height, 1/8in thick
3	Centering Ring	Holds motor tube, keeps it from moving
4	Bulkhead	Protects rest of launch vehicle from motor pressure
5	Parachute	Marin parchute, 66in diameter, connected to the bulkhead with 40ft of .5in tubular kevlar via a .5in hoist ring
6	Threaded Rod	Electronics bay, deploys booster drogue parachute and booster main parachute

Figure 7 Motor Subsection and Interstage

The Figure 7 depicts how the motor section, the body tube that houses the 72-inch main parachute, and the motor electronics bay link together. A 24.875-inch body tube is connected to the motor section coupler tube with four shear screws, that will enable the separation of the motor section and the motor electronics bay. This body tube is connected to the motor electronics via four set screws. Within the body tube are the shock cord tied to both the motor electronics bay and the motor section, and the main parachute that is also tied to this shock cord.

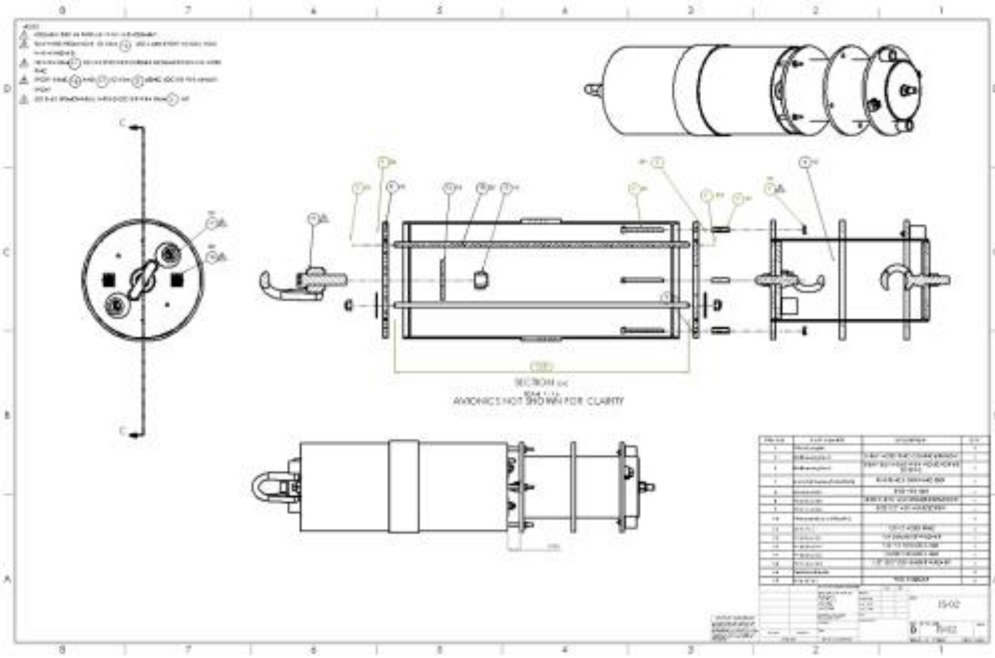


Figure 8 Motor Electronics Bay and Interstage

The motor electronics bay will be housed in a 14 inch long 6.003in diameter BlueTube coupler tube. A two inch 6.16 in diameter BlueTube body tube goes over the coupler tube and is attached to the middle of the coupler tube. At the top (right facing in the image) of the coupler tube, there is a ½ inch bulkhead will two holes drilled opposite of each other for threaded rod. Also there are four holes drilled evenly spaced with screws running through them and standoffs over the screws which line up with holes on the bottom centering ring of the Interstage inner tube system. Inside the coupler tube there is a piece of cut BlueTube permanently attached to the inside ½ from the lip of the tube one each side of the tube. This allows the bulkhead to rest on this piece of body tube and remain flush with the lip of the tube. The bottom bulkhead is ½ inch thick and in the center is a ½ inch hoist ring fastened to the bulkhead using a washer and locking nut with high strength Loctite on the other side of the bulkhead. This bulkhead also has holes on opposite side of the bulkhead for threaded rod that line up with those on the bulkhead on the other side. There are nuts on the outside of both bulkheads going over the threaded rods to hold the bulkheads in place.

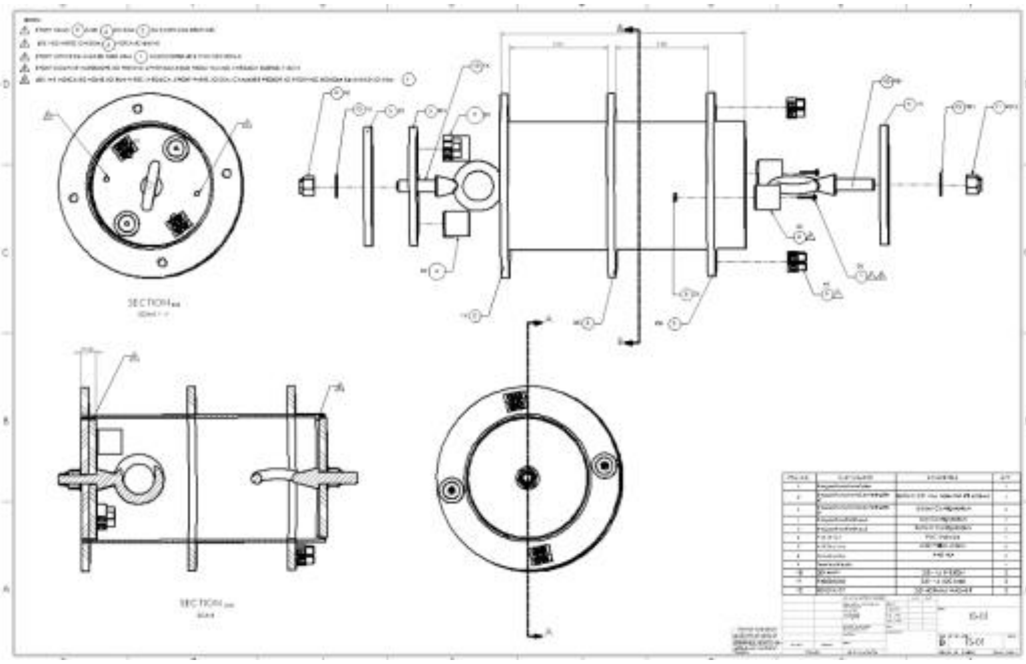
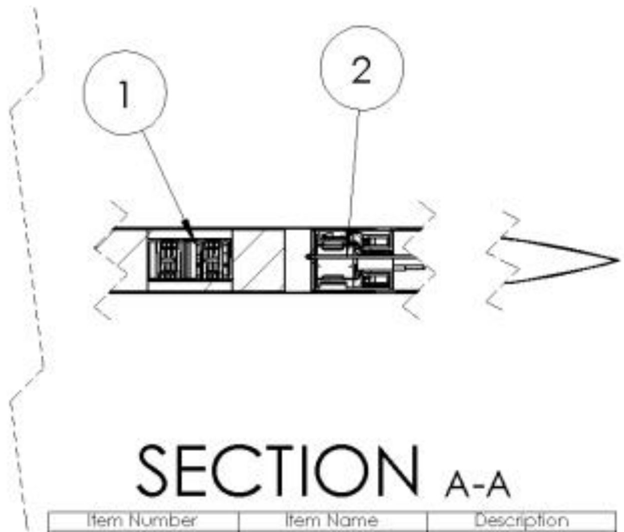


Figure 9 Interstage Drogue Parachute

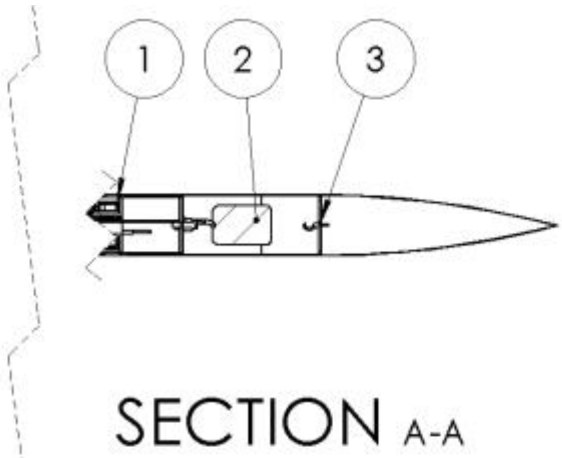
The motor drogue parachute system is the most complex system on our launch vehicle. Its purpose is deploy the motor drogue parachute at a delay from the separation of the motor section and the payload section. This keeps the drogue parachutes from becoming tangled while firing out of the same section of the launch vehicle. It is comprised of three centering rings, two bulkheads, two ⅜ in forged eye bolts, one 8-inch-long piece of 4-inch diameter BlueTube, four blast caps and four terminal blocks. The centering rings are positioned at the bottom, 3 inches from the bottom and 6 inches from the bottom as shown in the figure above. The topmost centering ring will have two evenly spaced blast caps for black powder charges and two evenly spaced terminal block to connect the electronic matches to the motor section electronics bay. The bottom bulkhead, which is permanently attached to the Interstage system, is comprised of two ¼ inch bulkheads to make a ½ inch bulkhead. In the center of this bulkhead there is a ⅜ inch forged eye bolt that faces into the inner tube to be attached to the motor drogue parachute shock cord. The eye bolt will be secured on the other side of the bulkhead using a locking nut and high strength Loctite. The bulkhead with also contain evenly spaced blast caps, to hold the black powder charges, and terminal blocks to connect the electronic matches which ignite the charges to the Stratologgers housed on the motor electronics bay. The top bulkhead is only one ¼ inch bulkhead. In the center of this bulkhead there is an identical ⅜ inch forged eye bolt that is fastened at the back of the bulkhead using a locking nut with high strength Loctite. This bulkhead will also be positioned with the eyebolt facing the inside of the inner tube. The other end of the shock cord for the motor drogue parachute attaches to this bulkhead. This bulkhead is not permanently attached to the Interstage system.



Item Number	Item Name	Description
1	Payload Protection System	The subsystem designed to protect the unknown payload utilizing a number of force-dampening methods
2	Upper electronics bay	Sets off the charge to deploy the main parachute and sends telemetry data back to the ground

Figure 10 Payload Protection System Section (Payload Drogue → Payload Electronics)

The Payload Protection system that will house the fragile object that NASA will give us on launch day is housed in a 22-inch body tube. For further description of this design, refer to section 4. The 14-inch coupler tube which houses the payload electronics bay slides into the 22-inch body tube 6 inches until it is stopped by the 2 inch strip piece of blue tube body tube fastened around the middle of the 14 inch blue tube coupler. The bulkhead at the bottom of the payload protection system simply has two holes positioned in line with those on the bulkhead on the opposite bulkhead. The threaded rod will run through the electronics bay and both bulkheads being secured on both sides using washers and nuts. The electronics bay contains two perfect flight StratoLoggers to initiate separation and main parachute deployment at an altitude of 500 feet.



Item Number	Item Name	Description
1	Upper Electronics Bay	Sets off the charge to deploy the main parachute and sends telemetry data back to the ground
2	Payload Section Main parachuteq	66 in diameter connected to the bulkhead with 30 ft .5in tubular kevlar
3	Bulkhead	Prevents the parachute from being shot into the nose cone on deployments and assists the increase in pressure to separate the two subsections

Figure 11 Nose Cone Subsection (Payload Electronics Bay → Nose Cone)

The nose cone is 24 inches long and made of fiberglass with a shoulder. Inside the shoulder of the nose cone there is a ½ bulkhead with ⅜ inch forged eye bolt attached with a washer, locking nut, and high strength Loctite. A 20-inch nose cone slides over the shoulder of the nose cone. The 20-inch piece of BlueTube slides over the 14-inch coupler tube housing the payload electronics bay. At the top of the payload electronics bay there is a ½ inch bulkhead which sits on a 1-inch piece of body tube along the inside of the coupler tube. This bulkhead is flush with the top of the coupler tube and has ½ inch hoist ring in the center. This hoist ring is secured using a fender washer, a locking nut, and high strength Loctite. Also on the bulkhead are holes for threaded rod which will run through the electronics bay to a bulkhead on the other side. There are also two evenly spaced blast caps to hold black powder charges for separation along with two evenly spaced terminal blocks to connect the electronic matches to the StratoLoggers on the payload electronics bay. The main parachute for the payload section is housed in the 20-inch body tube and attaches on one side to the hoist ring and on the other side to the nose cone at the ⅜ inch forged eye bolt with 35 feet of shock cord.

3.1.5. Flight Reliability Confidence

The success criteria are detailed below, including an explanation of their importance, along with the likelihood of failure for each, and the reasoning that led to these conclusions. The likelihood of failure was assessed using this system:

Table 6 Failure Likelihood Assessment

Likelihood	Definition	Ranking
Remote	Significant negligence and defects required for hazard to occur.	1
Unlikely	Significant negligence or major defects required for hazard to occur.	2
Possible	May occur despite proper safety measures and equipment checks taking place.	3
Likely	Expected to occur despite proper safety measures and equipment checks taking place.	4

Table 7 Success Criteria and Reliability Confidence

Success Criteria	Explanation	Likelihood of Failure	Reasoning
Reach the projected apogee of 5280 feet as one unit.	The rocket needs to reach apogee around 5318 feet, or else the recovery charges will go off at the wrong time. Theoretically this could result in problems with parachute deployment and recovery.	1	Barring a manufacturing error in the motor itself, there is little to cause the rocket to radically miss the target altitude.
Separate into the Booster Stage and the Payload Section at apogee.	This is the first separation. If this does not occur, the sections will fall together and the descent will rely entirely on the main parachutes.	2	Only a mistake in both the ejection charge and the backup ejection charge could cause this to fail.
Successfully deploy an 18 inch diameter drogue parachute out of the Booster Stage after initial separation.	This drogue will slow the descent of the Booster Stage before the main parachute deploys. If it does not deploy, the booster stage will be in free fall until the main parachute deploys, likely resulting in a higher impact velocity.	2	The only errors that could cause this are a drogue folding malfunction and/or a failed separation, both of which would be the result of negligent preparation.
Successfully deploy an 15 inch diameter drogue parachute out of the Payload Section after initial separation.	This drogue will slow the descent of the Payload Section before the main parachute deploys. If it does not deploy, the booster stage will be in free fall until the main parachute deploys, likely resulting in a higher impact velocity. This is especially problematic for the Payload Section, as the safety of the payload could be compromised.	2	The only errors that could cause this are a drogue folding malfunction and/or a failed separation, both of which would be the result of negligent preparation.
The drogue parachutes do not	If they do tangle, the sections will be tethered together and will likely	3	Tangles are somewhat unpredictable; proper drogue

tangle during descent.	spin uncontrollably. The descent will then be dependent on the main parachutes deploying properly, although this becomes more difficult under these conditions.		folding should prevent this, but, even still it is possible.
Separate the Booster Stage into two subsections, the Aft Parachute Subsystem and the Motor Subsystem, which are tethered together.	If the Booster Stage does not separate, the only thing slowing its descent will be the drogue parachute. This will result in the Booster Stage hitting the ground with high velocity.	2	A failure to separate would require both the separation charge and the backup charge to fail. This is highly unlikely if the proper procedures are followed during launch preparation.
Separate the Payload Section into two subsections, the Payload Subsystem and the Nose Cone, which are tethered together.	If the Payload Section does not separate, the only thing slowing its descent will be the drogue parachute. This will result in the Payload Section hitting the ground with high velocity, possibly critically damaging the payload.	2	A failure to separate would require both the separation charge and the backup charge to fail. This is highly unlikely if the proper procedures are followed during launch preparation.
Successfully deploy a 72 inch diameter main parachute that is connected to the two tethered booster subsections	The main parachute does the majority of work in slowing down the rocket from deployment velocity to terminal velocity. Should the parachute fail to deploy, the drogue will be the only thing slowing descent, resulting in a very high impact velocity. This threatens the safety of the rocket, and also makes the falling rocket potentially dangerous to people and property.	2	The only errors that could cause this are a parachute folding malfunction and/or a failed separation, both of which would be the result of negligent preparation.
Slow the two tethered booster subsections from a velocity of 90 feet per second to a final velocity of 19 feet per second	The parachute will control the descent upon its release, and if it releases successfully then the descent should slow to about 19 ft/s. If this does not occur properly, the section must be enduring impact at a higher velocity, potentially damaging it.	1	This criterion is tied to the successful launch of the parachute. If the parachute deploys successfully, this objective is all but given.
Successfully deploy a 60 inch diameter main parachute that is connected to the two tethered	The main parachute does most of the work in slowing down the rocket from deployment velocity to terminal velocity. Should the parachute fail to deploy, the drogue	2	The only errors that could cause this are a parachute folding malfunction and/or a failed separation, both of

payload subsections.	will be the only thing slowing descent, resulting in a very high impact velocity. This threatens the safety of the rocket, and makes the falling rocket potentially dangerous to people and property. This all but ensures that the payload is damaged during descent.		which would be the result of negligent preparation.
Slow the two tethered payload subsections from a velocity of 89 feet per second to a final velocity of 18 feet per second.	The parachute will control the descent upon its release, and if it releases successfully then the descent should slow to about 18 ft/s. If this does not occur properly, the section will be enduring impact at a higher velocity, potentially damaging it.	1	This criterion is tied to the successful launch of the parachute. If the parachute deploys successfully, this objective is all but given.
Descend with a maximum drift of 2500 feet.	The drift of the launch vehicle must be less than 2500 feet. If it is not, the rocket could potentially land on, or damage, private property, or in a place it cannot be reached after landing.	2	Simulations show that even in the worst launch conditions this will not fail, barring any manufacturing mistakes.
Safely descend in a manner that minimizes, or, ideally eliminates, all possible damage to the launch vehicle.	Should everything deploy and behave as expected, the launch will not damage any of the vehicle's components.	2	All the recovery system, including drogues and parachutes, contributes to this goal. The only thing that could potentially cause a failure is if the descending sections land someplace that damages the rocket, a result that is entirely uncontrollable.
Safely descend so that the launch vehicle will be able to be prepared to relaunch with minimal repair and replacement of part.	If the descent is safe and controlled, the components of the rocket should be in such a state that minimal repair is necessary to reconstruct and relaunch.	3	There is an element of randomness to the landing process; unforeseen landing conditions such as landing surface or obstacles could damage the vehicle without any failure in construction or launch.
Record and store flight data, including acceleration data,	Data must be collected to track the vehicle's performance and location in order to safely recover the rocket after landing as well as to check the accuracy of our predicted outcomes.	2	Unless the electronics are not activated properly, the data will be recorded.

using a Sensor Suite.			

3.1.6. Construction Process

Payload Section

Nose Cone Subsection
The nose cone is a 24 inch G10 ogival fiberglass nose cone that was purchased from Public Missile. The tip of the nose cone was filled with ballast with one end of shock cord. Both the ballast and shock cord were epoxied in place at the tip of the nose cone. A ¼ inch bulkhead, with a U-bolt attached to it, was then epoxied into place at the base of the nose cone. A hole was drilled in through this bulkhead and the shock cord threaded through. The cord was then tied around the U-bolt with enough length leftover to attach to the parachute and tie to the other end to the Payload Section electronics bay. The nose cone was attached to the body tube housing the parachute via 4 shear pins that would allow the nose cone to detach and deploy a parachute at apogee.

Payload Protection System (PPS) Subsection
This section is the body tube that houses the parachute above the payload electronics bay coupler tube. It is 20 inches of body tube with 4 holes drilled at either end. It connects to the nose cone by 4 shear screws and to the payload electronics bay by 4 set screws.

The payload electronics bay consists of 14 inches of coupler tube, 2 inches of body tube, two ½ bulkheads, two ¼ inch threaded rods, and the electronics bay. The 2 inches of body tube is epoxied into the center of the 14-inch coupler tube so that there is 6 inches of coupler tube on either side. Once the coupler and body tube were epoxied together, two holes, one on either side, were drilled into the body tube to grant access to the electronics bay key switches. The bulkheads for the electronics bay are each made of two ¼ inch circular cut plywood that were cut using a laser cutter. Two parts of coupler tube, each 1 inch in length, were epoxied in the inside of either end of the 14-inch coupler tube ½ an inch from the lip of the tube. This creates a ledge for the bulkheads to rest on so there is no possibility of the bulkhead sliding down into the tube.

The top bulkhead has four holes drilled in it, two for threaded rods, one for wires, and one for a hoist ring. The hoist ring was put in the center of the bulkhead. The two blast caps were screwed and hot glued to the top of the bulkhead. There were also two terminal blocks hot glued to the bulkhead. The lower bulkhead had two holes drilled in it for the threaded rods. The threaded rods run through these holes to the other bulkhead, restricting vertical motion of the bulkheads.

The electronics bay itself had to be 3D-printed. In the past, all the in-house designed electronics bays were too big to be printed in one session with the printers we had access to. However, this electronics bay design was small enough to theoretically work in just one print. Unfortunately, due to past problems, including the printer misaligning if the print went on too long, and due to the precision needed for the openings at the center of the electronics bay, it was decided to print this one in two smaller parts. This design is much more in depth than the subscale payload electronics bay, which was, in all intents and purposes, a sled. This design has designated spots for two StratoLoggers, two 9V batteries, and one 7.4V Lipo battery, which powers an XBee and a Teensy that are included in the electronics bay. This design allows the electronics to be very compact and easily wired, while also providing more support than necessary to prevent disconnect from vibrations.

The electronics bay is connected to two bulkheads by threaded rods. The two threaded rods run through the electronics bay and are connected the bulkheads on either side by a nut and washer. The bulkheads and electronics bay are then put inside the 14-inch coupler tube, and are held in place by each other and the smaller coupler tube inside of the 14-inch coupler tube.

For the Payload Protection System subsection, the body tube was cut to a length of 22 inches. Four holes were drilled equidistant around the body tube and coupler for the payload electronics bay, to be used for set screws. There was also 12 inches of coupler tube that was epoxied to one end of the body tube so that 6 inches of the coupler is inside the body tube, while 6 inches extend past the end of the body tube. At the end of this coupler tube is a bulkhead. The bulkhead has been epoxied into place, and has a hole drilled in the center where an eye bolt is connected with a washer and nut.

Interstage

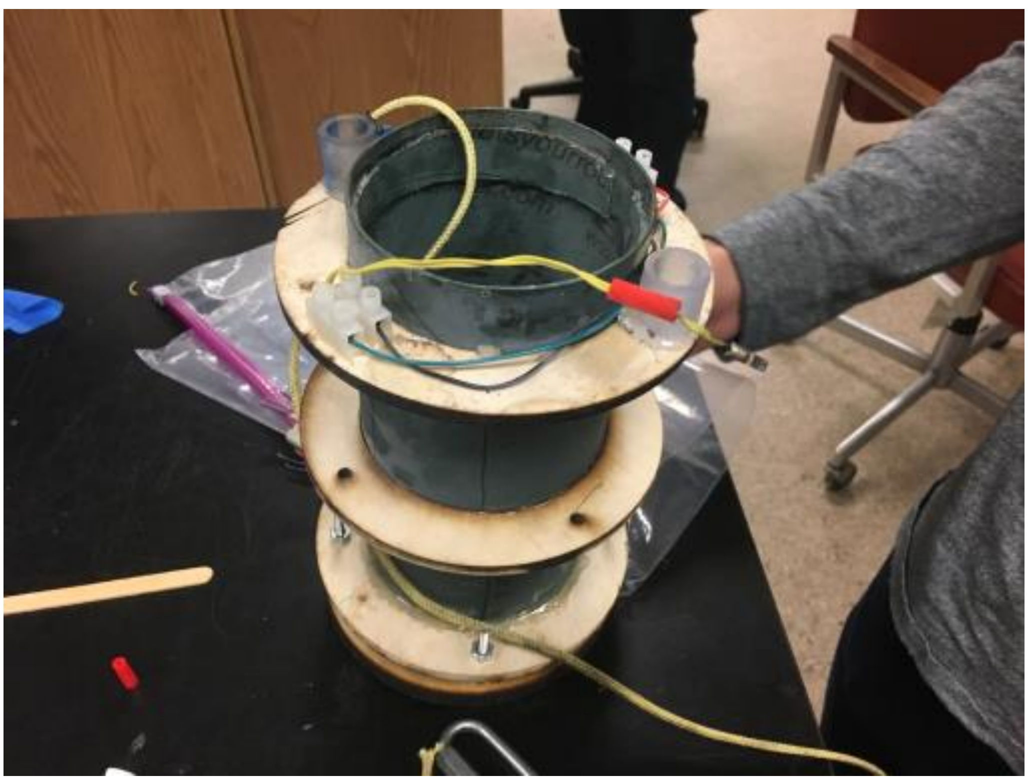


Figure 12 Interstage

The Interstage itself was made of 4-inch diameter BlueTube cut to a length of 8 inches. There are centering rings to keep the tube steady, while inside the 6-inch body tube. The first centering ring was attached to the bottom of the Interstage using five-minute epoxy. The second centering ring was epoxied 3 inches from the bottom and the third was epoxied to the inner tube 6 inches from the bottom, both again using five-minute epoxy. Four equally spaced holes are drilled in the bottom centering ring for screws. The same was done for the other two centering rings so that there are holes for the wires. There are blast caps hot glued to opposite sides of the topmost centering ring in the figure. These function as the containment units for black powder that serve to separate the Booster Stage from the Payload Section. Similarly, there are two terminal blocks hot glued to the topmost centering ring on opposite sides from each other. The terminal blocks connect wires from the StratoLoggers on the motor electronics bay to the electronic matches, which will ignite the black powder charges and separate the Booster Stage and Payload Section. At the bottom, in line with the bottommost centering ring, there is a ½ inch bulkhead epoxied into the 4-inch coupler tube using five-minute epoxy. This bulkhead has a ⅜ inch eye bolt that attaches to the drogue parachute. At the bottom of the component, there is a ½ inch bulkhead with four equally spaced holes that line up with those on the bottommost centering ring. The bulkhead will be attached to the bottom centering ring on the Interstage component using screws and nuts and will be separated using metal standoffs. The drogue parachute for Booster Stage with be housed within this 4-inch diameter inner tube. At the top of the inner tube there is another ½ inch bulkhead with a ⅜ inch eye bolt that is not permanently attached to the inner tube. The bulkhead was placed so that the eyebolt is facing the inside of the tube and is attached to the drogue parachute. This bulkhead is friction fit and secured over the top with a piece of tape that will come off during parachute deployment. Under the bottom, it is secured with a strip of BlueTube, which has been epoxied to the inside using five-minute epoxy ½ inch from the top of the tube, so that bulkhead can rest on this and cannot at any point slide down into the tube.

Booster Stage

Aft-Parachute Subsection

Between the electronics bay and the motor subsection is a body tube that holds the parachutes for the booster section. The body tube was cut to a length of 24.875 inches. There are four holes drilled equidistant around the body tube at each end of the body tube. The electronics bay is connected to the body tube by four set screws. The motor section is connected to the body tube by four shear pins.

Electronics Bay

The construction of the electronics bay was among the tougher aspects of constructing the launch vehicle. This process started with the initial 3D design used in the subscale that we then adjusted to improve on the effectiveness by widening the radius and incorporating tunnels for wiring, rather than just indents. The motor electronics bay has the same components as the subscale: four StratoLoggers, four 9V batteries--one for each StratoLogger, and two double pole double throw keylock switches--each keylock switch activates two StratoLoggers for deploying the main and drogue parachutes. The design is too large to have printed in one session with the 3D printers that we had access to, so the design was split into two sections. However, because the printer that was easiest to access was malfunctioning part way through the print, the team decided to go to the next 3D printer that was easiest to access. This was the Snell Library 3D printing center. Unfortunately, there were many complications, including multiple poorly printed iterations, one of which is seen below, which was so bad that there were parts coming off to the point that it needed to be glued back together.

Figure 13 Half of the 3D printed electronic bays

After this attempt at the library, another design was made to be made of multiple laser cut pieces of wood that fit together. Additionally, the 3D print was tried one more time with different settings, as the 3D printed design is more ideal in terms of wiring and manipulability. Thankfully, this attempt worked, and this section, the other half of the electronics bay, and the Payload Section electronics bay could be 3D printed. The two sections of the electronics bay, as well as the bulkheads on either side of the electronics bay, are held together by two ¼ inch threaded rods. There are nuts on the threaded rods just outside of both bulkheads keeping them tight together. The wiring for the electronics bay can be seen in Section 3.1.3. The bulkhead adjacent to the Interstage has two blast caps and e-matches. This is the same setup as mentioned above within the Payload electronics bay.

The BlueTube is also very similar to the Payload electronics bay. There is a coupler section which is 14 inches long, and will have 6 inches on either side of the 2-inch-long outer BlueTube part, which has two holes drilled into it for the keylock switch keys to be able to turn the electronics bay off and on.

Motor Subsection

BlueTube was cut to a length of 22 inches to serve as the body tube for this subsection. Four ⅛ inch wide slots of length 10.25 inches were cut parallel to the length of the body tube, with 90 degrees between the center of each slot. Four fins of the dimensions specified 3.1.2. were cut from ⅛ inch garolite using a waterjet. Then, four of the centering ring in Figure 1 were laser cut from ¼ inch plywood. With five-minute epoxy, two of these centering rings were aligned by fin slots and threaded rod holes and epoxied together, creating a centering ring with a thickness of ½ inch. This was then repeated for the two remaining centering rings. Then, two of the centering ring in Figure 1 were laser cut from ¼ inch plywood. One of these centering rings was aligned to each of the two blocks of centering rings and epoxied together. Next, the four fin slots in each block of centering rings were filled with five-minute epoxy and were used to interlock the fins together as shown in Figure 14.

Figure 14 Fins in Centering Rings

Threaded rods of size 10 were threaded through the four holes on each block of centering rings to keep the fins perpendicular to the centering rings. Once the epoxy had dried, the threaded rods were removed. Next, the BlueTube inner tube of 75 mm was inserted into both center holes of the centering ring block, with a protrusion of 1.5 inches of the

BlueTube at one end. Using G5000 RocketPoxy and a tongue depressor, fillets were made between the inner tube and the side of each fin.

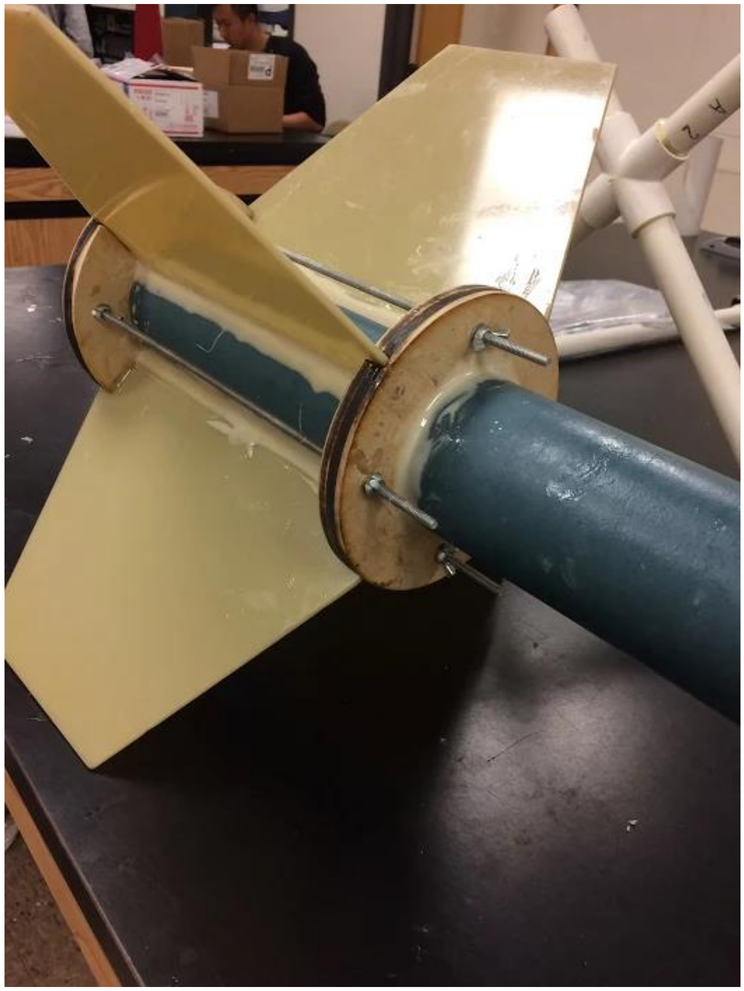


Figure 15 Inner Tube in Centering Ring with Fins

The circular edges of the two centering ring blocks were covered with five-minute epoxy. Then, the BlueTube with cut out fin slots was placed over and slid onto the now single part of centering rings and fins with the fins lining up with the fin slots. Using G5000 RocketPoxy and a large tongue depressor, fillets were made between the inner tube and the side of each fin for a total of eight fillets. Also, fillets were made between the inner tube and the sides of each centering ring block, effectively securing the fin system to the motor tube. A body tube was then slid around the outside of this with four cut outs for each fin. The five minute RocketPoxy was used to secure the body to the centering rings and fins. The tongue depressors were also used to make the fillets that hold the fins in their slots.

3.2. Recovery Subsystem

3.2.1. Structural Elements

Our launch vehicle has two different types of recovery subsystems: Main parachute recovery subsystems and drogue parachute recovery subsystems. Each subsystem is designed to different standards, so it is very important to distinguish between the two.

Main parachute recovery systems are recovery systems are attached to main parachutes, and therefore will see the greatest loads of any component on the rocket. To combat these loads, every component on this subsystem is designed to have a 5:1 safety factor on deployment, as per ASME 30.26, the ASME design standard for hoisting. Each main parachute recovery subsystems consists of 5 major structural components:

1) Recovery Bulkheads (one on each anchor point)
2) ½ inch Hoist Rings, one per anchor point for motor section and one hoist ring and one ⅜ inch eyehook attached to the nose cone for the payload section
3) Recovery Harness, secured to each anchor point
4) Swivels, one per parachute attachment.

Drogue parachute subsystems consist of 4 structural components, and are only anchored on one bulkhead, which varies from main parachute subsystems, which are anchored on two bulkheads:

1) Recovery Bulkhead
2) Eyebolts, ⅜ inch diameter
3) Recovery Harness
4) Swivels, one per parachute attachment.

Recovery Bulkheads

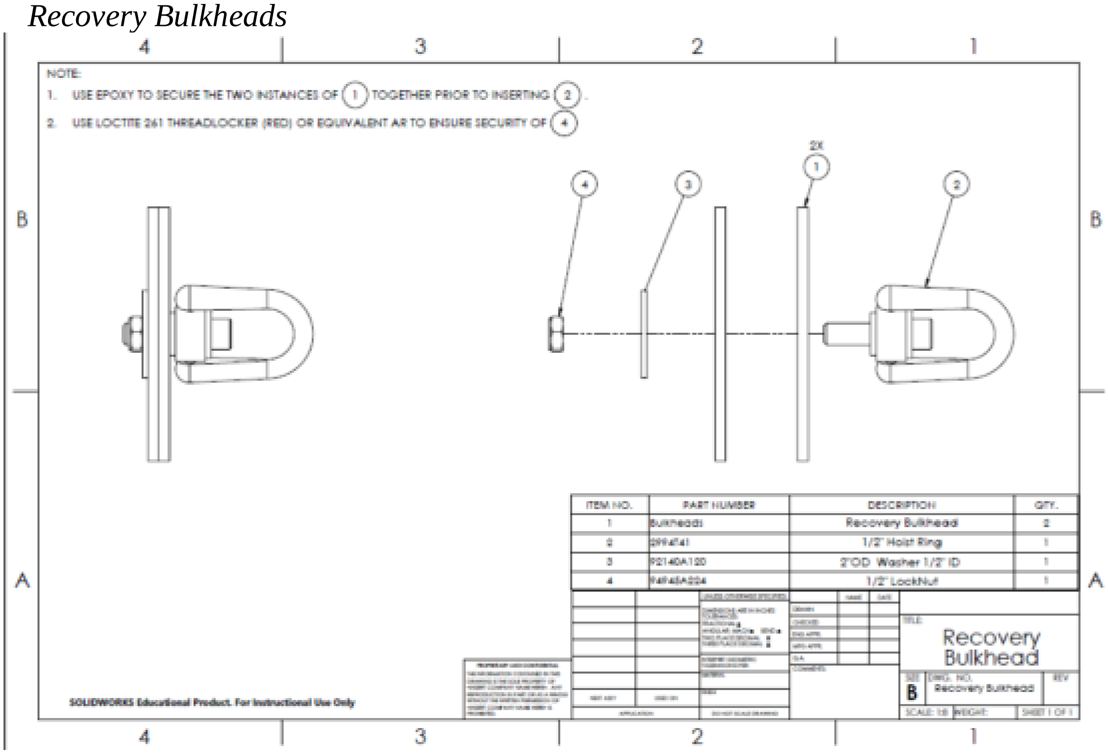


Figure 16 Recovery Bulkhead Specifications

A main parachute recovery bulkhead, shown in the figure above, consists of two ¼ inch 5-layer plywood bulkheads that are secured to each other via epoxy. To ensure a quality bond, they are clamped together during the adhesive process. This creates a single 10 layer ½ inch bulkhead.

A hoist ring secured runs through the through hole in the center of the recovery bulkheads, and is secured with a nylon locking nut and high strength Loctite. Hoist rings are slightly different from eyebolts. They are functionally identical, but as a bonus swivel and pivot about their Z and Radial axes respectively, which allows for them to take loads which may not be suitable for normal eye bolts. The below figures show the difference between an eye-bolt and a hoist ring, and show the swivel ability of the hoist ring. The bottom figure also gives an overview of good and bad eye-bolt loading practices.

This provides an advantage for us for two distinct reasons: 1. The recovery harness will be able to rotate independent of the vehicle sections, and 2. The section will generally remain perpendicular to the ground always, which allows for it to hit the ground on its strongest axis.

Our hoist rings are rated to 2,250 lbs, and underwent a proof load test to 4,000lbs before being shipped. The below table shows the factors of safety compared to the nominal load which they will carry. The nominal load is calculated to be 2* the weight of the section which it is supporting. The below table shows the safety factor for the nominal loading scenario (hoist ring supporting sections under chute at terminal velocity):

Table 8 Mass and Safety Factors

MASS	KG	Lb	Nominal Load	Hoist Ring Safety Factor
Booster	6.05	13.31	26.62	84.5229151
Booster Parachute	5.93	13.046	26.092	86.23332822
Payload	6.53	14.366	28.732	78.30989837

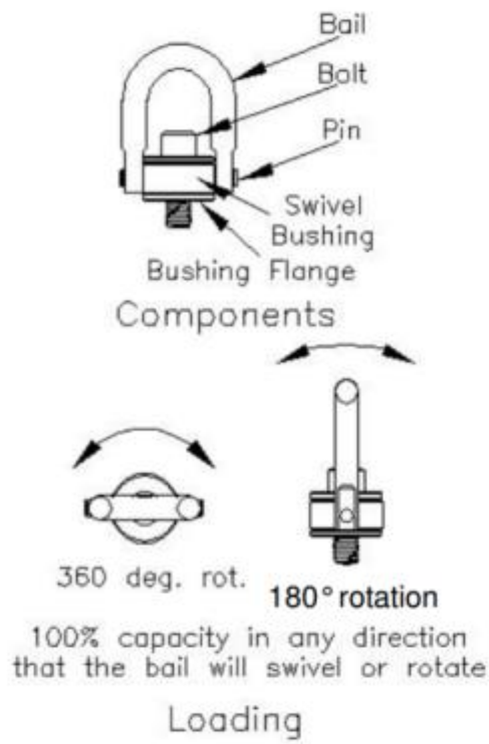


Figure 17 Hoist ring (ASME 30.26)

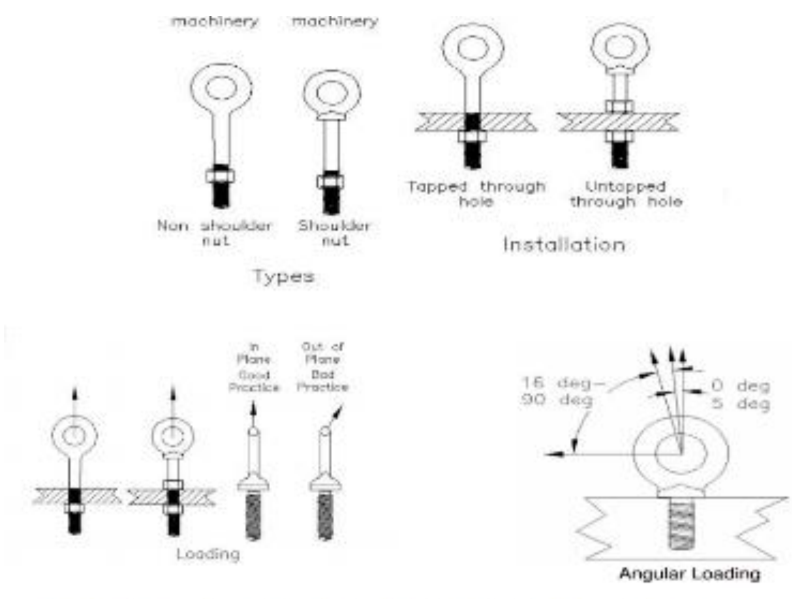


Figure 18 Proper Eyebolt Loading Practices (ASME 30.26)

3.2.2. Electrical Elements

Our Launch Vehicle will have six total PerfectFlite StratoLogger CF altimeters: four in the Booster Section electronics bay and two in the Payload Section electronics bay. The StratoLogger CF altimeter is a pressure-based altimeter that can power two deployment events. It has a built-in power switch, which allows for an external switch to turn the altimeter on and off. Each altimeter is powered by a single Duracell Quantum series 9-volt battery. The batteries are facing downwards so that when the rocket is accelerating upward the batteries are moving towards their terminals, not away.

