UC Berkeley Space Technologies and Rocketry
Flight Readiness Review
Project U.R.S.A.[1]

March 6, 2017

[1] Upright Recovery and Sight Acquisition

Contents

1 Summary

1.1 Team Summary

Team Name:
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1.2 Launch Vehicle Summary

Launch Vehicle Summary

- Total Length: 103”
- Diameter: 6”
- Weight: 33.3 lb
- Motor: AeroTech L1150
- Recovery system: **24” Elliptical Parachute (drogue); Iris Ultra 72” Compact Parachute (main); 3x 36” Iris Toroidal Parachute (payload)**
- Rail Size: 12 ft. 1515 Rod
- Milestone Review Flysheet: See stars.berkeley.edu/sl

1.3 Payload Summary

Payload Title: **SAGITTA-VL (Sight-Aided Ground IdenTificaTion And Vertical Landing)**
Our payload experiment is designed to perform two tasks: **Target Detection** and **Upright Landing**. The payload section of the vehicle consists of the uppermost 18” of the airframe tubing, as well as the nose cone, which has a transparent tip. A Raspberry Pi camera, mounted in the tip of the nose cone, views and photographs the ground during descent while a custom onboard software package identifies and differentiates three colored ground targets. After Target Detection has been completed, the payload section is ejected from the vehicle, as three landing legs built into the airframe are deployed to form a tripod. The landing legs are fixed to the airframe via spring-loaded hinges and sliding carriages on aluminum rails. The deployment of the legs causes the deployment of three parachutes mounted below the nose cone. This deployment procedure causes the payload section to turn upright and descend under an independent recovery system to land on the landing legs, thus achieving Upright Landing.

2 Changes Made Since CDR

2.1 Vehicle Criteria

There are very few changes to the vehicle design since the CDR. The vehicle has risen in weight from 32.06 lbs to 33.3 lbs, but the other dimensions have remained the same. The construction and assembly methods have been altered more radically. The fin slots were cut in a much more precise fashion (using a 3D printed jig). The fins were epoxied much more precisely with the use of a laser-cut jig. The fillets on the fins utilized more finely cut bits of carbon fiber.

2.2 Payload Criteria

Several changes have been made to the payload design, manufacturing plan, and criteria since the CDR. Most of these changes result from difficulties encountered during manufacturing and testing. The design of the spring-loaded hinge mechanism for leg deployment has been changed: instead of using a large torsion spring centered between the leg and rails, the hinge will have two small torsion springs centered on the hinge itself, pushing against the legs and the hinge posts. The tubing portion of the landing legs have been modified to provide sufficient clearance and extension length for the landing leg system. Most significantly, the solenoid actuators are no longer mounted in the nose cone, but in the payload tubing section (attached to the parachute container). In order to prevent binding of the solenoid pin, brass bushings have been added to both the parachute container and the landing leg frame.

The payload flight plan has been slightly modified as well. The leg deployments are more widely staggered, in order to prevent tangling of the parachutes. One leg will deploy before the payload ejection; however, as an additional safety mechanism, the ejection will not occur at all unless a photoresistor in the parachute container confirms that a leg has indeed been deployed.

2.3 Project Plan

Since the CDR, our projected materials budget raised significantly from \$3680.94 to \$4950.45. While we still have sufficient funding for this increase in budget, this reduces the amount of travel reimbursement we will be able to provide for team members. Weather caused our planned Full-scale launch to be delayed from February 4th to March 4th. As a result, this has pushed back several other items in our timeline (analysis of full scale test results, design modifications, etc.). The amount of Team Derived Requirements (TDR's) was increased from 10 to 30.

3 Vehicle Criteria

3.1 Design and Construction of Launch Vehicle

3.1.1 Mission Statement

CalSTAR's launch vehicle, URSA Major, is designed to fly to an apogee of 5280 feet AGL, deploy an experimental payload, and be safely recovered. The deployed payload is an independent section capable of detecting ground targets and landing upright. The following criteria are to be met for our project to qualify as a success:

- Apogee of 5280 feet AGL

- Drogue, main, and payload parachutes deployed and each section lands with a kinetic energy of less than 75ft-lbf
- Colored tarp targets identified by camera in the nosecone
- 3 landing legs unfold and payload lands upright
- Subscale and full scale test flights are successfully completed
- All safety procedures are adhered to at all steps in the project

3.1.2 Functional Requirements

The full scale rocket must meet all functional requirements as stated in the NASA Student Launch Handbook with an acceptable level of risk.

Requirement	**Risk Analysis**
1.1. The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	With the AeroTech L1150 motor and design, the estimated apogee is 5322 ft. This allows for significant breathing room (278 ft) until 5600 ft is reached. For the subscale launch, projected apogee had an error of 59 feet or 1.2% of the actual apogee. Following this error percentage, the full scale apogee has a range of 64 ft above or below 5322 ft, which is significantly lower than the disqualification altitude.
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 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 deductions.	The main altimeter is the Perfectflite Stratologger CF Altimeter. Additionally, there are three backup altimeters. Two are placed in the avionics bay, and two will be placed in the payload. Two of these altimeters are approved as scoring altimeters. Furthermore, all of these altimeters will have rotary switches which can be used to turn them off when not in use.
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 rocket's altimeters are capable of relaying apogee through audible beeps.
1.3. All recovery electronics shall be powered by commercially available batteries.	The recovery system in the rocket will be powered by 9V Duracell batteries.

1.4. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	For recovery, GPS units will be placed in both the payload and the avionics bay. This will ensure that both parts of the rocket can be recovered. In order for it to be reusable, significant research was done into the primary materials that are being used on this rocket. Blue Tube is being used as the primary airframe material. It is a strong composite (refer to Blue Tube strength analysis in **??**) which is resistant to shattering while being light enough so that the rest of the mission requirements could be met. The other major component of the airframe is fiberglass. Fiberglass will be used mainly for the fins as well as the nose cone. This material is also very strong (refer to Fiberglass strength analysis in **??**). The way that the rocket is expected to land, any impact on the fins and nose should be minimal and insignificant enough so that it can be reused.
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.	The independent sections of the rocket will be the booster section, the avionics bay, and the payload.
1.6. The launch vehicle shall be limited to a single stage.	The rocket is single stage with only one motor.
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.	The pre-launch actions for the subscale launch took significantly less than 4 hours and it is expected that the main launch checklist will be similar to the subscale checklist. Although the full-scale vehicle contains the upright landing payload, this is to be largely assembled prior to launch events. Therefore, it is expected that the pre-launch procedures for the main launch will also take significantly less than 4 hours.
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.	All of the batteries are made to last at least 3 hours in time and the microprocessor memory is large enough for more than than 1 hour of 1080p video. Therefore, there is significant margin of error, and the launch will not be hindered by waiting an hour at the pad.

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.	The motor in use (AeroTech L1150) is manufactured for this method of ignition. A similar motor was tested during the subscale launch and there was no need for any external circuitry. The main launch is expected to perform the same way.
1.10. The launch vehicle shall shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	The motor in use (AeroTech L1150) uses only a 12 volt direct current for ignition.
1.11. The launch vehicle shall use a commercially available solid motor propulsions ystem using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The AeroTech L1150 motor is an APCP solid propellant motor and is certified by both the National Association of Rocketry and the Tripoli Rocketry Association.
1.12. Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:	The vehicle does not contain any pressure vessels. All sections of the vehicle will contain vent holes to equalize internal air pressure with atmosphere.
1.13. The total impulse provided by a College and/or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	The AeroTech L1150 has an impulse of 3489 N-s. This meets the requirement.
1.14. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	As calculated by OpenRocket, the rocket has a static stability margin of 2.78. Small changes in the center of gravity during construction will not bring it lower than 2.0.
1.15. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The rail exit velocity is 73.7 ft/s using a 12 ft rail as simulated in OpenRocket.
1.16. All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	CalSTAR launched a subscale vehicle, URSA Minor, on Dec. 3, 2016. The model was scaled to 2/3 diameter and length of the full-scale design. An onboard altimeter recorded an apogee altitude of 4574 ft.
1.17. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.The rocket flown at FRR must be the same rocket to be flown on launch day.	CalSTAR plans to launch its full-scale vehicle, URSA Major, in February 2017.

1.18. Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	The only structural protuberances that the rocket has (prior to deployment of the payload) are the fins, which are positioned near the base of the vehicle. During launch, the payload is packed such that no part of it protrudes from the body.
1.19.1. The launch vehicle shall not utilize forward canards.	Forward canards will not be used on the rocket.
1.19.2. The launch vehicle shall not utilize forward firing motors.	Forward firing motors will not be used on the rocket.
1.19.3. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The motor used on the rocket will not expel titanium sponges.
1.19.4. The launch vehicle shall not utilize hybrid motors.	Hybrid motors will not be used on the full scale rocket.
1.19.5. The launch vehicle shall not utilize a cluster of motors.	A single motor will be used on the full scale rocket.
1.19.6. The launch vehicle shall not utilize friction fitting for motors.	Friction fitting will not be utilized on the rocket. Aluminum screw-on motor retainers will be used for motor retention.
1.19.7. The launch vehicle shall not exceed Mach 1 at any point during flight.	The rocket is not expected to reach velocities higher than Mach 0.61, meeting the requirement with a significant margin of error.
1.19.8. Vehicle ballast shall not exceed 10% of the total weight of the rocket.	Ballast used in the full scale rocket will be measured and used if and only if its weight is less than 10% of the rocket's total weight.

Team Requirements	**Risk Analysis**
2.1 Vehicle shall be less than 40 lbs in order to achieve proper apogee.	The rocket simulated and calculated is between 32 - 35 lbs. That is less than 40.
2.2 None of the vehicle components shall be broken. This is including but not limited to the BlueTube, coupler, nose cone, nose cone tip, and fins are in tact with no cracks or breaks.	There have been tests run REF: TESTS on all these components. They were all successful for flight predicted scenarios and should not break.
2.3 Nose cone tip shall have clear vision. Clear vision is defined as sufficient for the Raspberry PI camera to be able to take pictures of the targets which can be successfully identified and differentiated by our program.	We have used images from our sub-scale launch and run the program and it can successfully differentiate between two different colored objects.

2.4 The fins shall be 120 °(± 5 °) away from each other.	The fin jig that we created were 120 °apart and because the fins fit the jig, this requirement is met.
2.5 The fins shall be 120 °(± 5 °) away from perpendicular to the rocket.	The fin jig we created had an error of less than 5 °and because the fins fit the jig, this requirement is met.

3.2 Thoroughness and Validity of Analysis

Most of our predictions and analysis is done using the third party program, OpenRocket. This program provides a thorough report of all parts of the rocket. From component weights to accurate Center of Gravity and Center of Pressure calculations, this program has predictions for the structural build of the rocket and flight simulations. This program has proven to be successful in our sub-scale launch and is why we have deemed it reliable to use for our full-scale launch.

3.3 Drag Assessment

Our estimated drag coefficient for our full-scale flight is calculated to be .63 . This calculation assumed an elevation of 653 feet, based off nearby Telegraph City elevation, which gives us an air density (ρ) of .075 lb/cubic foot. Our actual apogee was recorded to be 4541 feet, using an Aerotech L1150 motor with a burn time of 3.04 seconds and a total impulse of 3489 Newton seconds. Our actual full-scale weight was recorded to be 25.18 pounds without the motor, and 33.3 pounds with the motor. From this information we were able to calculate a maximum velocity of 647.28 ft/s as well as a drag coefficient of .63 .

3.4 Scale Modeling Results

3.4.1 Design Overview and Integrity

Two main aspects are considered in evaluating the integrity of our design: the integrity of each individual part, and integrity of the entire assembly. For each individual part, it is important that the material it is constructed from is able to withstand the necessary loads.

The airframe is primarily is constructed from Blue Tube. Blue Tube is a very strong composite that is resistant to high impact fractures and shattering. This is preferable not only for reuse but also for safety and waste management.

The fins are constructed from G10 fiberglass. Fiberglass is well known to be able to withstand high forces and take hard impacts. For these reasons, the nose cone will also be constructed from fiberglass.

The motor mount is made of phenolic. Phenolic is very heat resistant and a good insulator which will protect the outer airframe from heat damage. Finally, the centering rings and bulkheads are constructed from plywood, which needs to be light and strong. A motor retainer will be epoxied to to the aft end of the phenolic tube to prevent the motor from coming loose during flight.

All bulkheads and centering rings will be constructed from thick plywood. Plywood offers sufficient strength and is capable of withstanding the loads that are expected to be experienced during flight. Additionally, plywood is very light, so its strength to weight ratio is quite high. The bulkheads and centering rings will be cut using a CNC laser wood cutter, allowing precision in size and shape. The different sections are connected using coupler tubes which are also constructed from blue tube and are attached using JB Weld epoxy.

An OpenRocket model of the rocket can be viewed in Figure 1. A CAD model of the rocket can be viewed in Figure 2. The rocket has an overall length of 103". The payload section includes a 24" nosecone and an 18" length of tube. Within the payload is a camera mounted to the nosecone, a Raspberry Pi microprocessor mounted in the nosecone, altimeters, GPS, landing legs, and three parachutes. The avionics bay consists of a 15" length of tube. Within the avionics bay are all recovery electronics, including two altimeters and a GPS device. The recovery section, an 18" length of tube, contains the drogue and main parachutes. The booster section, which is 27" long, contains the motor. All centering rings and bulkheads are 1/4 inch thick pieces of plywood. Centering rings are used to hold the motor mount in place. Bulkheads separate the booster and the avionics bay from the recovery section, and the payload from the avionics bay. Two 1515 rail buttons are attached to the main airframe, allowing the rocket to be launched off of an 8 or 12 ft 1515 launch rail.