We are using double pole double throw switches. This means that we have two keylock switches, each of which activate two StratoLoggers for main parachute in the Payload Section. In this way, there is multiple redundancies. In the Motor Section electronics bay, each key activates one StratoLogger used for the drogue parachutes and one for the main parachute.

In order to locate the launch vehicle we are using two types of locating devices. In the Payload Section we are using the XBee XSC Pro. In the Booster Section we are using the TeleGPS. More information on both can be found in Section 3.2.6.

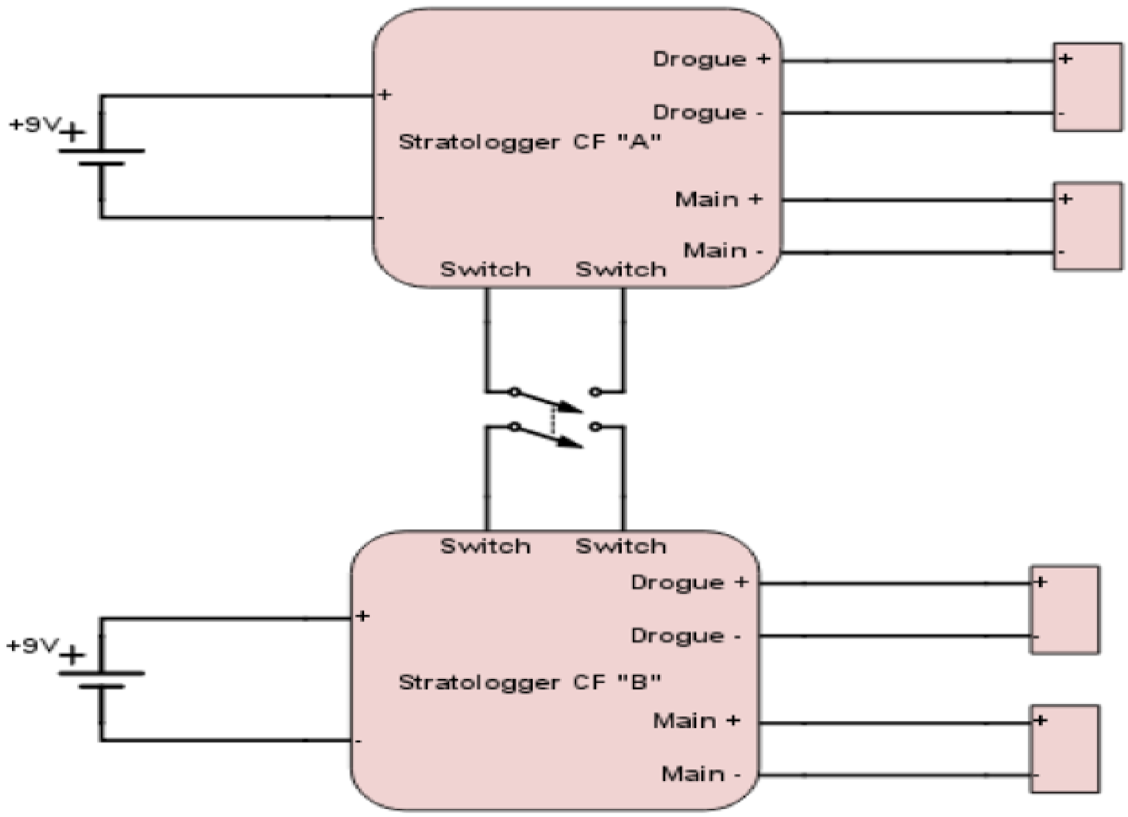


Figure 19 Keylock Switch Circuit

The setup here is for any of the keylock switches. When one switch is turned, it completes two circuits. Each StratoLogger, however, has a circuit from either the drogue ports or the main ports, not both

3.2.3. Redundancy Features

There are many contingencies within the launch vehicle to ensure that nothing will go wrong. For nearly every electronic component, there is a duplicate to make sure that all will go smoothly. One of these features is the redundancy surrounding the StratoLoggers in the electronics bays. In the upper electronics bay, which separates the upper section when the main parachute is deployed, there are two keylock switches, each of which turns on its own StratoLogger. This way, even if one keylock switch or StratoLogger fails - both of which are extremely unlikely - one of the two keylock switch-StratoLogger systems will still work. Additionally, each StratoLogger is wired to its own blast charge. If one charge does not work, the other charge will be enough to separate the Nose Cone and PPS subsections of the launch vehicle.

The motor electronics bay, on the other hand, is connected to two parachutes: the lower drogue and main parachutes. Because of this, the redundancy must be different. There are still two keylock switches, but four StratoLoggers; each switch activates one StratoLogger for the lower main parachute deployment and one StratoLogger for the drogue separation. Again, if one keylock switch fails in this system, there will still be one StratoLogger for both the drogue and main parachute deployment systems. Like the Payload Section's blast charge redundancy, the Booster Stage also has two blast charges on each bulkhead. This way, even if one of the charges fails to ignite, the other will be enough to separate either the Booster and Payload Sections or the Aft-Parachute and Motor Section.

3.2.4. Parachute Sizes and Descent Rates

All four of our parachutes, the Payload Section's main and drogue along with the Booster Stage's main and drogue have different sizes. The Payload Section drogue parachute has a 15 inch diameter and a terminal descent rate of 88.747 feet per second. The Payload Section main parachute has a 60 inch diameter and a terminal descent rate of 18.241 feet per second. The Booster Stage's drogue parachute has an 18 inch diameter and descent rate of 91.579 feet per second. The Booster Stage's main parachute has a 72 inch diameter and a descent rate of 18.904 feet per second.

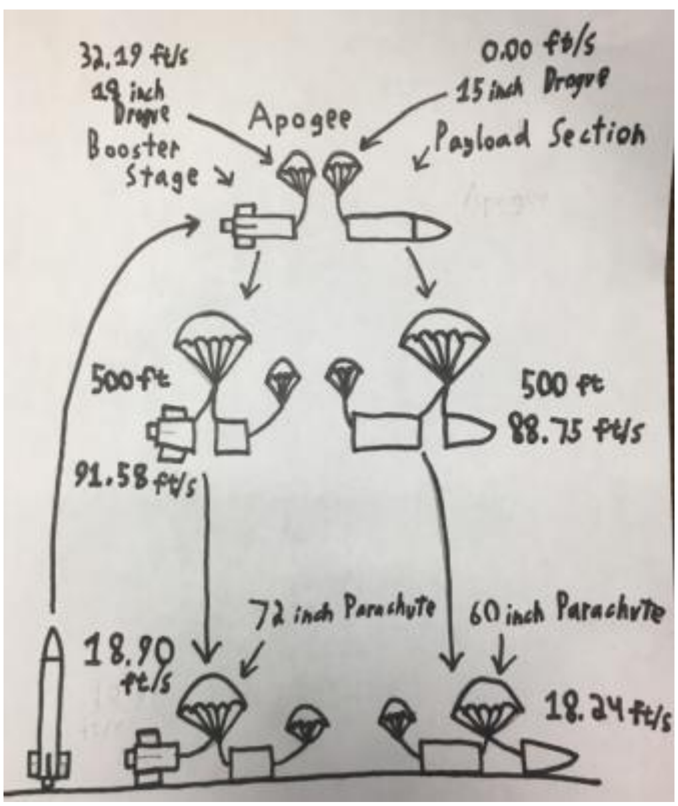


Figure 20 Parachute Deployment Sequence Diagram

3.2.5. Drawings and Schematics

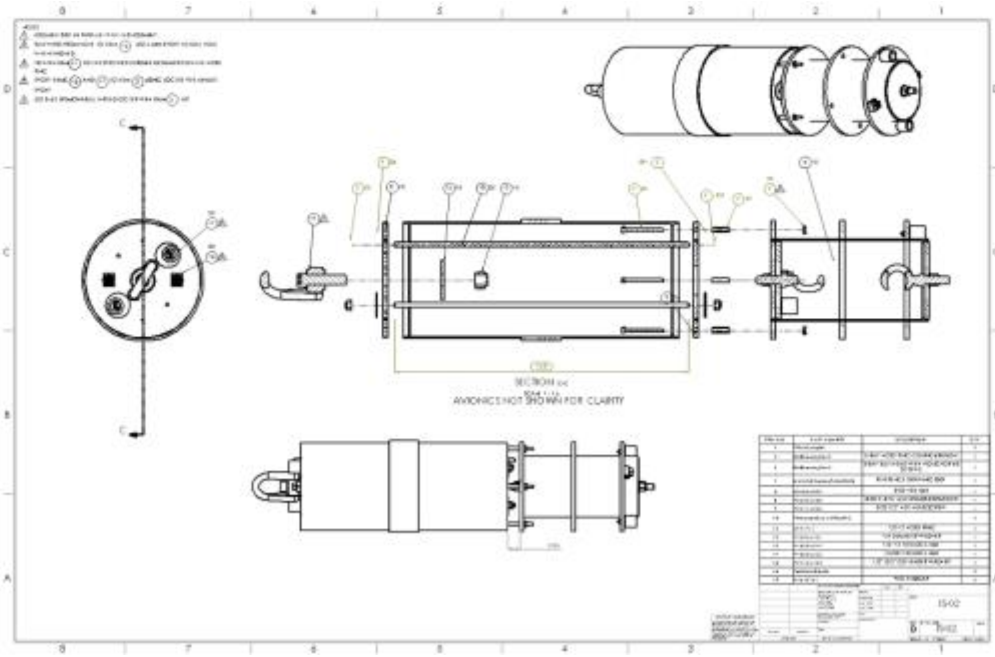


Figure 21 Motor Section Electronics Bay and Interstage Systems

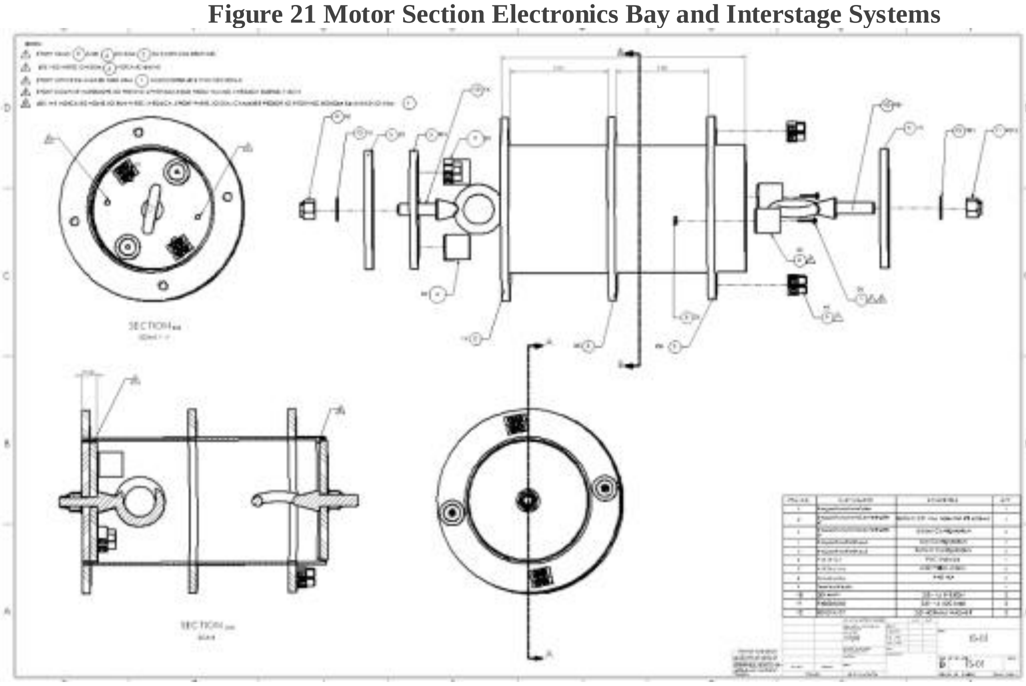


Figure 22 Motor Drogue Parachute

3.2.6. Rocket-locating Transmitters

There are two transmitters in the launch vehicle that are responsible for sending location data to the ground station, one in each separable section of the launch vehicle. The transmitter in the payload electronics bay is an XBee XSC Pro with a Pulse W1063 Antenna that transmits between

900 Mhz band and produces at up to 250 mW. The range on the XBee is up to 15 miles with a high gain antenna. The transmitter in the Booster Stage is a TeleGPS that uses a TI CC115L transmitter that produces at 10mW on the 70cm band. The range of the TeleGPS is approximately 24 miles. The range value for the TeleGPS was calculated using a 10dB margin to account for the possibility of the launch vehicle section falling onto terrain with bushes or trees using the following equation:

$$range = 10^{\left(\frac{P_{TX}-P_{RX}+G_{TX}+G_{RX}-Lm-36.6-20\log(f)}{20}\right)}$$

Where PTX and GTX are the power and gain of the transmitter, PRX is the receiver sensitivity, GRX is the gain of the receiver, Lm is the link margin, and f is the operating frequency.

3.2.7. Transmitter Interference Protection

The launch vehicle has two transmitters which will be sending data back to the launch site. However, there are other components in the electronics bays. For instance, the StratoLoggers are sensitive to interference from electromagnetic (EM) radiation from the other internal devices, such as the two transmitters present in the rocket. This is due to the ways in which waves interact as they cross paths. For instance, as the two EM waves pass one another they can produce a variety of effects when they superimpose upon each other, from negating one another to amplifying one another. This is especially true for the StratoLoggers whose readings depend greatly on a variable resistor within them to give specific voltage readings, leading to them being highly susceptible to outside EM radiation or electric fields.

To avoid any of this foreseen interference from other devices, faraday cages have been made around all electronic components of the electronics bay that require shielding from interference from other components such as transmitters. This includes both electronics bays, which each have their own faraday cage.

To best protect these electronics bays, they were wrapped in a wire mesh which consists of holes small enough to prevent any of the foreseen EM radiation from escaping. The faraday cages being made of a conducting material are a great solution to protect electronics from interference. This is due to the property of conductors: one being that if there is only an outside charge, there will be no electric field on the inside. The other property that helps with what we need is that EM radiation with an amplitude larger than the space between the wiring in the mesh cannot pass the faraday cage, shielding it from outside signals. Because of its property regarding outside charges and EM waves, we can apply Gauss's law then to see that the flux will also be 0.

$$\Phi = \oint E dA = \frac{q_{en}}{\varepsilon_0}$$

This in a way shields an internal enclosed device from outside sources because the outside electrical fields do not pass into the interior of the faraday cage since it cannot enter its interior. However, being a conductor, the faraday cage will adopt the electric field of the enclosed electronics themselves and thus not hinder the functioning of the internal electronic component.

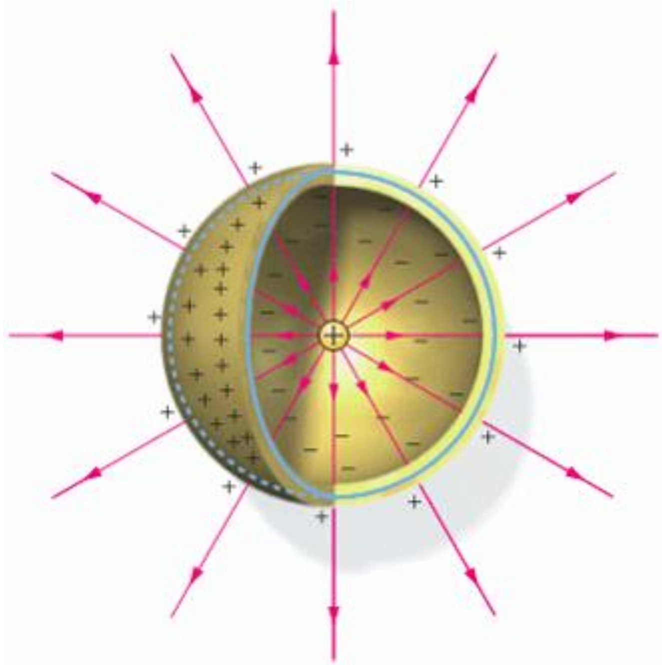


Figure 23 Conductor Interacting w/Electric Field

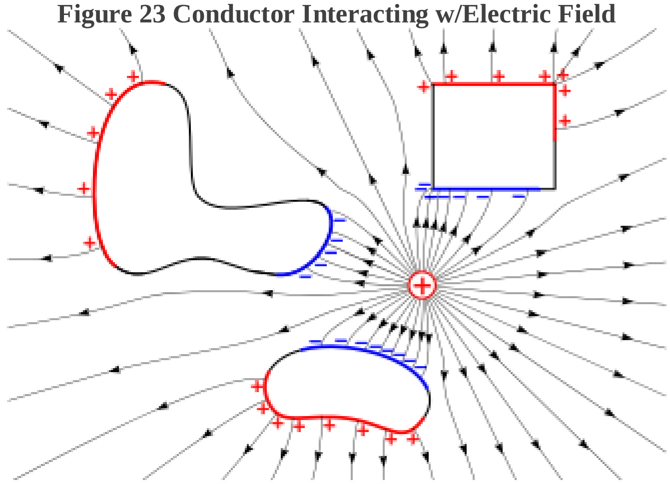


Figure 24 Conductors Interacting w/External Electric Field

Our faraday cage was constructed using a conductive wire mesh for flexibility, ease of construction, and to better remove the faraday cage so there will be easier access to the caged electronics. With the wire being easily bent into various shapes the cage can be easily conformed to a shape needed to properly shield the StratoLoggers and other valuable devices. Also, the conductive wire mesh allows for the faraday cage to be easily removed so there will be little to no difficulty in accessing the electronics underneath if need be.

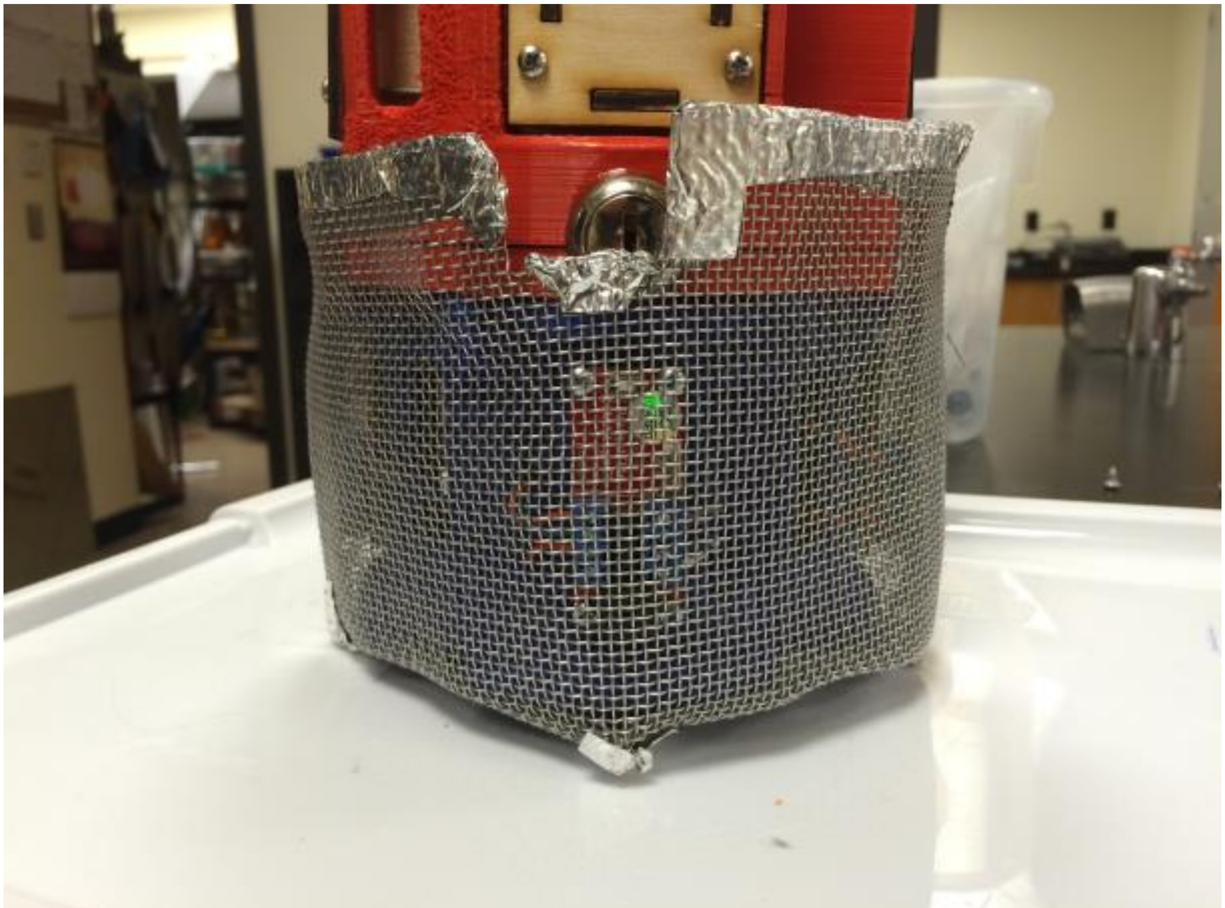


Figure 25 Prototype Faraday Cage Shielding StratoLoggers

3.3. Mission Performance Predictions

3.3.1. Mission Performance Criteria

Protect the payload suite and the unknown payload. The launch vehicle will send the supplied payload to an apogee of 5380 feet and then divide at the center as two segments; each of these both sections deploying their own drogue parachute. Each of the two sections will then deploy a main parachute at 500 feet. These sections will remain tethered with the main parachute in the center. These will land under the kinetic energy and drift requirements.

For the launch vehicle's mission to be deemed a success, the vehicle must:

1) Reach the one mile apogee as one unit
2) Separate into the Booster and the Payload Section at apogee
3) Successfully deploy an 18 inch diameter drogue parachute out of the Booster Stage after untethered initial separation
4) Successfully deploy a 15 inch diameter drogue parachute out of the Payload Section after untethered initial separation

5) Not allow the drogue parachutes to tangle during descent by using a system that ejects them a few seconds apart
6) Separate the Booster Stage into two subsections, the Aft Parachute Subsection and the Motor Subsection, which are tethered together
7) Deploy a 72 inch diameter main parachute that is connected to the two tethered booster subsections
8) Slow the two tethered booster subsections from a velocity of 91.5794 feet per second to a final velocity of 18.9048 feet per second
9) Separate the Payload Section into two subsections, the Payload Subsection and the Nose Cone Subsection, which are tethered together
10) Deploy a 60 inch diameter main parachute that is connected to the two tethered payload subsections
11) Slow the two tethered payload subsections from a velocity of 88.746 feet per second to a final velocity of 18.2415 feet per second
12) Descend with a maximum drift of 2500 feet for both sections
13) Safely descend in a manner that minimizes, or ideally eliminates, all possible damage to the launch vehicle
14) Safely descend so that the launch vehicle will be able to be prepared to relaunch with minimal repair and replacement of parts
15) Record and store flight data, including acceleration data, using a Sensor Suite given to the team by NASA

Reference Section 3.1.5. for a more detailed explanation of these criteria.

3.3.2. Flight Profile Simulations / Predictions

See Appendix B for OpenRocket calculated rocket data and component weights. The mass of each component of the launch vehicle is contained in the table. These components are those contained in the entire launch vehicle including the payload section and the booster section.

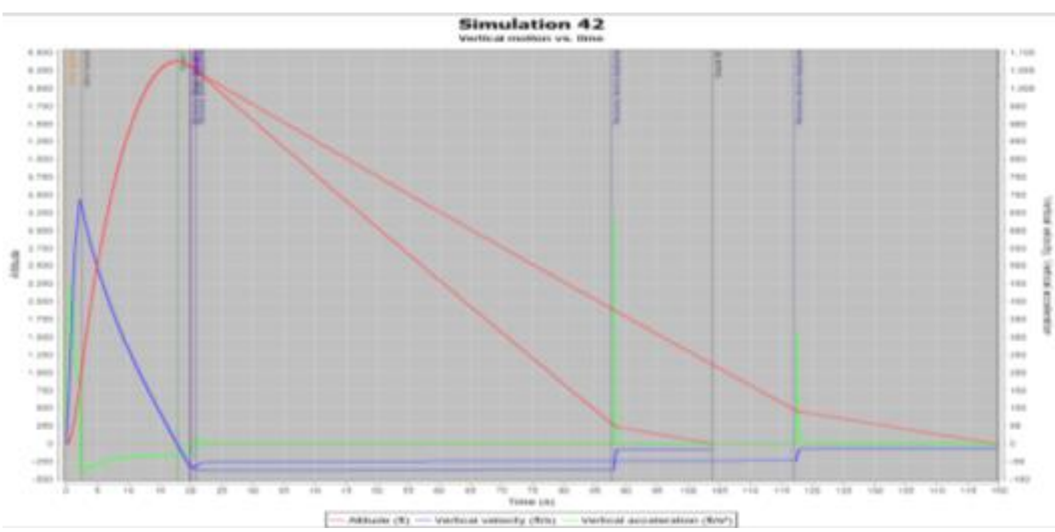


Figure 26 Full Scale Launch Vehicle Simulation with L2200G-18 Motor

The figure above shows simulation data of the full scale launch vehicle with the AeroTech L2200G-18 motor. The red line depicts the altitude of the launch vehicle in the simulation, the blue line is the vertical velocity, and the green is vertical acceleration. In the figure, the blue and green lines split in two when the Booster and Payload sections split in two. The mass of the entire vehicle as built is 42.87 lbs after the motor burns. The Payload section has a mass of 16.52 lbs. The main parachute splits these tethered sections into the Nosecone and Payload sections weighing 2.16 lbs and 14.366 lbs, respectively. The Booster Stage is 21.48 lbs in total. This splits into the Motor Subsection and Aft-Parachute Subsection, which are 13.299 lbs and 13.046 lbs, respectively. These weights are all represented in the simulation of the flight above.

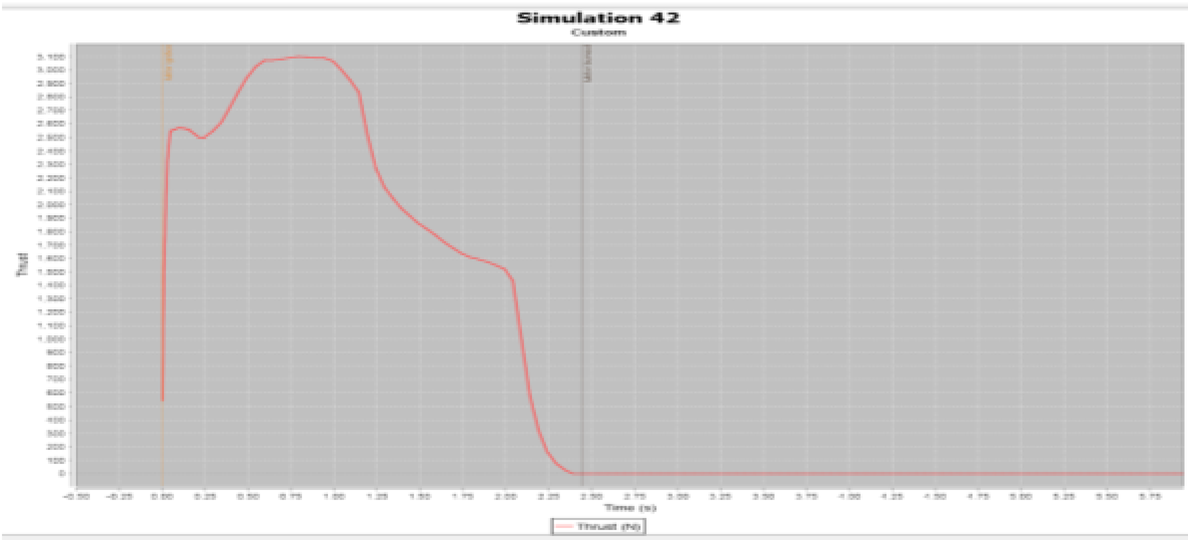


Figure 27 L2200G-18 Motor Thrust Curve

The figure above is the motor thrust over time curve. The thrust increases to the peak thrust over the first second then decreases thrust until 2.393 seconds at motor burnout. This is simulated with all the mass data and the AeroTech L2200G-18 motor. From this thrust curve the average thrust can be determined to be 2,132.5 N from the total impulse divided by the duration of the burn. The total impulse is 5,104 N-s for the AeroTech Motor.

3.3.3. Analysis / Simulations Comparison to Measured Values

For our predictions with regards to the rocket many of them came from previous flights and or Open Rocket simulations. Some of the most critical and testable predictions that could be made would be the value for apogee and velocity.

Using the most up to date designs for the rocket the resulting simulation was:

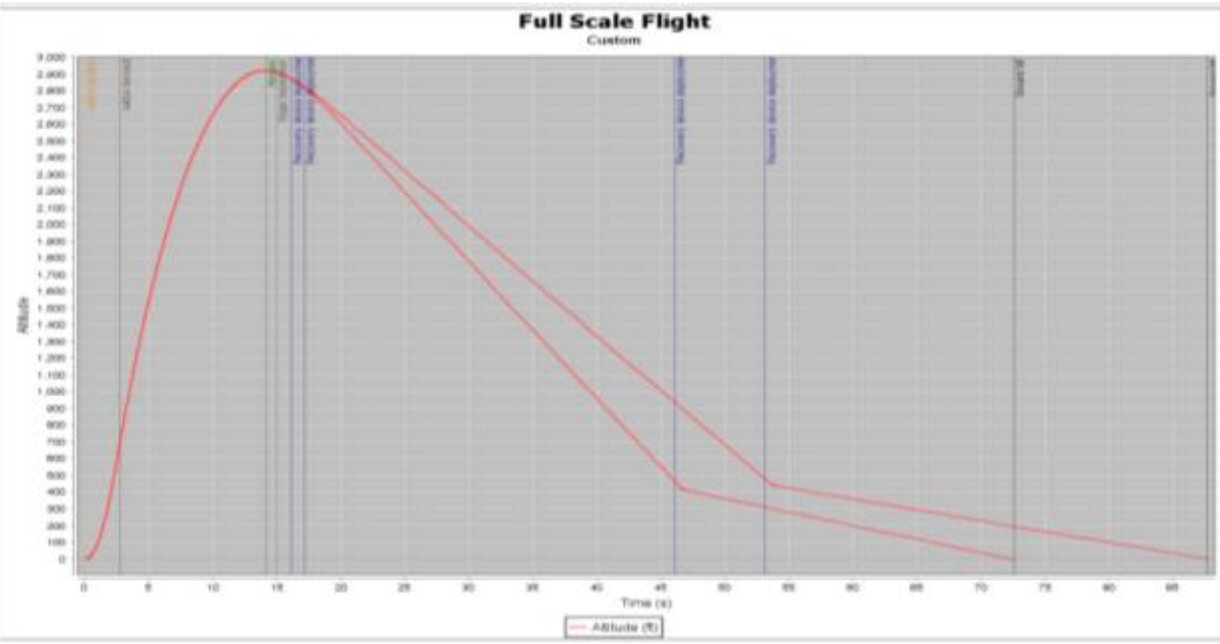


Figure 28 Full Scale Flight Sim

In which the red lines mark altitude and the blue lines represent vertical velocity. This graph gives an apogee value of 2,926 feet +/- 10 feet and total time of roughly 72.5s. Taking this simulation it was compared to that of the full scale flight (see Section 3.4). A graph of altitude was taken from the altimeters on board the rocket during flight giving the graph below:

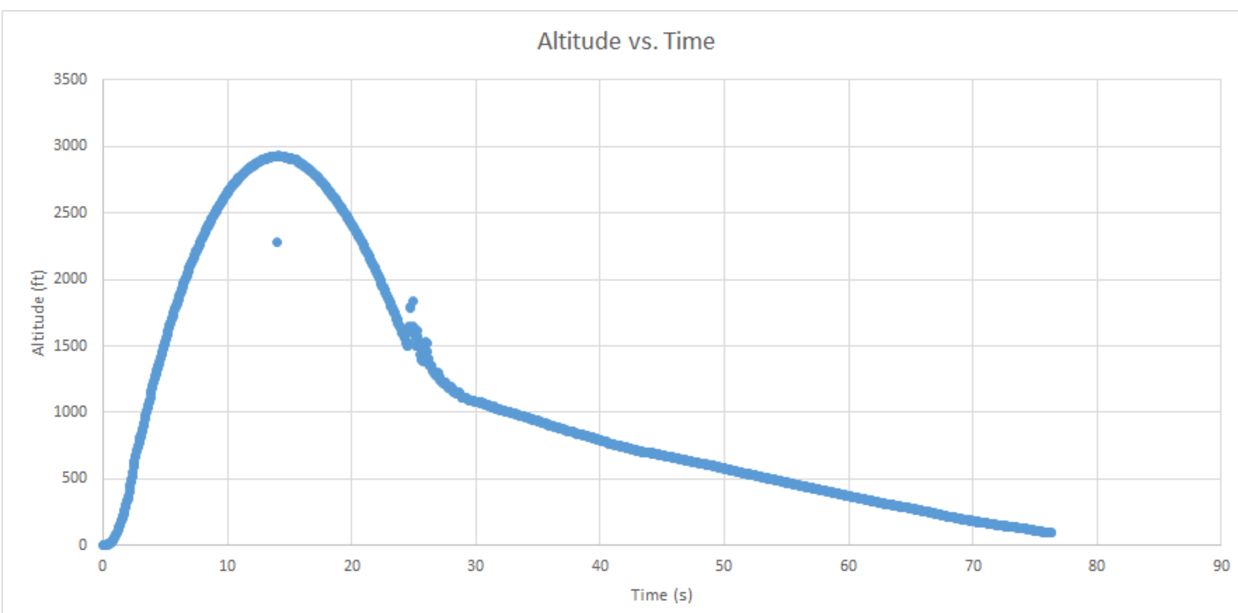


Figure 29 Flight Profile 3/4/17 Launch

This by comparison is relatively accurate. The apogee of the flight was 2927 feet to 2934 feet (depending upon which altimeter's data was used) Also the total flight time of the about 75s. Much can be extrapolated from this data. Since the apogee, total flight time, and time of parachute deployment are practically the same for the simulated predictions and the actual flight data it can be extrapolated that our drift data and kinetic energy predictions should be accurate. This is because since the apogee of the rocket is the same and flight time is the same it follows that the descent velocities would be the same because the parachutes and masses are the same in the predictions and the flight data. This means that the value of KE and drift should be the roughly the same from simulated predictions to actual flight.

Also, due to the flight time and apogee being the same this leads to the descent time to be the same in both. That means that the ascent time should also be the same. Since velocity is the distance traveled divided by time we can say that our predictions for ascent velocities should also be accurate to what is to be expected at the launch based upon this launches data.

This launch served as a good “experiment” in a way allowing us to know that the equations used and the methods employed by our team to make our predictions prelaunch are very accurate. However, upon inspection some of the methods (for instance those used for drag) may be a bit overly conservative. Further refinement can be achieved through accounting for aspects such as parachute design (i.e. holes in the center of parachute, pressure difference produced, or resulting turbulent forces) and rocket design (i.e. aerodynamic flow over rocket surface). In the future, these aspects can be accounted for to improve our predictive abilities.

3.3.4. Stability Margin (Center of Pressure and Gravity)

During flight, the launch vehicle will rotate about its center of gravity CG. The rotation causes the axis of the launch vehicle to be on an angle to the flight path. When the launch vehicle is inclined to the flight path, a lift force is generated by the body and fins, while the drag remains fairly constant for small inclinations. Lift and drag both act through the center of pressure CP of the rocket, which is below the CG. The distance between these affect the stability, or cal, of the rocket. Approximately about cal should be between 1 and 4 cal so that it is neither under nor over stable.

The stability of the launch vehicle was calculated by determining the center of gravity and the center of pressure. To calculate the center of gravity, we averaged the center of gravity to each component within the launch vehicle. To do this we had to make some assumptions about the launch vehicle. We assumed that all pieces had a uniform density throughout. This allowed us to say that center of mass of all the regular objects such as the various cylinders had their center of gravity concentrated in the center of the object. Therefore, all body tubes, bulkheads, centering rings as the other regular shapes were said to have their center of gravity in the center of the respective component. To find the center of mass you need to use a reference point and measure the distance from the center of gravity of each component to this point of reference. Going through the OpenRocket design, we recorded every mass and its location with respect to the nosecone. We organized this data in excel table to make calculations. From this data we found the center of mass using the equation

$$\sum \frac{M_i X_i}{M_{Total}},$$

representing the sum of the product of the mass and distance of component, then this sum is divided by the total mass. This represents the average force of gravity over the whole launch vehicle. We calculated the center of mass to be 93.95 inches.

The second value needed to find the stability of the launch vehicle is the center of pressure. This is average of the forces due to air pressure on the launch vehicle. The average of these forces acts on a single point in the launch vehicle and helps the launch vehicle correct its angle of attack during flight in an attempt to ascend completely vertical. The cylindrical body tubes do not contribute to the center of pressure because for an angle of attack less than 10 degrees the force on these pieces due to the air is negligibly small. The forces on the nose cone and fins are not negligible and have to be calculated. The force on the nose cone is independent of shape and is approximated to be 2 Newtons. The center of pressure at which this force acts is 0.466 times the length of nose cone away from the tip of the nose cone. This formula was by James Barrowman's document describing center of pressure and mass. The other important measurements are the center of pressure and magnitude of the normal force on the fins. The force on the fins is

$$F = \frac{4n\left(\frac{s}{d}\right)^2}{1+\sqrt{1+\left(\frac{2L}{a+b}\right)^2}},$$

where ***n*** is the number of fins, ***s*** is the height of the fins, ***d*** is the diameter of the body tube, ***L*** is the distance between the center of the base of the fins and the center of the top of the fins, ***a*** is the length of the base of the fin, and ***b*** is the length of the top of the fin. Because of the aerodynamics there interference between the fins. This interference value must be multiplied by the force calculated in the previous equation. The interference equation for three or four fins is $K_{fb} = 1 + \frac{R}{s+R}$, where ***s*** is the height of the fins and R is the radius of the body tube of the launch vehicle. To find the center of pressure of the fins is the equation

$$\overline{X_f} = X_f + \frac{m(a+2b)}{3(a+b)} + \frac{1}{6}\left(a + b - \frac{ab}{a+b}\right)$$

where ***m*** is the sweep length, and ***a*** and ***b*** are the same as before.

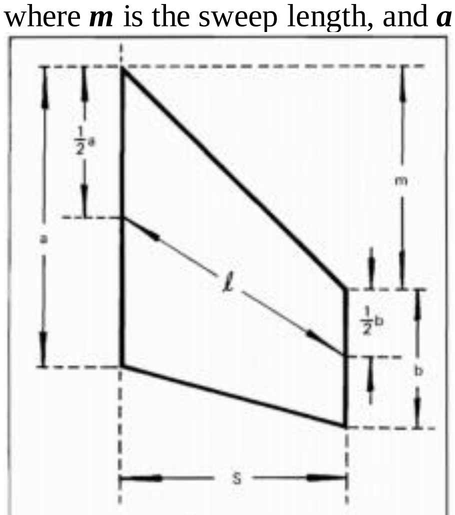


Figure 30 Fin

Then the average force and the distance from a reference point can be calculated using the equation,

$$\overline{X} = \frac{(C_{N\alpha})_n \overline{X_n} + (C_{N\alpha})_f \overline{X_f}}{C_{n\alpha}},$$

where the subscript n references the nose cone and the subscript f represents the fins. Using this equation, we calculated the center of pressure to be 115.2 inches from the tip of the nose cone.

The distance between the two is 24.15 inches. The stability produced on launch vehicle from this is 3.45 cal off the launch rail. The static caliber of stability of the launch vehicle after the motor has burned is 4.32. This decreased from the caliber of stability off the launch rail shown in CDR which was calculated to be 4.258 cal. This is due to the variations in mass that were result of epoxy, changes in bulkhead, shock cord and bolt sizes. Also, the anticipated weight of the backup motor being different from the primary motor makes the center of gravity closer to the center of pressure reducing the caliber of stability. Other variations in the mass that came because of actual construction and the increase in length also attributed to this change. The center of pressure did not change from the CDR because the nose cone and the fins are of the same dimension and construction as detailed previously. These are the only factors that contribute significantly to the center of pressure, and because these values stayed the same the center of pressure stayed the same relative to the back of the launch vehicle. Our final caliber of stability off the launch rail of 3.45 cal is between the range of 1 to 4 cal that it should be. It is not overstable, nor understable and is perfect for flight.

3.3.5. Kinetic Energy

When calculating the kinetic energy of the rocket the primary factors that must be considered are the mass of each subsection involved, terminal velocity of each subsection, and the parachutes being used by the rocket.

Some of the terminology for the tables must be noted now and is as follows. Due to the rocket breaking into two halves and then each section splitting again into two subsections once their main parachutes deploy, the descent of the rocket from apogee to impact with the ground was described in two separate stages: Stage 1, from apogee to the deployment of the main parachute; and Stage 2, from the deployment of the main parachute (at 500ft) to impact with the ground. During Stage 1, the primary source of drag was the drogue parachutes for each section, while in Stage 2 the primary source of drag was the main parachute of each section. For the masses and parachute specifications see the tables below.

Table 9 Mass by Subsection

Subsection	Sustainer Subsection 1	Sustainer Subsection 2	Booster Subsection 1	Booster Subsection 2	Rocket Total
Total Mass (g)	980	6530	5930	6045	19487

Total Mass (kg)	0.980	6.53	5.93	6.045	19.487

Table 10 Parachute Specifications

Measurement	Main 1	Drogue 1	Drogue 2	Main 2
Diameter (m)	1.524	0.381	0.4572	1.8288
Area (m^2)	1.82415119	0.114009449	0.16417361	2.626777714
Mass (g)	179	22.8	22.8	249.48
Drag Coeff.	2.2	1.5	1.5	2.2

The terminal velocity of the sections for the Sustainer were calculated using the terminal velocity calculator, https://fruitychutes.com/help_for_parachutes/parachute-descent-rate-calculator.htm. This was done to ensure accuracy and due to this calculator most likely accounting for the empty hole in the top of the chute. Due to this, the calculator was used to determine the terminal velocity of the Sustainer Section and subsections during its stages of descent (see table below).

For the Booster Section of the rocket, a more general calculation was opted for, leading to the use of simple physics relations. To calculate the terminal velocity, the drag force of the rocket was set to be equal to that of the sections weight so the net force, and thus the net force under that condition, would be zero and, by result, so would the acceleration. With the drag force of an object moving through a fluid (in this case the air) being given by the equation:

$$Drag\ Force = \frac{1}{2}AC_d v^2$$

In which, p, is the density of the fluid (in this case 1.225kg/m^3), C_d is the drag coefficient of the exposed surface, V is the velocity of the object, and A is the area of the exposed surface. Then, by setting this value equal to the weight of the object (mass times gravity), the velocity of the object was solved for giving the following equation:

$$Terminal\ Velocity = \sqrt{\frac{2mg}{pAC_d}}$$

This formula was used to calculate the terminal velocity of the rocket during each stage of descent. For Stage 1, only the drag produced by the drogues was used, however during Stage 2, only the drag produced by the main parachutes was used. This is due to the drag produced by the drogues being negligible once the main parachutes are deployed. For both stages, the drag produced by the rocket hull itself was ignored because it too is negligible in comparison to that of either the drogue or main parachute.

After the terminal velocity of each subsection was calculated, the time spent in each Stage of descent could be found, then followed by the kinetic energy of the rocket subsections upon impact. To find the kinetic energy, the mass of each subsection and the terminal velocity during Stage 2 were used, because this is the velocity of the rocket subsection upon impact. These two values were inputted into the classic equation for kinetic energy:

$$Kinetic\ Energy = \frac{1}{2}mv^2$$

(Please note that the mass used in the kinetic energy equation was just that of each individual subsection because although they have the same terminal velocity because they are tethered together they do not act as a single object for terms of kinetic energy). Then also using the terminal velocity of each stage of descent, the time to complete each stage of descent could be calculated. This was done by dividing the total height the rocket needs to descend in that specific stage by the terminal velocity of the rocket at that stage. The total time for both stages of descent were then calculated. All of these calculated data points are in the table below along with a table for the total height of each stage.

Table 11 Heights of Each Stage

Stage Height	Sustainer Subsection 1	Sustainer Subsection 2	Booster Subsection 1	Booster Subsection 2
Stage 1 (m)	1504	1504	1504	1504
Stage 1 (ft)	4934.38	4934.38	4934.38	4934.38
Stage 2 (m)	152.4	152.4	152.4	152.4
Stage 2 (ft)	500	500	500	500

Table 12 Terminal Velocities, Descent Times, and Kinetic Energy

Measurement	Sustainer Subsection 1	Sustainer Subsection 2	Booster Subsection 1	Booster Subsection 2
Terminal Velocity 1 (m/s)	27.05	27.05	27.91338891	27.91338891
Terminal Velocity 1 (ft/s)	88.7467193	88.7467193	91.57936007	91.57936007
Time in Stage 1 (s)	55.62292052	55.62292052	53.90244821	53.90244821
Terminal Velocity 2 (m/s)	5.56	5.56	5.762180578	5.762180578
Terminal Velocity 2 (ft/s)	18.24146984	18.24146984	18.90479195	18.90479195
Time in Stage 2 (s)	27.41007194	27.41007194	26.44832073	26.44832073
Impact Kinetic Energy (J)	17.2497888	100.932904	98.44607966	100.4382432

Impact Kinetic Energy (Ft-Lbs)	12.72278873	74.44427454	72.6100874	74.0794315
Total Descent Time (s)	83.03299246	83.03299246	80.35076894	80.35076894

As can be seen all the kinetic energies for each subsection falls within the 75 ft-lbs limitation.

3.3.6. Altitude / Drift Calculations

To calculate the total lateral drift of the rocket, total descent time was taken from the previous kinetic energy section (see Kinetic Energy Calculations Table 4). Then using the various wind speeds, the total lateral drift was calculated using the following equation:

$$Lateral\ Drift = v_w(t)$$

Where "t" is the total descent time and "v_w" is the wind speed. For these calculations, the rocket was assumed to have a completely vertical ascent (no lateral drift from launch to apogee) and only began to drift after apogee. This process was repeated, calculating the total lateral drift for various wind speeds, those being 0 mph, 5 mph, 10 mph, 15 mph, and 20 mph wind. These calculated values for lateral drift are shown in the table below.

Table 13 Lateral Drift by Subsection for Various Wind Speeds

Wind Speed (mph)	Wind Speed (ft/s)	Sustainer Drift (m)	Sustainer Drift (ft)	Booster Drift (m)	Booster Drift (ft)
0	0	0	0	0	0
5	7.33335	185.5957666	608.9099953	179.6004469	589.2403114
10	14.6667	371.1915331	1217.819991	359.2008938	1178.480623
15	22.00005	556.7872997	1826.729986	538.8013407	1767.720934
20	29.3334	742.3830662	2435.639981	718.4017877	2356.961246

As can be seen above, the drift for each individual subsection was not found and, instead, the drift for the Sustainer and Booster Sections were found. This is due to the subsections being connected via shock cord and through their parachutes causing them to drift together at the same terminal velocities, thus causing the two complete sections to drift the same distance.

Per our calculations, the total lateral drift for the Sustainer and Booster Sections of our rocket never exceeds the maximum allowed lateral drift of 2500 ft even under maximized wind conditions (20 mph wind speed) as can be seen in Table 1.

3.4. Full Scale Flight

3.4.1. Launch Day Conditions / Simulation

We conducted our full scale flight on March 4th 2017, at 3:05 PM, with the Valley AeroSpace Team (VAST), in Monterey, Virginia. The vehicle was cleared for flight by the RSO's and launched on a CTI 54mm 6 Grain XL L-1030 Red Lightning, with a Fully Ballasted Payload. The vehicle was not launched with transmitters, as our HAM radio licensed individual was not available for the launch.

The following Launch day conditions came from the National Weather Service national daily summary for KHSP, the closest weather center to Monterey, Virginia

Table 14 Full Scale Flight Weather Data

Weather	Value
Temperature	33.8 Farenheit
Pressure	30.39 in
Max Wind Speed:	18 MPH
Wind Speed at Launch Time (2:55 PM Values Used)	13.8 MPH West

Per the VAST website, the launch site is located approximately 2,675 feet above sea level. This was also factored into our flight simulation for the full scale.

With all the conditions entered into the simulation, the following flight profile was obtained:

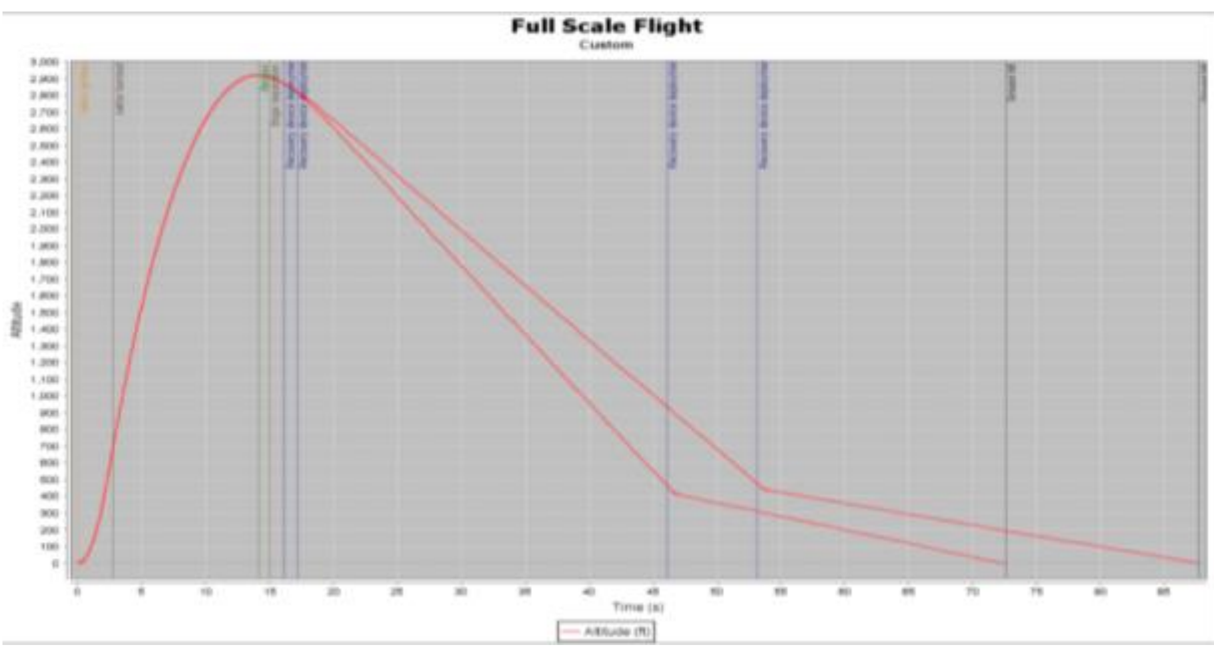


Figure 31 Full Scale Flight Simulation

Our simulation said that we should have expected a final apogee of 2,926 feet. This varied from simulation to simulation by about 20 feet, as values were reported up to approximately 10 above that apogee and 10 feet below that apogee. Total time of flight was 88 seconds for the booster, and 72.5 seconds for the sustainer.

3.4.2. Predicted vs. Actual Flight Data Comparison

Our predicted Flight model, as seen above, predicted an apogee of 2,926 feet +/- 10 feet. Our altimeters reported the final apogees:

Table 15 Altimeter Flight Data

Altimeter: Location in rocket	Reported Apogee (Feet)
1. Booster Stage electronics bay	2934
2. Booster Stage electronics bay	2927
3. Booster Stage electronics bay	2934
4. Booster Stage electronics bay	2931
5. Payload Stage electronics bay	2930
6. Payload Stage electronics bay	2930

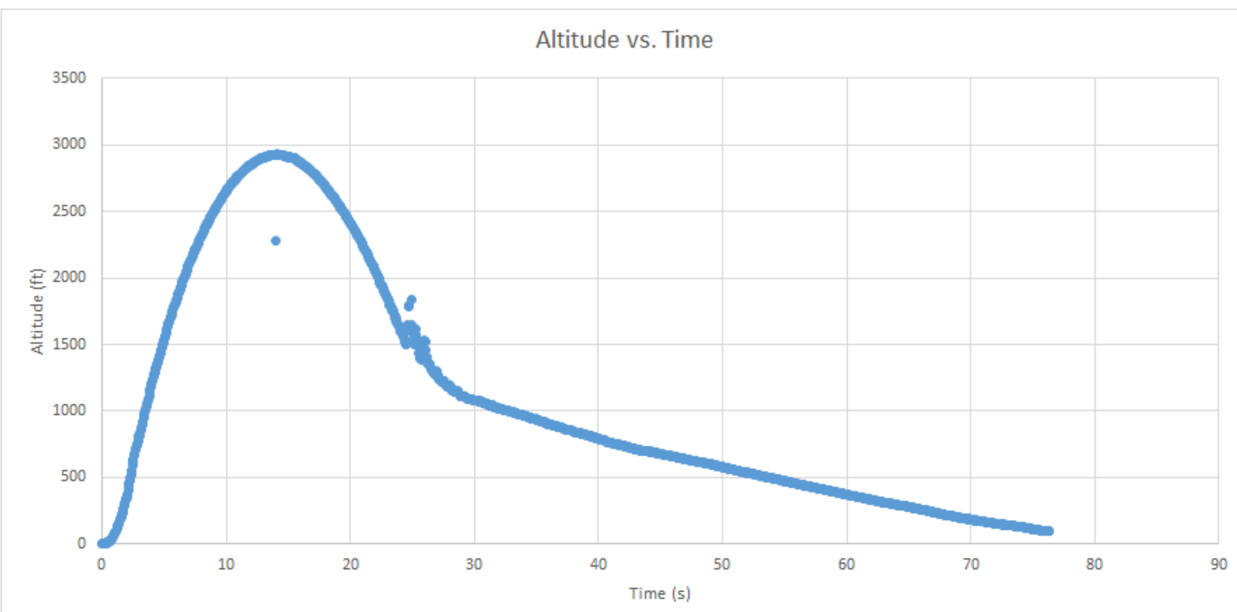


Figure 32 Motor Booster Stage Drogue 1

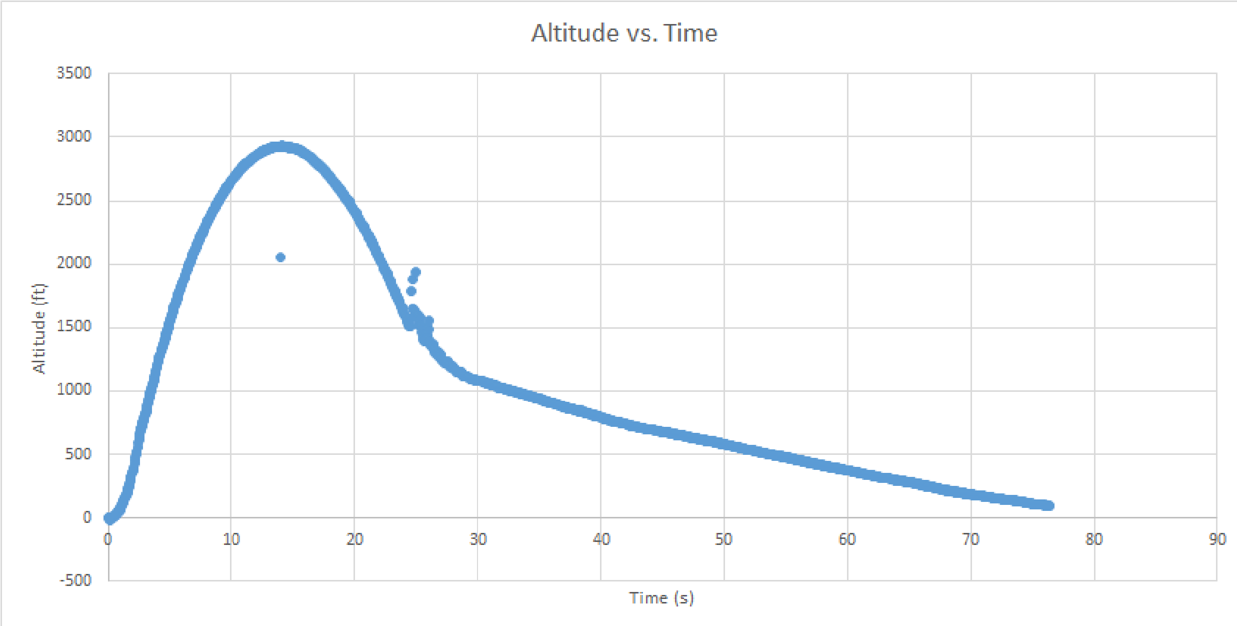


Figure 33 Motor Booster Stage Drogue 2

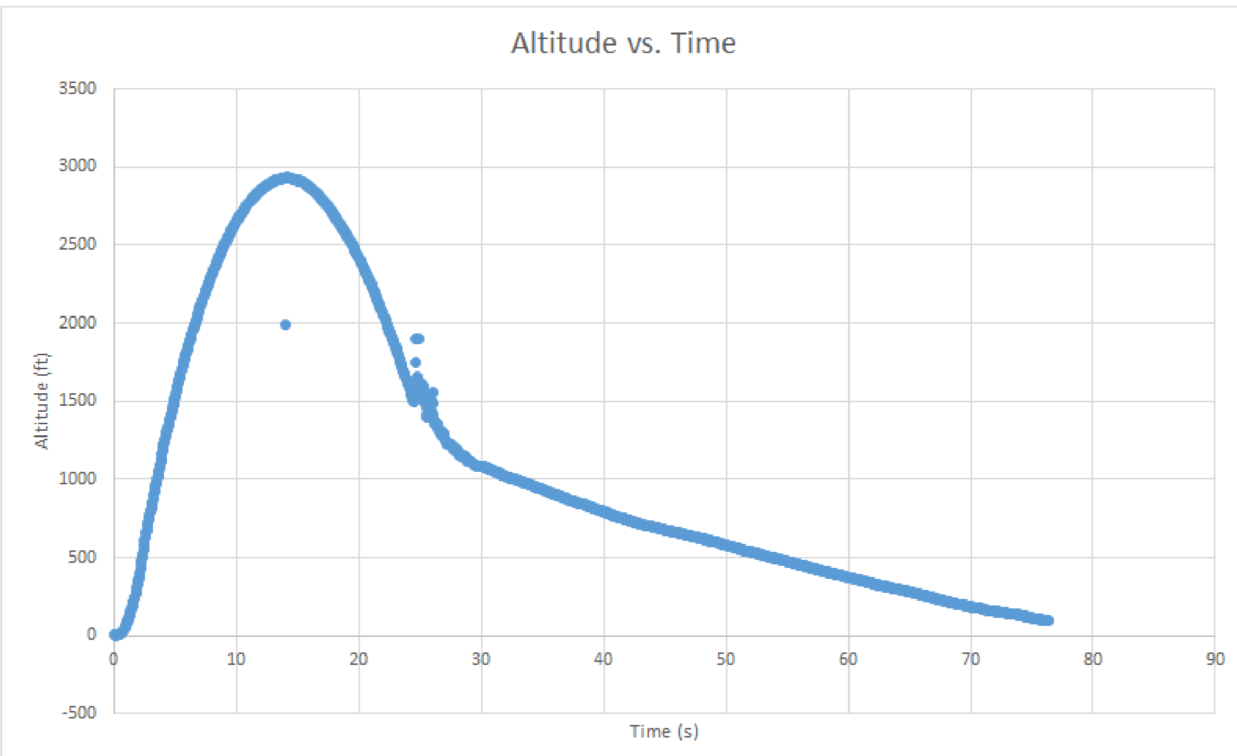


Figure 34 Motor Payload Section Drogue 1

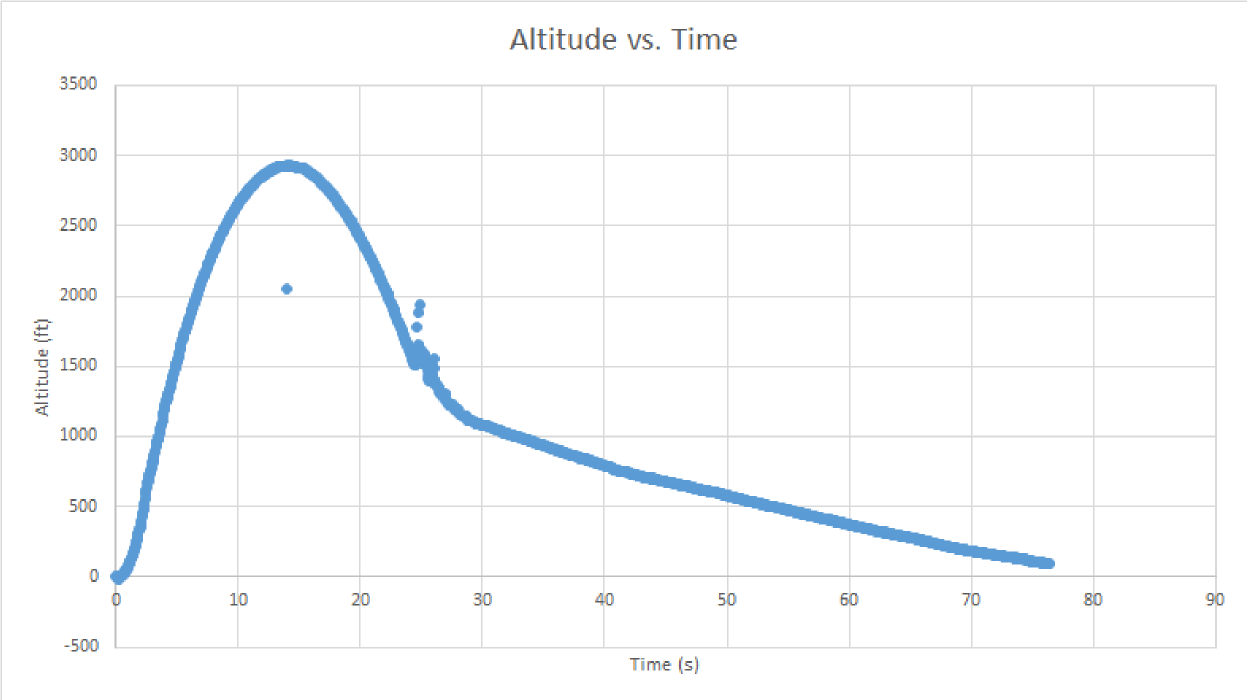


Figure 35 Motor Payload Section Drogue 2

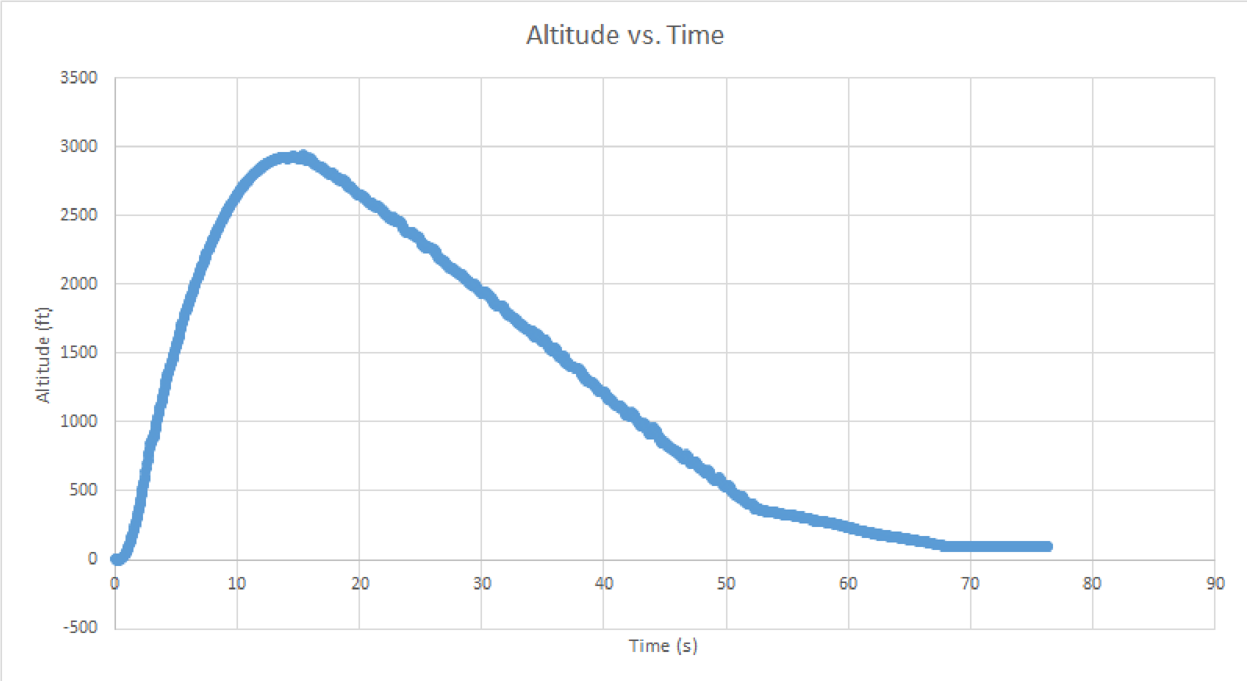


Figure 36 Payload 1

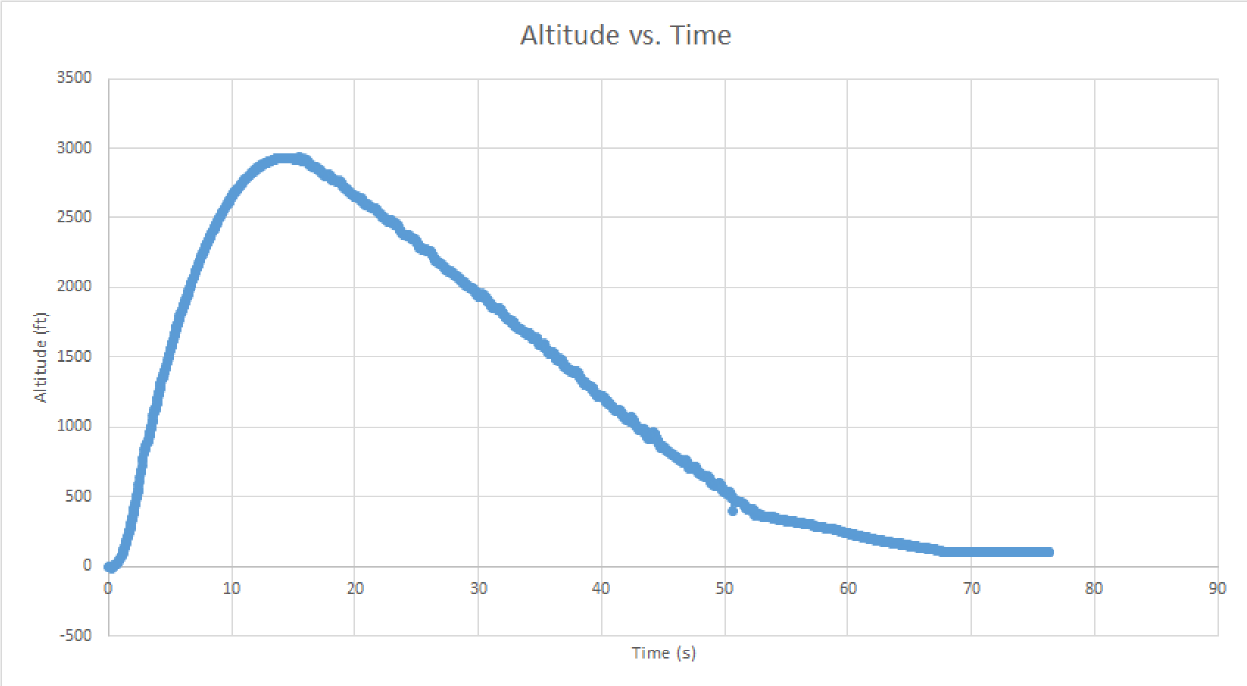


Figure 37 Payload 2

As shown in the above table, our altimeters had apogees ranging from 2927 ft to 2934 ft. This falls exactly within the range which our simulations predicted.

3.4.3. Error Between Predicted and Actual Flight Data

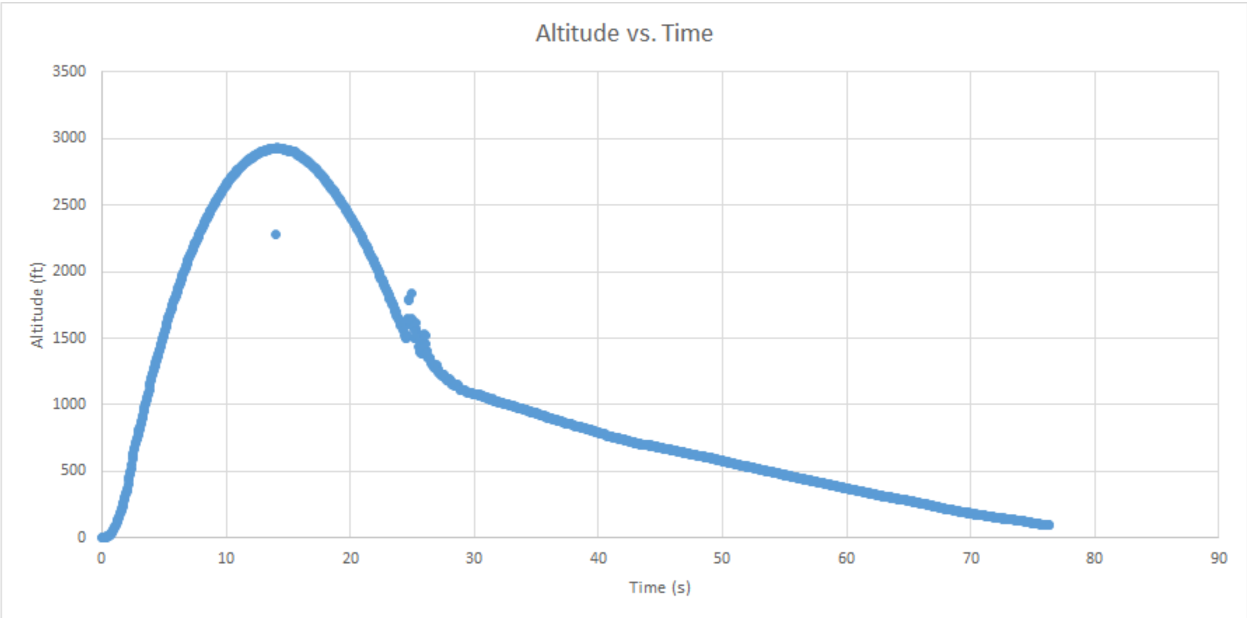


Figure 38 Booster Stage Flight Profile

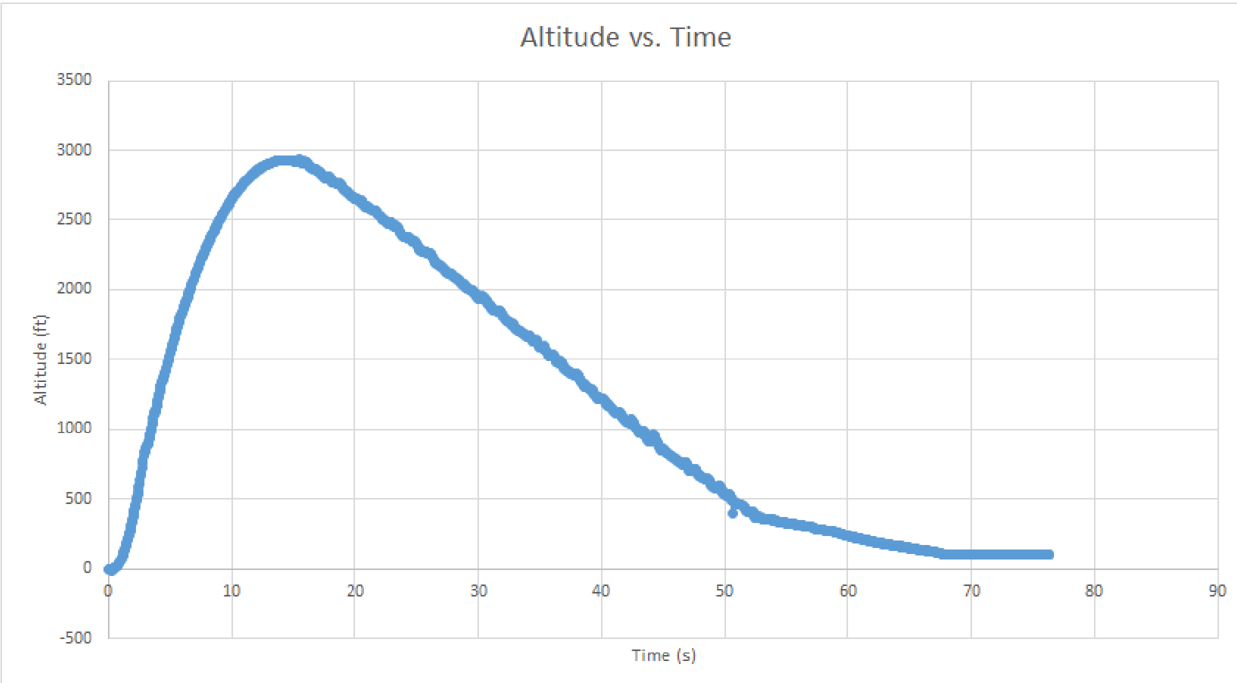


Figure 39 Payload Section Flight Profile

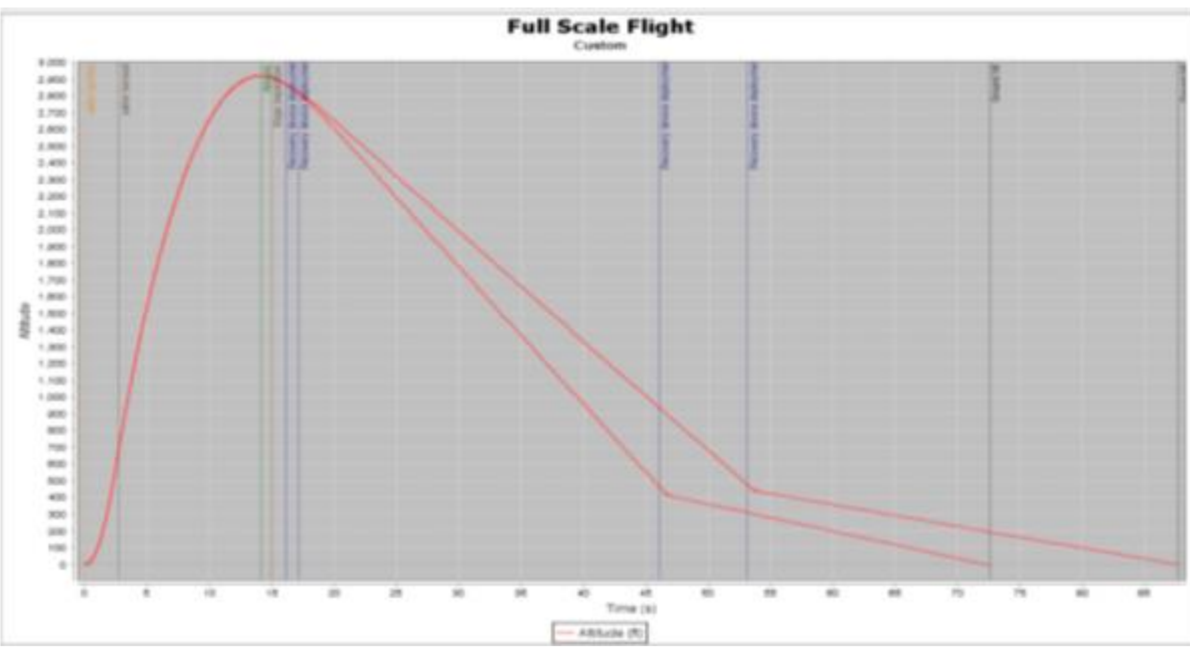


Figure 40 Predicted Full Scale Flight Profile

Our full-scale test apogee fell within the range predicted from Open Rocket. The flight profile for the Booster Stage deviated slightly from the expected descent values, due to a case of operator error. The launch day was very windy, and when the parachutes were folded, they were wrapped in the Nomex cloth, and then tape was wrapped around that cloth. For one of the drogue parachutes, this tape was not removed before flight, and it caused a delay in opening of about 1500 feet. After 1500 feet of free fall, the drogue opened, and the force of the drogue opening caused the shear pins holding in the main parachute to shear. This deployed the main parachute immediately.

We have static tested the system, and since it is a case of operator error, we are confident that this will not happen on launch day.

The overall predicted flight time was also different between the predicted simulations and the actual measured values. For the Booster Stage, OpenRocket predicted the flight time to be about 88 seconds, and the actual flight time was around 77 seconds. This 10 seconds of lost flight time was due to the rapid ballistic descent of 1500 feet the booster underwent before the drogue parachute opened.

The Payload Section had a descent profile that was consistent with what OpenRocket simulations predicted, however, the total flight time also differs from the OpenRocket profile. This is due to the launch site itself, as the payload section landed in a tree on a hill, which meant the flight ended at a different altitude than it began at.

3.4.4. Estimated Full Scale Drag Coefficient

Being that the material of the rocket is the same as prior launches, the drag coefficient can be estimated using the data from prior launches and can be predicted to be roughly the same as that of the test rockets.