Figure 1: Full Scale OpenRocket Model

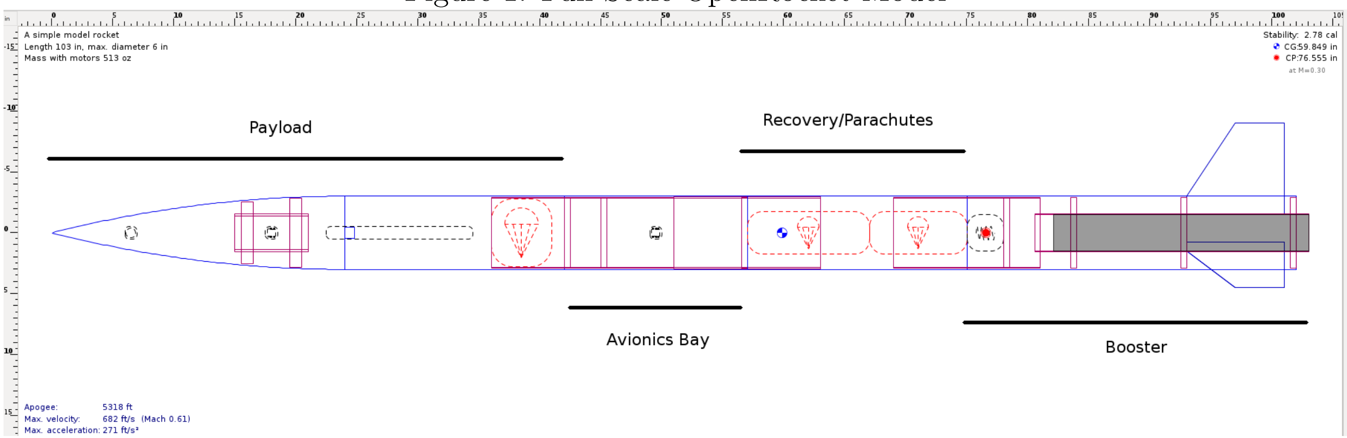
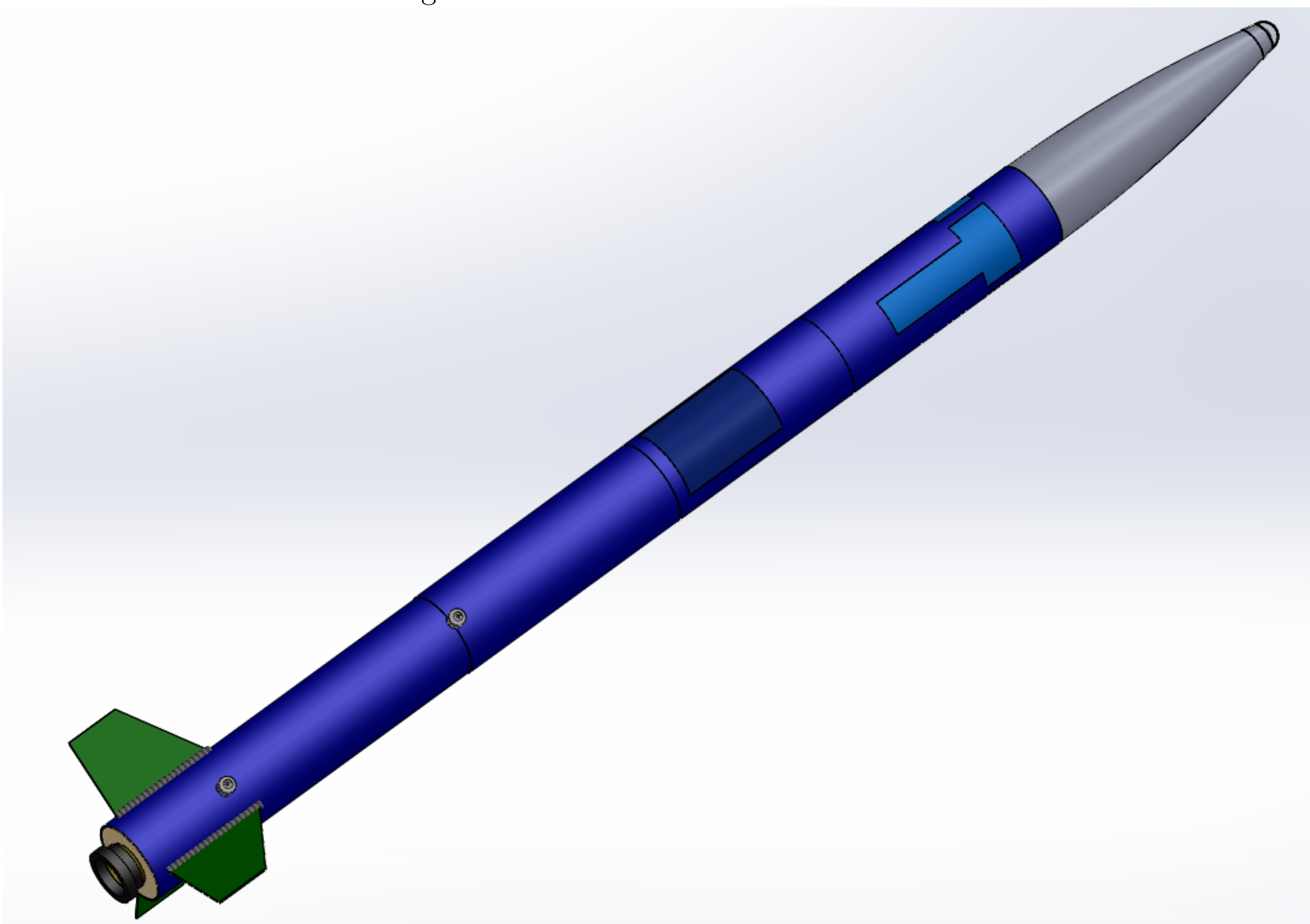
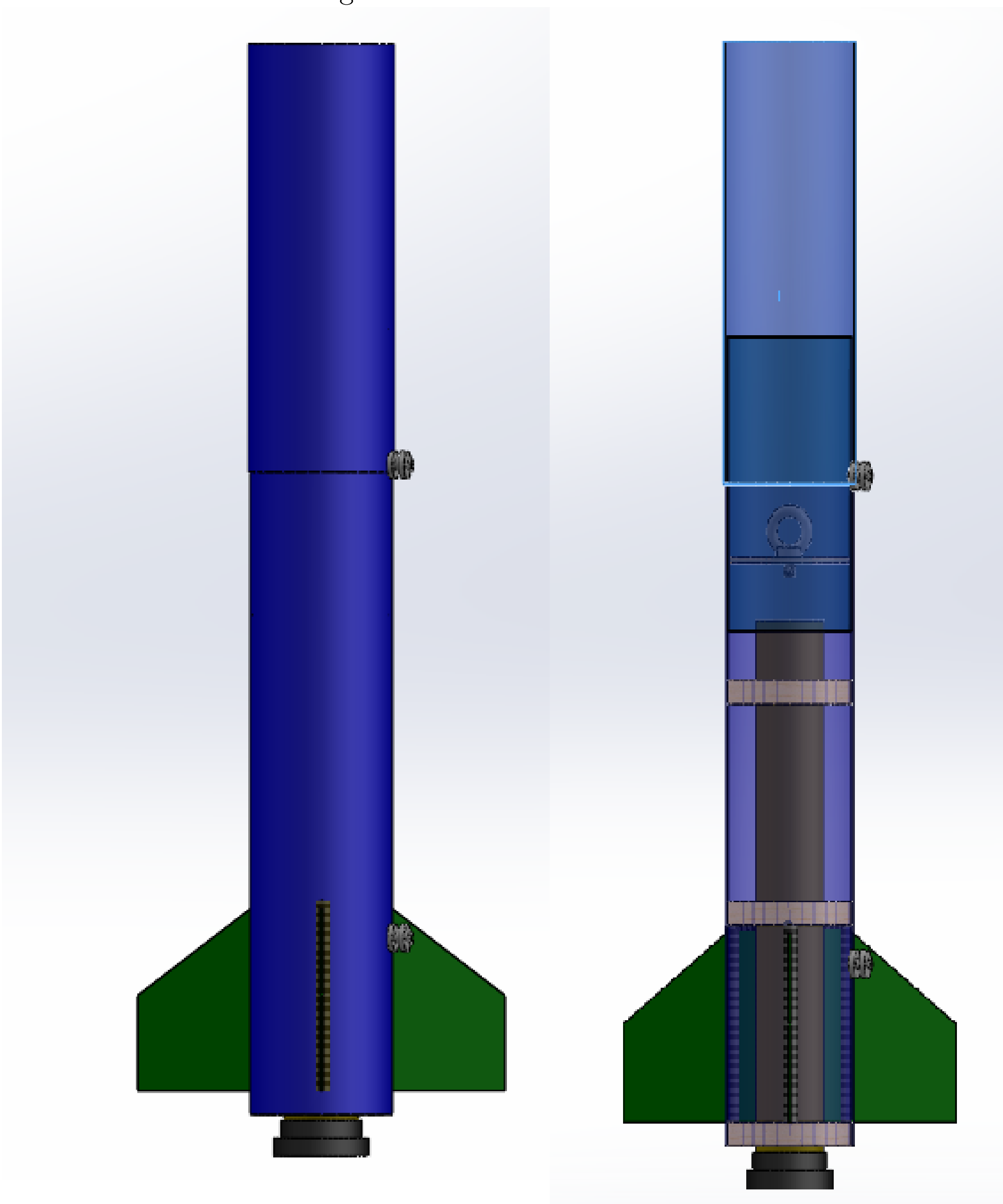


Figure 2: Full Scale Rocket CAD Model



A CAD model of the booster and its internals can be viewed in Figure 3. A dimensioned drawing of the booster and parachute section can be viewed in Figure 4. The fins will be trapezoidal delta fins with a root chord of 8”, a tip chord of 4”, and a height of 6”. The trapezoidal delta shape has been chosen due to its relatively low induced drag compared to rectangular fins. Although the induced drag caused by smoother, more curved fins is lower than the drag caused by delta fins, the simple design of the delta fin was chosen in order to ease the construction process as well as ensure that the fins are as similar as possible in shape. Three fins are used, as they provide sufficient stability. Four fins provide marginally more stability, but increase weight and drag.

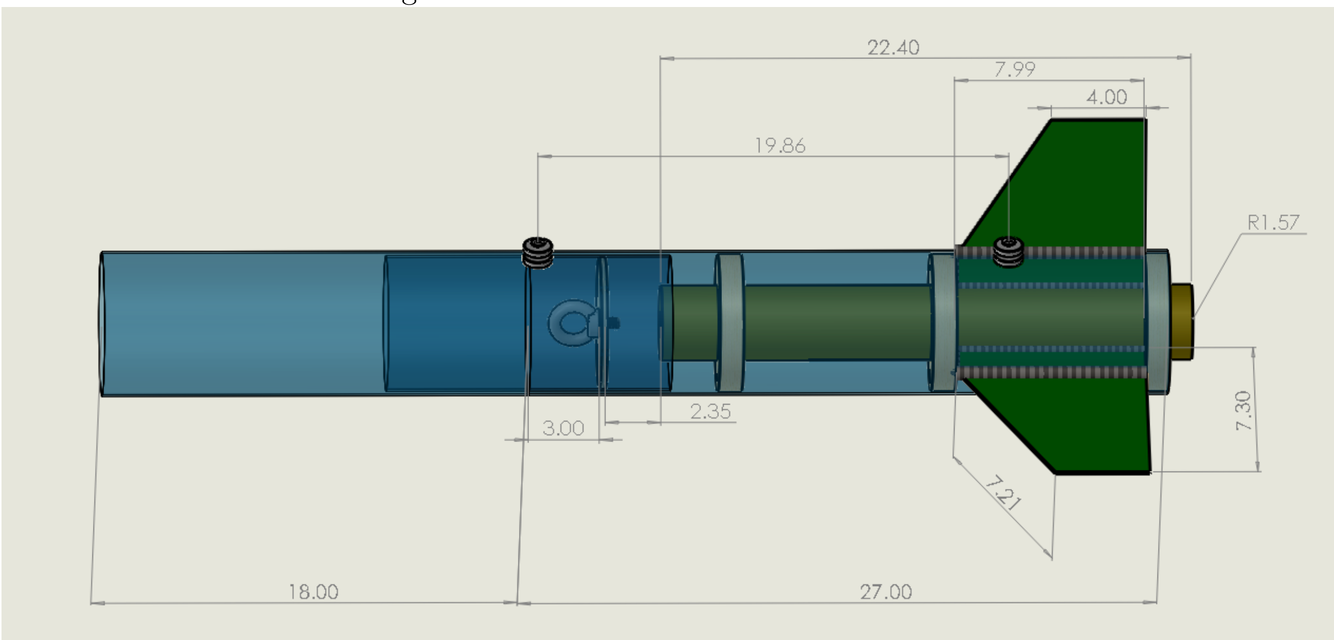
Figure 3: Booster CAD Model



The estimated weights of the various sections of the rocket are displayed in the following table.

Section	**Weight (lb)**
Payload (including nosecone)	10.1
Avionics Bay	4.68
Booster/Booster+	10.4
Total	**33.3**

Figure 4: Booster Dimensioned CAD Model

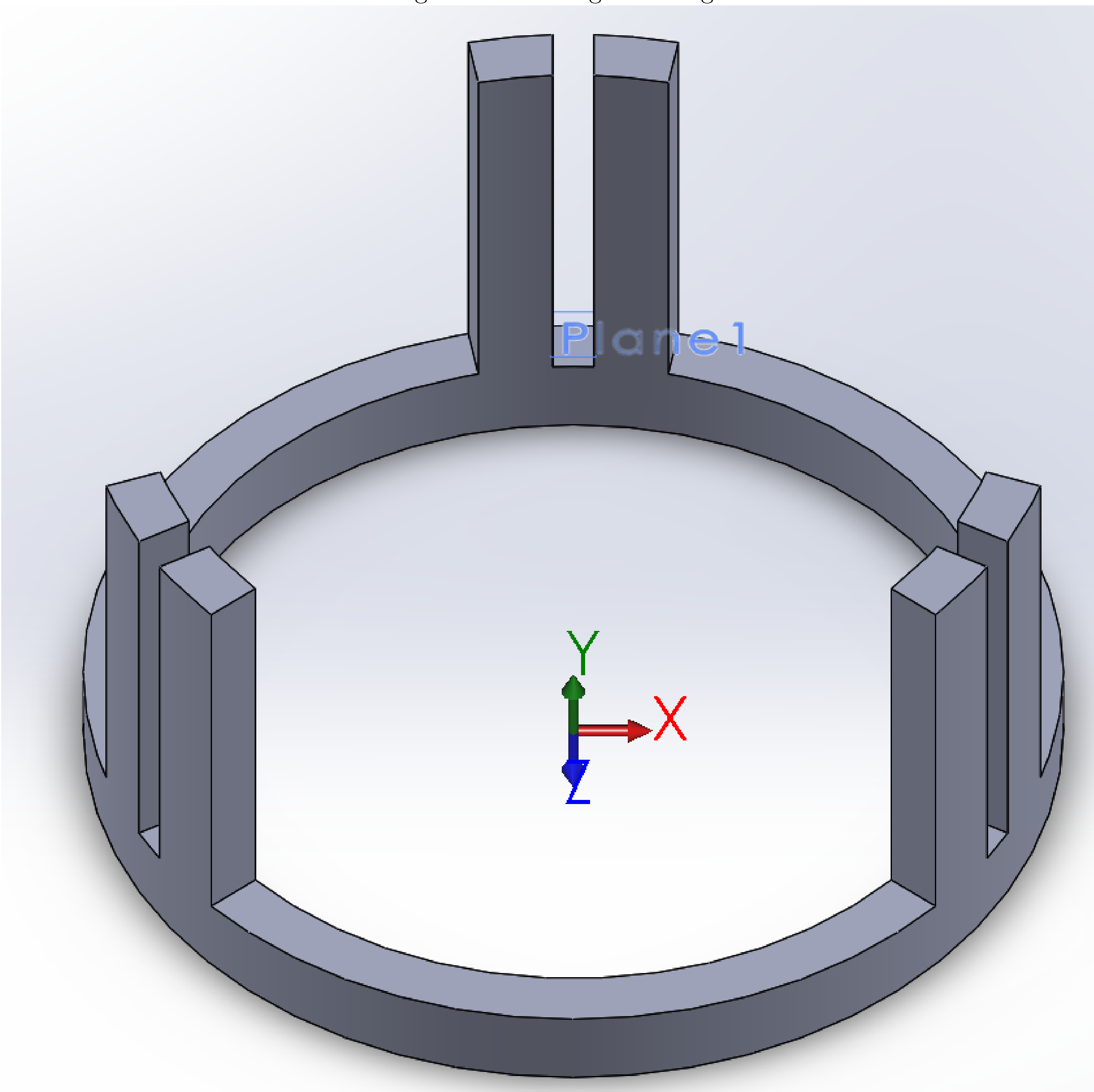


3.5 Construction of Vehicle

3.5.1 Booster/Booster+

The construction of the booster began with a 27 inch length of 6 inch diameter BlueTube. Three ten inch fin slots were cut at the end of the tube. The slots were cut using a table saw. The slots were aligned at an angle of 120 degrees using a 3D printed jig.

Figure 5: Slot Alignment Jig



The motor mount began with a 21 inch length of 3 inch diameter phenolic tubing. Two centering rings were glued onto the tube. The centering rings were cut using a laser cutter. The first ring was epoxied to the motor mount a distance of ten inches from the fore end. The second ring was epoxied a distance of 9.5 inches from the aft end. The motor mount was then placed and epoxied into the booster tube. The aft end of the motor mount extended from the booster tube by one inch.

After the motor mount was glued into the booster, the fins were glued to the motor mount. Epoxy was applied to the phenolic tube and the fins were slid into the slots onto the phenolic. The fins were held in the correct position using a laser cut alignment jig and a hose clamp.

Figure 6: Fin Alignment Jig

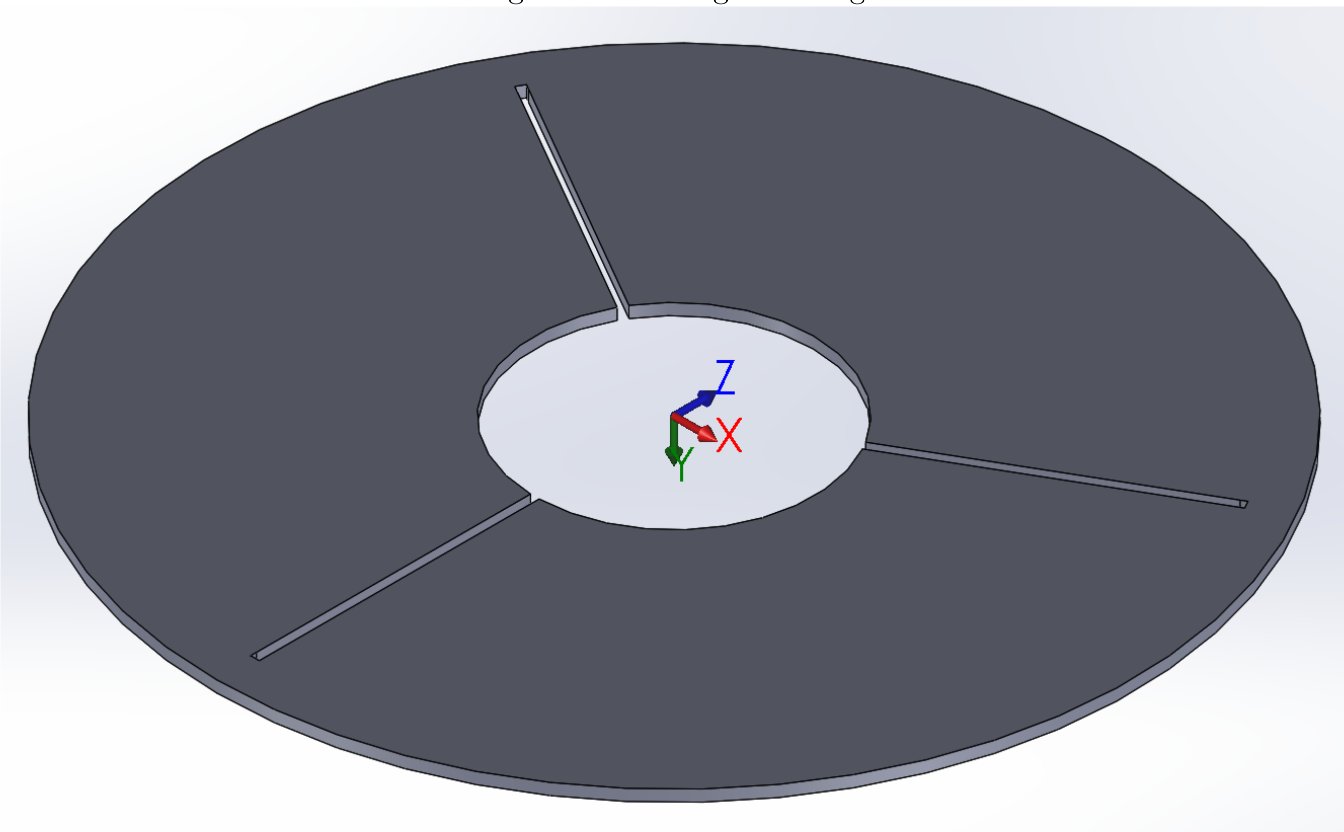
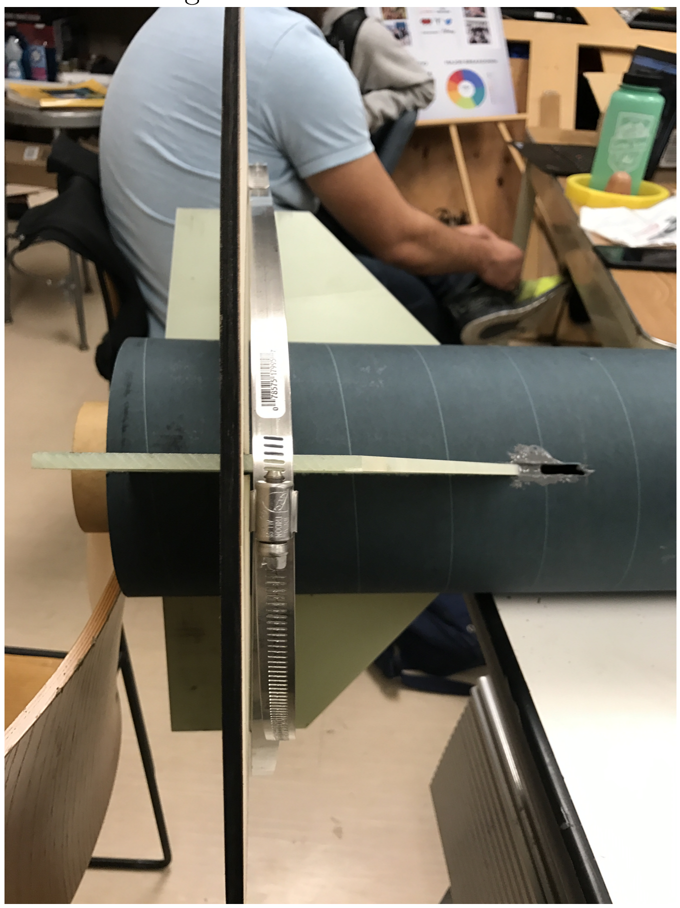


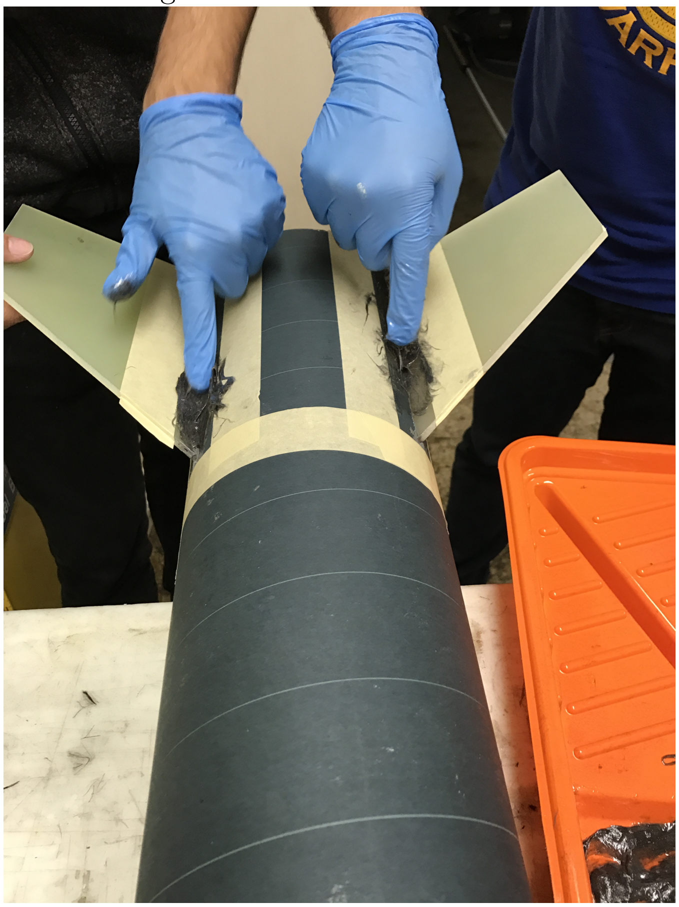
Figure 7: Fin Construction



Once the epoxy had set, a third centering ring was glued to the aft end of the motor mount so that one face was against the fins and the other face was flush with the aft end of the blue tube. The screw-on motor retainer was glued to the protruding section of the motor mount. Additionally, a bulkhead was glued into the booster to the fore end of the motor mount. A U-bolt was screwed to the bulkhead, which is connected to the parachute shock cords during flight. A 12 inch coupler tube was also glued into the fore end of the booster. The placement of the objects in the booster was done such that the motor mount, bulkhead, and coupler had no empty space in between them in order to maximize both space efficiency as well as provide structural integrity.

Afterwards, carbon fiber fillets were added to the fins in order to increase structural integrity. Small carbon fiber strips were mixed with West System 105/205 epoxy resin and then applied to the fins.

Figure 8: Carbon Fiber Fillets



The booster+ section of the rocket was an 18 inch length of Bluetube. The tube was connected to the the booster via the booster's coupler tube. The booster+ was secured using three 1.5 inch M4 nuts and bolts.

Figure 9: Fin Alignment Jig

3.6 Recovery Subsystem

3.6.1 Terminology:

- **Avionics Bay** (also known as Av-Bay) - refers to the entire completed section of the rocket that houses the altimeters

- **Booster+** - This refers to the airframe tube between the av-bay and booster sections that houses both the main chute and drogue chute, both L2 Tender Descenders, and all the shock cords, and the black powder charges. The booster+ section is screwed together with the booster section and connected to the a-bay with one 4-40 shear pin

- **Stingray** - The main parachutes parachute bag

- **BAY-to-MAIN (B2M)** - This is the shock cord length between QL_1, which is attached to the Av-Bay, and the main chute. This is stored as a closed loop and will not be extended until after the Tender Descender Charges are released.

- **MAIN-to-DROGUE (M2D)** - This refers to the length of shock cord between the Main Chute and the Drogue Chute. It is pulled out during the first Av-Bay and Booster section separation stage when the drogue chute catches air.

- **DROGUE-to-BOOSTER (D2B)** - This refers to the length of shock cord between the Drogue Chute and QL_3, which is directly attached to the Booster section of the rocket. Like the M2B, it is also pulled out during the first two stage separation.

3.6.2 Structural Elements

Bulkheads

The bulkheads used on both sides of the avionics bay are 1/2" thick, as is the bulkhead in the booster section. However, each bulkhead is slightly different in structure. The bulkhead dividing the Av-Bay and the Payload has a consistent diameter throughout such that it sits flush inside the coupler tube inside the Av-Bay. It is consisted of two 1/4" plywood bulkheads epoxied together with J.B. Weld. This sits on top of a supported frame of 3/4" near the top of the Av-Bay, in order to ensure that the impact from the payload ejection charge does not infringe upon the recovery section. The bottom bulkhead dividing the Av-Bay and the Booster+ section is fit completely flush inside and outside of the Av-Bay. Thus, there are two diameters for this bulkhead: one that matches the diameter of the coupler, and one that fit insides the coupler tube. Each has a thickness of 1/4", and both were epoxied together with J.B. Weld. This ensures easy access to the U-Bolt when attaching the quick links for the dual deployment systems. These worked well in both the ground tests and full-scale flight. Both the booster bulkhead and the lower avionics bulkhead have a 5/16" u-bolt that is used to attach the quick links of the recovery section. There are able to withstand the forces applied by the recovery harnesses. The upper bulkhead of the avionics bay is prevented from moving by a $\frac{3}{4}$" ring that is also secured via JB weld to the inside of the avionics bay. This bulkhead is attached to the lower bulkhead with $\frac{1}{4}$-20 threaded rods. Combined, the bulkhead system provides a sturdy, reliable, and tested component to the success of our recovery section.

Dual Deployment System

1. The following orientation will be described in order beginning from the Av-Bay section to the Booster.
2. Two L2 Tender Descenders (TD) linked together in series
   (a) Will be designated as TD1 for the TD located closest to the Av-Bay and TD2 for the TD located after the TD2
   (b) Contains two small quick links on each side of the quick link
   (c) Will eventually contain an E-Match in each
   (d) Contains g of Black Powder in each
3. Shock Cords
   (a) Use one very long length of 1/4" tubular kevlar shock cord, knotted at various distances and attached with quicklinks.
   (b) BAY-to-MAIN (B2M): This is the shock cord length between QL1, which is attached to the Av-Bay, and the main chute. This is stored as a closed loop and will not be extended until after the Tender Descender Charges are released. Its length is 48.75 ft.

(c) MAIN-to-DROGUE (M2D): This refers to the length of shock cord between the Main Chute and the Drogue Chute. It is pulled out during the first Av-Bay and Booster section separation stage when the drogue chute catches air. Its length is 24.58 ft.

(d) DROGUE-to-BOOSTER (D2B): This refers to the length of shock cord between the Drogue Chute and QL3, which is directly attached to the Booster section of the rocket. Like the M2B, it is also pulled out during the first two stage separation. Its length is 12.00 ft.

4. Quicklinks

   (a) QL1 - the one closest to the avionics bay; is connected to the following: 1) U-Bolt connected to Av-Bay, 2) Stingray Main Chute Bag, 3) B2M, 4) TD1

   (b) QL2 - the one connected to the main chute; connected to the following: 1) TD2, 2) Shock Cord to QL1, 3) Main Chute, 4) M2D

   (c) QL3 - the one connected to the drogue chute; connected to the following: 1) M2D, 2) Drogue chute, 3), D2B

   (d) QL4 - the one connected to the booster; connected to the following: 1) D2B, 2) U-Bolt on the Booster Section Bulkhead

5. Parachutes

   (a) Drogue Chute: 24 Elliptical parachute from Fruity Chutes; the red and white one

   (b) Main Chute: 72 Toroidal parachute from Fruity Chutes; the orange and black one

6. Parachute Bag

   (a) Stingray: beige/off-white Kevlar bag with a custom fit pocket to protect the main chute during the black powder ejection charges. This is connected to QL1. The main chute is going to be pulled out of the Stingray when the Tender Descenders release the charges.

7. Parachute Blankets

   (a) Drogue Chute Blanket: Orange blanket that will cover the wrapped drogue chute

   (b) Complete Chute Blanket: Olive-green/gray blanket that will cover the stingray, drogue chute blanket, both tender descenders, and all shock cords excluding the D2B

3.6.3 Electrical Elements

Two different altimeters will be used to ensure the successful deployment of both the main parachute and drogue parachute. These altimeters are different to ensure that any environmental conditions that cause one altimeter will be less likely to make the other altimeter fail for the same reason. Both altimeters will be housed in the avionics bay, and will be screwed onto a 3D printed altimeter platform. Each altimeter will be powered by separate 9V batteries, which will also be secured onto the same altimeter platform. The altimeters, as well their key features, are listed below:

- PerfectFlight StratoLoggerCF:
  - Dual deployment

– Data storage after power shut-off
– Audible continuity checks
– Relays flight data via a series of beeps
– Tolerant to 2 seconds of power loss during flight
– Resistant to false readings due to wind gusts up to 100mph

- Missle Works RRC3 Sport:
  – Dual deployment
  – Data storage after power shut-off
  – Audible continuity checks
  – Relays flight data via a series of beeps
  – Tolerant to small periods of power loss during flight

Both of these altimeters have been extremely reliable in both the subscale and full-scale launch. All charges were successfully deployed in both launches, and altimeters read a nearly identical altitude. The electronics in the avionics section will be connected using 22-gauge wire. The e-match that is connected to TD2 will be connected to the avionics bay with micro deans so that the main parachute will not be hindered from fully opening. Both altimeters are wired to rotary switches that are mounted to the avionics bay door, allowing the altimeters to be armed or disarmed while the rocket is on the launch pad.

3.6.4 Redundancy Features

There are several redundant features built into the avionics bay to be certain that both the main and drogue parachute are deployed. The deployment system features two different altimeters, as described in the previous section, that will lead to a higher likelihood of success in the case that one of the altimeters malfunctions. There will be two drogue deployment charges, in the case that one of the e-matches is faulty. There will be two tender descenders, linked in series, that will allow the main parachute to open in the case that one of them fail. Both altimeters have brown out capabilities, which allow the altimeter to function for a short period of time if power is lost due to a faulty connection with the batteries. 9V Duracell batteries will be used to power the altimeters, as they have welded cells that will not separate under high g-forces.

3.6.5 Parachutes and Descent Rates

When determining the appropriate size of the parachutes, the team used a safety factor of 2, keeping in mind that the payload could fail to detach. In the worse case scenario the main and drogue parachutes would have to be able to slow the descent rate of the booster, avionics, and payload to an appropriate landing velocity. Currently with a 72" toroidal parachute and a 24" elliptical parachute from Fruity Chutes, the rocket would be slowed to 17.79 ft/s if the payload doesnt detach, allowing all sections to land with less that 75 ft-lbf. Another point of concern is the payload parachutes, which with a single 36" parachute will allow it to land under 75 ft-lbf, but with 3 parachutes for stability, it will remain well under that kinetic energy. The calculations for these were done first by hand with the drag equations, and then were put into Python code for quick modifications and changes in weights. As seen in Appendix subsection A.1.

Section	Scenario	Kinetic Energy (ft-lbf)	Landing Velocity (ft/s)
Avionics Bay	Payload Detaches	13.79	13.76
Booster	Payload Detaches	23.15	13.76
Payload	Payload Detaches and 3 parachutes deploy	24.76	13.01
*Avionics and Payload (attached)	Payload does NOT detach	72.70	17.79
*Booster	Payload does NOT detach	38.66	17.79
*Payload	Payload Detaches and 1 parachute deploys	74.27	22.55

Table 4: Kinetic Energy and Landing Velocity for Every Section

3.6.6 Drawings and Schematics

Drawings and schematics of the electrical and structural assemblies can be found below:

Figure 10: Avionics Bay

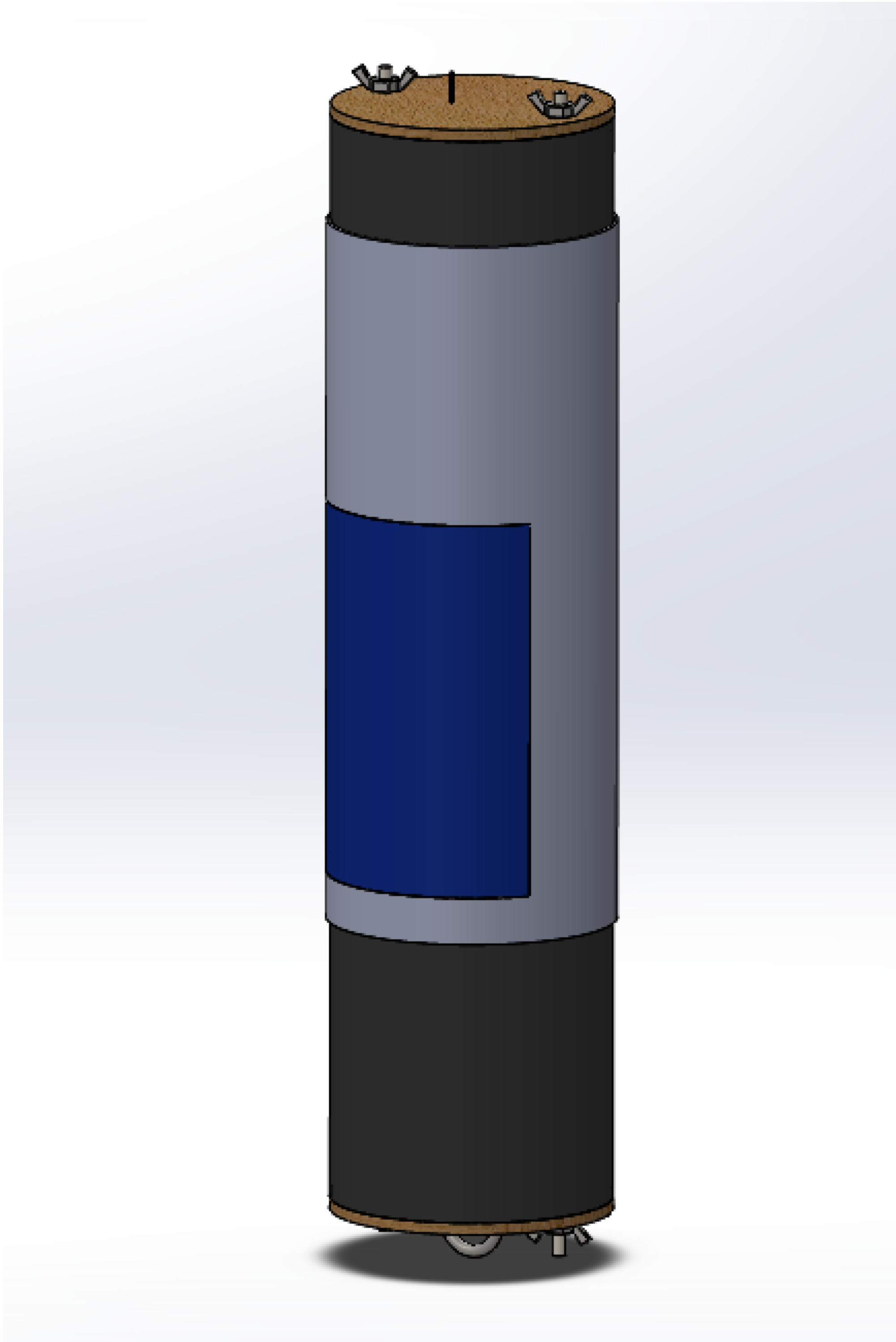


Figure 11: Avionics Bay Without Door

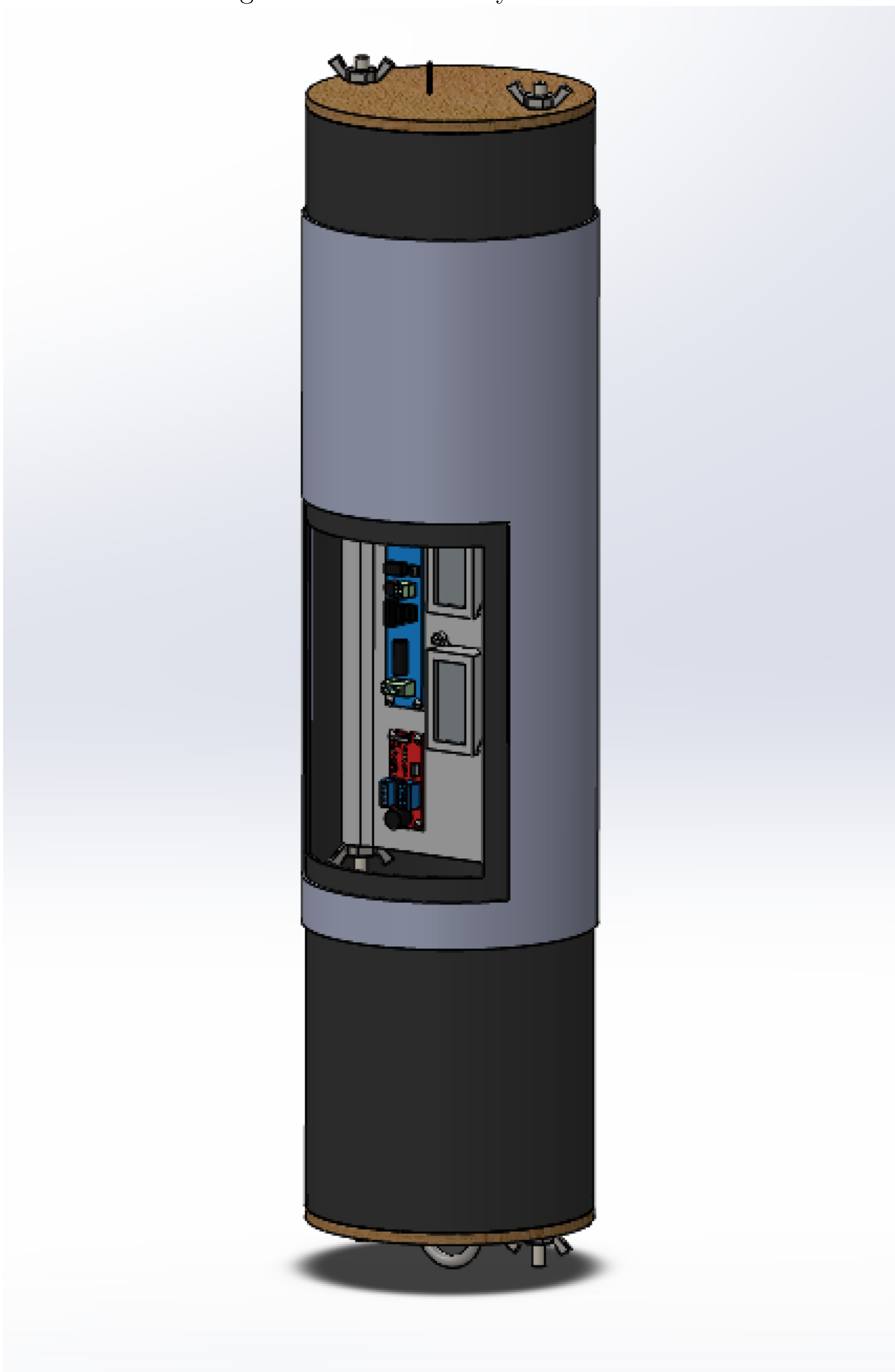


Figure 12: Avionics Bay Without Door (Close Up)