To find the drag coefficient of the prior rocket, a time in the rocket's ascent needs to be found in which velocity was roughly constant. So, looking through the flight data of our 12/3/2016 launch and graphing the altimeter readings of one of the altimeters versus time resulted in the graph below:

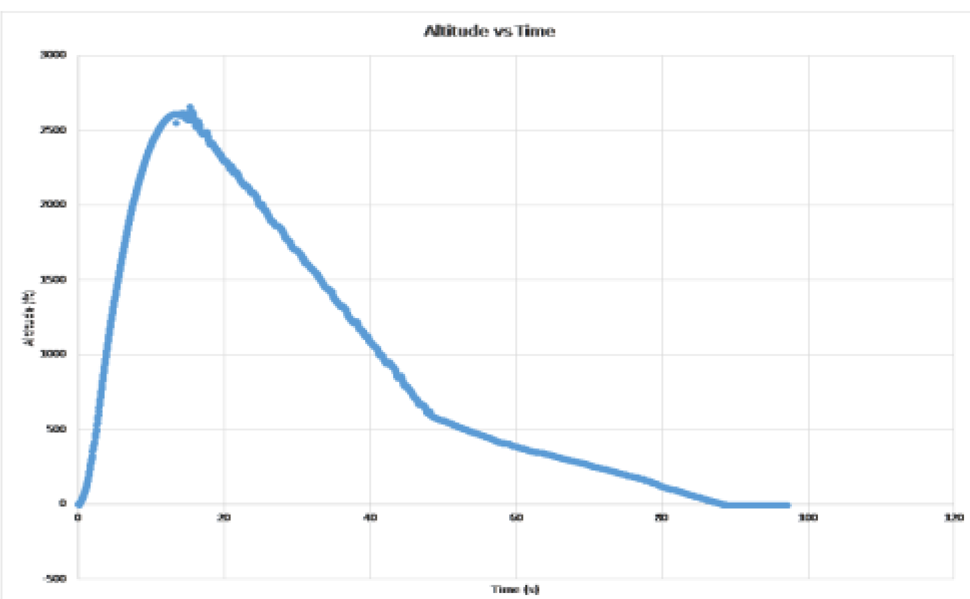


Figure 41 Altitude vs. Time

Then the graph's data was further analyzed to find a point before apogee when the slope of the graph was roughly constant. This time section was the period of time from launch until the burnout of the motor (roughly 7 s after launch). The data from the above graph for that interval of time was then graphed:

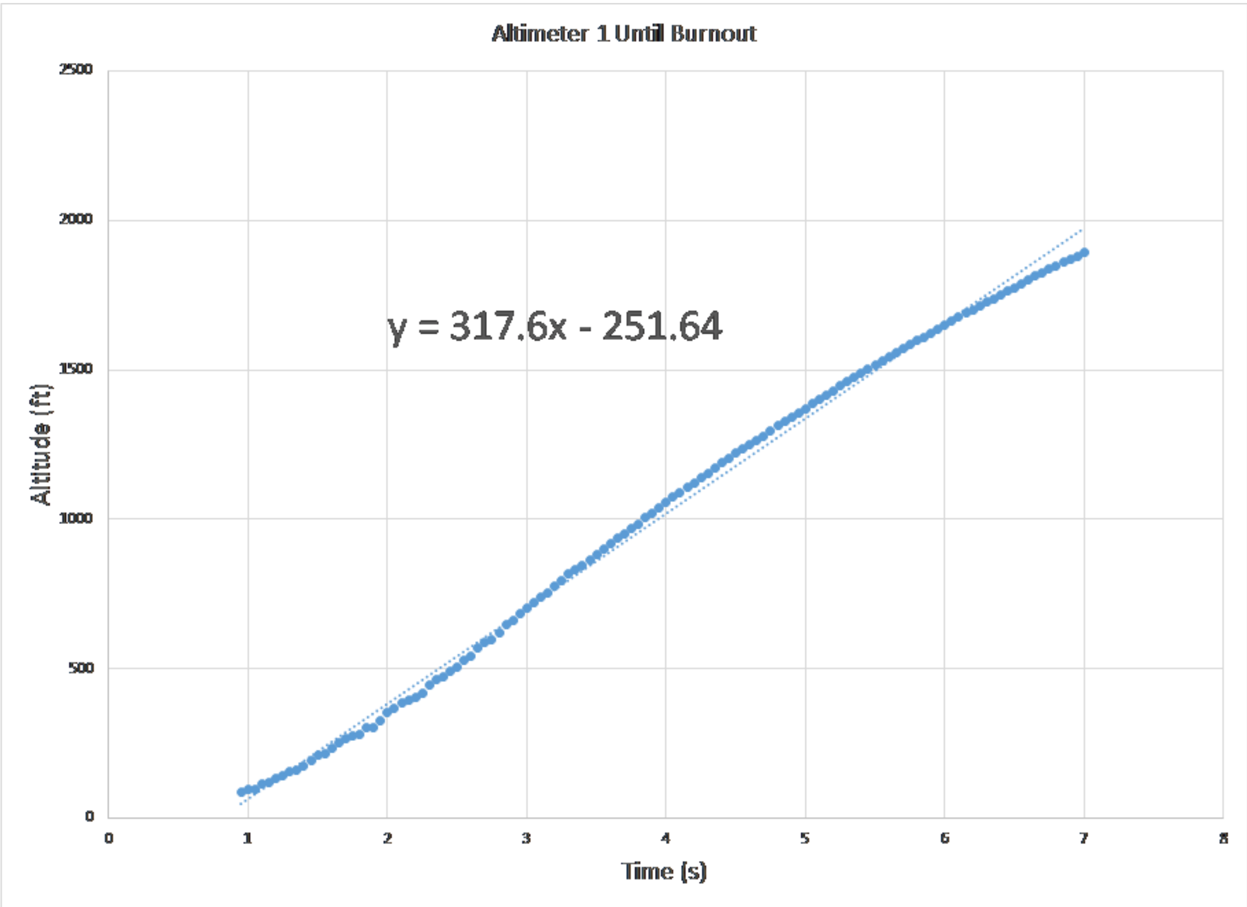


Figure 42 Altimeter 1 Until Burnout

A trendline was applied to the graph of this data. Due to this being a graph of altitude versus time, the slope of this trendline would be the velocity of the rocket during this period. The slope of this trendline was found to be 317.6ft/s, which is equivalent to 96.80448m/s. This will be used later for calculating the drag coefficient, since it is a major component of the drag force equation:

$$Drag\ Force = \frac{1}{2}AC_d v^2$$

Where C_d is the drag coefficient that is attempting to be solved for, p is the density of air (1.225kg/m^3), v is the velocity of the rocket, and A is the area exposed of the rocket. Since the p is constant and v was already determined, the only variable left to solve for was the area exposed.

To determine the value of A, the total was divided into 3 easier to solve sections based on the section of the rocket. The three sections used for determining area exposed were the nose cone, body of the rocket, and the rocket fins.

The exposed area of the body of the rocket would be the same as the surface are of a cylinder. The length of the body was 279.8 cm and the radius would be 7.8 cm. Then, by using the equation:

$$ABody = 2r\pi L$$

The area of the body of the rocket was found to be 13712.67494cm^2 or 1.371267494m^2. The next section would be the trapezoidal fins of the rocket. For this, the bulk of the exposed area would be the side faces of the fins and the forward face of the fins. The other faces of the fins were ignored due to most air flow passing over or around those sections. To do this, the area was found using simple geometric equations for trapezoidal prisms to find the surface area of the specific faces. The total surface area of the fins for the sections of the four fins in question was 0.20834338m^2.

The final segment of the rocket with a significantly exposed surface area that would contribute to drag is the nose cone of the rocket. To find the surface area of this section of the rocket the dimensions of the nose cone was placed into a CAD document and was used to determine the surface area. The surface area exposed by the ogive was found to be 0.0902836904m^2. With this final section, the total exposed surface area was known to be 1.669894564m^2.

Now to determine the drag coefficient the summation of forces acting upon to rocket were set to be 0:

$$F = 0 = Thrust - Weight - Drag\ force$$

$$F = 0 = FT - mg - \frac{1}{2}AC_d v^2$$

The above equation was used with the with the following values: F_T=1463N, m=20.933kg, g=9.81m/s^2, p=1.225kg/m^3, A=1.669894564m^2, C_d is the drag force that is being solved for, and v=96.80448m/s. Using all the listed values C_d, was solved for and found to be C_d=0.17406.

As previously said, since the rocket used for these calculations is constructed of the same material and has the same design (meaning orientation of parts and shape) as the rocket final rocket that shall be launched, the final rocket can be assumed to have roughly the same drag coefficient as the one calculated.

4. Payload Criteria

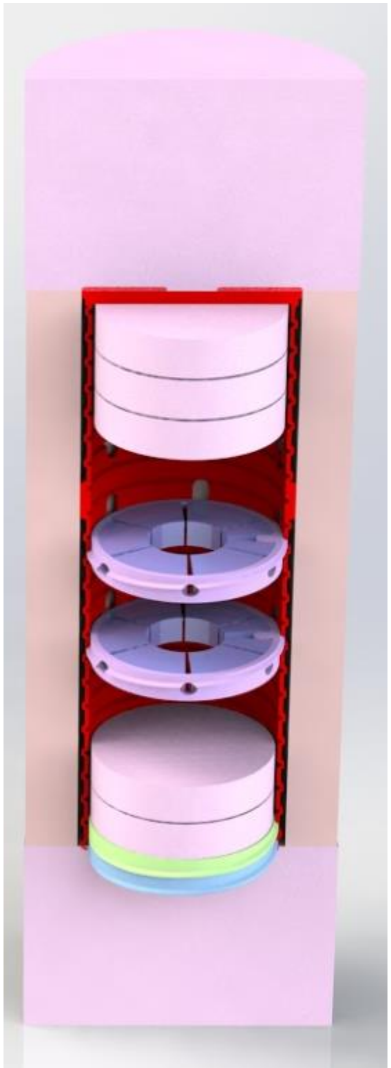


Figure 43 Final Canister Design

4.1. Payload Protection System Changes Since CDR

Several changes have been made and implemented to the Payload Protection System (PPS) since the Critical Design Review. The canister has been extended to 11.5 inches tall from the previous 8 inches. This change was an attempt to make the foam used above and below the canister the same as the foam that is used on the sides of the canister. Using a MATLAB script, we simulated the effects of different canister lengths on dampening, until the desired result was achieved, which are included below in Figure 44; with the full script being in Appendix C. This left empty room above and below the canister, prompting the height change.

```
>> foamDesign_FullScale
                            axial     radial
                            ______    ______

    Modulus (psi)           74.956    74.195
    Modulus (kPa)           516.82    511.57
    Acceleration (G's)      1.3699    2.7398
    Stop Time (s)           0.0084    0.0021
    Force (lb)              470.96    1883.8
```

Figure 44 Foam Stiffness MATLAB Calculation Results

Other major changes we have implemented concern the strap cushioning discs. The strap cushioning discs are designed to snugly secure any long and skinny objects to the side of the canister walls that we would not be able to adequately compress otherwise. During Critical Design Review, the objects would have been flush against the hard walls of the canister. This was identified as a potential failure point for payload protection, prompting a redesign. We designed a disc that could thread into the canister, with holes present to allow the straps to pass through, and feature foam along the inner circumference. Two will be used in the case of a long, skinny payload, allowing for two points of contact up against foam instead of the hard canister walls.

In addition to those changes to the strap cushioning system, the hole pattern along the canister walls was modified. Previously there were 3 rows of 10 holes along the circumference of the canister, with 2 inches of space between each row. In the current revision, this was changed to from 10 to 6. We found 10 to be excessive, and lowering the number of holes to 6 effectively doubled the amount of foam in one block. Before, a break was needed to allow the straps to go through. This gives a more secure foundation for the payload to be strapped against, and allows for the center of mass to be lower in the canister. Additionally, these sets of 6 holes have been shifted down 1 inch from the middle of the canister.

A second type of foam is also being used around the exterior of the canister. There is one inch of space around the canister that we intended to fill with one inch thick pieces of foam, but when the foam was curled into a circle it only measured ⅞ thick. This prompted the use of a harder outer foam that was an ⅛ inch thick. This foam ensures that there is no empty space in the PPS.

The final change to the strapping system came in the form of two clamps that we will use to secure the straps. These clamps will fasten the straps to a desired tension to ensure the secured object does not become looser in the straps as the rocket undergoes its flight. The prior idea present in the Critical Design Review was a buckle to secure the straps to a desired tension, but we found that the previous buckle design still allowed for motion in the straps.

The decision to use the LIS 331 sensor was finalized to record the acceleration our payload experiences. The LIS sensor can record up to 24 g-forces as opposed to the 16 g-force range of the other sensor we were considering, the MPU6050. It was decided that the sensor will be mounted to the bottom of the canister, since the top has the locking screw caps in lieu of a rigid top. Canister must be inserted upside down, to keep the LIS 331 close to the payload electronics bay for ease of wiring.

4.2. Final Design / Construction

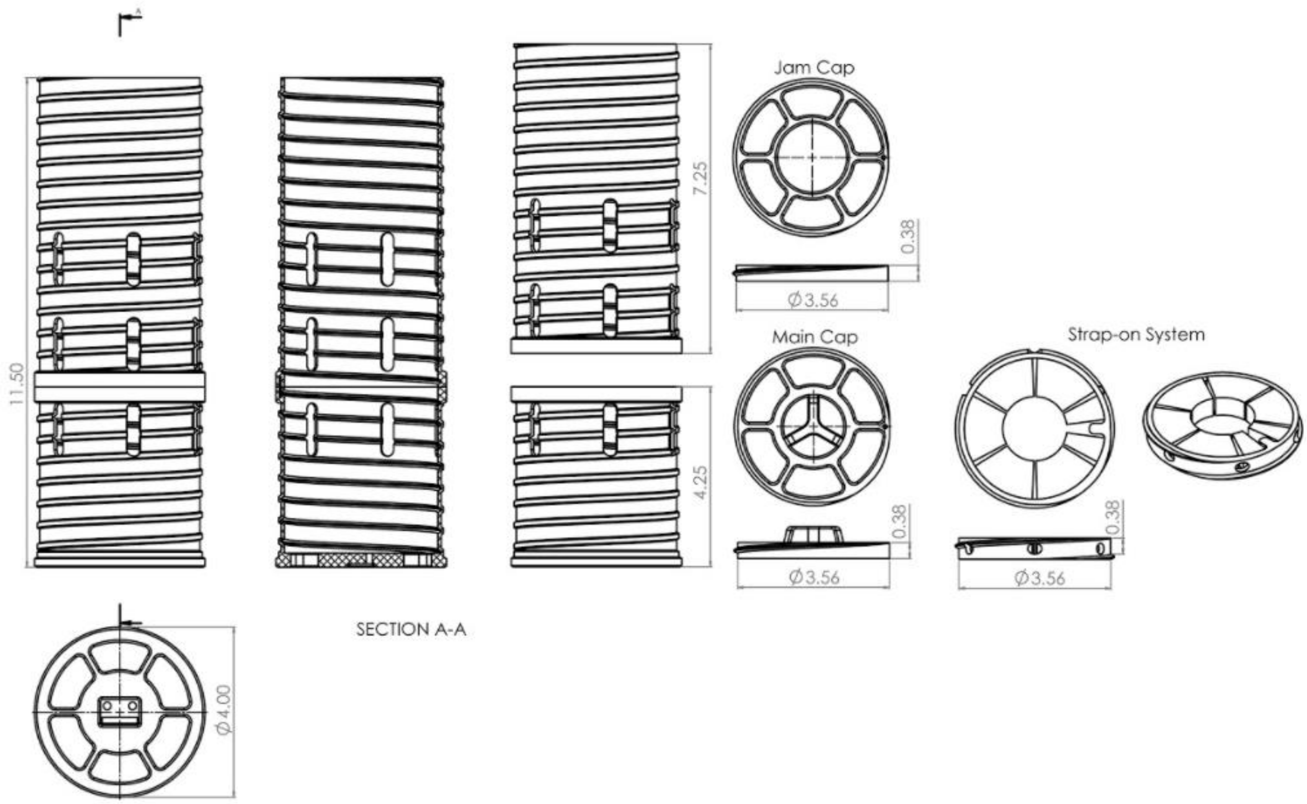


Figure 45 Canister Components and Dimensions

The PPS is designed to adequately protect payloads of any size, shape and quantity within the defined constraints of the competition. Payloads can be a maximum of 3.5 inches in diameter and 6 inches in height, as well as a maximum 4 ounces in weight; all of which the PPS can accommodate. The PPS is a passive system, meaning that once the object is loaded no additional work is required to ensure the security of the payload. Data, such as acceleration logs, will be transmitted to the ground through an XBee to allow the team to observe and analyze the forces our payload experiences during flight and landing.

The PPS system is composed of a canister surrounded in all directions by foam. The ideal foam, after the canister was adjusted to 11.5 inches tall, has been calculated to have very similar responses to both the radial and axial loading, and in turn, similar dampening effects. This allows for the use of the same type of foam in both directions. The foam used in the radial direction only measured ⅞ of an inch thick when it was curled around the canister, leading to the use of a harder, ⅛ thick foam between the launch vehicle wall and this foam to ensure there would be no empty space in the PPS. This foam should adequately dampen the expected forces on our payload.

The canister itself, as stated above, is 11.5 inches tall. It also has a diameter of 4 inches and internal threading. There are three rows of 6 holes, 1 inch below center, along the circumference of the canister. This allows the straps to pass through the outside. These straps are designed to secure any long and skinny objects we may receive. On the inside of the canister are two strap cushioning discs. These are hollow discs lined with foam, which provide a soft surface for this potential payload to rest against, instead of the hard canister walls. These discs are also threaded to move up and down the canister, allowing them to secure an object to any height. Finally, in the strapping system are two clamps. These will be used to secure the tension in each of the two straps that are fastening the object and ensure that the payload does not fall out of the straps.

In the case that we do not receive a long and skinny object, the two strap cushioning discs will sit out of the way on the bottom of the canister. The object will instead be secured by the two locking screw caps. These caps are threaded and adjustable to firmly secure any size of object we receive as payload. Multiple objects can be separated using foam spacers. There are 5 total throughout the canister: one on the top, one on the bottom, and three that can be moved. These three adjustable ones can separate multiple objects into different compartments. If they are not used, they can also rest at the bottom of the canister and act as additional vertical padding.

The payload electronics bay sits above the PPS on the rocket and contains the sensor suite. A coupler tube connects both sections of the rocket, extending 6 inches into both. This means that the internal radius of the payload section is slightly smaller for 6 inches at the top. The bottom of the coupler tube, or the section within the payload area, has two large set screws protruding through this bulkhead. Four more set screws secure this coupler tube.

A LIS 331 sensor is mounted to the bottom of the canister. This sensor records acceleration data for the flight. To make the wiring to the electronics bay as easy as possible, the canister will be loaded upside down.

Directly below the Payload Protection System is a coupler tube, which reaches about 6 inches into the payload. The coupler tube connects the Payload Section with the Interstage. It is attached to the Payload Section by epoxy, and to the Interstage system by shear pins. Upon the separation of the two stages and the deployment of the drogue parachutes, the shear pins detach.

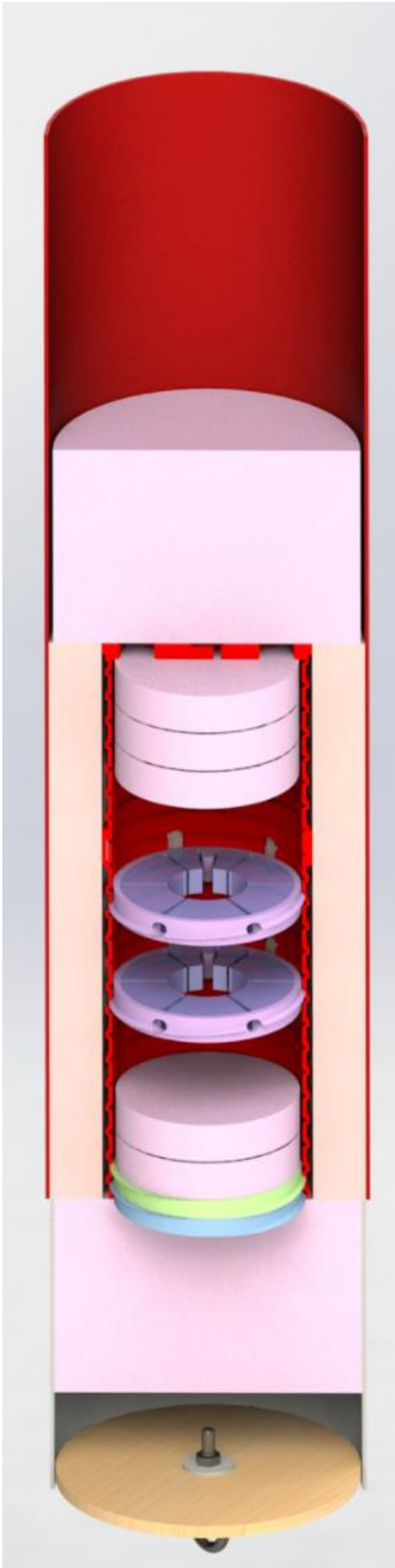


Figure 46 Canister Loaded into Launch Vehicle (Cut Out Image)

4.2.1. Structural Elements

The PPS is located inside the body tube of the Payload Section. The PPS occupies the lower portion of the Payload Section, immediately interfacing with the payload electronics bay above and Interstage below. The payload electronics bay above the PPS is housed in a section of 12 inch coupler tube that protrudes 6 inches into the PPS body tube. The bottom of the coupler tube in the payload section begins with a bulkhead which has two large set screws running through it vertically. The coupler tube itself is attached by four evenly spaced set screws around the circumference of it, close to the top.

Below the Payload System is another coupler tube, which connects the Payload System with the Interstage. It is permanently connected to the body tube surrounding the PPS through epoxy. This makes the overall inner radius of the top of the Payload System slightly smaller. Four shear pins connect the coupler tube with the Interstage, which detach when a blast occurs freeing the drogue parachutes. This coupler tube also extends 6 inches into the payload area, again making the bottom inner radius marginally smaller. The part of this coupler tube that extends into the Interstage ends with another bulkhead with an eye bolt that extends about an inch deeper.

4.2.2. Drawing and Schematics

Canister - The canister is 11.5 inches tall and 4 inches in diameter. It is 3D printed out of PLA thermoplastic. It contains internal threading to accommodate for the other systems that go inside of the canister, such as the locking screw caps and securing discs. The exterior of the canister includes three rows of 6 holes, spaced evenly with 2 inches in between each row. These are located an inch below the center of the canister.

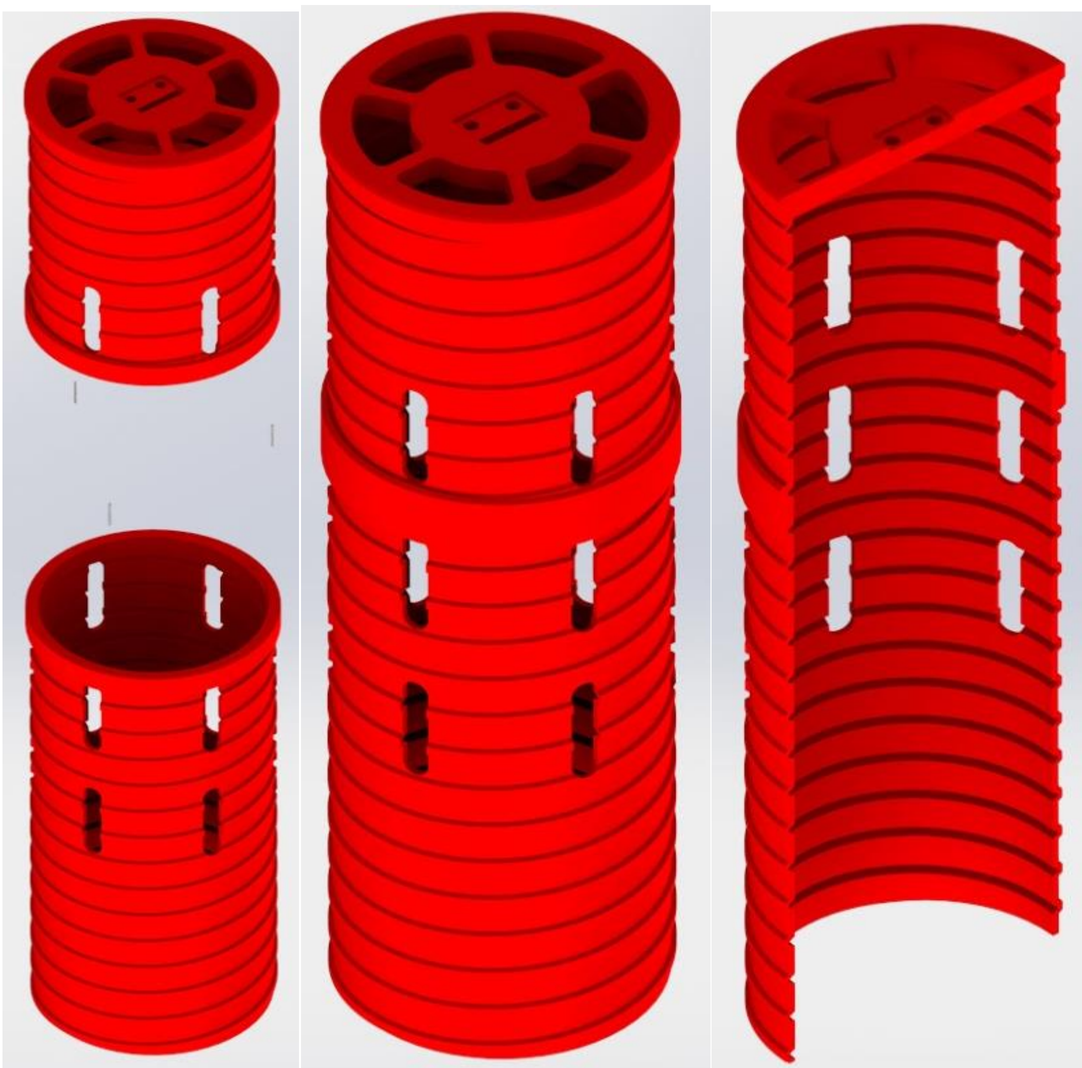


Figure 47 Three Canister Views

Locking Screw Caps - Within the canister are two screw caps that can move vertically along the internal threading. This vertical movement allows the PPS to accommodate varying payload dimensions. The screw caps are designed with a significant proportion of empty space, both to save weight and to be easily gripped for screwing in and out. The bottom screw cap features a three-pronged protrusion in the middle that allows it to be moved to the desired height before the top cap is screwed on top of it, locking both together.

Figure 48 Lower Locking Screw Cap

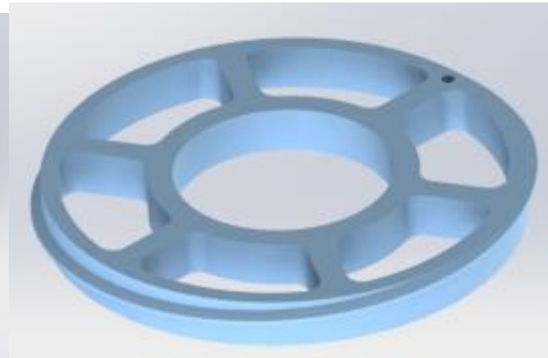


Figure 49 Upper Locking Screw Cap

Foam Spacers – Five, 0.75 inch thick polyurethane foam spacers are dispersed throughout the canister. They are laser cut to be the exact diameter of the canister interior for an optimal fit. One will be positioned at the top of the canister beneath the locking screw cap, and another will be positioned at the bottom. Three more are present throughout to split up the payload if we get multiple objects.

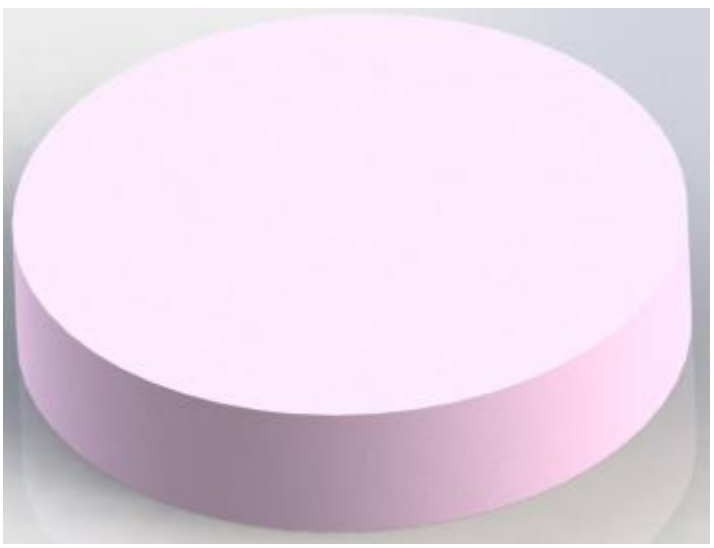


Figure 50 Foam Spacer (5 Discs, each 0.75 inch Thick)

Strap Cushioning Discs - Two hollow discs lined with foam along the internal circumference will be present within the canister. There are six periodic holes spaced along the canister to allow the straps to pass through this disc. The purpose of this system is to provide a surface other than the hard canister wall to secure a potential long and skinny payload against.

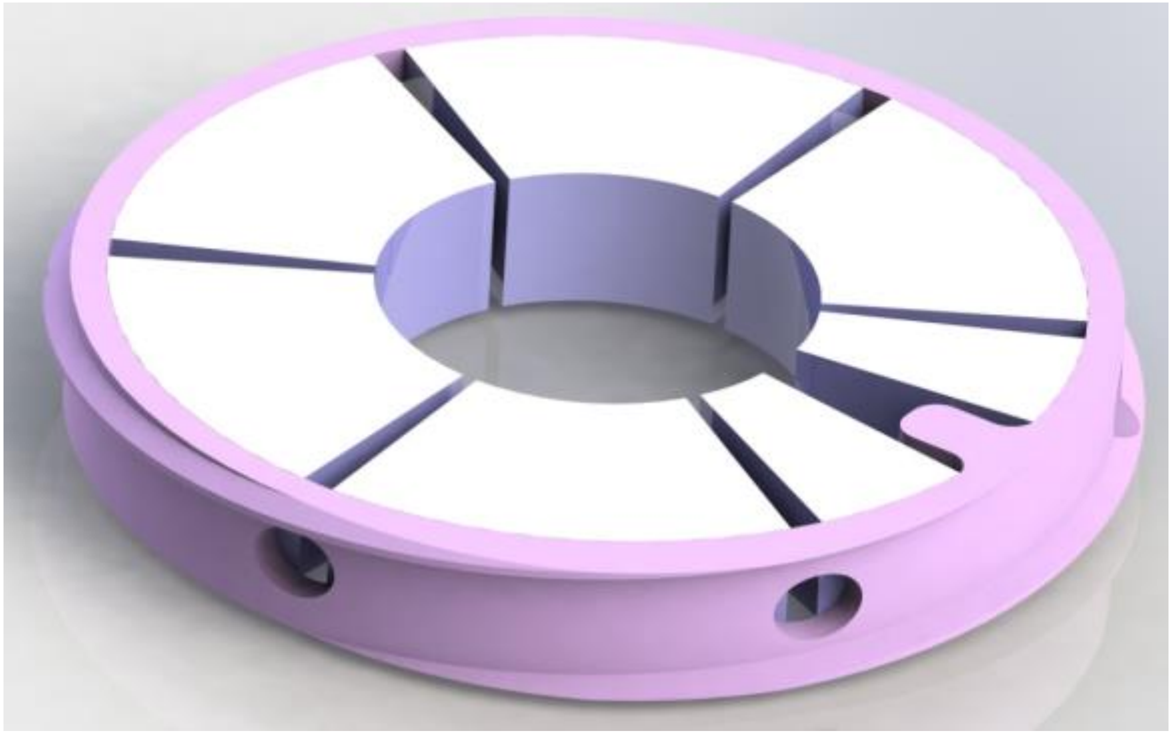


Figure 51 Strap Cushioning Discs

Clamps - There is a clamp present for each strap surrounding the canister. These clamps are used to tension the straps to properly secure the object and ensure that the payload will not slip. There are two identical parts to each clamp, each with jagged edges that fit into the other part. They are connected by putting a screw through each of the two pairs of holes, and securing each with a nut slotted into the hexagonal space.

Figure 52 Payload Strap Clamps

Vertical and Horizontal Dampening - There will be 4 inches of foam both above and below the canister. For the vertical and horizontal systems, the ideal moduli were made equal by adjusting the height of the canister. This allowed us to use the same type of foam for both. The function of these foam sections is to significantly dampen the expected force our payload will receive during flight. In the radial direction, a ⅛ inch thick piece of foam was added around the exterior circumference of the above described foam to ensure there would be no empty space in the PPS, as the first foam did not measure as thick as we initially expected.

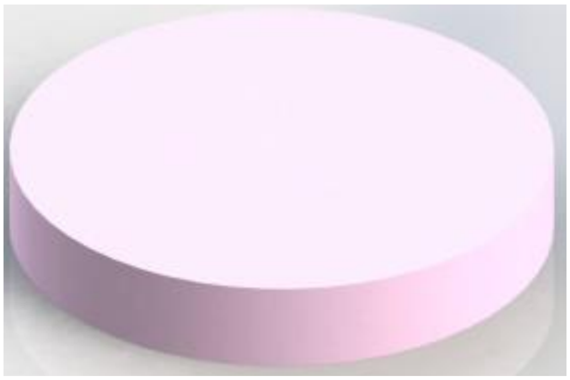


Figure 53 Vertical Dampening Foam (Axial)

Figure 54 Horizontal Dampening Foam (Radial)

LIS 331 - The LIS 331 sensor is used to collect acceleration data up to 24 g-forces. It is mounted to the bottom of the canister. To allow easier pathing when connecting the sensor to the electronics bay, this resulted in the canister being loaded into the launch vehicle upside down.

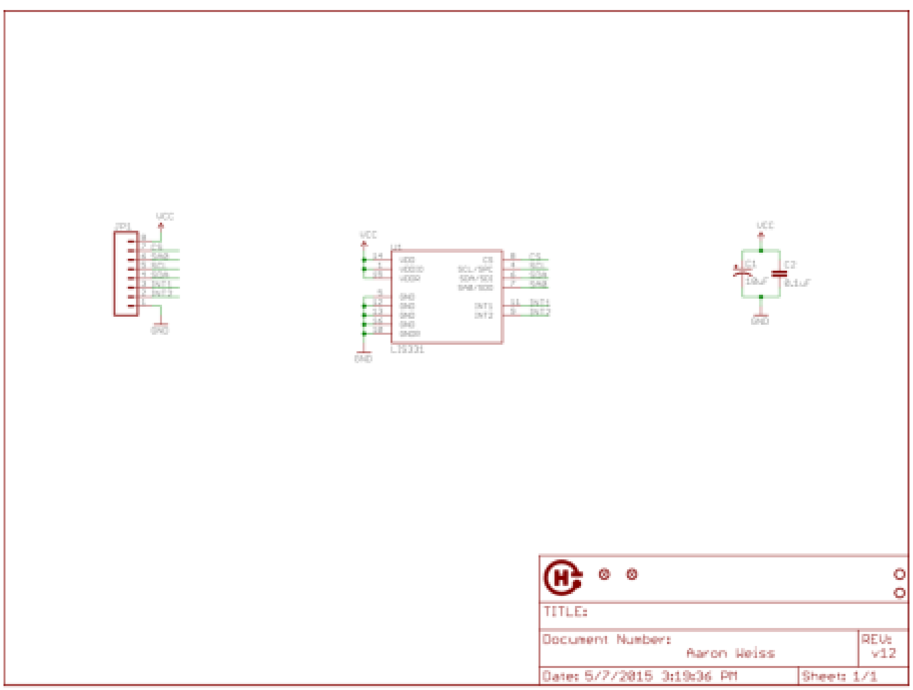


Figure 55 LIS 331 Schematic

Table 16 Payload Protection System Component Masses

Component	Mass (oz)
Payload Canister	7.6
Vertical Damping Foam	2.7
Horizontal Damping Foam	3.1
Inner Canister Foam Spacers	0.4
Strap Cushioning Disc	0.4
Straps	0.5
Locking Caps (both components)	1.1

4.3. Precision and Reliability

The PPS was designed to be reusable without needed replacement parts each launch. All force-dampening components— the vertical and horizontal dampening systems, as well as the spacers internal to the canister— are made of highly resilient polyurethane foam, which should withstand repeated compression. If a foam component is damaged, replacement is fast and simple; with the material on hand, identical cylinders can be laser-cut within minutes. The canister and locking rings are 3D printed out of PLA thermoplastic, and are also easily replaceable as they require no machining.

The StratoLoggers provide individual altitude measurements with a resolution of up to 1’. The LIS 331 accelerometer provides 12-bit acceleration measurements across a range of ±24G with a precision of approximately 12 mG/digit.

4.4. Payload Electronics

The payload electronics bay consists of a Teensy 3.6 micro controller (which has an onboard microSD card reader), two StratoLoggers, an Adafruit Ultimate GPS module, and an Xbee XSC Pro. There is a LIS 331 accelerometer mounted to the bottom of the canister of the PPS, rather than on the bottom of the electronics bay, to give the most accurate acceleration readings on the payload. To reduce the distance between the LIS 331 and the rest of the electronics bay, the canister will be loaded upside down. This reduces the length of the wires between the LIS 331 and the electronics bay, which will help minimize the possible points of failure or data loss due to wire damage.

The components of the payload electronic configuration communicate with each other and the ground station. Data from the LIS 331 is sent to the Teensy 3.6, along with the altitude data from the StratoLoggers and position data from the GPS module. Data is then stored on a microSD card through the Teensy's onboard microSD card reader. Data is also transmitted to a ground station via the XBee XSC Pro for live telemetry and data redundancy purposes, using another XBee XSC configured to receive transmissions. There was a connectivity minor issue with the USB receiver dongle initially, but this has since been corrected with a hardware modification, and there should be no debilitating issues with receiving data from the ground station.

The choice in 3-axis accelerometer for the Payload Section was between the MPU 6050 and the LIS 331. Based on the requirement that the sensor should be able to pool above 500 Hz, and can collect ±16 G-force, these were the two most appropriate sensors found. The MPU 6050 is a 6 DOF accelerometer that outputs data at 1000 Hz and has a programmable force range of up to ±16 G-force. The LIS 331 is a 3 DOF accelerometer that outputs data at 1000 Hz, and has a ±24G range. Ultimately, the LIS 331 was chosen as the accelerometer to be used in the Payload Section since it had the larger sensitivity range and simpler control, although the MPU is kept on hand in case a substitute is needed.

Our ground station will consist of a python script that parses the serial data being imported into the ground station computer, and redisplays / logs the data on screen for live telemetry purposes. This can also be adapted into other receiver programs, so long as they can hook into the computer's serial connection.