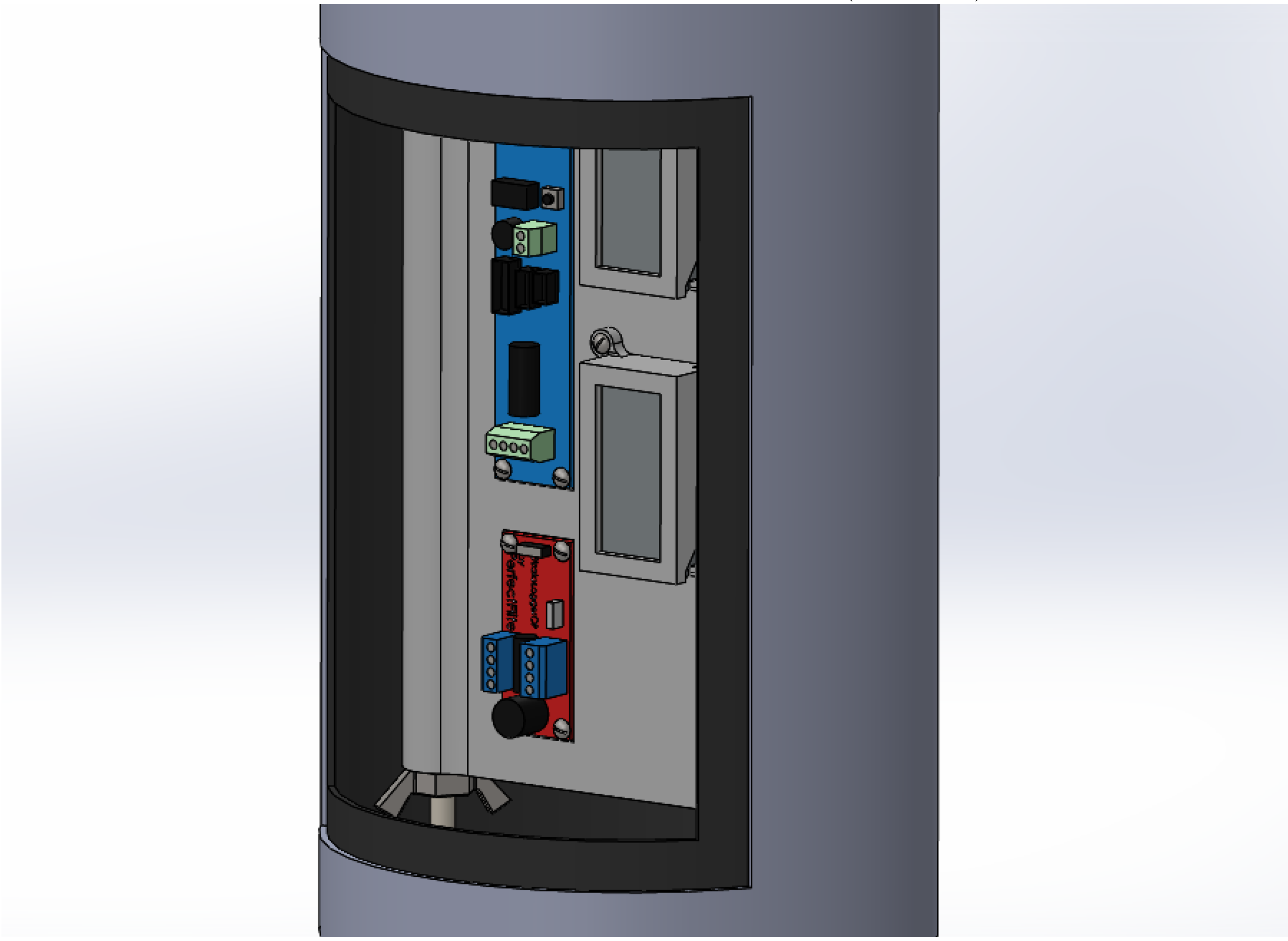


Figure 13: Avionics Bay Internals

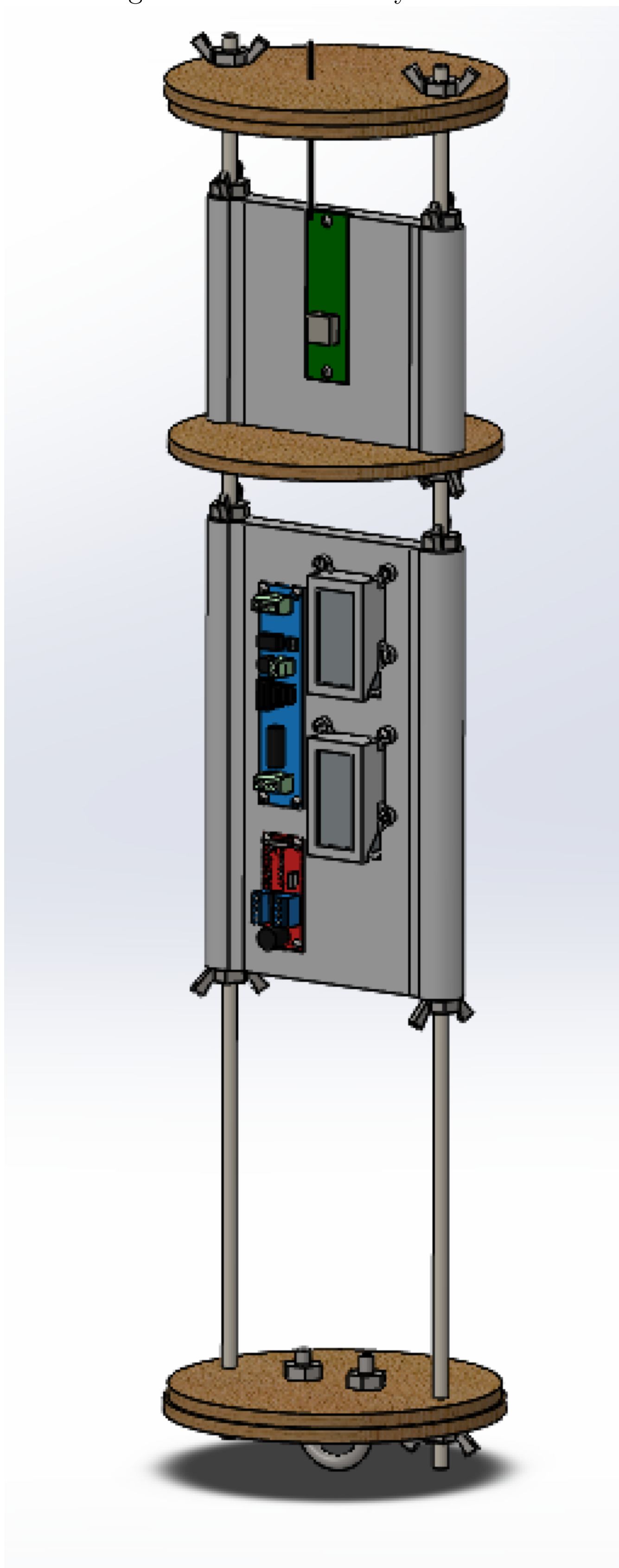


Figure 14: Altimeter Sled

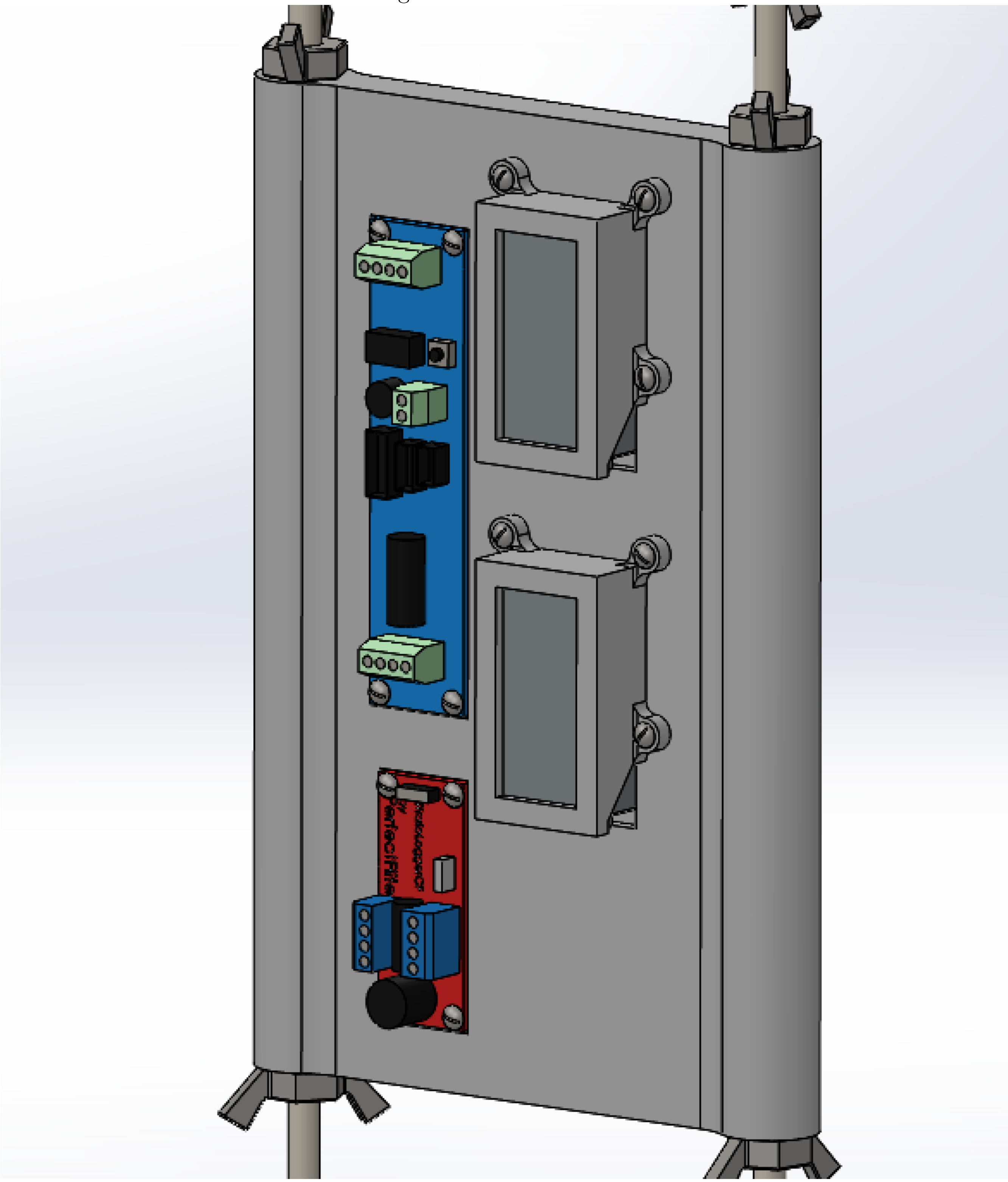


Figure 15: GPS Sled

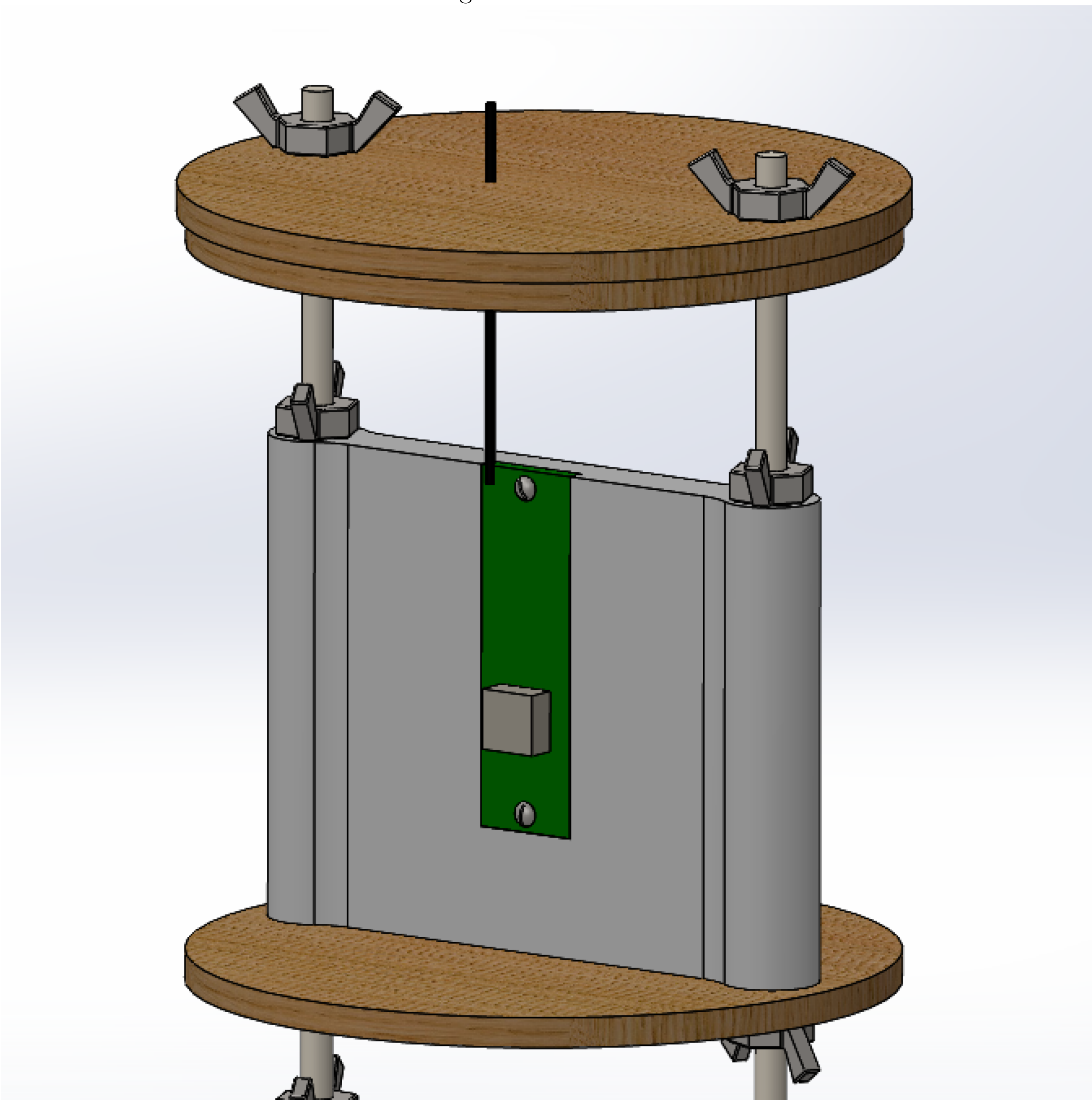


Figure 16: Dimensioned Avionics Bay

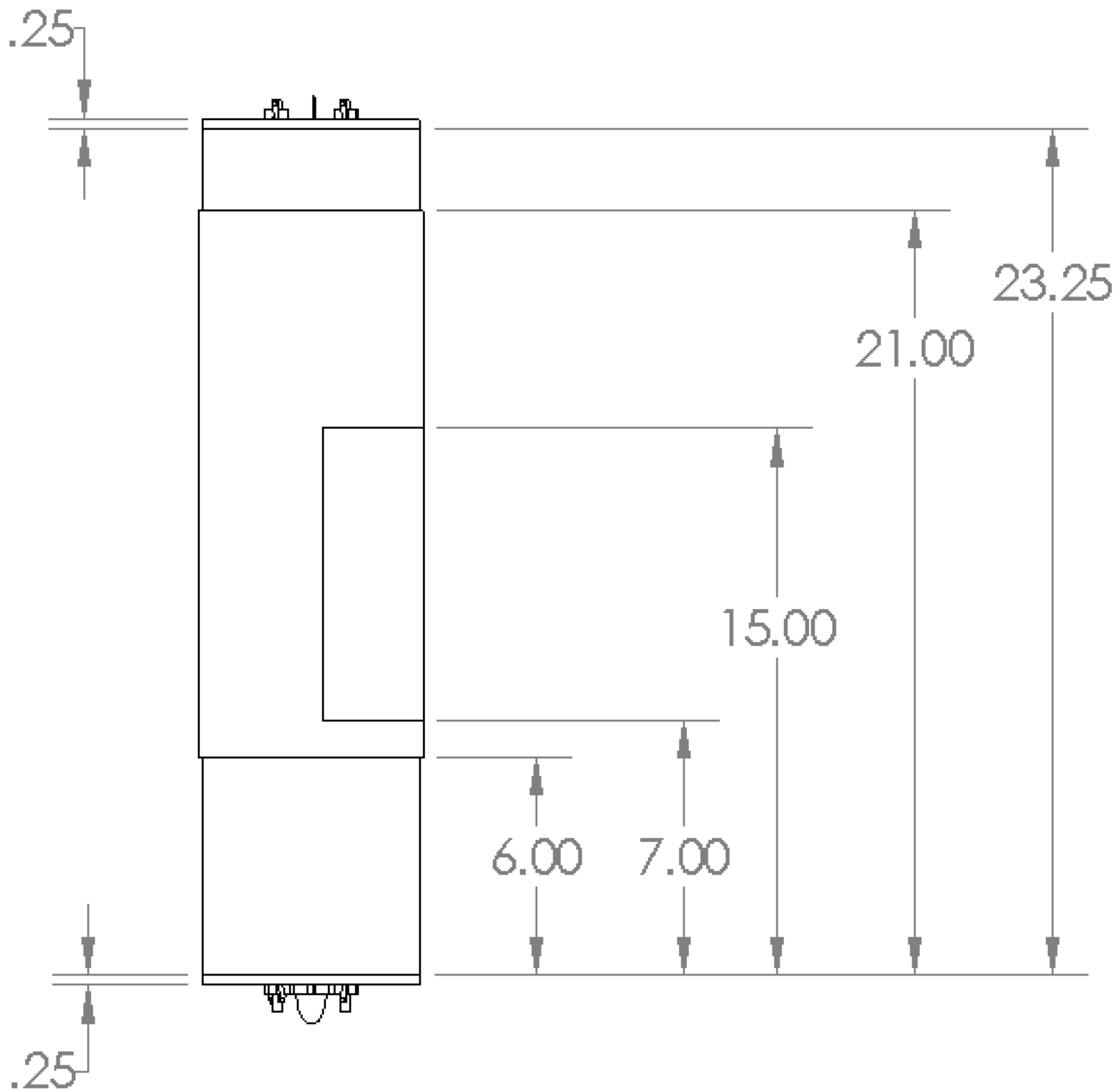


Figure 17: Dimensioned Avionics Bay Internals

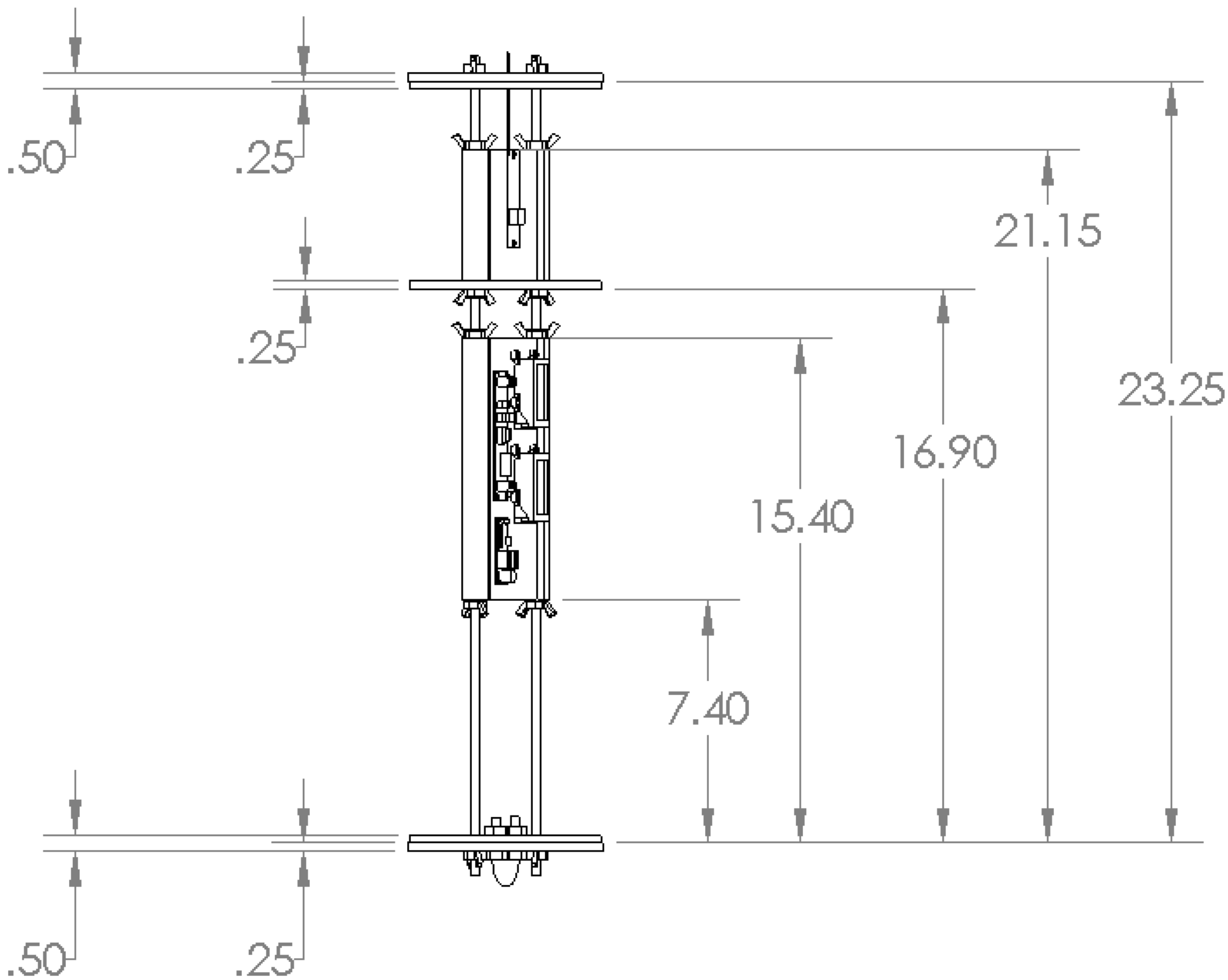


Figure 18: Dimensioned Altimeter Sled

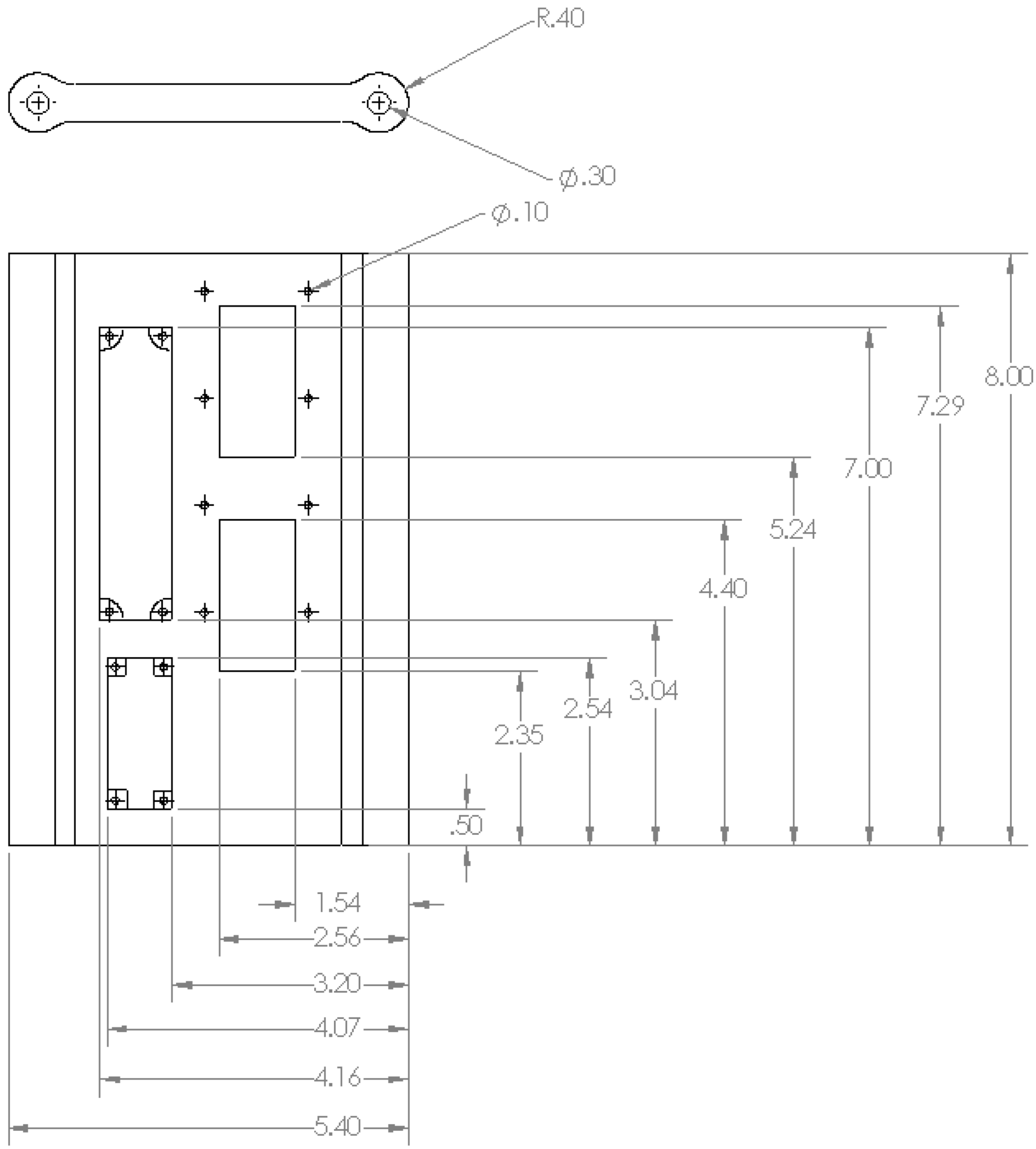


Figure 19: Dimensioned GPS Sled

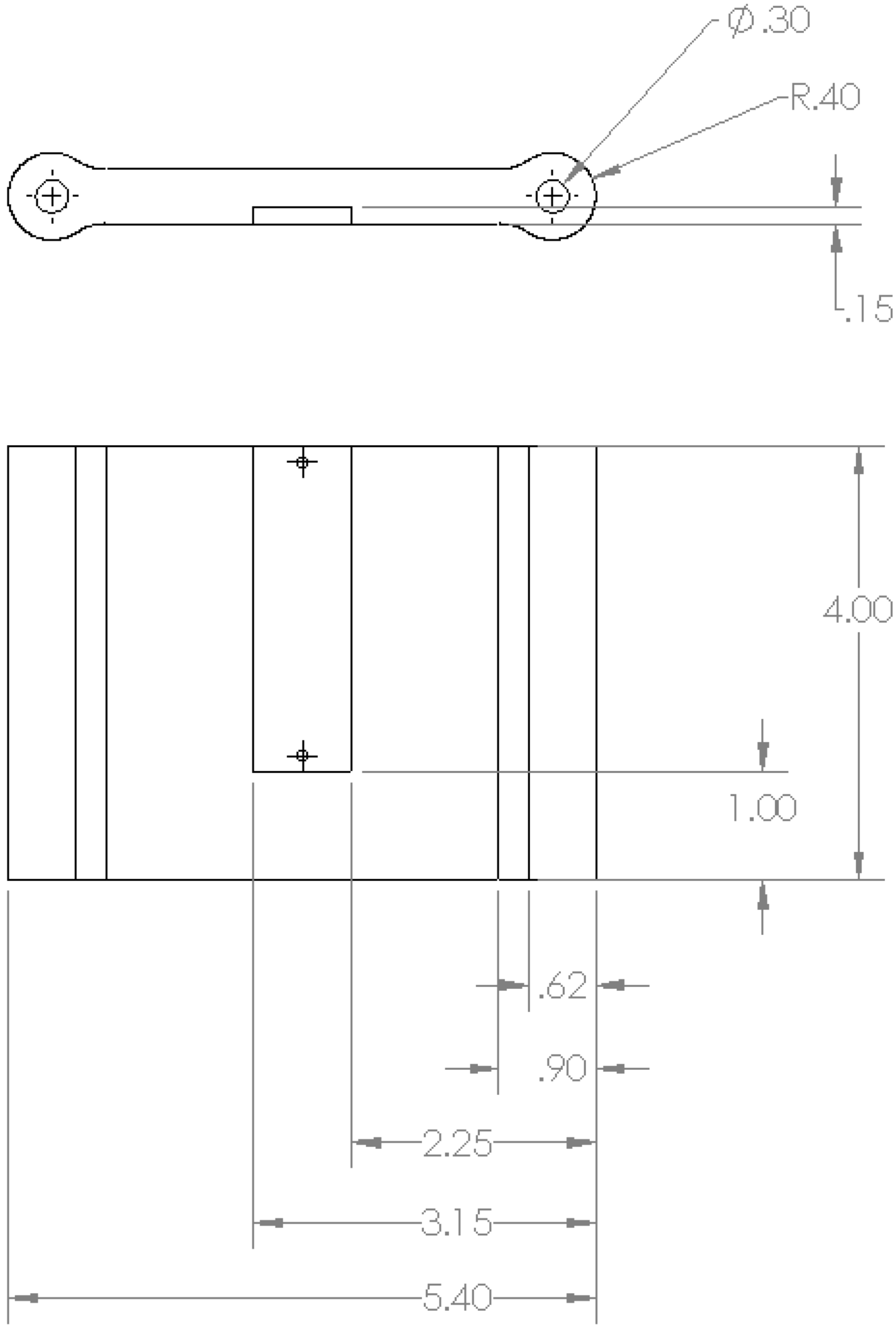


Figure 20: Altimeter Electrical Schematic

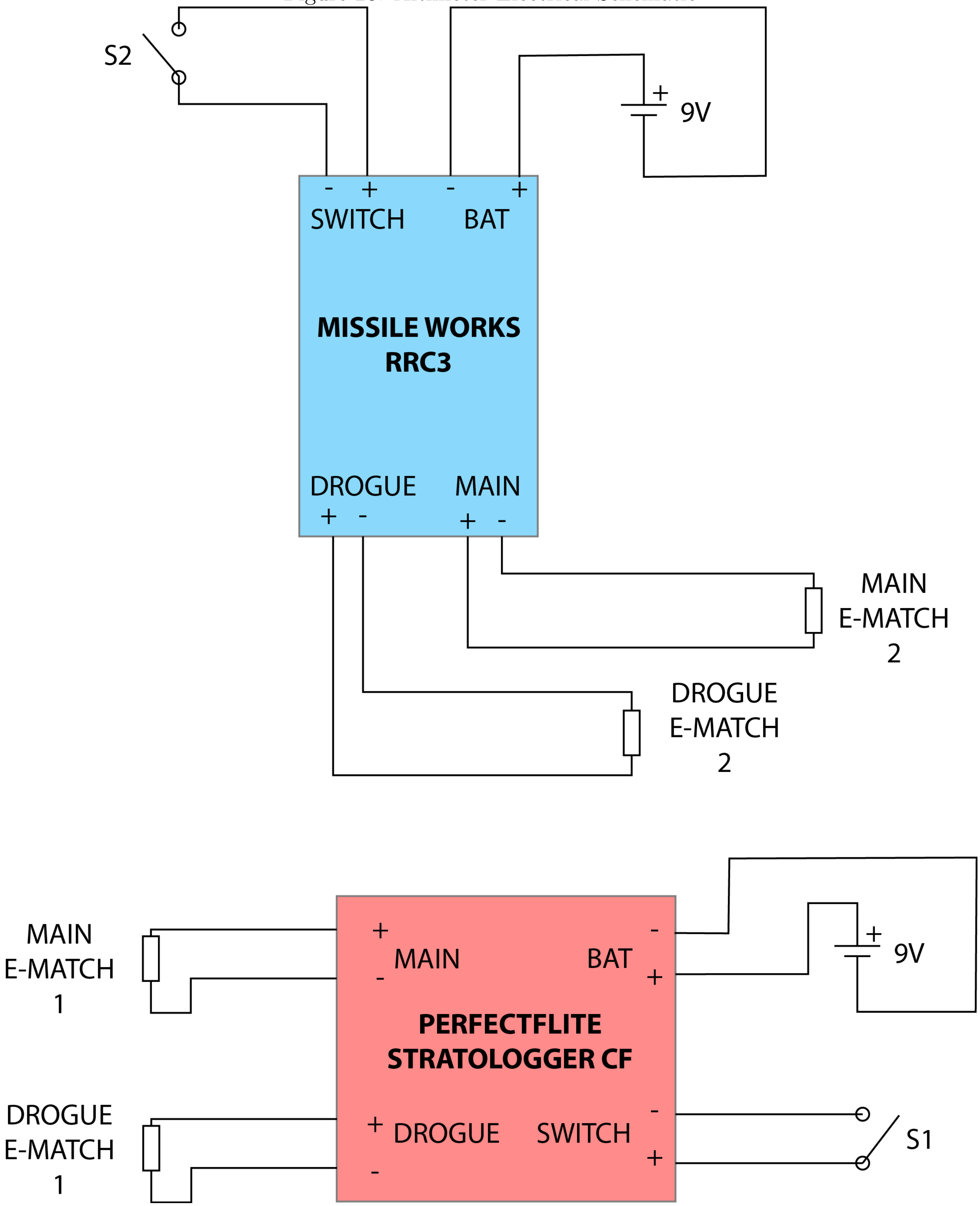


Figure 21: Avionics Bay Without Door

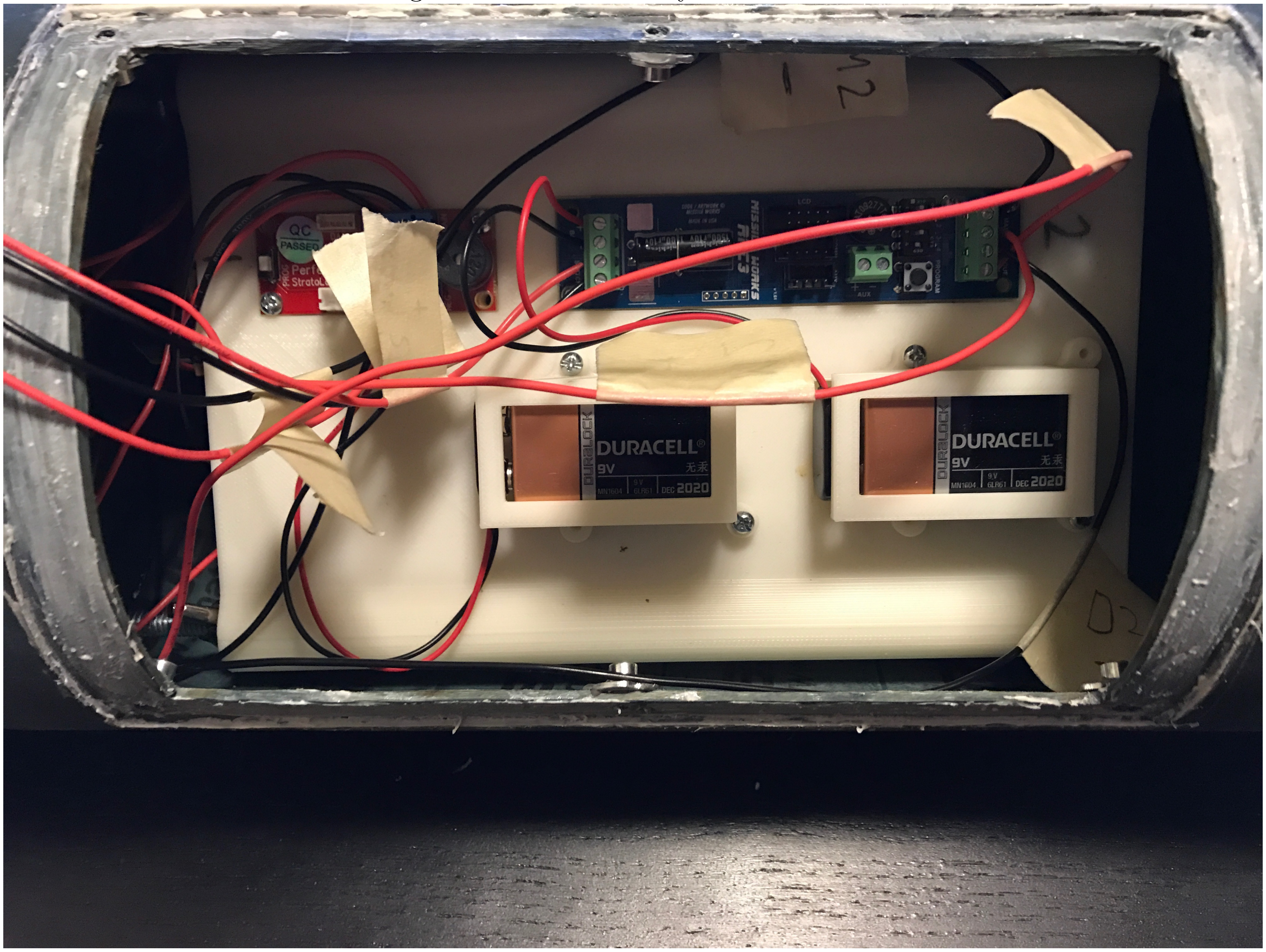
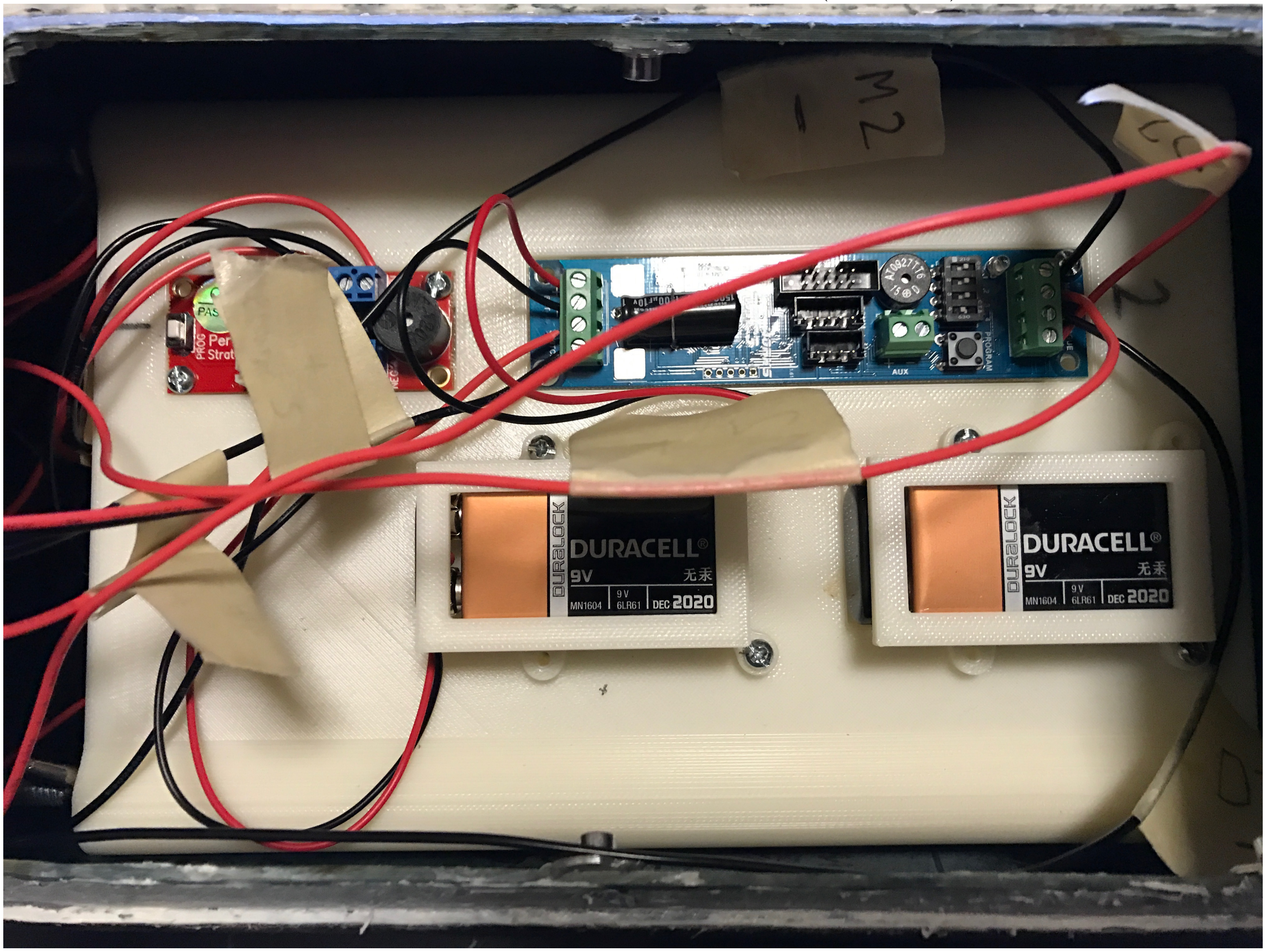


Figure 22: Avionics Bay Without Door (Close UP)



3.6.7 Rocket Locating Transmitters

The GPS system used the track the avionics bay and booster is the Eggfinder TX Module, which operates at 923.000 MHz. This GPS has a clear-air operating range of 8,000 feet, which is well over the maximum drift limit. The GPS will be powered by a 2S 7.4V LiPO Battery, and experiences a current draw of 70mA - 100mA while operating, and 10mA - 20mA while on standby. This gives the GPS a maximum operating wattage of 0.74 Watts. This GPS has been found to be fairly reliable during testing. It will be separated from the altimeters by a bulkhead, but mounted on the same rail system.

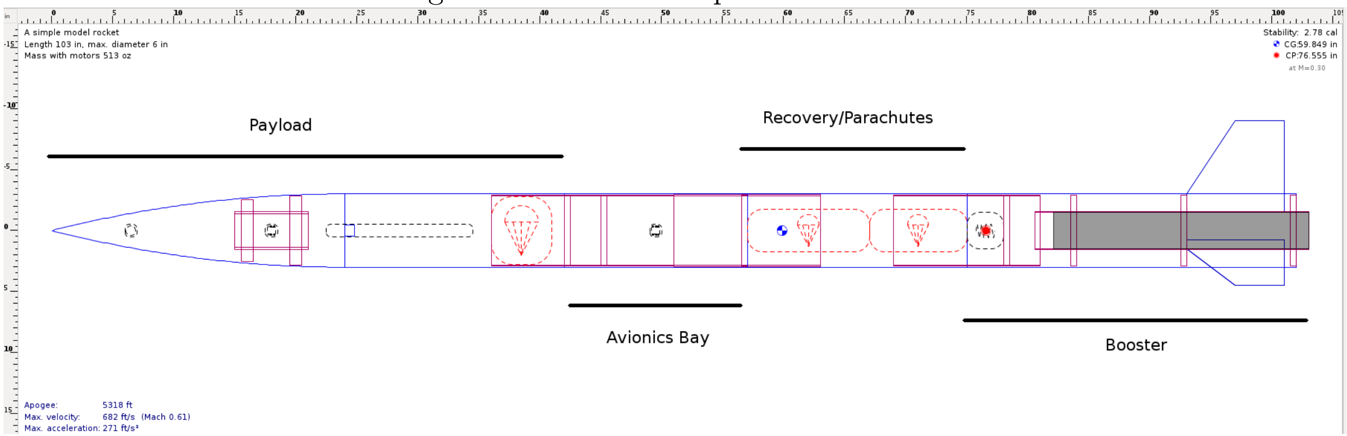
3.6.8 EMF Sensitivity

None of the altimeters in the avionics section are sensitive to the minimal amount of EM radiation from the transmitting GPS. This has been verified through testing, and none of the altimeters have experienced any sort of malfunctions when placed near the live GPS system. However, the GPS system and altimeters will be separated by bulkhead to ensure that there is no interference between the altimeters and GPS during flight.