4.4.1. Drawings and Schematics

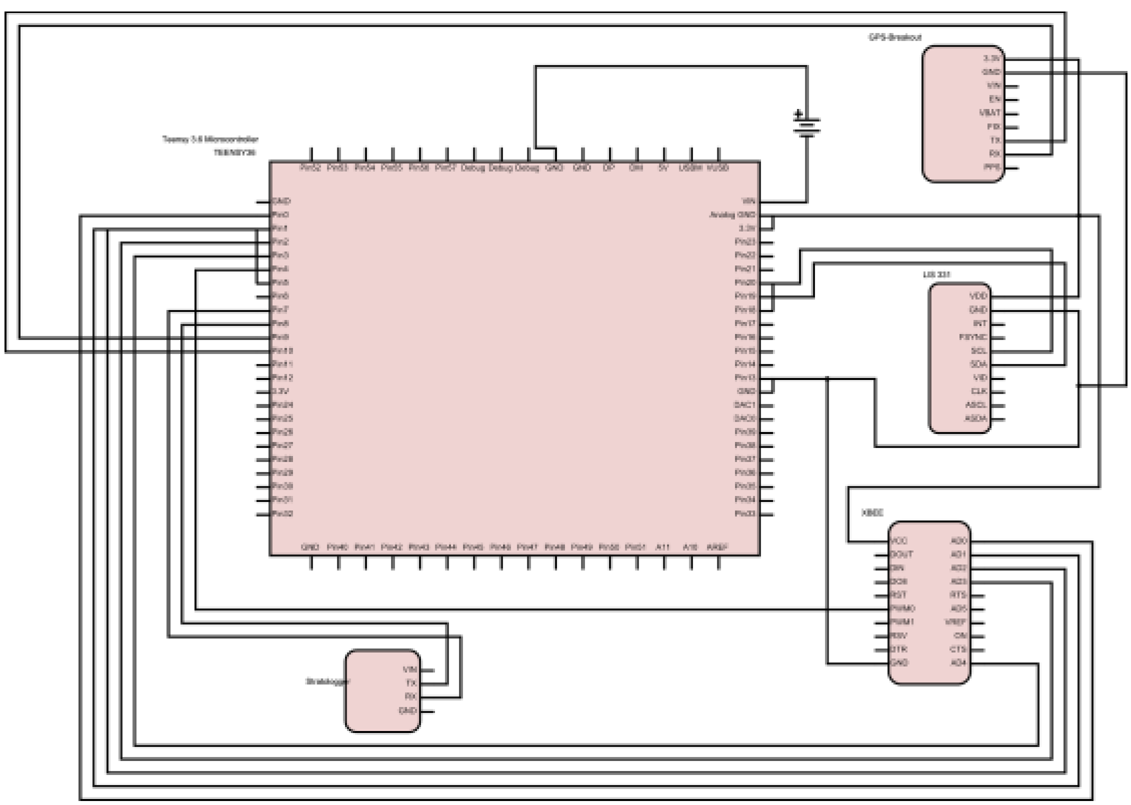


Figure 56 Telemetry System Schematic

4.4.2. Block Diagrams

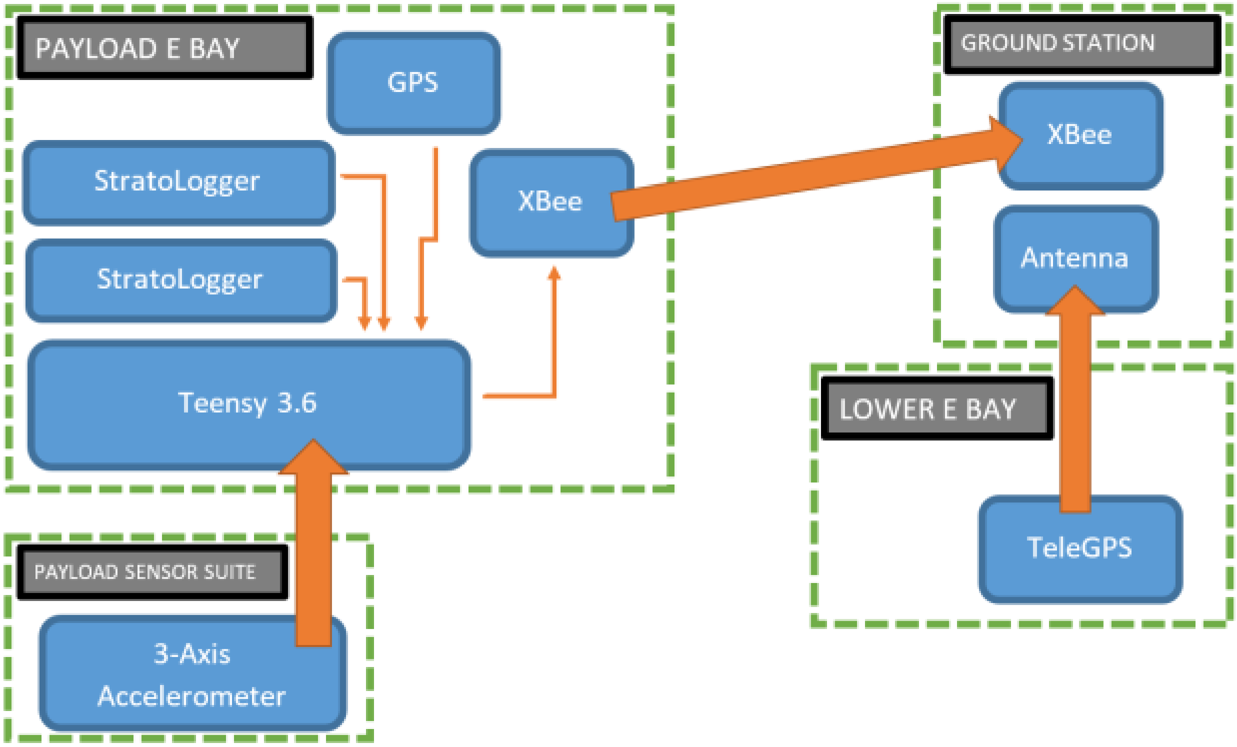


Figure 57 Telemetry to Ground Station Block Diagram

4.4.3. Batteries / Power

The PPS is an entirely passive system, meaning that once it is loaded into the launch vehicle, it should not need to be altered again throughout the entire flight. All electronics, save for the LIS 331, are located within the electronics bay. A Zippy Compact 1300 2 Cell 7.4 V battery is used to power the sensors and components located within the electronics bay located above the Payload Section. This does not include any of the StratoLoggers. These sensors will take critical readings that will help us to evaluate our success criteria, such as height and acceleration that the payload undergoes during launch and landing.

4.4.4. Igniter Installation

Because the entire payload electronics systems simply record and transmits what occurs during the flight, the need for emergency switches is very limited. The payload system only receives data from the StratoLoggers, and is not involved in their triggering or deployment. Therefore, the only real need for indicators can be supplied by the LEDs that indicate current states on the Teensy microcontroller itself. If more output is needed, additional LEDs can be added to the payload electronics bay, to indicate the current state of the system and provide feedback in the event of errors.

4.5. Payload Testing

We conducted a drop test of the PPS in its housing from a height of 5’ 2” to simulate the forces the payload would experience during impact with the ground. The acceleration, as measured by the LIS 331 accelerometer, was recorded with the PPS fully assembled. The electronics system in place for this drop test was composed of the LIS331 and an Arduino with a microSD card reader. The acceleration data showed that impact resulted in an approximately 19g magnitude acceleration reading for a loaded payload section. The raw accelerometer data for the drop test is shown in Figure 58. Figure 59 isolates the z-axis acceleration since it corresponds directly with the direction of the PPS travel, i.e. straight down towards the Earth.

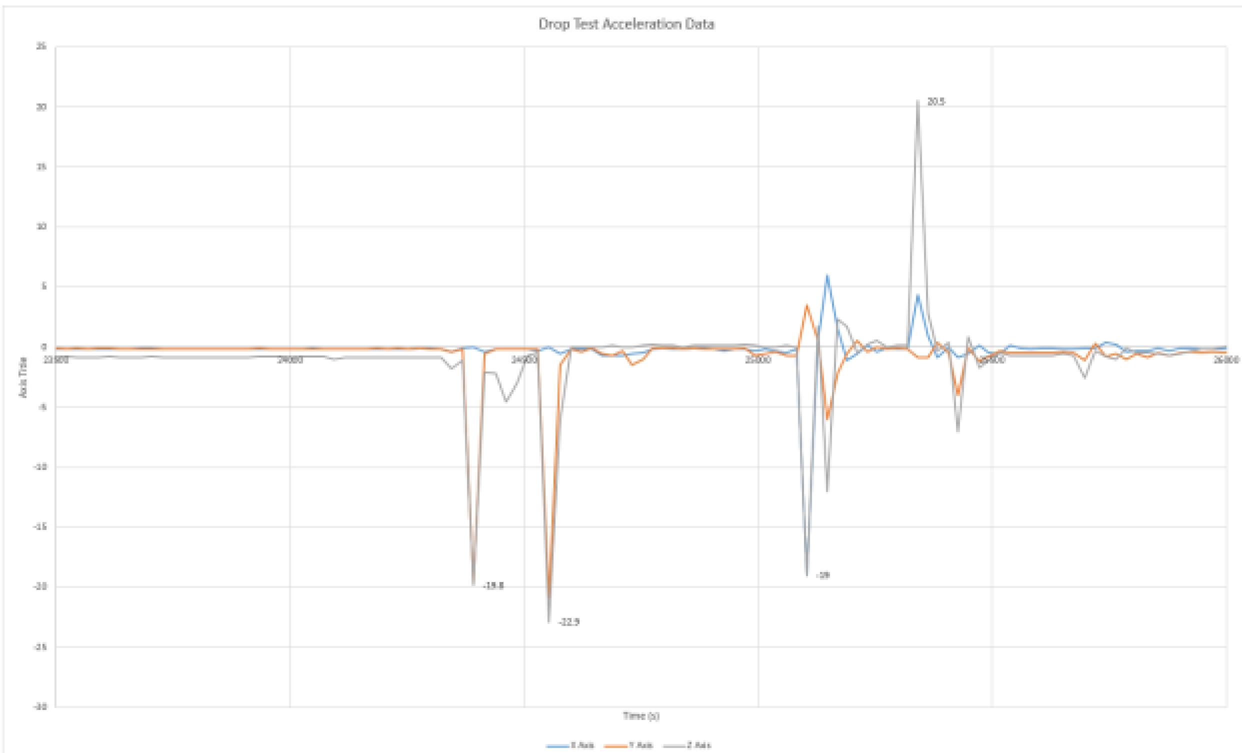


Figure 58 Drop Test Acceleration Data (x, y, z)

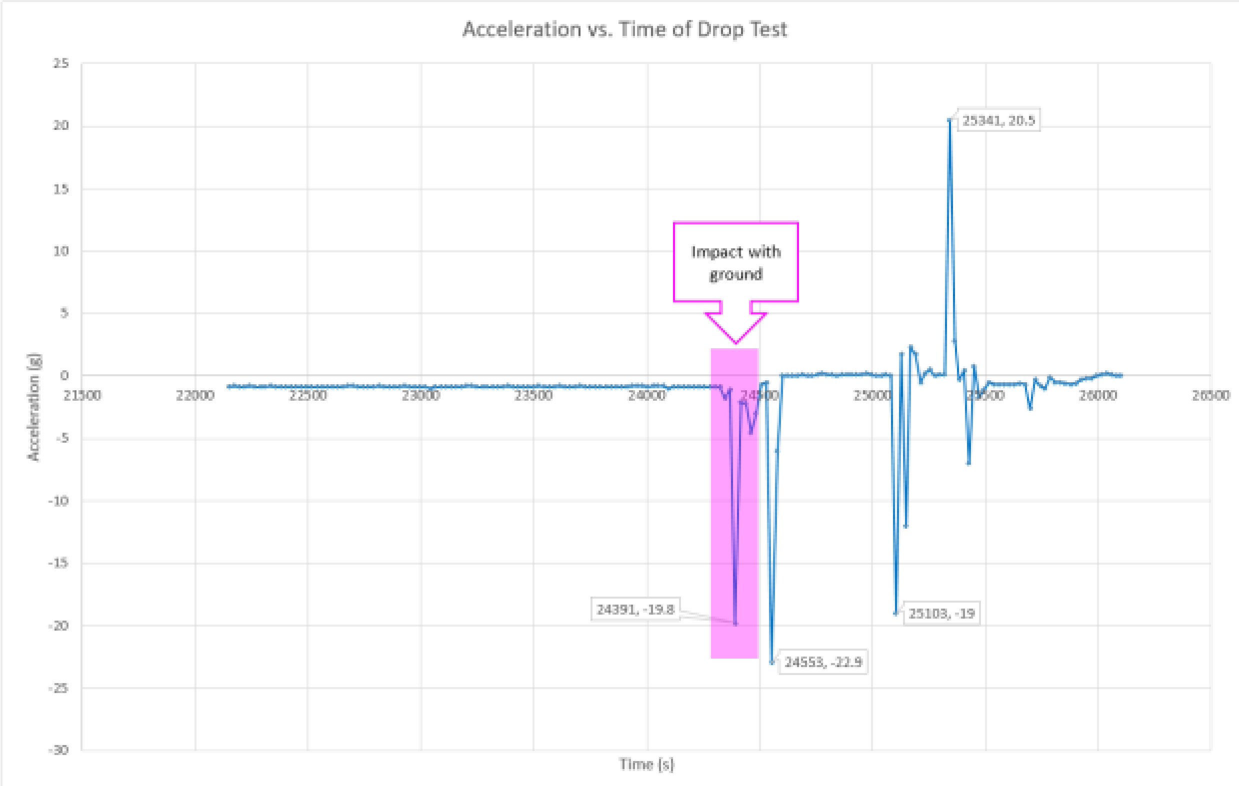


Figure 59 Acceleration vs. Time of Drop Test Showing Impact with Ground

The spikes in the data following the fire initial greatest magnitude are due to bouncing and are extraneous values that were affected by external forces such as picking it up and retrieving the electronics sensor system. The values produced from this test can give us some estimates on the impact acceleration that the PPS could experience. Comparing the empty payload to the dampening of the foam we should be able to dampen the acceleration felt by the payload by approximately half.

5. Safety

5.1. Failure Modes and Effects Analysis (FMEA)

All tests referred to as “L#” or “P#” are recorded in Section 7.1.

5.1.1. FMEA Likelihood Definitions

Likelihood	Definition	Ranking
Remote	Significant negligence and defects required for hazard to occur.	1
Unlikely	Significant negligence or major defects required for hazard to occur.	2
Possible	May occur despite proper safety measures and equipment checks taking place.	3
Likely	Expected to occur despite proper safety measures and equipment checks taking place.	4

5.1.2. FMEA Severity Definitions

Severity	Definition	Ranking
Catastrophic	Total loss of launch vehicle and payload. Extreme risk to personnel and bystander safety.	4
Major	Loss of system functionality and some risk to personnel and bystander safety. Probable loss of launch vehicle and payload.	3
Moderate	Partial loss of system functionality and some risk to personnel and bystander safety.	2
Minor	Partial loss of system functionality with minor/no risk to personnel and bystander safety.	1
No Effect	No loss of system functionality with no risk to personnel and bystander safety.	0

5.1.3. Failure Modes and Effects Analysis

Item	Failure Mode	Effects	Potential Causes	Severity	Probability	Mitigation	Verification
	Drogue parachute fails to deploy	Launch vehicle will not decelerate prior to main chute deployment. Increa sed risk of main parachute failure, loss of payload, and personnel injury.	Improper packing of drogue parachute causes tangling upon deployment. Improper deployment charge used, destroys parachute.	2	1	Main parachute will deploy even if drogue parachute fails. Main parachute and shock cord are able to take loads of main parachute deployment without drogue. Charges and packing will be checked prior to launch.	Max force of ½" tubular Kevlar shock cord is 7.2 kips. Resulting factor of safety is 335. In the event of a drogue failure, max load on main chute would be 403.6lb, resulting in a factor of safety of 17.8. Tests L10 and L11 verified proper packing, and ensured that charges would not damage parachutes. Parachute packing procedures 6.1.7 and 6.1.24 will be followed.
	Main parachute fails to deploy	Launch Vehicle will descend under drogue parachute, faster than	Improper packing of main parachute causes tangling upon deployment. Improper	3	1	RSO will alert crowd to Launch Vehicle with parachute failure, Launch Vehicle will be aimed away from spectators,	Tests L10 and L11 verified proper packing procedure, and ensured that charges would not

Launch Vehicle		nominal. Likely loss of payload and increased risk to personnel.	deployment charge used, destroys parachute.			and all spectators will be made aware of launches occurring. Charges and packing will be checked prior to launch.	damage parachutes. Parachute packing procedures 6.1.7 and 6.1.24 will be followed.
	Both main/drogue parachutes fail to deploy	Launch Vehicle will be in freefall. Total loss of launch vehicle and substantial risk to personnel.	Improper packing of main and drogue parachute causes tangling upon deployment. Improper deployment charge used, destroys parachutes.	3	1	RSO will alert crowd to launch vehicle with parachute failure, Launch Vehicle will be aimed away from spectators, and all spectators will be made aware of launches occurring. Charges and packing will be checked prior to launch.	Tests L10 and L11 verified proper packing procedure, and ensured that charges would not damage parachutes. Parachute packing procedures 6.1.7 and 6.1.24 will be followed.
	Shock cord failure (drogue)	Parachute detaches from Launch Vehicle. Increased loads on main parachute deployment. Increased risk of main parachute failure, loss of payload, and personnel injury.	Weakening or damage to shock cord from accidental cutting or epoxy.	2	1	Shock cord will be kept away from unintentional cutting and epoxy.	According to OpenRocket simulations, max drogue deployment load is 21.5lb, max force of ½” tubular Kevlar shock cord is 7.2kip. Resulting factor of safety is 335. In the event of a drogue failure, max load on main chute would be 403.6lb, resulting in a factor of safety of 17.8.
	Shock cord failure (main)	Parachute detaches from Launch Vehicle. Launch Vehicle will descend under drogue parachute at increased speed. Likely loss of payload and	Weakening or damage to shock cord from accidental cutting or epoxy.	3	1	Attachment point is reinforced. Shock cord will be kept away from unintentional cutting and epoxy.	Shock cord for both drogue and main is ½” tubular Kevlar with max load of 7.2kips. According to OpenRocket simulations, max main deployment load in the event of a drogue failure is 403.6lb. Resulting factor of safety is

		increased risk to personnel.					17.8. Preparation procedure 6.1.2 will be followed to verify proper connection of shock cord to eyebolt.
	Shock cord failure (both)	Both parachutes detach from Launch Vehicle. Launch Vehicle will be in freefall. Total loss of launch vehicle and substantial risk to personnel.	Weakening or damage to shock cord from accidental cutting or epoxy.	3	1	Shock cord will be kept away from unintentional cutting and epoxy. Shock cord will be inspected prior to launch for damage or defects. RSO will alert crowd to launch vehicle with parachute failure, Launch Vehicle will be aimed away from spectators, and all spectators will be made aware of launches occurring.	Shock cord is ½” tubular Kevlar with max load of 7.2kips. According to OpenRocket simulations, max main deployment load in the event of a drogue failure is 403.6lb, max drogue deployment load is 21.5lb. Resulting factor of safety is 17.8. Preparation procedure 6.1.2 will be followed to verify proper connection of shock cords to eyebolt.
	Parachute Bulkhead failure	Bulkhead connected to parachutes fails. Parachutes no longer connected to launch vehicle. Total loss of launch vehicle and some risk to personnel.	Weakening or damage to epoxy securing bulkhead to body tube. Damage to bulkhead providing a point of failure. Too little epoxy used. Load of parachute deployment exceeds failure stress of bulkhead or epoxy.	3	1	Epoxy will be properly stored and applied as per Loctite Epoxy Instant Mix technical specifications; used on clean surfaces, and components joined within 4 minutes of application. Bulkhead will be visually inspected for damage or structural flaws prior to launch. Liberal amount of epoxy will be used.	Failure shear force on nominal amount of epoxy applied is 29.6kips as per Loctite Epoxy Instant Mix specifications. Failure shear force on 5.883” diameter, ½” thick bulkhead is 11.9kips according to Table 2 Birch Material Properties, and assuming the lowest specified transverse shear modulus. Using highest possible loads on bulkhead

							(main deployment without prior drogue deployment), resulting factor of safety of epoxy is 73, and for the wood bulkhead it is 29.5.
	Ejection charges fail to ignite	Launch Vehicle will not separate for parachute ejection and will fall in a ballistic trajectory. Total loss of Launch Vehicle and substantial risk to personnel.	Improper connection to charges, improper installation of charges, defective charges, Stratologger improperly calibrated. Stratologger or keylock switch failure.	4	1	Confirm black powder in ejection charges is sufficient to separate Launch Vehicle sections, check recovery systems electronics bay for proper connections, verify altimeter calibration. Charges will be handled as per AeroTech provided MSDS and installed as per Charge Packing Procedure (section 6.1.1). Multiple redundancy features built into keylock switches and Stratologgers connected to ejection charges. Refer to section 3.2.3 for detailed description of redundancy features.	Tests L2, L3, L4, L10, and L11 in section 7.1 detail testing performed on parachutes and electronics to verify performance and consistency in deployment. Procedure 6.1.4 and 6.1.20 will be followed to ensure proper installation of motor and upper electronics bays. Black powder calculations in section 6.1.2 will be used to determine amount needed per charge, with a factor of safety of 1.5.
	Premature detonation of ejection (charges in Launch Vehicle)	Premature separation of vehicle stages. Rapid unplanned disassembly of vehicle.	Improper calibration of altimeter. Improper handling of e-matches.	4	1	Ejection charges will be handled as per AeroTech provided MSDS and installed as per Charge Packing Procedure (section 6.1.1). Charges will be kept in original packaging until ready for use. Charges will be stored at least 25ft away from any heat or flame source.	Tests L2, L3, L4, L10, and L11 in section 7.1 detail testing performed on parachutes and electronics to verify performance and consistency in recovery system deployment. Recovery Preparation Procedure 6.1.4 and 6.1.20 will be followed to ensure proper

							installation of motor and upper electronics bays. Black powder calculations in section 6.1.2 will be used to determine amount needed per charge, with a factor of safety of 1.5.
	Partial deployment of drogue parachute	Launch Vehicle will decelerate less until main chute deployment. Increa sed risk of main parachute failure, loss of payload, and personnel injury.	Drogue parachute becomes tangled upon deployment. Improper packing.	2	2	Main parachute will deploy even if drogue parachute fails. Main parachute and shock cord are able to take loads of main parachute deployment without drogue. Packing will be checked prior to launch.	Max load on shock cord is 7.2kip. Max load resulting from main parachute deployment without a prior drogue deployment is 403.6lb. Resulting factor of safety is 17.8. Tests L10 and L11 verified proper packing procedure, and ensured that parachutes would not tangle. Parachute packing procedures 6.1.7 and 6.1.24 will be followed.
	Partial deployment of main parachute	Launch Vehicle will descend under drogue parachute and partially deployed main, faster than nominal. Likely loss of payload and increased risk to personnel.	Main parachute becomes tangled upon deployment. Improper packing.	3	2	Launch Vehicle will be aimed away from spectators, and all spectators will be made aware of launches occurring. Packing will be checked prior to launch.	Tests L10 and L11 verified proper packing procedure, and ensured that parachutes would not tangle. Parachute packing procedures 6.1.7 and 6.1.24 will be followed.

	Partial deployment of both drogue/main parachutes	Vehicle will fall at increased speed under partially deployed parachutes. Potential loss of launch vehicle and substantial risk to personnel.	Main and drogue chutes could become tangled with one another. Improper packing.	3	1	RSO will alert crowd to launch vehicle with parachute failure, Launch Vehicle will be aimed away from spectators, and all spectators will be made aware of launches occurring. Packing will be checked prior to launch.	Tests L10 and L11 verified proper packing procedure, and ensured that parachutes would not tangle. Parachute packing procedures 6.1.7 and 6.1.24 will be followed.
	Rapid unplanned disassembly of Vehicle (RUD)	Vehicle will break apart in an unplanned manner. Loss of vehicle structural integrity and increased risk to personnel due to vehicle components in freefall.	Structural defect in Launch Vehicle body, or damage to the body caused by drop, material flaw, moisture, or improper application of epoxy.	4	1	In the event of a RUD with the vehicle breaking apart along its coupler tubes, parachutes may passively deploy for each section. Verify that the Vehicle is structurally stable.	Launch vehicle BlueTube will be inspected for delamination, flaws, or other damage prior to launch. Test L3 verified sound structure of launch vehicle.
Payload	Payload canister has oscillation inside launch vehicle	Potentially cause oscillation in overall Launch Vehicle that could result in loss of longitudinal stability.	Payload inner canister separating from foam damper and oscillating on springs.	1	1	Payload oscillation will likely be small enough to not require mitigation due to mass of payload and damping coefficient of foam used.	Tests P1, P2, and P3 verified that payload will not oscillate under flight-like conditions.
	Protected object comes loose inside payload canister	Protected object could be damaged or destroyed.	Adjustable height canister top coming loose.	1	2	Ensure adjustable canister top is fitted properly. Threaded top with locking bulkheads is unlikely to come loose.	Test P2 was performed with an object in the canister to verify that object will not come loose.

Launch Operations	Explosive motor failure on launch pad	Significant risk of severe personnel harm and fire hazard. Significant risk of loss of vehicle and payload.	Defective or damaged motor.	4	1	Maintain personnel a safe distance away from launchpad (300-500 ft according to National Association of Rocketry (NAR) High Power Rocket Safety Code). Follow MSDS storage requirements; keep the motor in its original packaging until time for installation. Insert and prepare motor properly before launch sequence is initiated.	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members to reduce the risk of inadvertent damage. Motor will be inspected before launch. Procedure section 6.2 will be followed for motor preparation and installation.
	Premature motor ignition (on launch rail)	Significant risk of personnel harm, fire hazard, and uncontrolled launch. Potential loss of vehicle and payload.	Improper storage or handling of motor. Improper connection between motor and igniter.	4	1	Maintain personnel a safe distance away from launchpad (300-500 ft according to National Association of Rocketry (NAR) High Power Rocket Safety Code). Follow MSDS storage requirements. Insert and prepare motor properly before launch sequence is initiated.	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members to reduce the risk of inadvertent damage. Motor will be inspected before launch. Procedure section 6.2 will be followed for motor preparation and installation.
	Motor fails to ignite	Vehicle will not launch.	Improper connection between motor and igniter Motor igniter falls out. Defective motor. Motor is wet.	0	1	Follow NAR safety procedure (60 second wait before approaching) before accessing Launch Vehicle following motor failure to ignite. Check connections prior to launch. Insert and prepare motor properly before launch	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members to reduce the risk of inadvertent damage. Motor

						sequence is initiated. Motor will be inspected before launch.	will be inspected before launch. Procedure section 6.2 will be followed for motor preparation and installation.
Ground Support Equipment	Premature motor ignition (prior to installation)	Significant risk of personnel harm and general fire hazard.	Heat source placed near motors. Improper handling of motors.	4	1	Motors will be provided the day of launch. Will only be handled by qualified personnel. Follow MSDS storage requirements.	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members.
	Premature detonation of ejection charges (prior to installation)	Significant risk of personnel harm and general fire hazard.	Heat source placed near charges. Improper handling of charges.	4	1	Black powder will be provided the day of launch. Will only be handled by qualified personnel. Follow MSDS storage requirements.	Altimeters will be calibrated before they are connected to charges. Test L10 verified performance and reliability of ejection charges. The black powder will be handled by team mentor Robert DeHate, and will not be handled by student team members.

5.2. Personnel Hazard Analysis

5.2.1. Personnel Hazard Analysis Likelihood Definitions

Likelihood	Definition	Ranking
Remote	Significant negligence and defects required for hazard to occur.	1
Unlikely	Significant negligence or major defects required for hazard to occur.	2
Possible	May occur despite proper safety measures and equipment checks taking place.	3
Likely	Expected to occur despite proper safety measures and equipment checks taking place.	4

5.2.2. Personnel Hazard Analysis Severity Definitions

Severity	Definition	Ranking
Catastrophic	Total loss of launch vehicle and payload. Extreme risk to personnel and bystander safety.	4
Major	Loss of system functionality and some risk to personnel and bystander safety.	3
Moderate	Partial loss of system functionality and some risk to personnel and bystander safety.	2
Minor	Partial loss of system functionality with minor/no risk to personnel and bystander safety.	1
No Effect	No loss of system functionality with no risk to personnel and bystander safety.	0

5.2.3. Personnel Hazard Analysis

Section	Hazard	Effects	Potential Causes	Severity	Probability	Mitigation	Verification
Launch Hazards	Premature Motor Ignition	Severe burns/bodily harm, general fire hazard	Improper storage and handling of motor. Motor placed near heat source.	4	1	Follow MSDS storage requirements. Keep away from ignition sources	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members.
	Explosive Motor Failure on Launchpad	Severe burns/bodily harm, general fire hazard	Defective or damaged motor.	4	1	Maintain personnel a safe distance away from launchpad (300-500 ft according to NAR High Power Rocket Safety Code). Follow MSDS storage requirements. Insert and prepare motor correctly.	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members to reduce the risk of inadvertent damage. Motor will be inspected before launch. Procedure section 6.2 will be followed for motor preparation and installation.
	Motor fails to ignite	Indicative of potential	Improper connection	0	1	Follow NAR safety procedure (60 second wait) before	Motors will be handled by mentor Robert DeHate or NAR

		miswiring of engine ignitor, or defect in engine (see "Explosive Motor Failure on Launchpad")	between motor and igniter, defective motor, or wet motor.			accessing Launch Vehicle following motor failure to ignite. Check connections prior to launch. Insert and prepare motor properly before launch sequence is initiated. Motor will be inspected before launch.	L2 certified member Evan Kuritzkes, and will not be handled by other student team members to reduce the risk of inadvertent damage. Motor will be inspected before launch. Procedure section 6.2 will be followed for motor preparation and installation.
	Unstable Flight Path	The Vehicle goes on a flight path that was unanticipated	One or more fins falls off, unintended oscillation of the rocket as a result of dislodged internal components, or high winds during launch	4	1	Maintain personnel a safe distance away from launchpad (300-500 ft according to NAR High Power Rocket Safety Code). Verify internal components in electronics bays and payload are secure. Do not launch in high wind conditions above 20mph.	Team will ensure pad area is clear of personnel within 300-500ft of the launch vehicle. Wind conditions will be monitored, and structural integrity of fins and other aerodynamic elements will be checked prior to launch.
	Total Recovery Systems Failure	No parachutes are deployed, the Vehicle is in freefall	The charges do not detonate or the sections do not separate to release the parachutes.	4	1	Confirm that quantity of black powder in ejection charges is sufficient to separate launch vehicle sections, check recovery systems in electronics bay for proper connections, and verify altimeter performance. Maintain personnel a safe distance away from launchpad (300-500 ft according to NAR High Power Rocket Safety Code).	Tests L2, L3, L4, L10, and L11 in section 7.1 detail testing performed on parachutes and electronics to verify performance and consistency in recovery system deployment. Procedure 6.1.4 and 6.1.20 will be followed to ensure proper installation of motor and upper electronics bays. Further verifications for various recovery system failures detailed in section 5.1 FMEA.
	Partial Recovery	Either the drogue	The charges do not separate some	3	2	Confirm that quantity of black powder in ejection charges is	Tests L2, L3, L4, L10, and L11 in section 7.1 detail testing

	Systems Failure	parachutes or the main parachute is not deployed, the Vehicle descends faster than anticipated	of the sections, the sections do not release the parachutes, or the parachutes get tangled on release. Drogue parachute or main parachute fails to deploy.			sufficient to separate launch vehicle sections, check recovery systems in electronics bay for proper connections, and verify altimeter performance. Confirm the parachute is packed correctly. Maintain personnel a safe distance away from launchpad (300-500 ft according to NAR High Power Rocket Safety Code).	performed on parachutes and electronics to verify performance and consistency in recovery system deployment. Procedure 6.1.4 and 6.1.20 will be followed to ensure proper installation of motor and upper electronics bays. Further verifications for various recovery system failures detailed in section 5.1 FMEA.
	Shock Cord Failure	The Vehicle would not be connected to the parachute(s) and would either descend faster than anticipated or be in freefall	Damage or defect to the shock cords connecting the drogue and/or main parachute to the vehicle. Shock cord improperly secured to bulkhead.	4	1	The final assembly checklist will be followed and the shock cord will be inspected.	Shock cord is ½" tubular Kevlar with max load of 7.2kips. According to OpenRocket simulations, max main deployment load in the event of a drogue failure is 403.6lb, max drogue deployment load is 21.5lb. Resulting factor of safety is 17.8. Recovery Preparation procedure 6.1.2 will be followed to verify proper connection of shock cords to eyebolt.
Construction Hazards	Power Tool Injury	Injury incurred while using a power tool	Improper training or tool maintenance. Human error	4	2	Properly train team members on power tool handling, wear proper Personal Protective Equipment according to each power tool's operator's manuals.	Only qualified team members operated power tools or machine shop equipment. Only LV and Payload team leads have keycard access to lab workspace with power tools.

	Tool Injury	Injury incurred while using a power tool	Improper training or tool maintenance. Human error	4	2	Properly train team members on tool handling, wear proper PPE, ensure First Aid equipment is available.	Only qualified team members operated power tools or machine shop equipment. Only LV and Payload team leads have keycard access to lab workspace with power tools.
	Chemical Hazards	Injury incurred while using chemicals	Improper training or equipment maintenance Human error	4	2	Train team members on chemical handling, and follow proper storage requirements listed on MSDS, provide proper PPE according to the material's instructions, utilize chemicals only in areas designated for their use.	Only LV and Payload team leads have keycard access to lab workspace with chemicals. Foam mixing will take place under a fume hood in the lab space. Team will refer to Loctite provided MSDS for resin and hardener agents.
	Fire Hazard	Injury incurred due to a fire	Improper training. Human error	4	2	Keep fire hazardous materials stored properly according to MSDS.	MSDS for epoxy and hardener will be followed. Epoxy and foam mix will be stored in a cool, dry area at least 25ft away from any flame or heat source. As per Aerotech MSDS, all ejection charges and motors will be stored at least 25ft away from any flame or heat source. Additionally, mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes will handle motors. Team mentor will be sole member to handle black powder for ejection charges.

5.3. Environmental Hazard Analysis

5.3.1. Environmental Hazard Analysis Likelihood Definitions

Likelihood	Definition	Ranking
Remote	Significant negligence and major defects required for hazard to occur.	1
Unlikely	Significant negligence or defects required for hazard to occur.	2
Possible	May occur despite proper safety measures and equipment checks taking place.	3
Likely	Expected to occur despite proper safety measures and equipment checks taking place.	4

5.3.2. Environmental Hazard Analysis Severity Definitions

Severity	Definition	Rank
Catastrophic	Environment causes complete loss of system, or system causes significant permanent damage to environment.	4
Major	Major depletion of system functionality, substantial effect on environment.	3
Moderate	Partial effect on system functionality, some effect on environment.	2
Minor	Small effect on system functionality, mild environmental concern.	1
No Effect	System stays intact, environmental conditions never altered.	0

5.3.3. Environmental Hazard Analysis

Environmental Concern	Effects	Potential Causes	Severity	Probability	Mitigation	Verification
Motor Chemicals	Possible contamination of environment surrounding Launch Vehicle during launch preparations or launch sequence.	Improper handling of motor. Propellant falls out of dropped motor.	1	1	Transport and load motor into launch vehicle properly, according to MSDS and motor operator's manuals.	Motors will be handled by mentor Robert DeHate or NAR L2 certified member Evan Kuritzkes, and will not be handled by other student team members to reduce the risk of inadvertent damage. Motor will be inspected before launch. Procedure section 6.2 will be followed for motor preparation and installation.
Impact of Motor Ignition on Launch Area	Possible fire or heat damage to immediate area around launch area. Potential fire hazard.	No shield between motor exhaust and ground.	1	1	Plate mounted on launch rail between motor to prevent motor exhaust from burning launch area.	Plate will be checked to ensure it is secure on the launch rail.
Debris from rapid unplanned disassembly of Launch Vehicle	Depending on the scale of the vehicle failure, debris consistency and size may vary. Debris may consist of	Catastrophic failure of separation charges or recovery system of	2	1	Launch Vehicle systems will be fully inspected before launch to mitigate probability of vehicle failure. In the event of a	Launch vehicle BlueTube will be inspected for delamination, flaws, or other damage prior to launch. Test L3 verified sound structure of launch vehicle.

	fiberglass, epoxy, and BlueTube fragments.	vehicle. Structural failure of vehicle.			failure, area will be policed for debris.	
Debris from launch preparation	Garbage and disposable waste (garbage bags, wrappers, tape, etc.) do not decompose in a natural environment and must be collected.	Lack of proper disposal plan for consumables and waste products.	2	2	Ensure any waste is properly collected and disposed of at launch site. Team area will be policed for debris and waste, and any found will be properly disposed of.	Launch site will be policed for debris and waste after launch, and all material will be found and disposed of properly.
Precipitation	Loss of electrical system function due to moisture. Motors and separation charges can also be affected by moisture, resulting in a motor failure to ignite, or a failure of the Launch Vehicle to deploy parachutes. Moisture can also compromise structural integrity of launch vehicle body.	Rain.	2	2	Team will ensure vehicle is protected from precipitation prior to launch. Team will avoid launching when rain is occurring or predicted.	Team members will monitor weather forecast
Bird Strike	Risk of death or serious injury to bird. Risk of significant damage or complete loss of Launch Vehicle, depending on the size of the bird hit.	Bird flies into path of Launch Vehicle on ascent.	4	1	Airspace above launch area will be cleared. Team will not launch if there are significant numbers of birds above the launch site.	Team members will monitor sky conditions above the launch site.
High Winds	Significant changes to flight path or vehicle stability due to high winds. Increased wind drift after parachute deployment can prevent recovery of Launch Vehicle.	Inclement weather or high winds.	2	2	Weather will be monitored and launches will not take place if wind speed is too high.	Team members will monitor weather forecast. Team will not launch if wind speed exceeds 20mph.

5.4. Launch and Autonomous Operations Procedures / Checklists

Everything that is **bolded** below, if not followed correctly will result in a safety risk. The checklist should be followed to ensure safety during launch.

1) Ensure that all shock cord and parachutes are accounted for including:
   a) Two 66in diameter main parachutes.
   b) Two 18in diameter drogue parachute.
   c) 40 ft long .5in tubular kevlar for the Booster Section main parachute.
   d) 30 ft long .5in tubular kevlar for the Booster Section main parachute.
2) **Ensure that all shock cords are attached to the corresponding parachute's hoist ring, which is used for the main parachutes, or swivel for the drogue parachutes. The other end should be attached to a quick link.**
3) Ensure that Robert DeHate, the team's advisor, has the black powder to pack the blast charges for separation.
4) Prepare the motor electronics bay.
   a) Attach a new 9-Volt battery to connectors and duct tape the batteries to the connectors.
   b) Check battery wiring to StratoLoggers to assure the StratoLoggers are receiving power.
   c) Insert threaded rods through the guide tubes within the body of the electronics bay.
   d) Connect the electronics bay output wires for the motor section and Interstage drogue parachutes to the upper bulkhead wires.
   e) Attach the top bulkhead by guiding the threaded rods through the holes and securing it with lock washers and lock nuts.
   f) Attach the Interstage section with set screws.
   g) Connect appropriate wires for Interstage charges.
   h) Put both electronics bays in the appropriate BlueTube sections.
   i) Attach electronics bay output wires for the motor section main parachute to the lower bulkhead wires.
   j) Attach lower bulkhead by guiding the threaded rods through the holes and securing it with lock washers and lock nuts.
   k) Turn the double pole double throw keys to close the circuit and listen for the beep that signals that there is continuity in the circuit. This ensures the altimeters are getting power. Turn the key again to open the circuit as to not unnecessarily drain the batteries.
   l) Blast charges are packed in the Interstage with 1.5g (calculation in Section 6.1.2) of powder for the payload drogue charges (Section 6.1.1. for procedure for packing charges).
   m) Blast charges are packed on the centering ring of the intersection with 1.75g (calculation in Section 6.1.2) of powder for the main drogue charges (See 6.1.1. for procedure for packing charges).
   n) Blast charges are packed on the lower bulkhead with 2g (calculation in 6.1.2) of powder for the main charges (See 6.1.1 for procedure for packing charges).
5) Attach the BlueTube for the main motor parachute to the bottom of the electronics bay with set screws.