3.7 Mission Performance Predictions

Full scale flight data is simulated using the OpenRocket software. Figure 23 shows the design in OpenRocket with each section labeled.

Figure 23: Full scale OpenRocket Model



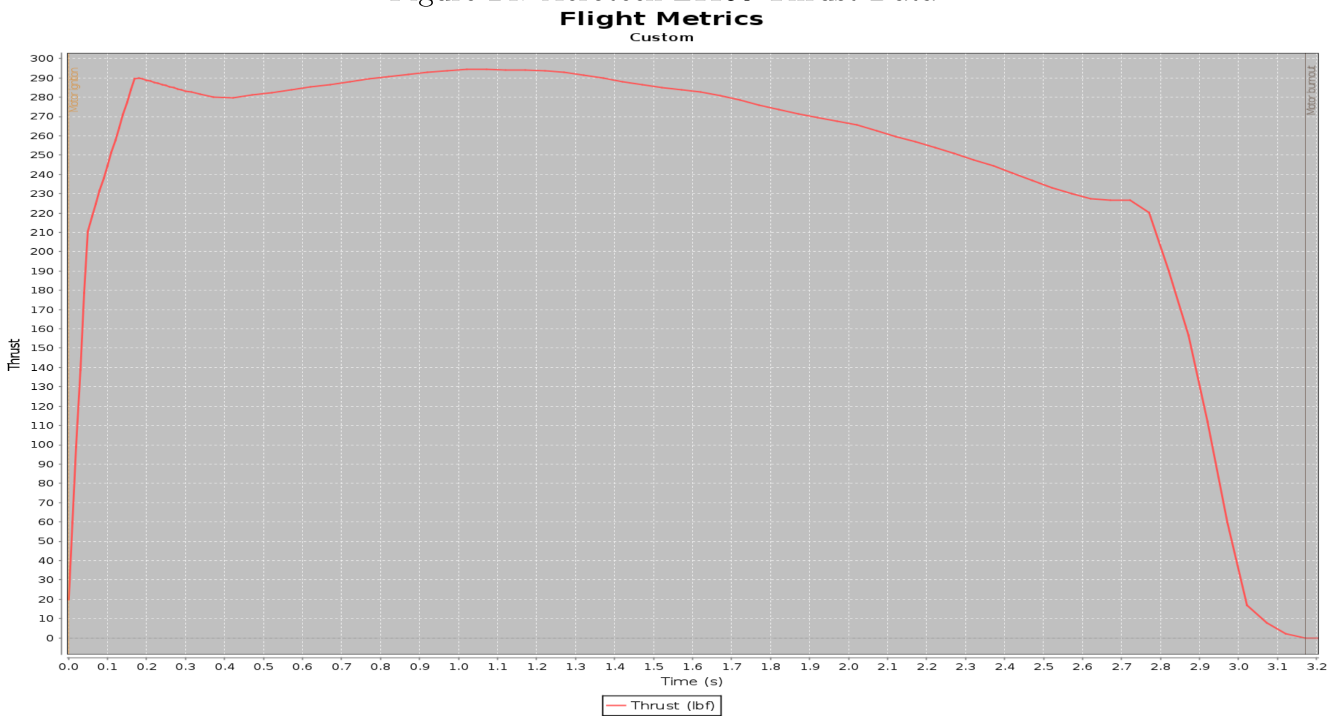
3.7.1 Motor

The full scale motor is an Aerotech L1150, which utilizes a solid ammonium perchlorate composite propellant. The simulated thrust curve is illustrated in Figure 24. The motor has a burn time of 3.17 seconds, a total impulse of 784 lbf-s, an average thrust of 247 lbf, and a peak thrust of 294 lbf. Motor data is displayed in the following table[1].

Class	36% L
Diameter	2.95 in
Length	20.9
Propellant	APCP
Propellant Weight	4.55 lb
Average Thrust	247 lbf
Peak Thrust	294 lbf
Total Impulse	784 lbf-s
Burn Time	3.17 s

[1] "Aerotech L1150R." Aerotech L1150R Rocket Motor Data. RocketReviews, n.d. Web. 06 Jan. 2017.

Figure 24: Aerotech L1150 Thrust Data



3.7.2 Pre-Flight Data

The weights of the individual rocket sections are shown in the following table.

Section	**Weight (lb)**
Payload (including nosecone)	10.1
Avionics Bay	4.68
Booster/Booster+	10.4
Total	**33.3**

OpenRocket simulations show the center of gravity to be 59.85 (CHANGE NOT ACCURATE) inches aft of the tip of the nose. The center of pressure is located approximately 76.56 inches aft of the tip of the nose. The static stability is given by

$$Stability = \frac{CP - CG}{D_m}$$

where
CP is the location of the center of pressure,
CG is the location of the center of gravity,
D_m is the maximum diameter of the rocket.
Using this formula, the static stability is approximately 2.78 calibers.