6) Attach the quick link on the shock cord to the hoist ring attached to the motor electronics bay section.
7) The 72 inch main parachute is folded and inserted into the motor parachute cavity as follows:
   a) Lay the parachute out flat.
   b) Organize the leads at the bridle into three sections.
   c) Fold first gore and continue folding the gores until all the gores are folded into each other.
   d) The parachute is folded in a z-fold.
   e) The lines are pulled up the center and the parachute is wrapped around the centered lines, and the lines are rolled around the canopy.
   f) Place thermal wadding over the opening of the tube from which the parachute will be ejected.
   g) Push folded parachute into ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.
8) **Attach the shock cord to the hoist ring attached to the motor section bulkhead.**
9) Attach the motor main parachute section of BlueTube to the motor section with 4 shear pins.
10) Both drogue parachutes, 18in and 15in for the Booster and Payload Sections respectively, are folded.
    a) Lie the parachute flat, ensuring that lines are not tangled. Fold the parachute into thirds repeatedly until reaching a point that you cannot continue folding it into thirds. At this point, fold in half.
    b) Execute a lengthwise Z-fold.
    c) Roll the parachute up lengthwise such that the lines remain uninhibited.
11) **Attach the shock cord to the eyebolt in the Interstage ejection tube.**
12) **Place thermal wadding over the opening of the tube from which the parachute will be ejected.**
13) **Push folded drogue parachute into Interstage ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.**
14) Place Interstage bulkhead on the end of the Interstage ejection tube.
15) Attach the payload drogue parachute section of BlueTube to the top of the Interstage with 4 set screws.
16) **Place thermal wadding over the opening of the tube from which the payload drogue parachute will be ejected.**
17) **Push folded drogue parachute into Interstage ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.**
18) **Attach the shock cord to the hoist ring attached to the payload section.**
19) Attach the drogue payload parachute section of BlueTube to the payload section with 4 shear pins.
20) Prepare the upper electronics bay as follows:
    a) Attach new 9-Volt batteries to connectors and duct tape the batteries to the cases.
    b) Check battery wiring to altimeters to assure the altimeters are receiving power.
    c) Insert threaded rods through the guide tubes through the electronics bay’s body.

d) **Attach the electronics bay output wires for the main parachute to the wires on the bulkhead.**
e) Attach the top bulkhead by guiding the threaded rods through the holes and secure it with lock washers and nuts.
f) Place upper electronics bay into appropriate BlueTube section.
g) Attach lower bulkhead by guiding the threaded rods through the holes and securing it with lock washers and nuts.
h) **Turn double pole double throw keys to close the circuit and listen for the beep that signals that there is continuity in the circuit to ensuring the altimeters are getting power, turn the key to open the circuit as not to waste batteries unnecessarily.**
i) **Blast charges are packed on the bulkhead with 2g of powder for the main charges (See 6.1.2 for procedure for packing charges).**

21) Attach the upper electronics bay to the payload section with 4 set screws.
22) Attach the BlueTube for the payload main parachute to the payload section with 4 set screws.
23) **Attach the shock cord to the hoist ring in the payload main parachute tube.**
24) The 60 inch main parachute is folded and inserted into the parachute cavity as follows:
    a) Lay the parachute out.
    b) Organize the leads at the bridle into three sections.
    c) Fold first gore and continue folding the gores until all the gores are folded into each other.
    d) The parachute is folded in a z-fold.
    e) The lines are pulled up the center and the parachute is wrapped around the centered lines, the lines are rolled around the canopy.
    f) **Place thermal wadding over the opening of the tube from which the parachute will be ejected.**
    g) **Push folded parachute into ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.**
25) **Attach the shock cord to the eyebolt attached to the nose cone.**
26) Attach the nose cone to the payload main parachute tube with 4 shear pins.
27) Gather all materials, tools, and personnel to take to launch pad, including:
    a) A step ladder.
    b) Team mentor Rob DeHate.
    c) Two team members for carrying the rocket, the minimum necessary.
    d) Completed launch card for RSO.
28) **Ensure launch rail has no visible flaws.**
29) Perform final checks to exterior of rocket
    a) **Count 4 shear pins on nose cone**
    b) **Count 4 set screw on upper section of payload electronics bay**
    c) **Count 4 set screws on lower section of payload electronics bay**
    d) **Count 4 shear pins connecting payload section to motor section**
    e) **Count 4 set screws on upper section of motor section electronics bay**
    f) **Count 4 set screws on lower section of motor section electronics bay**
    g) **Count 4 shear pins on motor assembly**
    h) Visually check alignment of paint job and rail mounts
30) Lower rail on launch pad to horizontal position for loading

31) Load rocket onto the 15-15 rail using rail mounts, but do not erect it
32) **Turn on electronics bays**
    a) Turn and remove keys
    b) **Listen to startup beeps to ensure all systems are connected**
33) Adjust launch rail to vertical position
34) **All members who are not level-2 certified retreat to the rest of the team, at least 300 feet from the launch pad.**
35) Prepare igniter by removing a single igniter from the package and inspecting:
    a) **Continuity.**
    b) **Resistance.**
    c) **The pyrogen for cracks or flaws.**
    d) **That the wires do not touch anywhere except in the combustible tip.**
36) Insert igniter into the motor through the nozzle and push it in until it hits a hard stop against the propellant grain.
37) Mark the point on the igniter at the bottom of the motor.
38) Pull the igniter out of the motor and make a small loop in the igniter directly below the mark.
39) Reinsert the full length of the igniter.
40) Place the motor cap over the end of nozzle.
41) Attach each end of the igniter to an alligator clip to finalize the connection.
42) C**heck for continuity by pressing the button attached to the alligator clips provided.**
43) **Make sure the rail is locked.**
44) **Make sure that all personnel are a minimum distance of 300ft from the launch pad.**
45) **Alert team members that launch is imminent and that they should attempt to make visual contact with sections of the launch vehicle during descent.**
46) Identify two team members who will be responsible for GPS tracking and retrieval of the two launch vehicle sections.
47) The RSO launches the launch vehicle when he or she deems the launch safe and prudent.
48) **Wait for the all clear from the RSO to send out retrieval team with GPS tracker.**
49) Retrieve sections of launch vehicle.
50) Prepare to perform post-flight inspection.

6. Launch Operations Procedure

6.1. Recovery Preparation

1) Ensure that all shock cord and parachutes are accounted for including:
    a) One 60in diameter main parachute.
    b) One 72in diameter main parachute.
    c) One 18in diameter drogue parachute.
    d) One 15in diameter drogue parachute.
    e) 40 ft long .5in tubular kevlar for the Booster Section main parachute.
    f) 30 ft long .5in tubular kevlar for the Booster Section main parachute.
2) Ensure that all shock cords are attached to the corresponding parachute's hoist ring, which is used for the main parachutes, or swivel for the drogue parachutes. The other end should be attached to a quick link.
3) Ensure that Robert DeHate, the team's advisor, has the black powder to pack the blast charges for separation.
4) Prepare the motor electronics bay.
    a) Attach new 9-Volt batteries to connectors and duct tape the batteries to the connectors.
    b) Check battery wiring to StratoLoggers to assure the StratoLoggers are receiving power.
    c) Insert threaded rods through the guide tubes within the body of the electronics bay.
    d) Connect the electronics bay output wires for the motor section and Interstage drogue parachutes to the upper bulkhead wires.
    e) Attach the top bulkhead by guiding the threaded rods through the holes and securing it with lock washers and lock nuts.
    f) Attach the Interstage with set screws.
    g) Connect appropriate wires for Interstage charges.
    h) Put both electronics bays in the appropriate blue tube sections.
    i) Attach electronics bay output wires for the motor section main parachute to the lower bulkhead wires.
    j) Attach lower bulkhead by guiding the threaded rods through the holes and securing it with lock washers and lock nuts.
    k) Turn the double pole double throw keys to close the circuit and listen for the beep that signals that there is continuity in the circuit. This ensures the altimeters are getting power. Turn the key again to open the circuit as to not unnecessarily drain the batteries.
    l) Blast charges are packed in the Interstage with 1.5g of powder for the drogue charges (See 6.1.2 for procedure for calculation).
    m) Blast charges are packed on the centering ring of the intersection with 1.75g (calculation in 6.1.2) of powder for the drogue charges (See 6.1.2 for procedure for packing charges).
    n) Blast charges are packed on the lower bulkhead with 2g (calculation in 6.1.2) of powder for the main charges (See 6.1.1 for procedure for packing charges).
5) Attach the blue tube for the main motor parachute to the bottom of the electronics bay with set screws.

6) Attach the quick link on the shock cord to the hoist ring attached to the motor electronics bay section.
7) The 72 inch main parachute is folded and inserted into the motor parachute cavity as follows:
   a) Lay the parachute out flat.
   b) Organize the leads at the bridle into three sections.
   c) Fold first gore and continue folding the gores until all the gores are folded into each other.
   d) The parachute is folded in a z-fold.
   e) The lines are pulled up the center and the parachute is wrapped around the centered lines, and the lines are rolled around the canopy.
   f) Place thermal wadding over the opening of the tube from which the parachute will be ejected.
   g) Push folded parachute into ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.
8) Attach the shock cord to the hoist ring attached to the motor section bulkhead.
9) Attach the motor main parachute section of blue tube to the motor section with 4 shear pins.
10) Both drogue parachutes, 18in and 15in for the Booster and Payload Sections respectively, are folded.
    a) Lie the parachute flat, ensuring that lines are not tangled. Fold the parachute into thirds repeatedly until reaching a point that you cannot continue folding it into thirds. At this point, fold in half.
    b) Execute a lengthwise Z-fold.
    c) Roll the parachute up lengthwise such that the lines remain uninhibited.
11) Attach the shock cord to the eyebolt in the Interstage ejection tube.
12) Place thermal wadding over the opening of the tube from which the parachute will be ejected.
13) Push folded drogue parachute into Interstage ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.
14) Place Interstage bulkhead on the end of the Interstage ejection tube.
15) Attach the payload drogue parachute section of blue tube to the top of the Interstage with 4 set screws.
16) Place thermal wadding over the opening of the tube from which the payload drogue parachute will be ejected.
17) Push folded drogue parachute into Interstage ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.
18) Attach the shock cord to the hoist ring attached to the payload section.
19) Attach the drogue payload parachute section of blue tube to the payload section with 4 shear pins.
20) Prepare the upper electronics bay as follows:
    a) Attach new 9-Volt batteries to connectors and duct tape the batteries to the cases.
    b) Check battery wiring to altimeters to assure the altimeters are receiving power.
    c) Insert threaded rods through the guide tubes through the electronics bay's body.
    d) Attach the electronics bay output wires for the main parachute to the wires on the bulkhead.

e) Attach the top bulkhead by guiding the threaded rods through the holes and secure it with lock washers and nuts.
f) Place upper electronics bay into appropriate blue tube section.
g) Attach lower bulkhead by guiding the threaded rods through the holes and securing it with lock washers and nuts.
h) Turn double pole double throw keys to close the circuit and listen for the beep that signals that there is continuity in the circuit to ensuring the altimeters are getting power, turn the key to open the circuit as not to waste batteries unnecessarily.
i) Blast charges are packed on the bulkhead with 2g of powder for the main charges (See 6.1.2 for procedure for packing charges).

21) Attach the upper electronics bay to the payload section with 4 set screws.
22) Attach the blue tube for the payload main parachute to the payload section with 4 set screws.
23) Attach the shock cord to the hoist ring in the payload main parachute tube.
24) Both parachutes are folded and inserted into the parachute cavity as follows:
    a) Lay the parachute out.
    b) Organize the leads at the bridle into three sections.
    c) Fold first gore and continue folding the gores until all the gores are folded into each other.
    d) The parachute is folded in a z-fold.
    e) The lines are pulled up the center and the parachute is wrapped around the centered lines, the lines are rolled around the canopy.
    f) Place thermal wadding over the opening of the tube from which the parachute will be ejected.
    g) Push folded parachute into ejection tube such that the thermal wadding wraps around the parachute and prevents direct contact between the black powder charge and the parachute.
25) Attach the shock cord to the eyebolt attached to the nose cone.
26) Attach the nose cone to the payload main parachute tube with 4 shear pins.

6.1.1. Charge Packing Procedure

1) Insert e-match into PVC blast cap.
2) Pour measured amount of black powder into blast cap, over e-match.
3) Compress the black powder with a small chunk of dog barf.
4) Cover the blast cap with tape and its contents with masking tape.
5) Connect wires to terminals

*The black powder is handled by our mentor Robert DeHate and will not be handled by the team

6.1.2. Black Powder Calculations

The amount of black powder needed for each charge was calculated with the aid of this website: http://www.rockethead.net/black_powder_calculator.htm

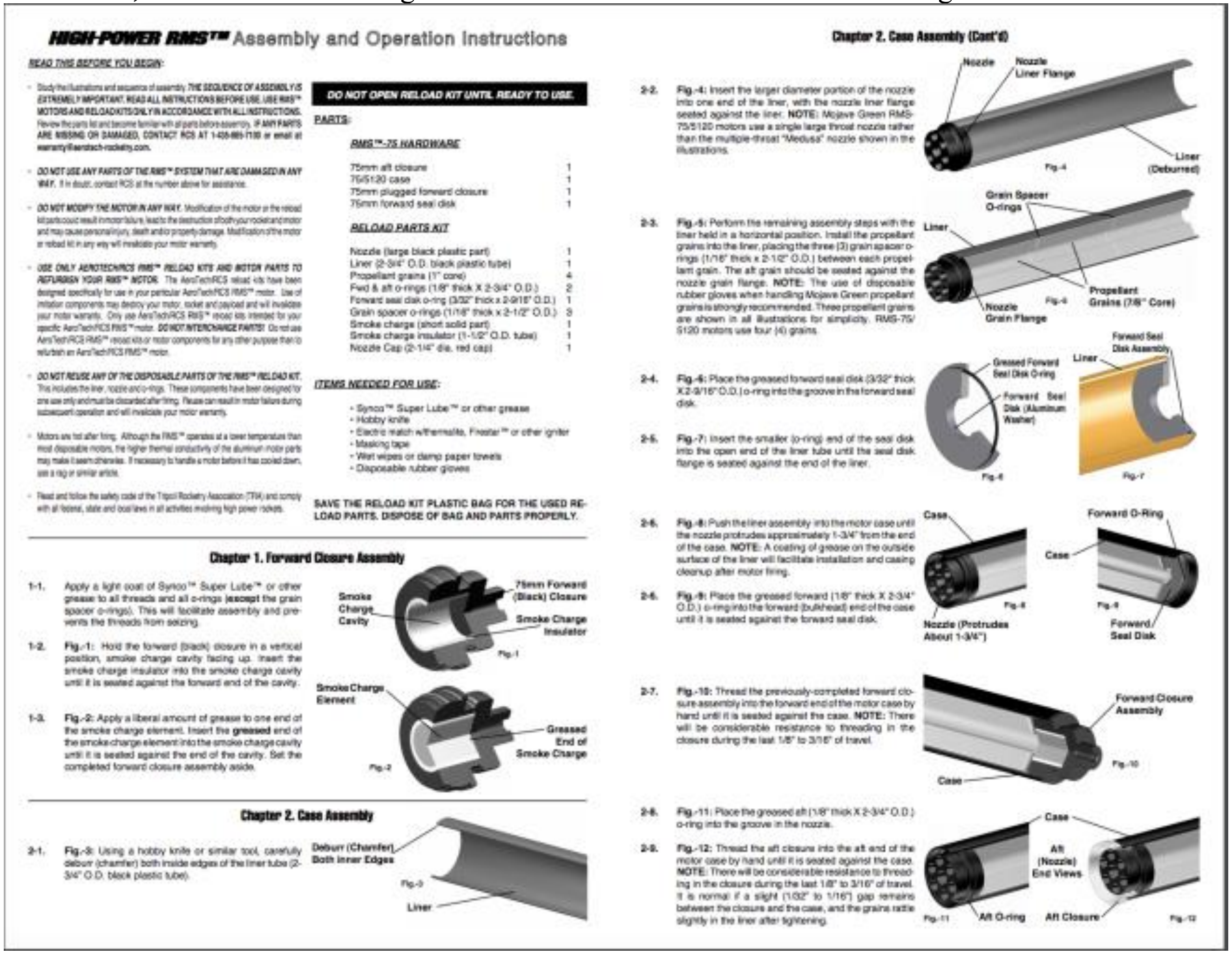
The value determined from this calculator is multiplied by a safety factor of 1.5 to ensure separation. The values, after multiplying by the safety factor by 1.5, resulted in 1.2g within the Interstage, 1.5g on the centering ring for the drogue parachutes, and 2g for the main parachute blast caps. However, larger charges of 1.5g and 1.75g were chose for the Interstage and centering ring, respectively, to further ensure proper deployment.

6.2. Motor Preparation

We will be referencing Cesaroni's online instruction in assembling a 75 millimeter motor found in Appendix D

Source: http://www.pro38.com/pdfs/Pro75_Instructions.pdf

In addition, we will be referencing Aerotech's online instructions in assembling the L2200G motor shown below.



HIGH-POWER RMS™ Assembly and Operation Instructions

READ THIS BEFORE YOU BEGIN:

- Study the illustrations and sequence of assembly. ***THE SEQUENCE OF ASSEMBLY IS EXTREMELY IMPORTANT. READ ALL INSTRUCTIONS BEFORE USE. USE RMS™ MOTORS AND RELOAD KITS ONLY IN ACCORDANCE WITH ALL INSTRUCTIONS.*** Review the parts list and become familiar with all parts before assembly. **IF ANY PARTS ARE MISSING OR DAMAGED, CONTACT RCS AT 1-435-865-7100 or email at** warranty@aerotech-rocketry.com.
- ***DO NOT USE ANY PARTS OF THE RMS™ SYSTEM THAT ARE DAMAGED IN ANY WAY.*** If in doubt, contact RCS at the number above for assistance.
- ***DO NOT MODIFY THE MOTOR IN ANY WAY.*** Modification of the motor or the reload kit parts could result in motor failure, lead to the destruction of both your rocket and motor and may cause personal injury, death and/or property damage. Modification of the motor or reload kit in any way will invalidate your motor warranty.
- ***USE ONLY AEROTECH/RCS RMS™ RELOAD KITS AND MOTOR PARTS TO REFURBISH YOUR RMS™ MOTOR.*** The AeroTech/RCS reload kits have been designed specifically for use in your particular AeroTech/RCS RMS™ motor. Use of imitation components may destroy your motor, rocket and payload and will invalidate your motor warranty. Only use AeroTech/RCS RMS™ reload kits intended for your specific AeroTech/RCS RMS™ motor. ***DO NOT INTERCHANGE PARTS!*** Do not use AeroTech/RCS RMS™ reload kits or motor components for any other purpose than to refurbish an AeroTech/RCS RMS™ motor.
- ***DO NOT REUSE ANY OF THE DISPOSABLE PARTS OF THE RMS™ RELOAD KIT.*** This includes the liner, nozzle and o-rings. These components have been designed for one use only and must be discarded after firing. Reuse can result in motor failure during subsequent operation and will invalidate your motor warranty.
- Motors are hot after firing. Although the RMS™ operates at a lower temperature than most disposable motors, the higher thermal conductivity of the aluminum motor parts may make it seem otherwise. If necessary to handle a motor before it has cooled down, use a rag or similar article.
- Read and follow the safety code of the Tripoli Rocketry Association (TRA) and comply with all federal, state and local laws in all activities involving high power rockets.

DO NOT OPEN RELOAD KIT UNTIL READY TO USE.

PARTS:

RMS™-75 HARDWARE

75mm aft closure	1
75/5120 case	1
75mm plugged forward closure	1
75mm forward seal disk	1

RELOAD PARTS KIT

Nozzle (large black plastic part)	1
Liner (2-3/4" O.D. black plastic tube)	1
Propellant grains (1" core)	4
Fwd & aft o-rings (1/8" thick X 2-3/4" O.D.)	2
Forward seal disk o-ring (3/32" thick x 2-9/16" O.D.)	1
Grain spacer o-rings (1/16" thick x 2-1/2" O.D.)	3
Smoke charge (short solid part)	1
Smoke charge insulator (1-1/2" O.D. tube)	1
Nozzle Cap (2-1/4" dia. red cap)	1

ITEMS NEEDED FOR USE:

- Synco™ Super Lube™ or other grease
- Hobby knife
- Electric match w/thermalite, Firestar™ or other igniter
- Masking tape
- Wet wipes or damp paper towels
- Disposable rubber gloves

SAVE THE RELOAD KIT PLASTIC BAG FOR THE USED RELOAD PARTS. DISPOSE OF BAG AND PARTS PROPERLY.

Chapter 1. Forward Closure Assembly

1-1. Apply a light coat of Synco™ Super Lube™ or other grease to all threads and all o-rings (**except** the grain spacer o-rings). This will facilitate assembly and prevents the threads from seizing.

1-2. **Fig.-1:** Hold the forward (black) closure in a vertical position, smoke charge cavity facing up. Insert the smoke charge insulator into the smoke charge cavity until it is seated against the forward end of the cavity.

1-3. **Fig.-2:** Apply a liberal amount of grease to one end of the smoke charge element. Insert the **greased** end of the smoke charge element into the smoke charge cavity until it is seated against the end of the cavity. Set the completed forward closure assembly aside.

Chapter 2. Case Assembly

2-1. **Fig.-3:** Using a hobby knife or similar tool, carefully deburr (chamfer) both inside edges of the liner tube (2-3/4" O.D. black plastic tube).

Chapter 2. Case Assembly (Cont'd)

2-2. **Fig.-4:** Insert the larger diameter portion of the nozzle into one end of the liner, with the nozzle liner flange seated against the liner. **NOTE:** Mojave Green RMS-75/5120 motors use a single large throat nozzle rather than the multiple-throat "Medusa" nozzle shown in the illustrations.

2-3. **Fig.-5:** Perform the remaining assembly steps with the liner held in a horizontal position. Install the propellant grains into the liner, placing the three (3) grain spacer o-rings (1/16" thick x 2-1/2" O.D.) between each propellant grain. The aft grain should be seated against the nozzle grain flange. **NOTE:** The use of disposable rubber gloves when handling Mojave Green propellant grains is strongly recommended. Three propellant grains are shown in all illustrations for simplicity. RMS-75/5120 motors use four (4) grains.

2-4. **Fig.-6:** Place the greased forward seal disk (3/32" thick X 2-9/16" O.D.) o-ring into the groove in the forward seal disk.

2-5. **Fig.-7:** Insert the smaller (o-ring) end of the seal disk into the open end of the liner tube until the seal disk flange is seated against the end of the liner.

2-6. **Fig.-8:** Push the liner assembly into the motor case until the nozzle protrudes approximately 1-3/4" from the end of the case. **NOTE:** A coating of grease on the outside surface of the liner will facilitate installation and casing cleanup after motor firing.

2-6. **Fig.-9:** Place the greased forward (1/8" thick X 2-3/4" O.D.) o-ring into the forward (bulkhead) end of the case until it is seated against the forward seal disk.

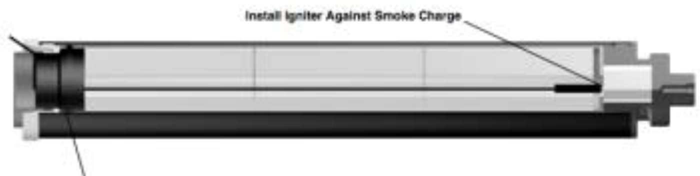
2-7. **Fig.-10:** Thread the previously-completed forward closure assembly into the forward end of the motor case by hand until it is seated against the case. **NOTE:** There will be considerable resistance to threading in the closure during the last 1/8" to 3/16" of travel.

2-8. **Fig.-11:** Place the greased aft (1/8" thick X 2-3/4" O.D.) o-ring into the groove in the nozzle.

2-9. **Fig.-12:** Thread the aft closure into the aft end of the motor case by hand until it is seated against the case. **NOTE:** There will be considerable resistance to threading in the closure during the last 1/8" to 3/16" of travel. It is normal if a slight (1/32" to 1/16") gap remains between the closure and the case, and the grains rattle slightly in the liner after tightening.

Figure 60 Motor Preparation Instructions (Part 1)

Chapter 3. Preparation For Flight



3-1. **Fig.-13:** Insert the coated end of a Firestar™ or other igniter through the nozzle throat until it stops against the smoke charge element.

3-2. Secure the igniter to the nozzle with a piece of masking tape or the 2-1/4" dia. red nozzle cap supplied with the reload kit. NOTE: Cut a 1/8"-1/4" wide slot in the corner of the cap to allow for igniter venting.

3-3. Install the motor into the rocket's motor mount tube. Ensure that the motor is securely retained in the rocket by using positive mechanical means to prevent it from being ejected during recovery system deployment.

3-4. Prepare the rocket's recovery system and then launch the rocket in accordance with the Tripoli Rocketry Association (TRA) Safety Code and National Fire Protection Association (NFPA) Code 1127.

Chapter 4. Post-Recovery Cleanup

NOTE: Perform motor clean-up as soon as possible after motor firing. Propellant and smoke charge residues become difficult to remove after 24 hours and can lead to corrosion of the metal parts. Place the spent motor components in the reload kit plastic bags and boxes and dispose of properly.

4-1. After the motor has cooled down, unthread and remove the forward and aft closures.

4-2. Remove the smoke charge insulator from the forward closure and discard. Using wet wipes or damp paper towels, remove all smoke charge and propellant residues from the closures.

4-3. Remove and discard the forward and aft o-rings from the motor case. Remove the liner, forward seal disk and nozzle from the casing by pushing on the nozzle end. Remove the forward seal disk from the liner, and remove and discard the forward seal disk o-ring. ***DO NOT DISCARD THE FORWARD SEAL DISK!*** Discard the nozzle and liner. Using wet wipes or damp paper towels, wipe the inside of the casing and the forward seal disk to remove all propellant residue.

4-4. Apply a light coat of grease to all threads and the inside of the motor case. Reassemble metal parts and store motor in a dry place.

Chapter 5. First Aid

DANGER: DO NOT INGEST PROPELLANT OR BREATHE EXHAUST FUMES! WASH HANDS AFTER HANDLING MOJAVE GREEN PROPELLANT AND BEFORE EATING. For a minor burn, apply a burn ointment. For a severe burn, immerse the burned area in ice water at once and see a physician as quickly as possible. In the unlikely event of oral ingestion of the propellant, induce vomiting and see a physician as quickly as possible. Mojave Green composite propellant consists primarily of Ammonium Perchlorate, Barium Nitrate and a rubber-like plastic elastomer.

Chapter 6. Disposal

Damaged or defective reload kits should be returned to RCS.

Chapter 7. Fire Safety

Tests show that the pyrotechnic components of RMS™ reload kits will not explode in fires and normally will not ignite unless subjected to direct flame and then will burn slowly. Use water to fight any fires in which AeroTech/RCS RMS™ reload kit pyrotechnic components may become involved: Direct the water at the AeroTech/RCS RMS™ reload kit pyrotechnic components to keep them below their 550 deg. F autoignition temperature. Foam and carbon dioxide fire extinguishers will NOT extinguish burning propellants of the type used in RMS™ reload kit pyrotechnic components. Keep reload kit pyrotechnic components away from flames, sources of heat and flammable materials.

Disclaimer and Warranty

NOTICE: As we cannot control the storage and use of our products, once sold we cannot assume any responsibility for product storage, transportation or usage. RCS shall not be held responsible for any personal injury or property damage resulting from the handling, storage or use of our product. The buyer assumes all risks and liabilities therefrom and accepts and uses AeroTech/RCS products on these conditions. No warranty either expressed or implied is made regarding AeroTech/RCS products, except for replacement or repair, at RCS's option, of those products which are proven to be defective in manufacture within one year from the date of original purchase. For repair or replacement under this warranty, please contact RCS. Proof of purchase will be required. Note: Your state may provide additional rights not covered by this warranty.

AeroTech Division
RCS Rocket Motor Components, Inc.
Cedar City, UT 84720
www.aerotech-rocketry.com

P/N 20086 Rev. 12/30/09
Made in U.S.A.

AEROTECH® CONSUMER AEROSPACE
Division of RCS Rocket Motor Components, Inc.

HIGH-POWER RMS™
Reloadable Motor System™
RMS™ 75/5120 Mojave Green™

This Package Contains One Reload Kit:

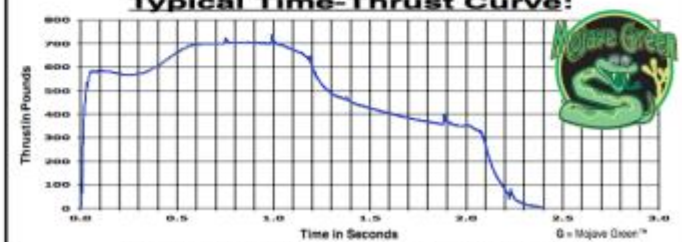
☐ ***L2200G-P*** (75/5120)

NOTE: This reload kit MUST be used with separately packaged Mojave Green™ propellant grains (P/N 03G046) and motor liner tube (03035-4). RMS™-75 reload kits do not include an ejection charge. RMS-75 motors must be used in conjunction with a timer, altimeter or radio-actuated recovery system.

NOTE: This reload kit is *ONLY* for use in AeroTech/RCS, Rouse-Tech™ or Dr. Rocket™ RMS™ 75/5120 high-power motors. Certified by the Tripoli Rocketry Association (TRA).

DO NOT OPEN RELOAD KIT UNTIL READY TO USE

Typical Time-Thrust Curve:



RMS™ 75MM MOJAVE GREEN RELOAD KIT DATA

Hardware Designation	Performance Designation	Total Impulse (Typical)	Propellant Weight	Loaded Motor Weight
RMS™-75/5120	*L2200G-P*	5,104 N-sec	2,516 g (5.54 lb)	4,751 g (10.46 lb)

NOTE: Total impulse shown is typical.

RMS™ 75MM HARDWARE DATA

Hardware Designation	Motor Diameter	Motor Length	Hardware Weight	Reload(s) Used
RMS™-75/5120	2.965" (75mm)	26.20"	1,408 g (3.10 lb)	L2200G-P

NOTE: Motor lengths are measured from end of aft closure to end of forward closure.

NOTE: SALE TO PERSONS UNDER 18 YEARS OF AGE PROHIBITED BY FEDERAL LAW. DANGER-POISON: Contains Barium Nitrate. DO NOT INGEST PROPELLANT OR BREATHE EXHAUST FUMES. WARNING-FLAMMABLE: Read Instructions Before Use. KEEP OUT OF REACH OF CHILDREN. FOR USE ONLY BY CERTIFIED HIGH-POWER USERS 18 YEARS OF AGE OR OLDER. DO NOT SMOKE when loading these motors or use in the vicinity of open flames.

Figure 61 Motor Preparation Instructions (Part 2)

6.3. Setup on Launcher

The launch vehicle should be inspected and cleared for launch between motor preparation and setup on the launch pad. The launch pad procedures are as follows:

1) Gather all materials, tools, and personnel to take to launch pad, including:
   a) A step ladder.
   b) Team mentor Rob DeHate.
   c) Two team members for carrying the rocket, the minimum necessary.
   d) Completed launch card for RSO.
2) Ensure launch rail has no visible flaws.
3) Perform final checks to exterior of rocket
   a) Count 4 shear pins on nose cone
   b) Count 4 set screw on upper section of payload electronics bay
   c) Count 4 set screws on lower section of payload electronics bay
   d) Count 4 shear pins connecting payload section to motor section
   e) Count 4 set screws on upper section of motor section electronics bay
   f) Count 4 set screws on lower section of motor section electronics bay
   g) Count 4 shear pins on motor assembly
   h) Visually check alignment of paint job and rail mounts
4) Lower rail on launch pad to horizontal position for loading
5) Load rocket onto the 15-15 rail using rail mounts, but do not erect it
6) Turn on electronics bays
   a) Turn and remove keys
   b) Listen to startup beeps to ensure all systems are connected
7) Adjust launch rail to vertical position
8) All members who are not level-2 certified retreat to the rest of the team, at least 300 feet from the launch pad.

6.4. Igniter Installation

The igniter installation happens after the e-bays are armed and before the rocket is erected. We will install the igniter per the following checklist:

1) Prepare igniter by removing a single igniter from the package and inspecting:
   a) Continuity.
   b) Resistance.
   c) The pyrogen for cracks or flaws.
   d) That the wires do not touch anywhere except in the combustible tip.
2) Insert igniter into the motor through the nozzle and push it in until it hits a hard stop against the propellant grain.
3) Mark the point on the igniter at the bottom of the motor.
4) Pull the igniter out of the motor and make a small loop in the igniter directly below the mark.
5) Reinsert the full length of the igniter.
6) Place the motor cap over the end of nozzle.

7) Attach each end of the igniter to an alligator clip to finalize the connection.
8) Check for continuity by pressing the button attached to the alligator clips provided.
9) Erect the rocket and check to make sure the rail is locked.

6.5. Launch Procedure

The launch procedure covers the time between leaving the launch vehicle on the launch pad and locating the launch vehicle sections post-launch. The procedure is as follows:

1. Make sure that all personnel are a minimum distance of 300ft from the launch pad.
2. Alert team members that launch is imminent and that they should attempt to make visual contact with sections of the launch vehicle during descent.
3. Identify two team members who will be responsible for GPS tracking and retrieval of the two launch vehicle sections.
4. The RSO launches the launch vehicle when he or she deems the launch safe and prudent.
5. Wait for the all clear from the RSO to send out retrieval team with GPS tracker.
6. Retrieve sections of launch vehicle.
7. Prepare to perform post-flight inspections.

6.6. Troubleshooting

Our main troubleshooting points are related to arming the launch vehicle, the electronics suite, and the telemetry system. The table below provides brief overviews of the of the troubleshooting we would have to perform should a system not arm or lose communication. The majority of the issues listed below will arise during the “Setup on Launcher” phase of launch operations.

Table 17 Troubleshooting

Issue	Launch Ops Phase	Possible Cause	Possible Solution
Ground station doesn’t communicate with XBee.	Setup on Launcher.	1. Ground station doesn’t communicate with XBee. 2. The battery is dead. 3. The radio on the ground station does not work.	1. Restart electronics and check whether this resolves the issue, if not take launch vehicle off pad and check connections . 2. Replace battery. 3. Unplug and plug back in the radio from the ground station, restart the ground station software, and if necessary, reboot the ground station.
Sensor data is incorrect (i.e., reporting movement	Set-up on launcher	1. Sensors are not properly installed. 2. Batteries are low.	1. Restart electronics. If this does not resolve the issue take the launch vehicle off the pad and check connections.

when none is present).		3. A software error is present.	2. Take the rocket safely off the pad and replace batteries. 3. Reboot electronics. If this does not resolve the issue take the launch vehicle safely off the pad and re-upload software to the electronics systems.
Electronics bay does not arm.	Set-up on launcher	1. Wires connecting the rotary switch to the electronic bay was disconnected on one end. 2. Batteries are dead.	1. Remove the launch vehicle from the launch rail and remove sections connected to the affected electronics bay. Resolder the connection. 2. Safely remove the launch vehicle from the launch rail and replace the batteries.
A structural crack or compromise in the launch vehicle.	Set-up on launcher	1. Damage during transportation	1. If the part is non essential, it will be attempted to be epoxied and repaired on the spot. If it is an essential part of the launch vehicle, the launch date will be postponed until the damage can be repaired.
Continuity is not reached between RSO and launch vehicle.	Set-up on launcher	1. Clips not attached properly. 2. Igniter was not properly set up to have continuity	1. Take off clips and re-attach. 2. Detach igniter and repeat steps in 6.4

6.7. Post-Flight Inspection

The post-flight inspections procedure covers the time after the sections of the launch vehicle have been retrieved.

1) Confirm via the RSO that the launch vehicle has landed in a safely retrievable area.
2) Ensure that both separate sections of the launch vehicle are recovered, as well as both parts of each section that are tethered together.
3) Move the launch vehicle to a safe location to inspect it.
4) Have the safety officer, Katherine Angus, examine the launch vehicle for any hazards (ie., any sharp edges, broken batteries, loose parts within the sections).
5) Ensure that an official altimeter is accessible, and, if possible, bring it to a NASA official to be read according to its beeps.
6) Have the Payload lead, Samantha Glassner, examine the PPS and assess for any damages.

7) Have the launch vehicle lead, Evan Kuritzkes, inspect the launch vehicle itself. Beginning at the motor section examining the aft to see if the drogue parachutes deployed properly.
8) Examine the main parachute and Booster Section electronics bay to see if the parachute fully deployed or if any damages were sustained in the Booster Section electronics bay.
9) Check the PPS Section electronics bay to see if its parachute deployed or if any damage was done to the PPS Section electronics bay.
10) Remove the motor casing from the launch vehicle and properly dispose of it. Ensure any other debris is properly disposed of.
11) After the launch, recover the hardware of the Payload Section electronic suite with its SD card and verify that data acquired during the launch is the same on the SD card.

7. Project Plan

7.1. Testing

Test Number	Test Name	Test Description	Test Results	Impact on Design	Operational Procedures
Launch Vehicle Tests					
Test #L1	Full Scale Altitude Test	The vehicle was launched to make sure that it reached the apogee as close to 5280 feet as possible, while remaining under 5600 feet maximum, and carrying all required objects, including: • Science or Engineering Payload • Commercially available barometric altimeter	Refer to section 3.4.3	Design was confirmed. Launch vehicle was not changed.	Refer to section 6
Test #L2	Tracking Test	A faraday cage will be placed over the StratoLoggers to ensure that the antennae do not interfere with them. This was tested using a receiver in a faraday cage and a transmitter immediately outside of the cage.	The test was inconclusive and further testing is required and will be conducted at next full scale launch.	The faraday cage was built using theory found in section 3.2.7. Because the test was inconclusive, the design was not impacted.	A receiver was placed under a faraday cage and a transmitter was placed next to the cage. It was determined if the faraday cage worked by testing if data was sent.

Test #L3	Parachutes and Sound Structure Test	In the test flights, the parachute deployment both before and during the flights were tested. Before the flights the parachutes were set off by igniting charges to be sure that the parachutes would deploy and the sections would separate. The altitudes at which the parachutes deployed were recorded using StratoLogger data. Also, the reusability of the launch vehicle was tested.	The results were very positive. Besides the first subscale test launch, in which there was a minor problem which was fixed immediately for the next flight, the parachutes have deployed and the launch vehicle has only suffered from minor damages. There were complications in the full scale test flight, which are discussed in section 3.4.5	Because the cause of this was most likely a short circuit due to wires being stripped too long, the fixed design will be careful to avoid that, which is also discussed in section 4.2.5	The launch vehicle was launched according to all safety procedures. The sensor suite was included and turned on to collect data.
Test #L4	Launch-ready Delay	Flight electronics were left on for 90 minutes to ensure that they could still function and remained operational.	After the 90 minutes of recording, the batteries were still mostly fully charged and the stratologgers were found to have been recording data consistently.	Nothing was changed on the launch vehicle.	The electronic suite was turned and left alone for 90 minutes. It remained under supervision.
Test #L5	Time to prepare the launch vehicle to launch	Launch assembly and preparation were practiced to ensure it took less than 4 hours.	At the full scale test launch, the launch vehicle was assembled in about 3 hours with a smaller team than will be traveling to Huntsville.	Nothing about the Launch vehicle was changed.	Activating the electronics bay, folding the parachutes, loading the motor, the black powder charges, the payload, and assembling the launch vehicle were all timed.
Test #L6	Twelve volt direct current firing test	The engine chosen was able to be ignited using a standard 12 volt current.	The engine was properly ignited and propelled the launch vehicle to a height of	Nothing, we will be ordering a motor from another similarly reputable company and	An igniter was placed up the rocket. It was ensured the current going

			2926 feet at the full scale test in Virginia.	will work igniting under the same current.	through that match was 12 volts. That igniter was then lit to ignite the motor.
Test #L7	Acceleration Test	Using acceleration data from the previous launches, the velocity off the rail will be confirmed to be greater than 52 feet per second. In addition, the maximum acceleration will be prove to be less than mach 1.	In the full scale test the rocket left the launch rail at 63.8 ft per second according to simulations which were matched by flight data recorded by the StratoLoggers	The team decided that nothing needed to be changed as it was within the parameters	The velocity was calculated from the acceleration values given from the sensors on the launch vehicle.
Test #L8	Kinetic Energy Test	Based on simulation calculations and launches, acceleration data was collected to ensure maximum kinetic energy was less than 75 ft-lbf.	The kinetic energy of all parts of the launch vehicle are under 75 ft-lbf, and can be verified in section 3.3.5	Because it was already within parameters, the launch vehicle did not change at all due to this guideline	The velocity was first calculated from the acceleration values returned by the sensors. Kinetic energy was then calculated using this velocity
Test #L9	Interference Test	The launch vehicle's electronic tracking devices were tested to ensure the location of the launch vehicle is known before launch. Our team then walked to the launch vehicle to see if the device is accurate, or if it is affected by onboard components.	Due to the lower altitude of the full-scale test, the launch vehicle did not utilize electronic tracking devices, as the launch vehicle in remained within sight during the duration of the test flight	No impact as the test was not utilized in the test launch.	With the launch vehicle on the launch rail, the tracking devices were turned on. It was ensured these devices pointed us towards the launch rail and vehicle.
Test #L10	Ejection test	Tested the separation of sections of the Launch vehicle using black powder.	When tested with 1.5 grams of black powder, the Interstage section separated by about 5 feet sliding across	After doing multiple trials, it was decided that 2 grams of black powder was sufficient to separate	The blast caps were loaded with a predetermined amount of black

			the grass. When tested with 1.2 grams of black powder the payload section drogue parachute deployed. The test with 2 grams of black powder separated the nose cone by about 10 feet by sliding across the grass.	each section and deploy main parachutes, 1.5 grams was sufficient to separate the interstage, and 1.2 grams was sufficient to deploy the payload section drogue parachute.	powder and sections assembled with shear pins to make sure that the sections separated and the parachutes would deploy.
Test #L11	Parachute deployment test	The deployment of the parachutes were tested from their folded position.	Both parachutes deployed as planned after running with them for about 5 feet.	Nothing was changed on the design.	Both main parachutes were folded as planned and team members ran down the hallway to make sure they opened up correctly.
Payload tests					
Test #P1	Payload Deployment Dampening Test	A drop test of the payload section was conducted to test our additional dampening system located between the eye bolt mounted to the payload section and the main parachute. This system was then removed and the payload was dropped again. The derived force data were then compared.	This test was not performed, due to safety concerns with the potential shock cord dampening system. Any shock dampening system on the paracord is another possible point of failure for parachute deployment, a risk that we decided was unwarranted.	This shock cord dampening system will not be incorporated into the rocket.	The drop of the payload without the dampening system would have acted as a control while we tested for the force experienced by the payload by deriving it from the measured acceleration.
Test #P2	Paracord Drop Test	The payload was dropped while loaded with accelerometers attached to a paracord and a variable amount of rubber bands	This test was also not performed; it tests the same shock cord dampening system that was determined	It was ultimately decided that the shock absorbing system will not be	The payload would have been carried to the top of a two story building and

		which acted as a shock absorber. It was dropped from a height of two stories to simulate the force it would experience upon deployment of the parachute, the largest estimated force.	to be an unnecessary risk to parachute deployment.	implemented into the rocket.	dropped off the roof. The amount of shock absorbed would have acted as the tested variable.
Test #P3	Foam Force Dampening Test	A drop test was conducted before our full scale from a height of 5' 2" to simulate the impact of the payload on the ground at its estimated landing speed. The forces the payload endured were recorded with the vertical and horizontal dampening systems in place around the internal canister, in order to verify that the foam would dampen the impact force on the canister as predicted by our MATLAB model.	The maximum acceleration was recorded using a LIS 331 accelerometer sending data to an Arduino UNO microcontroller. This measurement was found to be 19 g-force at the point of impact.	None so far. This test had to be performed using an Arduino UNO microcontroller rather than the Teensy 3.6 used in launches due to electronics issues; however, the Arduino UNO has a processor rate of 16 MHz, compared to the Teensy's 180 MHz, so the magnitude and resolution of this acceleration measurement may be completely off.	The payload subsection with the PPS in place was dropped from a height of 5' 2" with the Arduino UNO reading acceleration data from the LIS 331 accelerometer.
Test #P4	Electronics Bay Connections and Wiring Test	The test used a multimeter to test our soldering connections and that our wires were soldered to the correct locations.	All connections were observed to be fully connected and all wires that were supposed to have current had current.	No changes were made to the electronics bay based on the results of this test.	The multimeter was touched to the wires when current was supposed to flow through them. If the multimeter beeped or not was recorded.
Test #P5	Data Collection Test	The telemetry system ran for two hours to make sure that it held enough data for the flight, and to ensure that it worked properly.	After the telemetry system ran for 2 hours, the batteries were found to still be operational. The StratoLoggers had	No changes were made to the electronics bay.	The sensor suite was turned on and not touched for 2 hours. It was monitored to ensure no

			consistently taken data for the entire 2 hours.		malfunctions occurred. The voltage provided by the batteries were recorded before and after the test was conducted.
Test #P6	Subscale Vehicle Test	The subscale launch vehicle was launched and its altitude recorded with an onboard altimeter. The vehicle was also observed to see whether or not the parachutes deploy.	For Red 1, 3 out of 4 parachutes deployed; the main parachute of the booster stage did not deploy. Also, no electronics were present on this subscale. For Red 2, the accelerometers recorded data up to a maximum of only 2 g-forces in each direction. Also, the data capture rate was too low to accurately record the impacts and parachute deployments. Data that was recorded indicated a net force of 35m/s/s on the launch vehicle. For Red 2, every parachute deployed successfully. For Red 3, no data was taken due to an electronics issue that couldn't be resolved before the launch date.	The testing prompted the purchase of an accelerometer that could record g-forces more realistic for launch conditions and could record data at a faster rate. A rewiring of the electronics bay occurred to ensure all future parachutes deployed unlike subscale one.	The sensor suite was turned on and loaded into the rocket. All rocket launch procedures were observed.
Test #P7	Maximum Force Test	The test featured an analysis on the acceleration data and mass of the launch vehicle to find the	This test could not be performed in the Red 3 launch due to an electronics issue that couldn't be	No change was made to the PPS design, since this test could not be performed.	Acceleration data would have been converted to force data by multiplying

		total forces exerted on the payload.	resolved before the launch date.		by the mass of the launch vehicle.
Test #P8	Two Single Pole Double Throw Switch Test	Test involved turning each key switch in each electronics bay individually and checking if all components within the electronics bay are turned on.	When each key was turned all components were found to be turned on and functioning.	No change was made to the electronics bay.	Each key was turned in the electronics bay. Each component was confirmed for it to be functioning.

7.2. Requirements Compliance

7.2.1. Verification Plan

NASA Requirements	Verification Plan	Proof of verification
1. Vehicle Requirements		
1.1. The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL)	The apogee altitude will be determined by analysis of the 2 altimeters in the Payload Section of the launch vehicle after each full-scale test launch.	At this time only one full scale test launch has been performed. The analysis of the altimeter data can be found in sections 3.4.2 and 3.4.3 and in the results from test L1 in section 7.1.1.
1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL.	The Launch Vehicle carries at least one commercially available altimeter: two in the Payload Section electronics bay and four in the motor section electronics bay. The presence of these can be determined visually by inspecting the electronics	Proof of the inclusion of at least one commercially available altimeters can be seen in the schematics and discussions in sections 3.2.2, 3.1.4, and 4.3.1.

The team will lose one point for every foot above or below the required altitude. The altitude score will be equivalent to the percentage of altitude points remaining after and deductions.	bay on launch day or by inspecting the schematics beforehand.	
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 reporting of the altitude can be verified audibly before launch. We will listen for the correct pattern of beeps before loading the rocket onto the launch pad.	This must be verified on launch day, but the procedure for doing so is included in section 6.7
1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiment(s).	The addition of additional altimeters can be verified by visually inspecting the electronics bays or the schematics.	The additional altimeters can be verified in the schematics or discussions in sections 3.1.2, 3.2.5, and 4.3.1.
1.2.3. At the LRR, a NASA official will mark the altimeter that will be used for the official scoring.	The altimeters in each electronics bay can be inspected visually to verify that one and only one altimeter was marked by a NASA official.	This will be verified before the final launch. As such, no verification exists at this point.
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 ability to determine will be verified audibly after each test launch by listening to the beeps	This will be verified after the launch, so there is no verification currently
1.2.5. At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the	The ability to turn off all audible electronics other than the official altimeter can be verified visually by	Verification of this can be seen in the schematics in section 3.2.5.

official altitude-determining altimeter shall be capable of being turned off.	analyzing the schematics of the electronics bay.	
1.2.6.1. A score of zero for the altitude portion of the competition is warranted if the official, marked altimeter is damaged and/or does not report and altitude via a series of beeps after the team's competition flight.	The function of the altimeter after launch can be verified by analyzing the data from it after each test launch to make sure all altimeters report data that is reasonably close to each other.	Proof that all altimeters were functioning properly after launch can be seen in the analysis in section 3.4.2.
1.2.6.2. A score of zero for the altitude portion of the competition is warranted if 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.	This can be verified visually when the team reports to said NASA official on launch day.	This will be verified after the final launch. As such, no verification exists at this point.
1.2.6.3 A score of zero for the altitude portion of the competition will be warranted if the altimeter reports an apogee altitude over 5,600 feet AGL.	The apogee altitude will be verified by the 2 altimeters in the Payload Section after each full-scale test launch and it will be confirmed that the altitude is below 5600 feet.	At this time only one full scale test launch has been performed and the analysis of the altimeter data can be found in sections 3.4.2 and 3.4.3.
1.3. All recovery electronics shall be powered by commercially available batteries.	This can be verified visually by inspecting the electronics bays, or reading the discussions of them in the FRR.	The batteries can be verified in the discussions in sections 3.1.3, 3.2.2, or 4.3.3.
1.4. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to	This can be verified through intense visual inspection of the launch vehicle after all test launches to determine if it is safe to fly again.	Proof of reusability can be seen in the discussion of the full scale test in section 3.4.

launch again on the same day without repairs or modifications.		
1.5. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	This can be verified by visually inspecting the schematics prior to launch and counting 4 independent sections.	Confirmation of 4 sections can be seen in the schematics in section 3.1.4.
1.6. The launch vehicle shall be limited to a single stage.	This can be verified by visually inspecting the schematics prior to launch and counting only 1 stage.	Proof of this can be found in the schematics in section 3.1.4.
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.	Verification of this can be determined through a test of timing the assembly for the test launch.	Proof of this can be seen in the results from test L5 in section 7.1.1.
1.8. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	This can be verified before the launch by performing a test of how long the StratoLogger altimeters can continue recording data.	The results from this test can be found under test L4 in section 7.1.1.
1.9. The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	This will be verified through tests before launch.	Proof that the launch vehicle adheres to this regulation can be found in the results from test L6 in section 7.1.1.

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).	This can be verified through visual inspection of the exterior of the rocket and schematics.	Proof of this can be seen in the schematics in section 3.1.4.
1.11. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	This can be verified through visual inspection of the motor on launch day or through discussion of the motor used.	Proof that the motor follows all provided regulations can be seen in the discussion of final motor choice in section 1.2.
1.11.1. Final motor choices must be made by the Critical Design Review (CDR).	This can be verified by inspecting the CDR report for the final motor selection.	Proof of this can be seen in section 1.2 of our CDR and FRR.
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.	This can be verified through inspection of our previous motor and backup motor choices	Proof of this can be seen in section 1.2 of CDR and FRR
1.12.1. The minimum factor of safety (Burst or Ultimate Pressure versus Max Expected Operating	This can be verified by inspecting the schematics to make sure all pressure vessels abide by this rule.	Proof that our launch vehicle contains no pressure vessels violating this rule can be found in the schematics in section 3.1.4.

Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.		
1.12.2. The low-cycle fatigue life shall be a minimum of 4:1.	This can be verified by inspecting the schematics to make sure all pressure vessels abide by this rule.	Proof that our launch vehicle contains no pressure vessels violating this rule can be found in the schematics in section 3.1.4.
1.12.3. Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.	There are no pressure vessels, which can be verified by inspecting the schematics	Proof that our launch vehicle contains no pressure vessels can be found in the schematics in section 3.1.4.
1.13. The total impulse provided by a College and/or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	This can be verified by analyzing the simulations and looking for the total impulse of the rocket to make sure it doesn't exceed the limit.	Proof of this can be seen in the discussion in section 3.3.2.
1.14. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	This can be verified by analyzing the simulations and looking for the static stability margins.	This can be found in section 3.3.4.
1.15. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	This can be verified by performing a test and analyzing the data from at the acceleration.	Proof can be seen in the results from test L7 in section 7.1.1.
1.16. All teams shall successfully launch and recover a subscale model of their launch vehicle prior to CDR.	This can be verified by reading the CDR document to see the analysis of the subscale test.	Proof of this can be seen in section 3.2 of the CDR report.
1.16.1. The subscale model should resemble and perform as similarly as possible to the full-scale model,	This can be verified through either visual inspection of the subscale to confirm it is different from the full	Proof of the differences between the subscale and full-scale can be seen in section 3.2 of the CDR and PDR reports.

however, the full-scale shall not be used as the subscale model.	scale dimensions or in the discussion of it in the CDR report.	
1.16.2. The subscale model shall carry an altimeter capable of reporting the model's apogee altitude.	This can be verified by visually inspecting the subscale for said altimeters or by looking at the data from them post launch.	Proof that these altimeters were included can be seen in the analysis of them in section 3.2.1 of the CDR report.
1.17. All teams shall successfully launch and recover their full-scale launch vehicle prior to FRR in its final flight configuration. The launch vehicle flown at FRR must be the same vehicle to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full scale demonstration flight:	The launch itself can be verified visually by the team members in attendance. The success of the launch can be verified through analysis of the data from the StratoLoggers and visual inspection of the structural integrity of the launch vehicle post flight.	Proof of the success of the flight can be seen in the analysis and discussion of the flight data in section 3.4.
1.17.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:		

1.17.2.1. If the payload is not flown, mass simulators shall be used to simulate the mass of the payload.	This can be verified in visual inspection before launch to make sure the mass simulators are inserted and in the correct location.	Verification that a mass simulator was used can be found in the discussion in section 3.4 of the results of the full scale test.
1.17.2.1.1. The mass simulators shall be in the same approximate location on the launch vehicle as the missing payload mass.	This can be verified in visual inspection before launch to make sure the mass simulators are inserted and in the correct location.	Verification that a mass simulator was used can be found in the discussion in section 3.4 of the results of the full scale test.
1.17.3. If the payload changes the external surfaces of the launch vehicle (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.	There are no external surfaces affected by the payload	Proof of this can be seen in the schematics for the full scale in sections 3.1.4 and 4.1.2.
1.17.5. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight.	Verification of the use of full ballast can be done by visual inspection and measurement of the ballast on each test launch and final launch and comparison to the calculations done beforehand.	Proof for the first full-scale launch can be seen in the discussion of the data in section 3.4.
1.17.6. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Verification of this can be done by visually inspecting the launch vehicle and comparing it to the design that corresponds to the demonstration flight.	Proof of this can be seen by comparing the launch vehicle design at the actual competition to the launch vehicle design at the demonstration flight and in the schematics in 3.2.5 and 3.1.4

1.18. Any structural protuberance on the launch vehicle shall be located aft of the burnout center of gravity.	This can be verified by a simple visual inspection of either the launch vehicle or its schematics and the center of mass analysis.	Proof that any protuberances are aft of the center of gravity can be found in the schematics in section 3.1.4 and the analysis in
1.19.1. The launch vehicle shall not utilize forward canards.	This can be verified by inspecting the launch vehicle itself or the schematics.	Proof that no forward canards are used is shown in the schematics in section 3.1.4.
1.19.2. The launch vehicle shall not utilize forward firing motors.	This can be verified by inspecting the launch vehicle itself or the schematics.	Proof that no forward firing motors are used is shown in the schematics in section 3.1.4.
1.19.3. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	This can be verified by inspecting the launch vehicle itself or the discussion of motor used.	Proof that a regulation motor is used can be seen in the discussion in section 1.2.
1.19.4. The launch vehicle shall not utilize hybrid motors.	This can be verified by inspecting the launch vehicle itself or the discussion of motor used.	Proof that a regulation motor is used can be seen in the discussion in section 1.2.
1.19.5. The launch vehicle shall not utilize a cluster of motors.	This can be verified by inspecting the launch vehicle itself or the discussion of motor used, as only one motor is used.	Proof that a regulation motor is used can be seen in the discussion in section 1.2.
1.19.6. The launch vehicle shall not utilize friction fitting for motors.	This can be verified by inspecting the launch vehicle itself, the discussion of motor used, and the schematics.	Proof that a regulation motor that is secured in a better manner than friction can be seen in the discussion in section 1.2 and the schematics in section 3.1.4.

1.19.7. The launch vehicle shall not exceed Mach 1 at any point during flight.	This can be verified by analyzing the full-scale test data from the StratoLoggers to make sure the velocity doesn't exceed Mach 1.	Proof that the vehicle doesn't exceed Mach 1 can be seen in the analysis in Section 3.4.
1.19.8. Vehicle ballast shall not exceed 10% of the total weight of the rocket.	This can be verified by comparing the mass of the vehicle to the mass of the ballast.	Proof that our ballast meets regulation can be seen in the discussion in Section 1.2.
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. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.	Verification that this requirement is met can be done visually at one of the test launches, by analyzing the StratoLogger data post launch or by reading the discussion on the recovery subsystem.	Proof that the recovery system is up to standards can be found in the discussion in Section 3.2 and data analysis in Section 3.4.
2.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	This can be verified by performing tests prior to each launch and confirming the expected results.	Proof that this has been completed so far can be seen in the results for test L3 in Section 7.1.1.
2.3. At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	This can be verified by performing calculations and a test of the launch vehicle hitting the ground.	Proof that the kinetic energy does not exceed the amount can be seen in the results for test L8 in Section 7.1.1.
2.4. The recovery system electrical circuits shall be completely independent of any payload electrical	This can be verified by inspecting the schematics and confirming their independence.	Proof of their independence can be seen in the schematics in Sections 3.2.5 and 4.3.1.

circuits.		
2.5. The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	This can be verified by inspecting the schematics for the electronics bays to confirm redundancies.	Proof of the redundancies can be seen in the discussion in 3.2.3 and in the schematics in sections 3.2.5 and 4.3.1.
2.6. Motor ejection is not a permissible form of primary or secondary deployment.	This can be verified by inspecting the schematics and discussion of the recovery system.	Proof of this can be seen in the schematics and discussion in section 3.2.
2.7. Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the launch vehicle airframe when the vehicle is in the launch configuration on the launch pad.	This can be verified through testing the arming of the electronics bays.	Proof that the electronics bay follows this regulation can be seen in the results from test P8 in section 7.1.1.
2.8. Each altimeter shall have a dedicated power supply.	This can be verified by examining the schematics for the electronics bays.	Proof that each altimeter has its own power supply can be seen in the discussion in 3.2.2 and in the schematics in sections 3.2.5 and 4.3.1.
2.9. Each arming switch shall be capable of being locked in the ON position for launch.	This can be verified through testing and inspecting electronics bay schematics	Proof for this can be found in the results from test P8 in section 7.1.1 or in the schematics in sections 3.2.5 and 4.3.1.
2.10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	This can be confirmed by visually inspecting the rocket before launch and by inspecting the schematics.	Proof of this can be found in the schematics in section 3.1.4.

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.	This can be verified visually by looking for this tracker and by examining the schematics.	The proof for this can be seen in the schematics in section 3.1.4.
2.11.1. Any rocket section, or payload component, which lands untethered to the launch vehicle, shall also carry an active electronic tracking device.	This can be verified visually by looking for this tracker and by examining the schematics.	The proof for this can be seen in the schematics in section 3.1.4.
2.11.2. The electronic tracking device shall be fully functional during the official flight on launch day.	This can be verified by testing the tracking device before launch.	Proof of function on launch day will be determined then, proof of function so far can be seen in the results of tests L9 and L2 in section 7.1.1.
2.12. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	This can be verified by testing the faraday cages before launch	Proof of this can be seen in the results of test L9 in section 7.1.1.
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.	This can be verified by inspecting the schematics for the recovery system, as they are separated into different compartments with a faraday cage.	Proof of this can be seen in the schematics in section 3.2.5.
2.12.4. The recovery system electronics shall be shielded from any other onboard devices which may adversely	This can be verified by examining the schematics for the electronics bays and the faraday cage.	Proof of this can be seen in the schematics in sections 3.2.5 and 4.3.1 and test #L9 in 7.1.1.

affect the proper operation of the recovery system electronics.		
3.1.1. Each team shall choose one design experiment option from the following list.	We chose option 3, the fragile material protection project option.	N/A
3.4.1. Teams shall design a container capable of protecting an object of an unknown material and of unknown size and shape.	This can be verified by examining the Payload Section schematics and performing tests to see if it does its job.	Proof of this can be seen in the schematics in section 4.3.1 and in the results from tests P1-P3 in section 7.1.1.
3.4.1.1. There may be multiple of the object, but all copies shall be exact replicas.	This can be verified through visual inspection.	Proof of this will only be available on competition day.
3.4.1.2. The object(s) shall survive throughout the entirety of the flight.	This can be verified through visual inspection post-flight.	Proof of this will only be available after the competition flight.
3.4.1.3. Teams shall be given the object(s) at the team check in table on launch day.	This can be verified through visual inspection.	Proof of this will only be available on competition day.
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.	This will be verified visually by a NASA official.	Proof of this will only be available on competition day, and can be confirmed by analyzing our discussion and schematics in 4.1.2 and comparing it to what we have.
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 inches in diameter, and 6 inches in height.	This can be verified through visual inspection.	Proof of this will only be available on competition day.

3.4.1.6. The object(s) shall have a maximum combined weight of approximately 4 ounces.	This can be verified through weighing the objects.	Proof of this will only be available on competition day.
4.1. Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	This can be verified by reviewing the checklists in this report.	Proof of this can be seen in section 6.
4.2. Each team must identify a student safety officer who shall be responsible for all items in section 4.3.	This can be verified by reviewing the team summaries of the CDR and FRR reports.	Proof of this can be found in section 1.1 of the CDR and FRR reports.
4.3.1. The role and responsibilities of each safety officer shall include monitoring team activities with an emphasis on Safety during the scope of the 8 month project	This can be verified by reviewing the team summaries of the CDR and FRR reports.	Proof of this can be found in section 1.1 of the CDR and FRR reports.
4.3.2 The role and responsibilities of each safety officer shall include implementing procedures developed by the team for construction, assembly, launch, and recovery activities	This can be verified by reviewing the procedures outlined by the safety officer.	Proof of this can be found in the checklists in section 6.
4.3.3. The role and responsibilities of each safety officer shall include managing and maintaining current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	This can be verified by reviewing the hazard analysis written by the safety officer.	Proof of this can be seen in section 5.

4.3.4. The role and responsibilities of each safety officer shall include assisting in the writing and development of the team’s hazard analyses, failure modes analyses, and procedures.	This can be verified by reviewing the hazard analysis written by the safety officer.	Proof of this can be seen in section 5.
4.4. Each team shall identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle, and the rocketeer shall have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the launch vehicle for liability purposes and must travel with the team to launch week.	This can be verified by reviewing the team summary and confirming the existence of the team mentor.	Proof can be found in section 1.1.
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	This can be verified through visual observation of the team’s proceedings.	Proof of this can be found in section 3.4.1.

configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.		
5.2. The team shall provide and maintain a project plan to include, but not limited to, the following items: project milestones, budget, community support, checklists, personnel assigned, educational engagement events, risks and mitigations.	This can be confirmed by reviewing the PDR and CDR documents.	Proof of this can be found in sections 1, 2, 5, 6, and 7.
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.	There are no Foreign National team members, which can be confirmed by asking for and analyzing the citizenship statuses of the team members.	Proof of this can be found in section 1.1 of the PDR report.
5.4. The team shall identify all team members attending launch week activities by the Critical Design Review (CDR). Team members shall include:	This can be verified by reviewing the CDR report and the identification of team members attending.	Proof of this can be seen in section 1.1 of the CDR report.

5.4.1. Students actively engaged in the project throughout the entire year	This can be verified by reviewing the CDR report and the identification of team members attending.	Proof of this can be seen in section 1.1 of the CDR report.
5.4.2. One mentor (see requirement 4.4).	This can be verified by reviewing the team summary section.	Proof of this can be seen in section 1.1 of the CDR report.
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.	Verification of this can be seen by visual observation of the team undertaking such outreach.	Proof of this can be seen in separate reports submitted to NASA Student Launch.
5.6. The team shall develop and host a Web site for project documentation.	This can be confirmed by visually confirming the existence of our website.	Proof of this can be found at http://www.northeastern.edu/aiaa/nasa-student-launch/nasa-sl-2017/nasa-sl-2017-news/
5.7. Teams shall post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	This can be confirmed visually to verify the required items are uploaded.	Proof of this can again be found at http://www.northeastern.edu/aiaa/nasa-student-launch/nasa-sl-2017/nasa-sl-2017-news/
5.12. All teams will be required to use the launch pads provided by NASA Student Launches launch service	This can be verified by visually inspecting the schematics to make	Proof of this can be seen in the schematics in section 3.1.4.

provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	sure the design will fit on the launch pad.	

7.2.2. Team Derived Requirements

Team Derived Requirements	Verification Plan	Proof of Verification
All edges must be sanded down to be smooth so there are no protrusions	The Launch Vehicle will be inspected to make sure no sharp edges are present, this can be verified visually.	Proof of this is on the launch vehicle itself, and can be verified visually/tactilely.
Recovery forces should not exceed 2500 lbf	This can be determined by testing with a full scale launch or simulations and calculations.	Proof of this can be seen in the test results for tests L1 and P7 in section 7.1.1.
There will be at least two test launches for our full scale before the actual competition	This can be verified visually by members at each launch.	Only one test launch has already been conducted and another will be completed so proof of this will be provided later.
The electronics bays will have neat, organized, and compact wiring	This can be verified by visually inspecting the electronics bays.	Proof of this can be seen in the discussion in 3.1.3, including Table 5.
We will have extra keys to the key switches in the case that any are lost.	This can be verified visually.	Proof of this can be seen in the discussion in section 3.2.3.
Our electronics bays will be designed so we can optimize storage of wiring and ease of access	This can be verified by visually inspecting the electronics bays.	Proof of this can be seen in the schematics in section 4.3.1.

The antennae of the XBee and the BigRedBee will point downwards so they will transmit towards the ground when the main parachute has deployed	This can be verified by visually inspecting schematics or the electronics bay.	Proof of this can be seen in the schematics in section 4.3.1.
The antennae will be far from StratoLoggers and the StratoLoggers will be shielded from the antennae using Faraday cage materials	This can be verified through visual inspection of the electronics bay and through a test of the faraday cage.	Proof of this can be seen in the discussion in section 3.2.7 and in the results from test L9 in section 7.1.1.
Both switches on each electronics bay will turn on all components contained within the electronics bay	This can be verified through testing and examining the schematics for the electronics bay.	Proof of this can be seen in the schematics in section 4.3.1 and in the results for test P8 in section 7.1.1.
The electronics bays will be printed solid where the tapping inserts are needed to mount components	This can be verified visually by inspecting the electronics bay once the holes are drilled.	Proof of this exists physically within the electronics bay but not in this document.
The top and bottom bases of the electronics bays will be printed 30% fill to keep it light	When the electronics bays are being designed on the computer, the top and bottom bases will be designated as being 30% fill	Proof of this exists physically within the electronics bay but not in this document.
The payload protection system must be able to withstand multiple trials and have some form of reusability	This can be verified through testing the canister at similar forces and accelerations as in the final launch.	This can be seen in the results of tests L1 and P7 in section 7.1.1.
The Payload Protection System will be passive and not have any active system once the payload is added to the launch vehicle	This can be verified by visually inspecting the schematics.	Proof of this can be seen in the schematics in section 4.1.2.

Payload Protection System must support live telemetry to record data from test and actual launch	Verification of this can be done by visually inspecting the electronics bay schematics.	Proof of this can be seen in the inclusion of the Xbee in the schematics in section 4.3.1
The PPS should be fully removable from the launch vehicle	This can be verified visually by pulling out the Payload protection system.	Proof of this can be seen in the schematics in section 4.1.2.
Have an inner system within the PPS that can adjust size to deal with any sized object smaller than the maximum size.	This can be verified by inspecting the schematics for the PPS.	Proof of this can be found in the schematics in section 4.1.2.
The loaded PPS should be as close to 4 lbs as possible	This can be verified by massing the PPS loaded to the mass of the payload make sure it is close to this.	Proof of this can be found in the table in 3.3.2
The PPS should be able to protect the payload when it experiences an energy of 75 ft lbs or less	This can be verified by performing tests.	Proof of this can be found in the results from test P3 in section 7.1.1.
Payload should be able to adequately secure long and skinny objects	This can be verified visually by inspecting the final payload container and its design which includes this specifically.	Proof of this can be seen in the discussion in section 4.1.1 or the schematics in section 4.1.2.

7.3. Budgeting and Timeline

7.3.1. Budget

Item	Vendor	Quantity	Price	Total Price
FALL 2016 SPENDING				
LAUNCH VEHICLE				
Remove before flight tags	Amazon	1	$9.95	$9.95
Insert Before Flight Tags	Amazon	1	$5.95	$5.95
54mm 3-Grain Motor Case	Animal Motor Works	1	$65.00	$65.00
J355-Red Lightning	Animal Motor Works	2	$93.00	$186.00
SMS GPS	Animal Motor Works	3	$100.00	$300.00
98mm Blue Tube	Apogee Rockets	3	$38.95	$116.85
98mm Full Length Coupler	Apogee Rockets	2	$39.95	$79.90
4 inch 98mm Fiberglass Nosecone	Apogee Rockets	2	$39.95	$79.90
54 mm blue tube mmt	Apogee Rockets	2	$23.95	$47.90
54mm end closure	Apogee Rockets	1	$42.75	$42.75
54mm aeropack retainer	Apogee Rockets	1	$31.03	$31.03
Shock Cord	Apogee Rockets	150	$0.97	$145.50
18x18 Black Nomex Parachute Protector	Apogee Rockets	4	$10.49	$41.96
Tracking Powder	Apogee Rockets	1	$6.25	$6.25
Rail Buttons for 1010 rail	Apogee Rockets	2	$3.22	$6.44
808 Keychain Camera	Apogee Rockets	1	$41.35	$41.35
60" Frutiy Chute	Fruity Chutes	2	$275.00	$550.00
18" Fruity Chute	Fruity Chutes	2	$53.00	$106.00
G10 Garolite	McMaster-Carr	2	$56.69	$113.38
Quick Links	McMaster-Carr	4	$11.20	$44.80
2-56 Nylon Shear Screws	McMaster-Carr	2	$5.50	$11.00
3/8-16 Flex lock Nuts	McMaster-Carr	2	$7.29	$14.58
3/8 Washers	McMaster-Carr	1	$12.36	$12.36
Limit Switches	McMaster-Carr	10	$3.81	$38.10
3/8-16 U bolt	McMaster-Carr	4	$2.16	$8.64

Spring Pin	McMaster-Carr	4	$2.37	$9.48
Adjustable Polyprolene Strap, Steel Hooks, 10-54" Long	McMaster-Carr	1	$3.22	$3.22
Polypropylene Covered Elastic Adjustable Tie-Down Cord with Plastic Coated Steel Hooks, 22" to 32" Overall Length	McMaster-Carr	1	$3.09	$3.09
Extra-Stretch Extension Spring with Ultra-High Resistance 12" Long Band	McMaster-Carr	1	$23.50	$23.50
Perfectflite Stratologger	Perfectflite	5	$46.99	$234.95
PAYLOAD				
10-DOF IMU	Adafruit	3	$29.95	$89.85
Xbee FTDI breakout board	Adafruit	2	$10.00	$20.00
2mm female headers	Adafruit	2	$0.95	$1.90
Extra long male headers	Adafruit	5	$3.00	$15.00
Micro SD card breakout	Adafruit	2	$7.50	$15.00
GPS	Adafruit	2	$39.96	$79.92
Halfsized Protoboard	Adafruit	2	$12.50	$25.00
ZIPPY Compact 1300mAh 2S 25C Lipo Pack	Amazon	2	$7.26	$14.52
Shipping	Amazon			$5.20
Xbee Pro SC3	Digikey	3	$42.00	$126.00
Xbee antennas	Digikey	2	$7.63	$15.26
Shipping	Digikey			$12.80
Tax	Digikey			$8.83
Shredded Latex	DiyNaturalBedding	1	$8.00	$8.00
Shipping	DiyNaturalBedding			$2.00
NinjaFlex® Flexible 3D Printing Filament	FennerDrives	1	$41.99	$41.99
Shipping	FennerDrives			$8.51
PLA Filament	Makergear	1	$35.00	$35.00
Shipping	Makergear			$12.00
2" Thick, 12" x 12"	McMaster-Carr	1	$30.00	$30.00
24" x 18", Coarse Polyethylene, 2" Thick, Extra Soft	McMaster-Carr	1	$31.63	$31.63
1" Thick Antistatic Polyurethane, 24" x 24	McMaster-Carr	1	$14.05	$14.05
1" Thick, 24" x 24" Cubed Sheet	McMaster-Carr	1	$22.97	$22.97
1/2" Thick, 12" x 12"	McMaster-Carr	1	$8.15	$8.15

3/4" Thick Antistatic Polyurethane, 24" x 24"	McMaster-Carr	1	$11.45	$11.45
Polyurethane Foam, 2" Thick, Set of Two 18" x 24" Sheets	McMaster-Carr	1	$28.71	$28.71
Shipping	McMaster-Carr			$26.12
Polycarb Tube Replacement	McMaster-Carr	1	$23.17	$23.17
Super-Cushioning High-Strength EVA Foam Sheets	McMaster-Carr	1	$86.05	$86.05
High-Temperature Silicone Foam Sheets	McMaster-Carr	1	$28.47	$28.47
High-Temperature Silicone Foam Sheets	McMaster-Carr	1	$28.47	$28.47
High-Temperature Silicone Foam Sheets	McMaster-Carr	1	$23.05	$23.05
High-Temperature Silicone Foam Sheets	McMaster-Carr	1	$23.05	$23.05
Ultra-Strength Wear- and Weather-Resistant Ionomer Foam Sheets	McMaster-Carr	1	$5.71	$5.71
1/4" dia. AL6061 rod, 12" length	McMaster-Carr	1	$2.00	$2.00
1/2" dia. AL6061 rod, 12" length	McMaster-Carr	1	$3.08	$3.08
Steel bracket (Pkg of 50)	McMaster-Carr	1	$4.64	$4.64
Spring (1 pkg of 12)	McMaster-Carr	1	$7.26	$7.26
Springs (1 pkg of 12)	McMaster-Carr	1	$7.26	$7.26
Springs (1 pkg of 12)	McMaster-Carr	1	$7.26	$7.26
Springs (1 pkg of 12)	McMaster-Carr	1	$7.26	$7.26
Elastic fabric	McMaster-Carr	1	$9.85	$9.85
Instant Expanding Package Foam	McMaster-Carr	2	$5.59	$11.18
Shipping	McMaster-Carr			$39.19
Sd cards	Newegg	2	$19.98	$39.96
SD card reader	Newegg	1	$14.99	$14.99
Teensy 3.6	PJRC	2	$33.25	$66.50
Teensy 3.5	PJRC	1	$28.25	$28.25
Shipping	PJRC			$9.75
Purple cushion	Purple	1	$39.99	$39.99
Xbee breakout board	Sparkfun	3	$2.95	$8.85
XBee Dongle	Sparkfun	1	$24.95	$24.95
Shipping	Sparkfun			$4.60
MPU 6050	Sparkfun	2	$39.95	$79.90
LIS 331	Sparkfun	2	$9.95	$19.90
Discount	Sparkfun			-$9.96

PROJECTED SPRING 2017 SPENDING (SGA REQUEST)				
LAUNCH VEHICLE				
Mouser	538-63828-0200	1	$269.99	$269.99
Arduino Uno R3 (Atmega328)	Adafruit	2	$24.95	$49.90
BMP180 Barometric Pressure/Temperature/Altitude Sensor	Adafruit	2	$9.95	$19.90
Cheetah 3D Printer Filament - 1.75mm Diameter 0.5kg - Midnight	Adafruit	2	$59.95	$119.90
High-G Triple-Axis Accelerometer (ADXL377)	Adafruit	4	$24.95	$99.80
Raspberry Pi 3 - Model B - ARMv8 with 1G RAM	Adafruit	2	$39.95	$79.90
Triple Axis Accelerometer (ADXL345)	Adafruit	1	$17.50	$17.50
Triple-Axis Gyro Breakout Board	Adafruit	2	$12.50	$25.00
75mm Aeropack Motor retainer "P"	Aeropack	1	$44.00	$44.00
5-Layer Aircraft Plywood (12x24 sheets)	Aircraft Spruce	4	$16.85	$67.40
Color Puddy (oil based wood filler)	Amazon	1	$7.68	$7.68
Primer (for spray paint	Amazon	2	$11.20	$22.40
Remove Before Flight Keychain	Amazon	4	$4.99	$19.96
Spray Paint (Gray)	Amazon	4	$7.66	$30.64
75mm 4grain Blue Streak	Animal Motor Works	3	$271.70	$815.10
75mm Motor Casing	Animal Motor Works	1	$209.00	$209.00
3 Gallon Vacuum Chamber & 3 CFM Single Stage Vacuum Pump	Best Value Vacs	1	$215.00	$215.00
BRB 900 Mhz Transmitter	Big Red Bee	2	$199.00	$398.00
High Density Polyurethane Mix and Pour Foam	BJB Enterprises	1	$55.00	$55.00
Low Density Polyurethane Mix and Pour Foam	BJB Enterprises	1	$55.00	$55.00
Molex Microfit 3.0 Au Female term	Digikey	100	$0.12	$11.90
Molex Microfit 3.0 Au Male term	Digikey	100	$0.11	$10.81
Molex Microfit 3.0 Female Housing	Digikey	25	$1.55	$38.80
Molex Microfit 3.0 Male Housing	Digikey	25	$0.42	$10.44
24 inch Ellipitcal parachtues	Fruity Chutes	2	$67.00	$134.00
60 Inch Iris ultralight chute	Fruity Chutes	1	$275.00	$275.00
72 inch Iris Ultralight Chute	Fruity Chutes	1	$315.00	$315.00
.5 In Kevlar Harness	Giant Leap	2	$63.93	$127.86

1//4 inch tubular kevlar, 15 feet pre sown loops	Giant Leap	2	$17.41	$34.82
Parachute Protecter	Giant Leap Rocketry	4	$12.45	$49.80
1" Thick Polyethylene Foam (Density 2.2~2.3 lbs./cu. ft)	McMaster-Carr	1	$60.39	$60.39
1/2-13 Flexlock Locknut	McMaster-Carr	2	$9.07	$18.14
1/2-13 Stainless Steel Washer	McMaster-Carr	4	$6.59	$26.36
2" Thick Egg Crate Polyurethane Foam Sheets (Density 1.5 lbs./cu. ft.)	McMaster-Carr	2	$28.71	$57.42
2" Thick Super-Cushioning Polyethylene Laminated Sheet	McMaster-Carr	1	$36.24	$36.24
3/4" Thick Polyurethane Foam (Density 6 lbs./cu. ft.)	McMaster-Carr	4	$17.97	$71.88
3/8-16 Aluminum Threaded Rod	McMaster-Carr	4	$17.83	$71.32
3/8-16 Flexlock	McMaster-Carr	2	$7.29	$14.58
3/8-16 Stainless Steel Washer	McMaster-Carr	2	$7.14	$14.28
8-32 Truss Screws	McMaster-Carr	1	$5.36	$5.36
Hoist Rings 1/2-13	McMaster-Carr	4	$73.14	$292.56
Hoist Rings 3/8-16	McMaster-Carr	2	$55.19	$110.38
Nylon Machine Screws 2-56	McMaster-Carr	3	$5.55	$16.65
Quick link 1/2	McMaster-Carr	4	$8.82	$35.28
Quick Link 3/8	McMaster-Carr	4	$14.31	$57.24
Swivels 1/4	McMaster-Carr	2	$23.13	$46.26
Swivels 5/16	McMaster-Carr	2	$26.93	$53.86
Perfect Flite Stratologger CF	PerfectFlite	6	$46.99	$281.94
PRM/EXT Carbon Fiber 6 inch NC	Public Missiles	1	$199.99	$199.99
PAYLOAD				
PROJECTED COMPEITION TRAVEL COSTS				
Hotel Room for 5 Nights (2 Double Beds) April 14th - 19th Embassy Suites by Hilton Huntsville Hotel & Spa		4	$519.15	$2,076.60
Gas (3 Cars)		3	$200.00	$600.00
Tolls (3 Cars)		3	$260.00	$780.00
Camping		1	$325.00	$325.00
GRAND TOTAL				**$12,615.55**
FUNDING SOURCES				
SGA Equipment Fund (Fall 2016)	*Requested*	$4,029.49	*Awarded*	$4,029.49
Provost Grant	*Requested*	$3,000.00	*Denied*	$0.00

COE Scranton Fund	*Requested*	$5,333.40	*Awarded*	$5,500.00
SGA Equipment Fund (Spring 2016)	*Requested*	$5,099.63	*Awarded*	$5,099.63
Total Funding				**$14,629.12**

7.3.2. Funding Plan

AIAA at Northeastern has planned and secured several channels of funding to be utilized in preparation for the 2017 NASA SLI competition.