3.7.3 Flight Profile Simulations

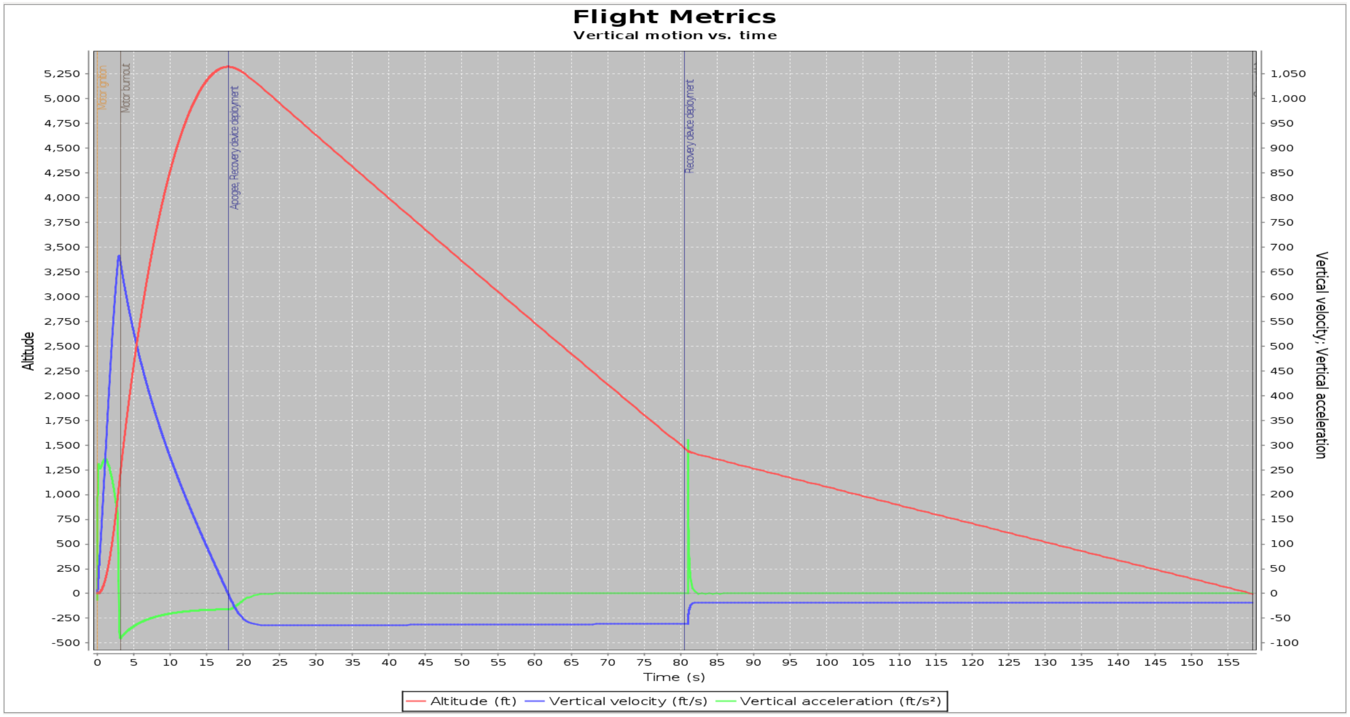
Flight profile simulations were conducted with zero wind and International Standard Atmospheric conditions. The simulated rocket is launched at a vertical angle off of a 12 foot rod. The OpenRocket simulation uses the extended Barrowman method for calculations. The simulation is conducted using a 6-DOF 4th order Runge-Kutta algorithm. Geodetic calculations approximate the earth as a perfect sphere.

Results of the simulation are shown in the following table.

Apogee	5131 ft
Velocity off Rod	62.9 ft/s
Velocity at Chute Deployment	62.6 ft/s
Maximum Velocity	656 ft/s (Mach 0.61)
Maximum Acceleration	260 ft/s^2
Ground Hit Velocity	18.8 ft/s
Time to Apogee	17.8 s
Flight Time	152 s

The simulated apogee is 5322 feet, 42 feet more than a mile, which is a percent difference of 0.8. The maximum velocity is Mach 0.61, well under the maximum of Mach 1 as stated in the NASA SL Handbook. The maximum acceleration experienced by the rocket is 8.5 Gs. A graph of the flight profile can be viewed in Figure 25.

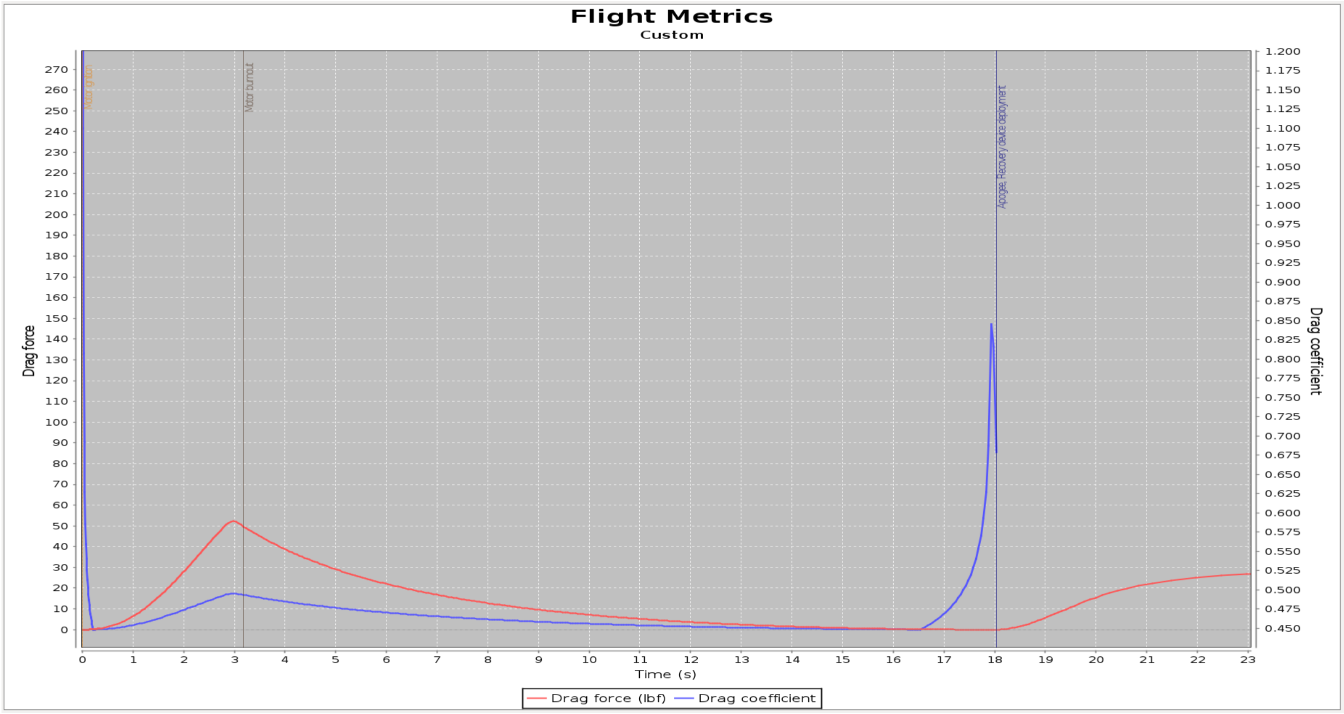
Figure 25: Rocket Flight Profile



The maximum velocity occurs just before motor burnout. The highest accelerations occur at motor ignition and at the main parachute deployment. The largest changes in acceleration occur at motor ignition, motor burnout, and main parachute deployment.

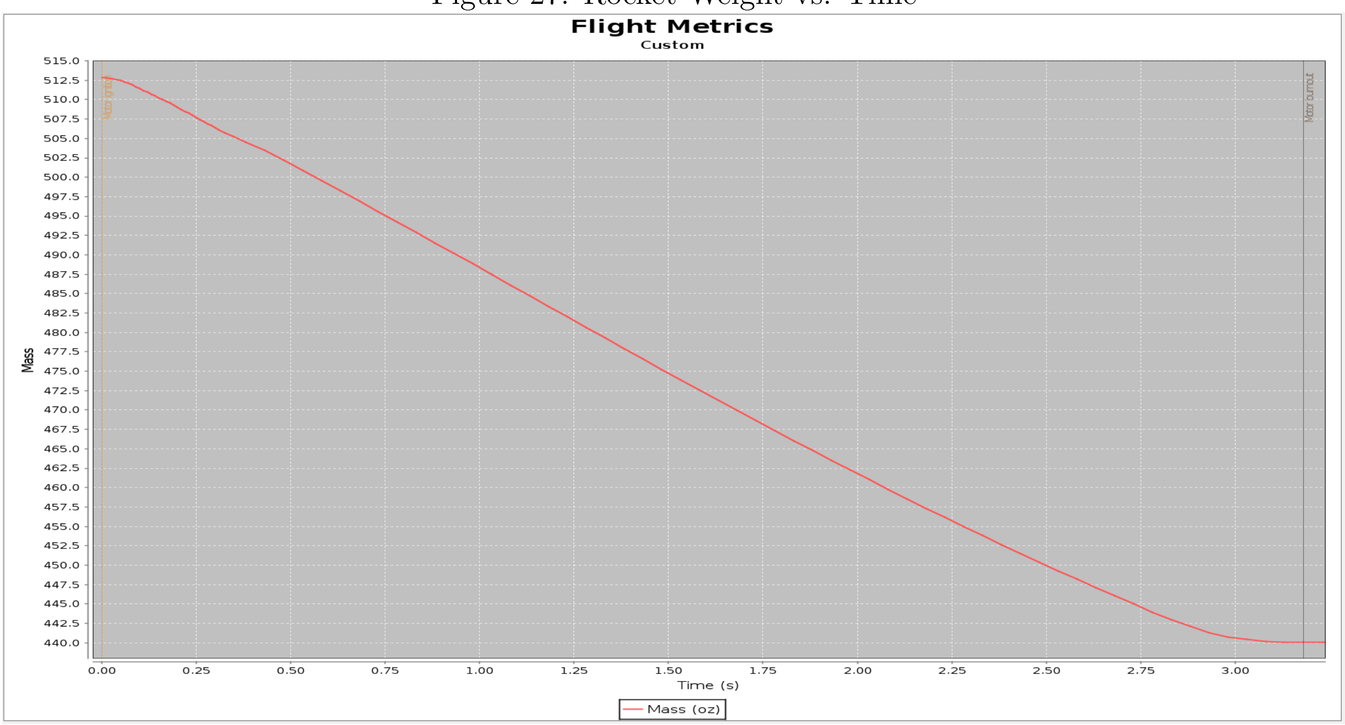
Drag simulation data is illustrated in Figure 26. The maximum drag coefficient during flight occurs just before apogee, and is approximately 0.85. The drag coefficient at motor burnout is about 0.49. The drag force steadily increases from motor ignition and peaks at a value of about 52 lbf just before apogee before gently leveling off until apogee. After apogee, the drag force slowly increases and then plateaus as the rocket increases speed and reaches terminal velocity.

Figure 26: Flight Drag Data



The rocket's weight vs. time is displayed in Figure 27.

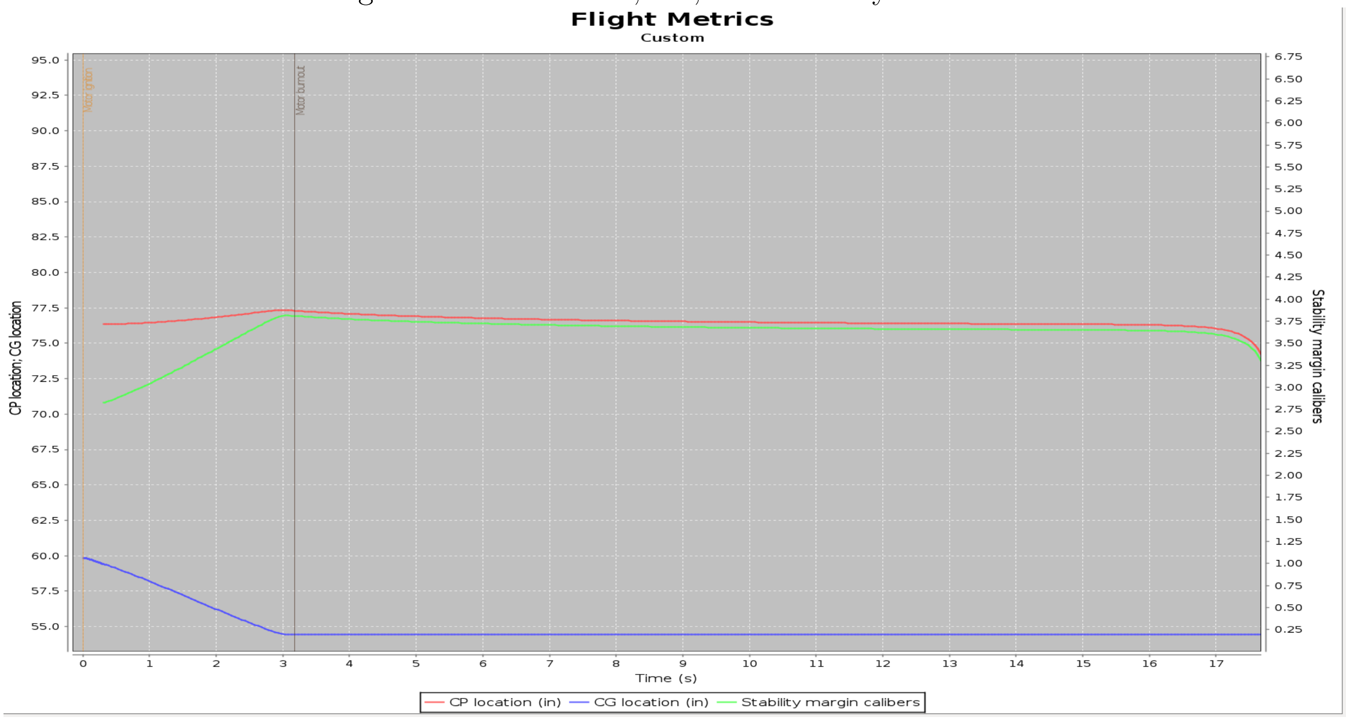
Figure 27: Rocket Weight vs. Time



The mass of the rocket decreases linearly as the motor burns, and levels off at motor burnout.

Figure 28 displays the rocket's CG, CP, and static stability as functions of time. The CG and CP are measured in inches aft of the tip of the nosecone.

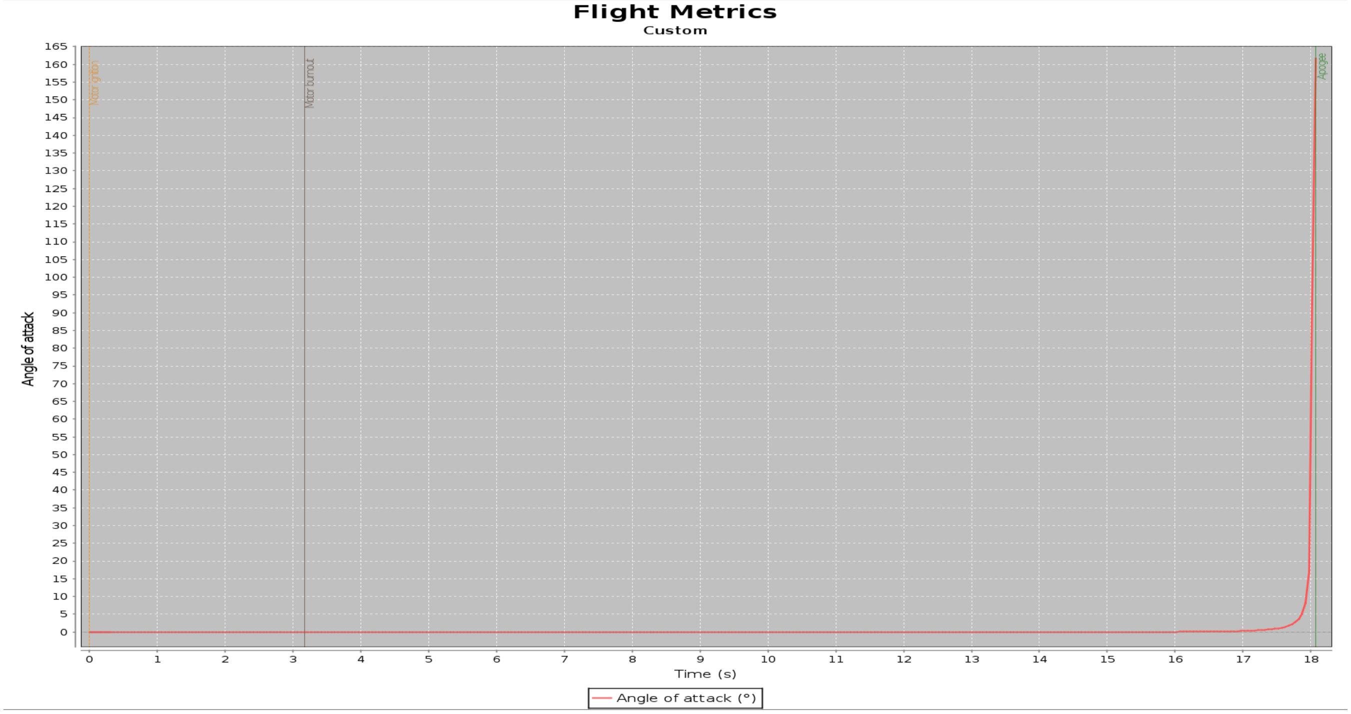
Figure 28: Rocket CG, CP, and Stability vs. Time



The location of the CG decreases and moves closer to the nosecone as the motor burns. The CP location increases slightly as the motor burns, and the stability margin increases. Once motor burnout is achieved, the CP and CG locations plateau until apogee is reached and the parachutes are deployed.

Figure 29 shows the rocket's angle of attack as a function of time. The angle remains constant during ascent, and only changes once apogee is reached. However, this simulation is done with zero wind, and it is likely that different wind conditions would affect the rocket's angle of attack during flight.