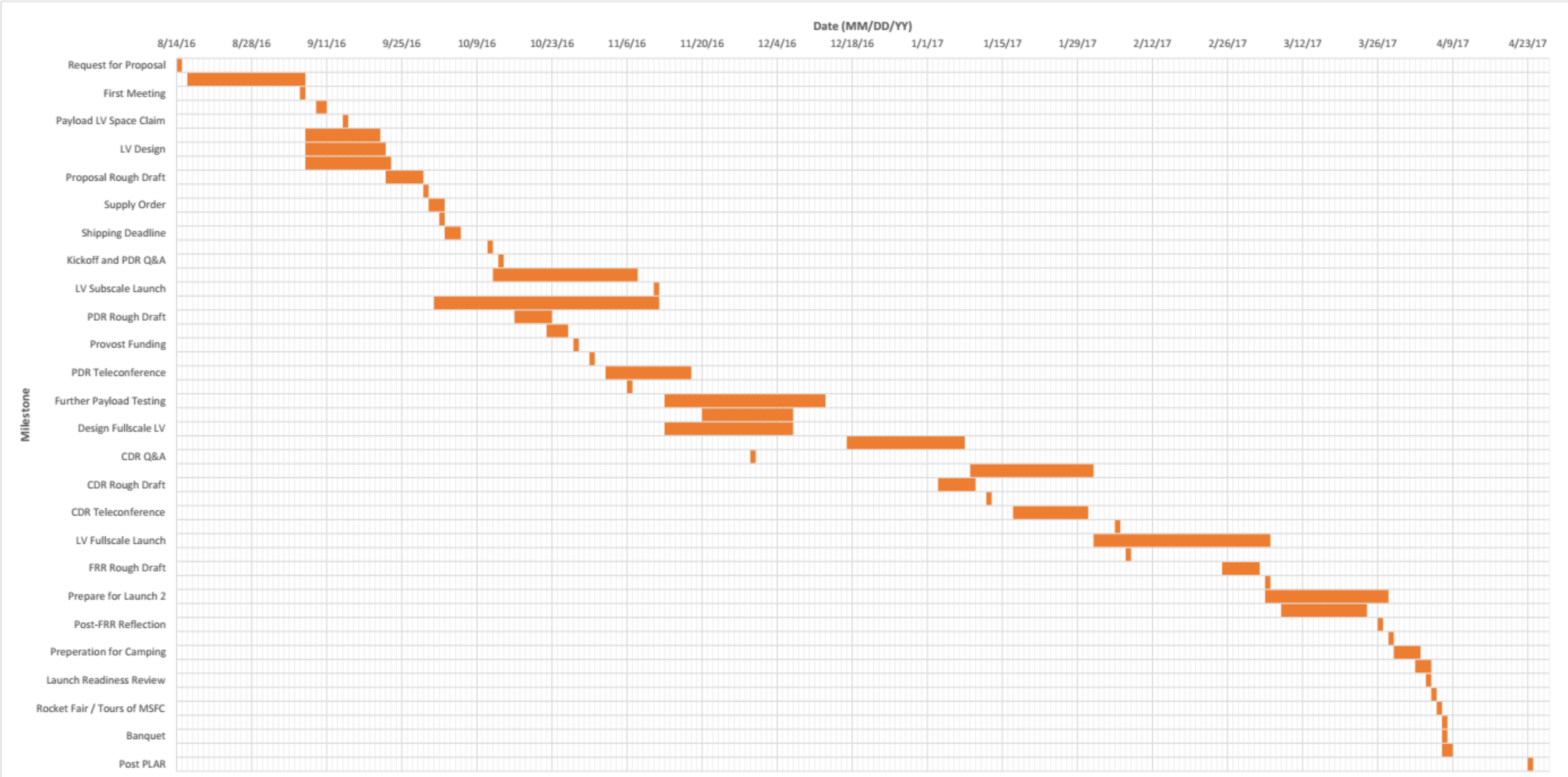
Our first source of funding is received from Northeastern's Student Government Association (SGA), which provides most our funding. We have followed through with the required procedure to apply for funding through SGA, which includes presenting to their finance board and following up with their requests. This was done once in the fall semester and then again in the spring semester. Our requests were granted, with $4,029.49 being granted in the fall and $5,099.63 being granted in the spring.

We have also applied to the Richard J. Scranton fund, which supports the activities of student groups in the College of Engineering. To apply, we submitted a proposal detailing how the money would be spent, the mission of the project, and how the spending would further the mission. We have requested $5,333.40 from this source. We succeeded in receiving this money, and even received more than requested, at $5,500.

Lastly, there is the Husky Starter crowd funding program. This is exclusive to Northeastern and allows the NU community to support the projects that they are interested in. In the case that our present funding plan does not fully cover our expenses, we plan to enter the program to garner further funding. To apply, we will need to submit an online application which stipulates that we further document our project as it progresses with either video or photo coverage.

In addition, we have sought corporate sponsorship and assistance. So far, we have received support from Dassault Systemes in the form of 40 keys for the student version of SOLIDWORKS. We are still looking for further opportunities for cooperation and with AIAA's successes, we believe this is possible.

7.3.3. Timeline



Appendix A: Flight Readiness Review Flysheet

Milestone Review Flysheet

Institution	Northeastern University	Milestone	Flight Readiness Review

Vehicle Properties	
Total Length (in)	146
Diameter (in)	6.16
Gross Lift Off Weight (lb)	48.9
Airframe Material	Blue Tube
Fin Material	G10 FIber Glass
Coupler Length	2 x 12 inch coupler with 6 inch overlap, 2 x 14 inch coupler with 7inch overap

Motor Properties	
Motor Designation	L2200G-18
Max/Average Thrust (lb)	697.37 / 504.25
Total Impulse (lbf-s)	1135.73
Mass Before/After Burn	10.474lb/4.927lb
Liftoff Thrust (lb)	560
Motor Retention	AeroPack 75mm Motor Retainer

Stability Analysis	
Center of Pressure (in from nose)	115.2
Center of Gravity (in from nose)	93.95
Static Stability Margin	4.32
Static Stability Margin (off launch rail)	3.45
Thrust-to-Weight Ratio	10.3
Rail Size and Length (in)	144
Rail Exit Velocity (ft/s)	91

Ascent Analysis	
Maximum Veloxity (ft/s)	684
Maximum Mach Number	0.608
Maximum Acceleration (ft/s^2)	444
Target Apogee (From Simulations)	5380
Stable Velocity (ft/s)	52
Distance to Stable Velocity (ft)	3.8

Recovery System Properties Drogue Parachute	
Manufacturer/Model	FruityChutes/
Size	Payload Section- 15 in Booster Stage- 18 in
Altitude at Deployment (ft)	Payload Section - 5380.577 Booster Stage - 5380.577
Velocity at Deployment (ft/s)	Payload Section - 0 Booster Stage - 32.1850394
Terminal Velocity (ft/s)	Payload Section - 88.7467 Booster Stage - 91.5794
Recovery Harness Material	Kevlar
Harness Size/Thickness (in)	0.5 Diameter

Recovery System Properties Main Parachute	
Manufacturer/Model	FruityChutes/
Size	Payload Section - 60 in Diameter Booster Stage - 72 in Diameter
Altitude at Deployment (ft)	Payload Section - 500 Booster Stage - 500
Velocity at Deployment (ft/s)	Payload Section - 88.7467 Booster Stage - 91.5794
Terminal Velocity (ft/s)	Payload Section - 18.2415 Booster Stage - 18.9048
Recovery Harness Material	Kevlar
Harness Size/Thickness (in)	0.5 Diameter

Recovery Harness Length (ft)			Payload Section - 15 Booster Stage - 15	
Harness/Airframe Interfaces		3/8in Eyebolt		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	12.7228	74.4443	72.6101	74.0794

Recovery Harness Length (ft)			Payload Section - 30 Booster Stage - 40	
Harness/Airframe Interfaces		1/2in Hoist Ring with 2in washers		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	12.7228	74.4443	72.6101	74.0794

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	PerfectFlite StratoLoggers SL100
Redundancy Plan	Redundant StratoLoggers - 4 in Booster Stage, 2 in Payload Section.
Pad Stay Time (Launch Configuration)	At least two two hours according to StratoLogger manual

Recovery Electronics	
Rocket Locators (Make/Model)	Payload Section - XBee XSC Pro Booster Stage- TeleGPS
Transmitting Frequencies	902Mhz-928Mhz 464 MHz (can support 300 - 348 MHz, 387 - 464 MHz, and 779 - 928 MHz)
Black Powder Mass Drogue Chute (grams)	Payload Section - 1.5g Booster Stage - 1.75g
Black Powder Mass Main Chute (grams)	Payload Section - 2g Booster Stage - 2g

Milestone Review Flysheet

Institution	Northeastern University	Milestone	Flight Readiness Review

Autonomous Ground Support Equipment (MAV Teams Only)	
Capture Mechanism	Overview
	N/A
Container Mechanism	Overview
	N/A
Launch Rail Mechanism	Overview
	N/A

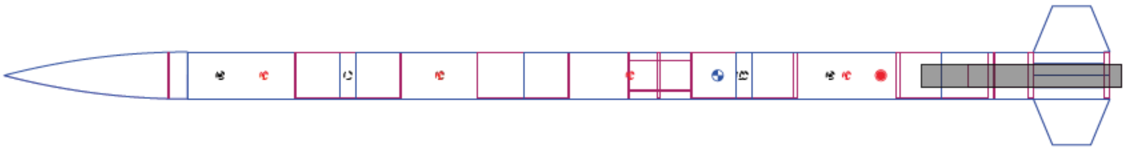
Igniter Installation Mechanism	Overview
	N/A

Payload	
Payload 1	Overview
	Our payload is a very passive system because we wanted to minimize failure of the system. The payload should not leave the launch vehicle at any point during the launch. It will be recovered with the rocket via parachute and should not itself affect safety of the launch vehicle
Payload 2	Overview
	N/A

Test Plans, Status, and Results	
Ejection Charge Tests	The ejection charges were tested statically for each separtion event. The blast caps were filled with black powder and the sections were fitted together to simulate how separation would occur during flight. Wires were connected to the electronic matches and the wires ran to a power source a safe distance away. The wires were attached to the pwoer source setting off the charges anad cuases safef separation and deployment of aprachutes in all three tests. This showed that our ejection system worked and should perform during actual flight, and it did during our test flight.
Sub-scale Test Flights	The sub-scale was tested to prove aerodynamic stability of design and deployment of paracutes. The subscale and full scale designs had similar reynolds numbers and therefore had similar coefficeints of drag. This means that they would both behave about the same during flight so the subscale test would validate the flight of the full scale. The design of the interstage to have delayed drogue parachute for the booster stage was tested of the subscale flight and this system worked in preventing the two parachutes, which come out the same section at apogee, from tangling. Our deployment system separating untethered at the interstage at apogee, then the booster separating tethered with a main parachute and the payload sections separating tethered with the other main parahute was tested and verified.
Full-scale Test Flights	We conducted our full scale flight on March 4th 2017, at 3:05 PM, with the Valley AeroSpace Team (VAST), in Monterey, Virginia. The vehicle was cleared for flight by the RSO's and launched on a CTI 54mm 6 Grain XL L-1030 Red Lightning, with a Fully Ballasted Payload. The vehicle was not launched with transmitters, as our HAM radio licensed individual was not available for the launch.

Appendix B: OpenRocket Calculated Rocket Data and Component Weights

Rocket Design



Rocket
Stages: 4
Mass (with motors): 22000 g
Stability: 3.46 cal
CG: 93.388 in
CP: 115 in

None; None; None; L2200G-0

Altitude	5380 ft
Flight Time	101 s
Time to Apogee	17.8 s
Optimum Delay	15.5 s
Velocity off Pad	28 m/s
Max Velocity	209 m/s
Velocity at Deployment	26.3 m/s
Landing Velocity	5.26 m/s

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
L2200G	2243 N	2.27 s	3102 N	5104 Ns	10.40:1	2516 g	2.95/26.2 in

Parts Detail

Sustainer

Nose cone	Carbon fiber (1.78 g/cm^3)	Ogive	Len: 24 in	Mass: 500 g
Bulkhead	Cardboard (0.68 g/cm^3)	Dia$_{out}$ 5.892 in	Len: 0.25 in	Mass: 232 g

Booster stage

Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.002 in Dia$_{out}$ 6.16 in	Len: 20 in	Mass: 548 g
Payload Main Parachute	Ripstop nylon (67 g/m^2)	Dia$_{out}$ 60 in	Len: 0.984 in	Mass: 294 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 11.811 in	
Payload Main Shock cord (30 ft .5in Tubular Kevlar)	Tubular nylon (14 mm, 9/16 in) (16 g/m)		Len: 360 in	Mass: 346 g
Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.003 in Dia$_{out}$ 6.16 in	Len: 2 in	Mass: 64.1 g
Tube coupler	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 5.883 in Dia$_{out}$ 6.003 in	Len: 14 in	Mass: 470 g
Bulkhead	Birch (0.67 g/cm^3)	Dia$_{out}$ 5.883 in	Len: 0.25 in	Mass: 514 g
Bulkhead	Birch (0.67 g/cm^3)	Dia$_{out}$ 5.883 in	Len: 0.25 in	Mass: 514 g
Payload E-Bay		Dia$_{out}$ 0.984 in		Mass: 2000 g
Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.003 in Dia$_{out}$ 6.16 in	Len: 22 in	Mass: 1098 g
Tube coupler	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 5.883 in Dia$_{out}$ 6.003 in	Len: 12 in	Mass: 0 g
Bulkhead	Birch (0.67 g/cm^3)	Dia$_{out}$ 5.883 in	Len: 0.25 in	Mass: 0 g
Payload		Dia$_{out}$ 0.984 in		Mass: 680 g
Paylaod Drogue Parachute	Ripstop nylon (67 g/m^2)	Dia$_{out}$ 15 in	Len: 0.984 in	Mass: 0 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 11.811 in	

Booster stage

Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.003 in Dia$_{out}$ 6.16 in	Len: 27.812 in	Mass: 906 g
Tube coupler	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 5.883 in Dia$_{out}$ 6.003 in	Len: 14 in	Mass: 488 g

Booster E-bay		Dia$_{out}$ 0.984 in		Mass: 1130 g
Bulkhead	Birch (0.67 g/cm^3)	Dia$_{out}$ 5.883 in	Len: 0.5 in	Mass: 514 g
Bulkhead	Birch (0.67 g/cm^3)	Dia$_{out}$ 5.883 in	Len: 0.25 in	Mass: 386 g
Unspecified		Dia$_{out}$ 0.984 in		Mass: 1000 g
Inner Tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 3.842 in Dia$_{out}$ 4 in	Len: 8 in	Mass: 560 g
Centering ring	Birch (0.67 g/cm^3)	Dia$_{in}$ 4 in Dia$_{out}$ 6.003 in	Len: 0.25 in	Mass: 0 g
Centering ring	Birch (0.67 g/cm^3)	Dia$_{in}$ 4 in Dia$_{out}$ 6.003 in	Len: 0.25 in	Mass: 0 g
Booster Drogue Parachute	Ripstop nylon (67 g/m^2)	Dia$_{out}$ 18 in	Len: 0.984 in	Mass: 0 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 11.811 in	
Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.003 in Dia$_{out}$ 6.16 in	Len: 2 in	Mass: 0 g
Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.003 in Dia$_{out}$ 6.16 in	Len: 24.875 in	Mass: 682 g
Booster Main Shock cord (40 ft .5in Tubular Kevlar)	Tubular nylon (14 mm, 9/16 in) (16 g/m)		Len: 360 in	Mass: 461 g
Tube coupler	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 5.883 in Dia$_{out}$ 6.003 in	Len: 12 in	Mass: 0 g
Bulkhead	Cardboard (0.68 g/cm^3)	Dia$_{out}$ 5.883 in	Len: 0.5 in	Mass: 0 g
Booster Main Parachute	Ripstop nylon (67 g/m^2)	Dia$_{out}$ 72 in	Len: 0.984 in	Mass: 304 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 11.811 in	
Booster stage				
Body tube	Blue tube (1.3 g/cm^3)	Dia$_{in}$ 6.002 in Dia$_{out}$ 6.16 in	Len: 22 in	Mass: 707 g
Trapezoidal fin set (4)	Fiberglass (1.85 g/cm^3)	Thick: 0.125 in		Mass: 895 g
Centering ring	Birch (0.67 g/cm^3)	Dia$_{in}$ 2.953 in Dia$_{out}$ 6.002 in	Len: 0.75 in	Mass: 177 g
Centering ring	Birch (0.67 g/cm^3)	Dia$_{in}$ 2.953 in Dia$_{out}$ 6.002 in	Len: 0.75 in	Mass: 177 g
Centering ring	Cardboard (0.68 g/cm^3)	Dia$_{in}$ 2.953 in Dia$_{out}$ 6.002 in	Len: 0.25 in	Mass: 59.7 g
Inner Tube	Cardboard (0.68 g/cm^3)	Dia$_{in}$ 2.953 in Dia$_{out}$ 3.031 in	Len: 20 in	Mass: 82.5 g

Appendix C: MATLAB Calculating Optimal PPS Foam Modulus (Axial and Radial)

```
function foamDesign_FullScale
%foamDesign Outputs foam modulus given geometric constraints
%   Units in slinches (English-2 in table linked below)
%   http://www.quartus.com/resources/white-papers/nastran-units/

%% Geometric Parameters
OD = 6; % Outer diameter of radial foam padding
ID = 4; % Inner diameter of canister-- assumed diameter of axial foam
L0 = 4;  % Height of axial foam support
h = 11.5; % Height of canister (and radial foam support)
comp = .5;  % Allowable compression of foam (.5 = 50%)
% LOOK UP COMPRESSIVE RATE
%% Impact Parameters
w_lb = 1.3;  % Weight of canister (lbs)
m = blobs(w_lb);   % Mass of canister
v_mph = 42.5;  % Impact velocity (mph) ~ 19 m/s @ apogee
v = ips(v_mph);
Uk = .5*m*v^2;

%% axial foam
A = pi/4*ID^2;
da = comp*L0;  % compression distance
Ua = A*da^2/(2*(L0-da));  % Ustrain/E
Ea = Uk/Ua; % Modulus
ka = Ea*A/(L0-da);  % Equivalent spring stiffness
[aa, ta] = dynamics(ka, m, da);
Fa = Uk/da;

%% radial foam
ro = OD/2;
ri = ID/2;
dr = comp*(ro-ri);    % compression distance

%% x strain energy (without E)
xo = @(y) sqrt(ro.^2-y.^2);
xa = @(y) sqrt(ri.^2-y.^2);
xb = @(y) sqrt(ri.^2-y.^2)+dr;
ux = @(y)(xb(y)-xa(y)).^2./(xo(y)-xb(y));

%% y strain energy (without E)
yo = @(x) sqrt(ro.^2-x.^2);
ya = @(x) sqrt(ri.^2-x.^2);
yb = @(x) sqrt(ri.^2-(x-dr).^2);
uy = @(x)(yb(x)-ya(x)).^2./(yo(x)-yb(x));

%% get E
Ur = h*(integral(ux,0,ri)+integral(uy,0,ri));

Er = Uk/(Ur);
```

```
%% old code below
%{
denom = @(y)(sqrt(ro.^2-y.^2)-sqrt(ri.^2-y.^2)-dr).^-1; %Ustrain/E
Ur = h*dr^2*integral(denom,0,ri);
Er = Uk/Ur; % Modulus
%}

%% get spring stiffness & force -- remember, the forces aren't quite accurate.
% based on these equations, you can do a bit more work to get a better F.
% get a stiffness K for a variable L, then integrate (k*x)x*dx
% just a thought, if that doesn't make sense it's probably wrong.
kr = 2*Uk/dr^2;  % Equivalent spring stiffness
[ar, tr] = dynamics(kr, m, dr);
Fr = Uk/dr;

%% output results
format short
property = {'Modulus (psi)', 'Modulus (kPa)', 'Acceleration (G''s)', 'Stop Time (s)', 'Force (lb)'};
axial = [Ea; kPa(Ea); grav(aa); ta; Fa];
radial = [Er; kPa(Er); grav(ar); tr; Fr];
T = table(axial,radial,'RowNames',property);
disp(T)

end

%% Helper Functions

% get max acceleration and half period
function [a, t] = dynamics(k, m, d)
a = sqrt(k*d/m);
t = pi*sqrt(m/k);
end

% convert mass to consistent units
function m = blobs(lb)
m = .00259*lb;
end

% convert acceleration to Gs
function g = grav(a)
g = a/386.1;
end

% convert mph to in/s
function ips = ips(mph)
ips = 17.6*mph;
end

function kPa = kPa(psi)
kPa = 6.895*psi;
end
```

Appendix D: Instructions to Assemble Cesaroni 75mm Motor

Pro75® High-Power Reloadable Rocket Motor Systems

FOR USE ONLY BY CERTIFIED HIGH-POWER ROCKETRY USERS 18 YEARS OF AGE OR OLDER

FLAMMABLE MATERIAL – KEEP AWAY FROM OPEN FLAME, CIGARETTES OR OTHER HEAT SOURCES AT ALL TIMES

USE WITHIN 1 YEAR OF MANUFACTURING DATE **TEMPERATURE RANGE: -5 to 30°C**

Read this BEFORE you start assembly:

- If you have any questions or require assistance, please contact your dealer. If you are unable to resolve your questions or problems then please contact the manufacturer directly. Assistance is available Mon – Fri. 9am – 4:30pm at (905) 887-2370. Ask for ProXX motor products technical support.
- Read all instructions carefully and be sure you fully understand each step before proceeding with motor assembly.
- **Make sure to also read the Pro75 Product Notes for reload specific instructions. Your reload may require bonding of grains into the case liner. For moonburner reloads there are also separate moonburner instructions for gluing the grains.**
- Inspect the components of your reload kit carefully before you start assembly. DO NOT use any parts that appear damaged or faulty in any way.
- Do not tamper with or modify the hardware or reload kit components in any way. Not only will this void all product warranty, it could cause catastrophic failure of your motor system and result in damage to your rocket vehicle, launch equipment and create a hazard to persons or property.
- Reload kit components are designed for ONE USE ONLY, and may not be reused. Reuse of any of these components could result in motor failure and will void product warranty.
- Follow the safety code and all rules and regulations of your sport rocketry association. Also ensure that you are in compliance with all local, state/provincial, and Federal laws in all activities involving high power rockets and rocket motors.
- Parts checklist:

Pro75® Instructions, July 2015 revision

Pro75® hardware components (if used):

- ✓ Appropriate size of motor case
- ✓ Forward closure
- ✓ Nozzle holder
- ✓ Threaded retaining rings (2)

Reload kit components:

- ✓ Case liner (phenolic tube)
- ✓ Nozzle
- ✓ Forward insulator disk
- ✓ P75-ORK (o-ring kit)
- ✓ P75-TSI-KIT (smoke tracking grain/insulator & igniter kit)
- ✓ Propellant grains (check reload kit package for number and type required for your motor)

Assembly instructions

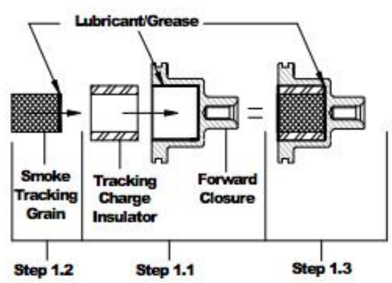
- Be sure to follow the correct instructions for the brand of motor hardware you are using!
- Step 1 is the same for both brands of hardware.
- All o-rings are pre-lubricated at the factory where required.
- Three o-rings are supplied in the P75-ORK o-ring kits. The two larger o-rings are used with both Pro75® and RMS™ hardware. The smaller o-ring is only used with Pro75® hardware.
- Do not apply lubricant to the grain spacer o-rings, they are for spacing only.
- Phenolic and phenolic/paper components such as the nozzle and case liner tube are brittle and can be cracked, broken or otherwise damaged by excessive force or impact. Please be careful during handling and assembly. If you suspect a part has been damaged in any way, STOP and do not proceed with assembly and especially firing until inspected and replaced if necessary.

1. Forward Closure Assembly

1.1. Apply a light coating of o-ring lubricant or grease to the inside of the cavity in the forward closure. Insert the smoke tracking charge insulator into this cavity and ensure it is seated fully.

1.2. Apply a liberal layer of grease or o-ring lubricant to one end of the smoke tracking grain. Be sure the entire face is coated.

1.3. Insert the smoke tracking grain into the smoke tracking charge insulator, coated end <u>first</u>. Push the grain in with sufficient force to fully seat it and spread the lubricant as shown. The excess lubricant will help prevent gas leakage forward as well as protecting the forward closure from heat and combustion products from the smoke tracking charge.



You may now proceed to the remainder of the instructions for your brand of motor hardware.

Step 2 is for Pro75® hardware users.

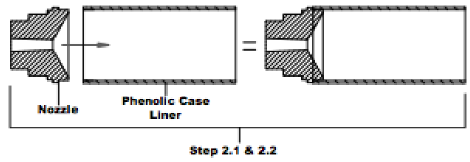
Pro75® Instructions, July 2015 revision

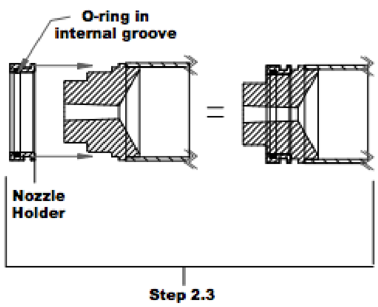
Step 3 is for RMS™ hardware users.

2. Motor Assembly: Pro75® Hardware.

Before proceeding, inspect the external o-ring grooves on the forward closure and nozzle holder, as well as the internal groove on the nozzle holder. Clean thoroughly if necessary to remove ALL combustion residue and debris. Also ensure that the inside of the motor case has been thoroughly cleaned.

2.1. Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.



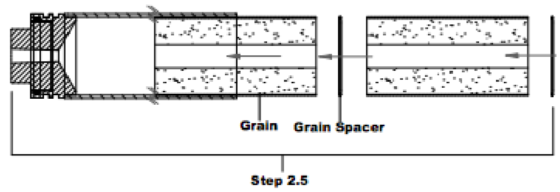


2.2. Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.

2.3. Locate the smaller o-ring in the P75-ORK o-ring kit. Fit the o-ring to the internal groove of the nozzle holder. Push the nozzle holder over the nozzle until fully seated. Apply additional lubricant to the nozzle exit section if necessary to facilitate assembly.

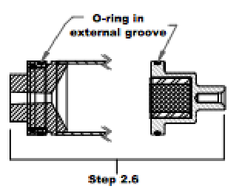
2.4. For steps 2.5 – 2.6 work with the nozzle/case liner assembly and motor case horizontally on your work surface.

2.5. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.

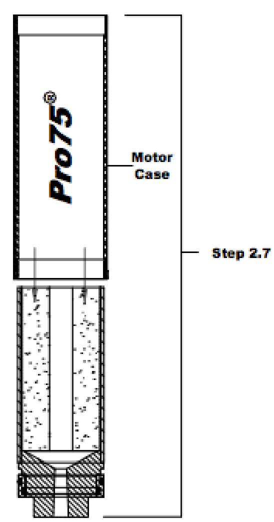


2.5.1. There should be sufficient space after the last grain is inserted to fit the last spacer in place so that it is flush or extends only slightly from the end of the tube. If it extends out by more than 1/3 of its own thickness, remove it and do not use. Only this spacer may be omitted and only if necessary to fit.

2.6. Carefully install the two larger o-rings into the external grooves of the nozzle holder and forward closure. Handle these components with care from this point on so as not to damage or contaminate the o-rings.



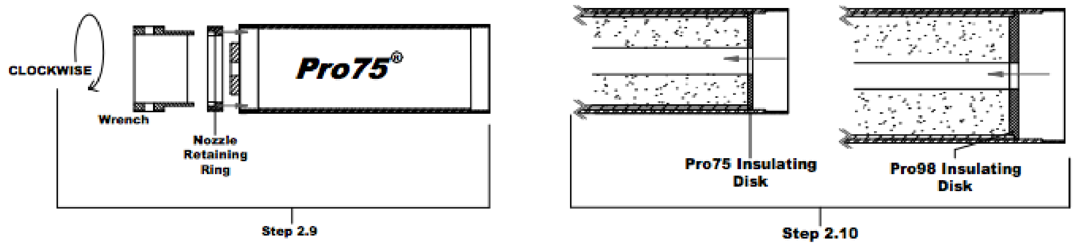
2.7. Place the case liner/nozzle assembly on your work surface with the nozzle end down, and slide the motor case down rear end first (end with thrust ring) over the top of the liner towards the nozzle. **Note:** a light coat of grease on the liner exterior will aid assembly, disassembly and cleanup!



2.8. Lay the motor case assembly down horizontally, and push on the nozzle ring until the assembly is far enough inside the case that the threads are partly exposed and the screw ring can be threaded into the rear of the case. Don't push on the nozzle itself as you will push it out of the nozzle holder.

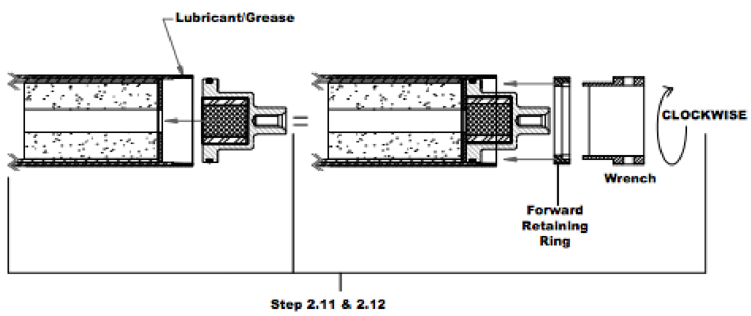
2.9. Screw in the nozzle retaining ring using the supplied wrench, pushing the nozzle/nozzle ring/case liner assembly forward as you proceed. Screw it in *only until the retaining ring is* *exactly even with the end of the motor case* - do not thread it in as far as it will go. Then, back the retaining ring out one half of a turn.

2.10. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.



2.11. Verify that the inside of the motor case is clean ahead of the liner assembly before proceeding. Wipe with a clean rag, tissue or wet-wipe if required. Apply a light coat of silicone o-ring lubricant onto this area after cleaning.

2.12. Insert the assembled forward closure into the top of the motor case, pushing it down carefully with your fingers until you can thread in the retaining ring. Thread in the forward retaining ring using the wrench, until you feel it take up a load against the top of the case liner. At this point the ring should be approximately flush with the end of the motor case, or slightly submerged. If it extends out the case at this point by more than about one half a turn, check the nozzle end to make sure the ring is not screwed in too far forward. If so, unscrew the nozzle retaining ring another half turn and screw the forward closure retainer in further.



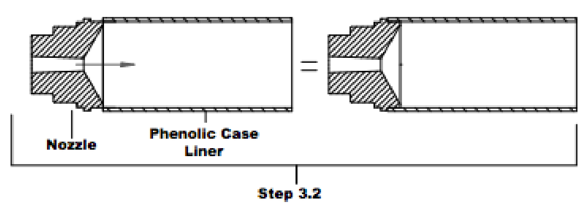
NOTE: it is best to have the forward closure retaining ring flush or slightly submerged and the nozzle retaining ring protruding by a half turn or so, than vice versa. There is more tolerance for o-ring location at the nozzle end. There will always be some minor variation in the length of internal components due to manufacturing tolerances.

2.13. Skip ahead to Section 4, Preflight preparation.

3. Motor Assembly, RMS™ Hardware.

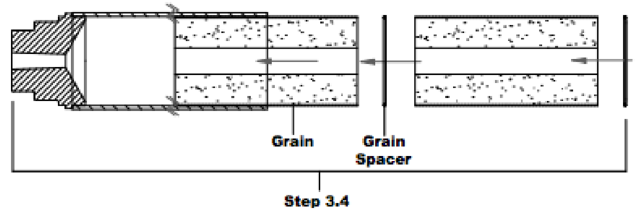
3.1. Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.

3.2. Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.



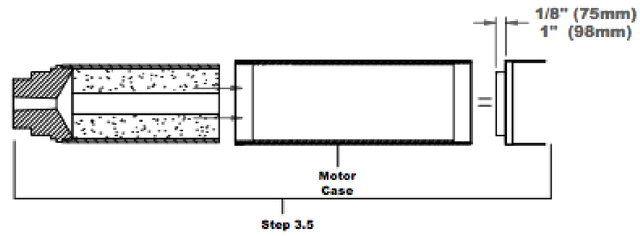
3.3. For steps 3.4 – 3.8 work with the nozzle/case liner assembly and motor case horizontally on your work surface.

3.4. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.

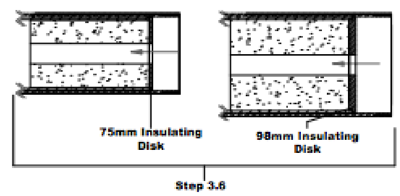


3.4.1. There should be sufficient space after the last grain is inserted to fit the last spacer in place so that it is flush or extends only slightly from the end of the tube. If it extends out by more than 1/3 of its own thickness, remove it and do not use. Only this spacer may be omitted and only if necessary to fit.

3.5. Slide the completed liner/nozzle/grain assembly into the motor case until the nozzle protrudes about 1/8" from the end of the case. **Note:** a light coat of grease on the liner exterior will aid assembly, disassembly and cleanup!



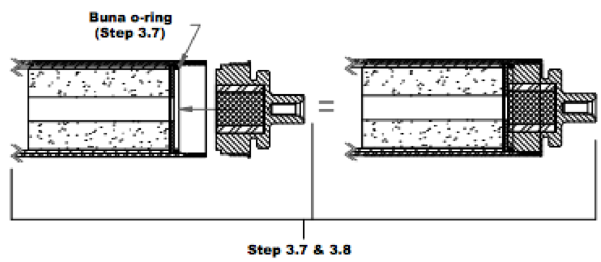
3.6. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.

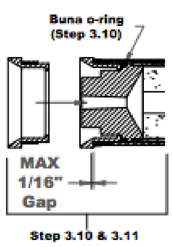


3.7. Place one of the larger pre-lubricated o-rings from the P75-ORK kit into the forward end of the case until it is seated against the forward insulator.

3.8. Thread the completed forward closure into the forward end of the motor case by hand until it is seated against the case. NOTE: There will be considerable resistance to threading in the closure in the last 1/8" to 3/16" of travel, due to compression of the o-ring.

3.9. Hold the motor vertically on your work surface with the forward closure downwards, and push down on the nozzle to ensure the liner/nozzle assembly is seated fully forward.





3.10. Place the other identical o-ring into the groove in the nozzle.

3.11. Thread the aft closure into the motor case until it is seated. It is normal for a small gap (up to about 1/16") to remain between the closure and the end of the case, due to manufacturing tolerances on internal components. Note: There will be considerable resistance to threading in the closure in the last 1/8" to 3/16" of travel, due to compression of the o-ring.

3.12. Proceed to Section 4, Preflight preparation.

4. Preflight Preparation.

4.1. Prepare the rocket's recovery system, before motor installation if possible.

4.2. Install the motor in your rocket, ensuring that it is securely mounted with a positive means of retention to prevent it from being ejected during any phase of the rocket's flight.

4.3. IMPORTANT: **DO NOT INSTALL THE IGNITER IN THE MOTOR UNTIL YOU HAVE THE ROCKET ON THE LAUNCH PAD, OR IN A SAFE AREA DESIGNATED BY THE RANGE SAFETY OFFICER**. Follow all rules and regulations of your rocketry association, and/or the National Fire Protection Association (NFPA) Code 1127 where applicable.

4.4. Install the supplied igniter, ensuring that it travels forward until it is in contact with the forward closure. Securely retain the igniter to the motor nozzle with tape, or (if supplied) the plastic cap, routing the wires through one of the vent holes. Ensure that whatever means you use provides a vent for igniter gases to prevent premature igniter ejection.

4.5. Launch the rocket in accordance with all Federal, State/Provincial, and municipal laws as well as the Safety Code of your rocketry association, as well as NFPA Code 1127 where applicable.

5. Post Flight Cleanup.

Do not try to dismount or disassemble your motor until it has thoroughly cooled down after firing. Some components such as the nozzle may be extremely hot for some time after firing.

Perform motor cleanup as soon as possible after firing, however, as combustion residues are corrosive to motor components, and become very difficult to remove after several hours.

5.1. Unthread and remove the forward and rear closures. Remove the nozzle holder from the nozzle.

5.2. Remove the phenolic tracking smoke charge insulator from the forward closure.

5.3. Remove all o-rings.

5.4. Discard all reload kit components with regular household waste, after they have completely cooled down.

5.5. Use wet wipes, or paper towels or rags dampened with water or vinegar to thoroughly clean all residue, grease etc. off all hardware components. Pay close attention to internal and external o-ring grooves. A cotton swab or small stick of balsa is an excellent tool for cleaning these grooves.

5.6. Apply a light coat of grease or o-ring lubricant to all threaded sections and reassemble threaded components for storage.

MEANS OF DISPOSAL: The propellant grains, smoke tracking charge, and the igniter are extremely flammable and burn with an intense, hot flame. The remainder of the components are inert and may be disposed of with household trash. To destroy the flammable components, dig a shallow hole in the ground in a remote area, away from any buildings, trees, people, or any other combustibles. Place the propellant grains and smoke tracking module in the hole. Install the igniter into the core of one of the propellant grains and secure with tape. Ignite electrically from a minimum distance of 15 meters. Douse any smoldering paper residue and discard. Ensure that you are not in violation of any local or state regulations for this procedure. If in doubt, contact your local fire department. Please direct any questions regarding safe disposal to our technical support number on page one of this document.

First Aid: If ingested, induce vomiting. Burns from flames are to be treated as regular burns with normal first aid procedures. In either case, seek medical attention.

⇒ Check out our web site at http://www.Pro-X.ca for tech tips, FAQ's, user feedback and photos, or e-mail us at ProX@cesaroni.net
⇒ For technical and warranty inquiries, please contact your Pro75® dealer.