Figure 29: Rocket Angle of Attack vs. Time

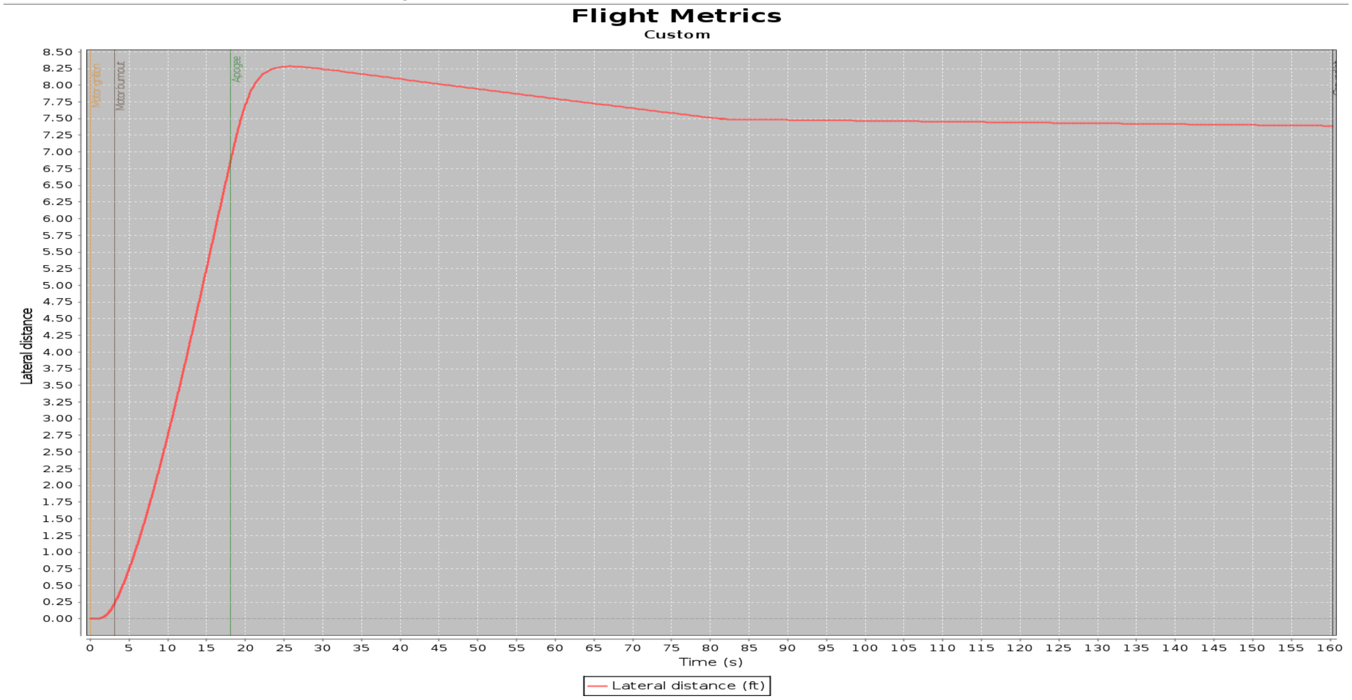


3.7.4 Simulated Drift

Zero Wind

Figure 30 plots the rocket's lateral distance from launch location vs. time. The greatest displacement occurs during ascent, and minimal changes in lateral location occur during descent. The maximum lateral distance is approximately 8.25 feet, and the lateral distance upon landing is approximately 7.4 feet.

Figure 30: Rocket Lateral Distance vs. Time



5 mph Wind

Simulation results for 5 mph wind are shown in the following table.

Apogee	5308 ft
Velocity off Rod	78.7 ft/s
Velocity at Chute Deployment	61.1 ft/s
Maximum Velocity	683 ft/s (Mach 0.61)
Maximum Acceleration	272 ft/s^2
Ground Hit Velocity	18.3 ft/s
Time to Apogee	18 s
Flight Time	158 s

The results are mostly the same as the results of the zero wind simulation. Apogee is approximately 14 feet lower, and the velocity off the launch rod is marginally higher. Drift simulations for 5 mph wind are shown in Figure 31. The maximum lateral distance from the launch location is approximately 640 feet. The greatest change in position occurs during descent, after recovery devices have been deployed.

Figure 31: Rocket Lateral Distance vs. Time

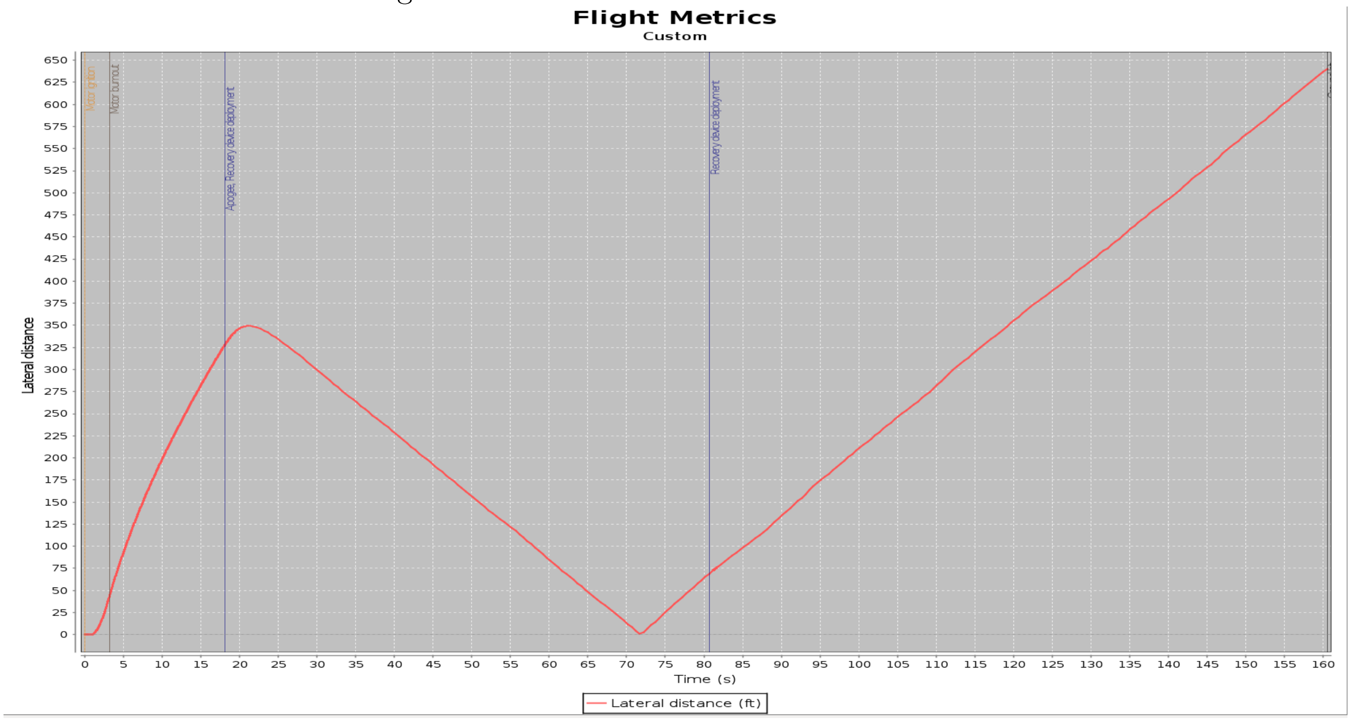
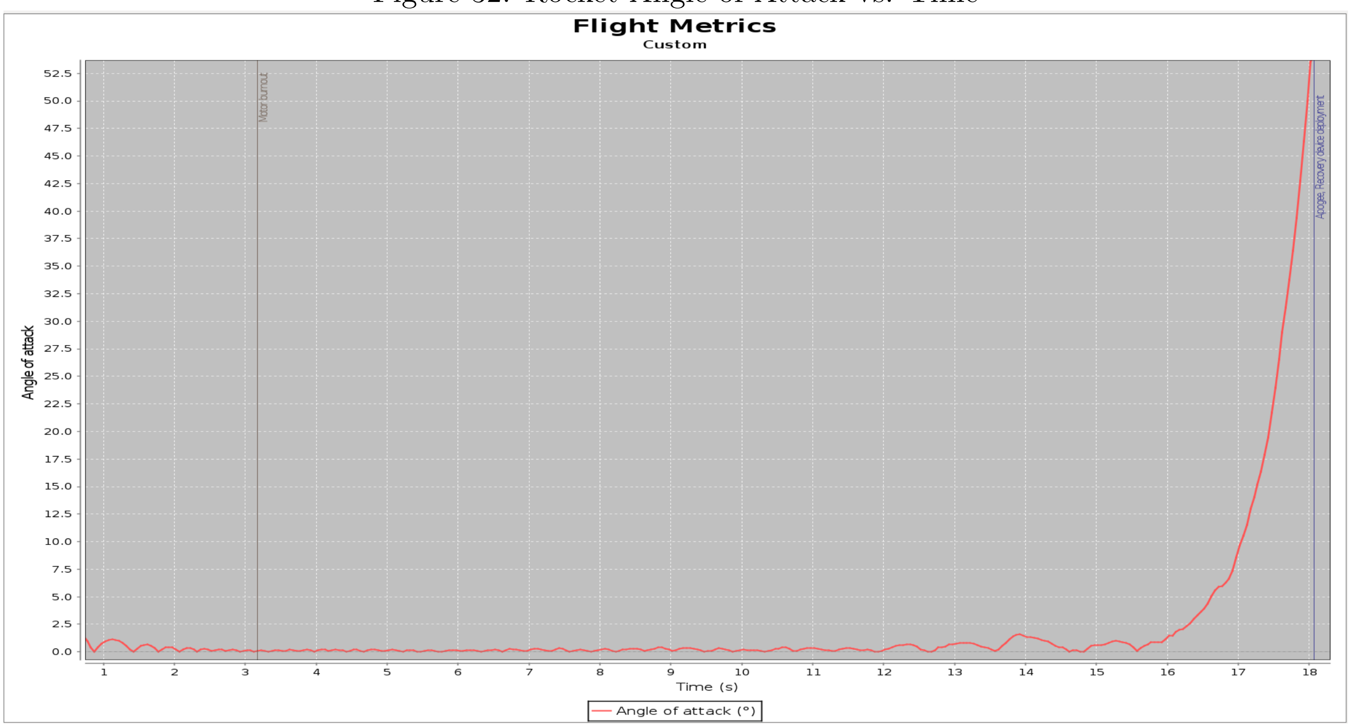


Figure 32 graphs the rocket's angle of attack in 5 mph wind vs. time. During ascent, the angle of attack oscillates with an amplitude of approximately 1 degree. As the rocket approaches apogee, its speed is greatly reduced, and the angle of attack sharply increases until apogee.

Figure 32: Rocket Angle of Attack vs. Time



10 mph Wind

Simulation results for 10 mph wind are shown in the following table.

Apogee	5278 ft
Velocity off Rod	78.7 ft/s
Velocity at Chute Deployment	61.1 ft/s
Maximum Velocity	682 ft/s (Mach 0.61)
Maximum Acceleration	273 ft/s^2
Ground Hit Velocity	18.3 ft/s
Time to Apogee	18 s
Flight Time	159 s

As with the 5 mph simulation, apogee is slightly reduced by 30 feet from the 5 mph simulation. Most other values remained constant. There were very small changes in the maximum velocity and acceleration. Drift simulations for 10 mph wind are shown in Figure 33. The greatest displacement also occurs during descent, and the maximum lateral distance is about 1340 feet from the launch location.

Figure 33: Rocket Lateral Distance vs. Time

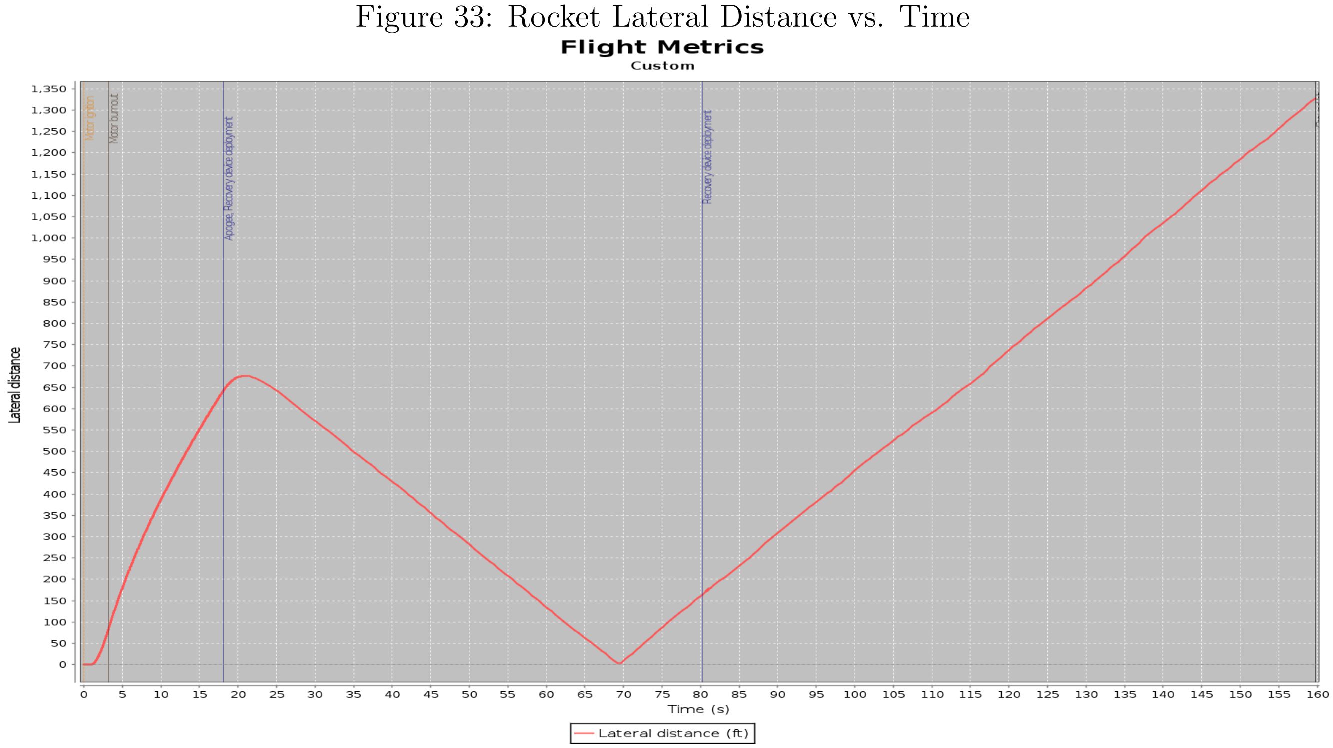
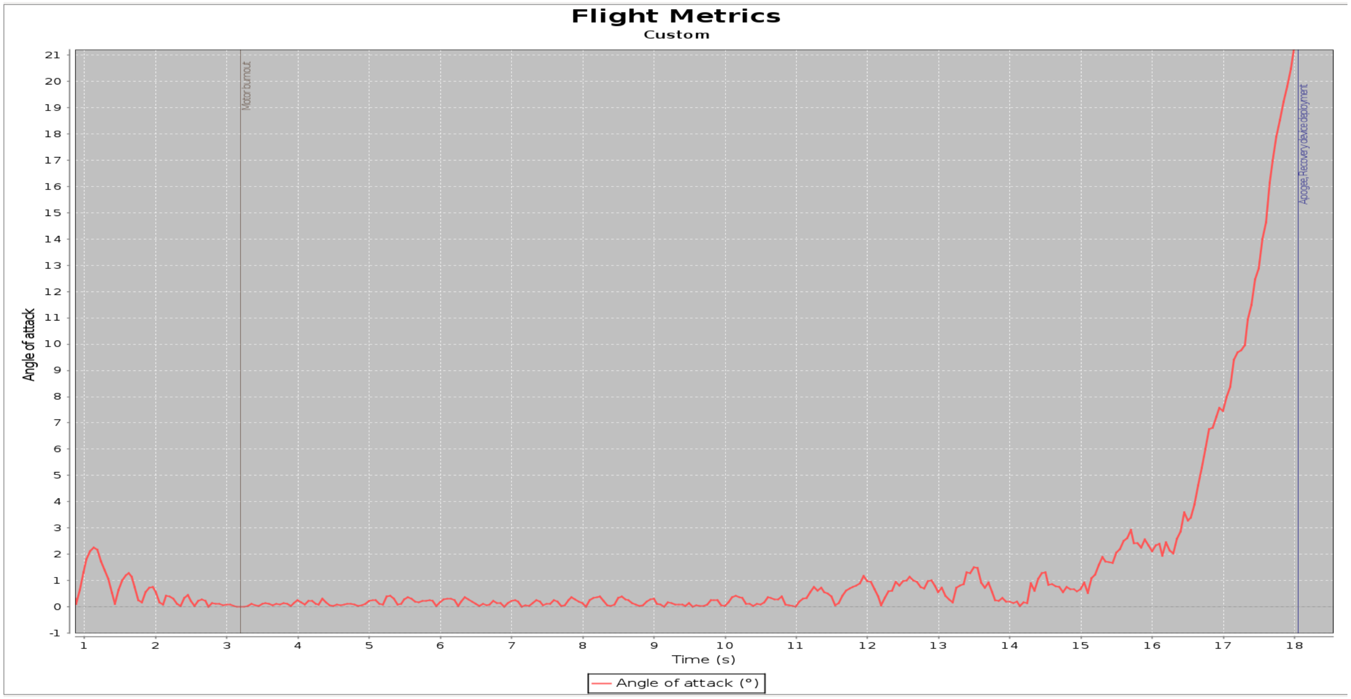


Figure 34 plots the rocket's angle of attack in 10 mph wind vs. time. The results are very similar to the 5 mph wind case. The angle of attack oscillates at a similar frequency and amplitude.

However, the maximum angle of attack is greater in 10 mph wind than in 5 mph wind. Much like in 5 mph wind, the angle of attack sharply increases as the rocket approaches apogee.

Figure 34: Rocket Angle of Attack vs. Time



15 mph Wind

Simulation results for 15 mph wind are shown in the following table.

Apogee	5213 ft
Velocity off Rod	78.7 ft/s
Velocity at Chute Deployment	61.1 ft/s
Maximum Velocity	680 ft/s (Mach 0.61)
Maximum Acceleration	273 ft/s^2
Ground Hit Velocity	18.3 ft/s
Time to Apogee	18 s
Flight Time	157 s

The only major changes are a reduction of about 65 feet in apogee compared to the 10 mph wind simulations. Figure 35 shows the drift simulations for 15 mph wind. As before, the greatest lateral displacement occurs during descent, and the maximum lateral distance is approximately 2000 feet from the launch location.

Figure 35: Rocket Lateral Distance vs. Time

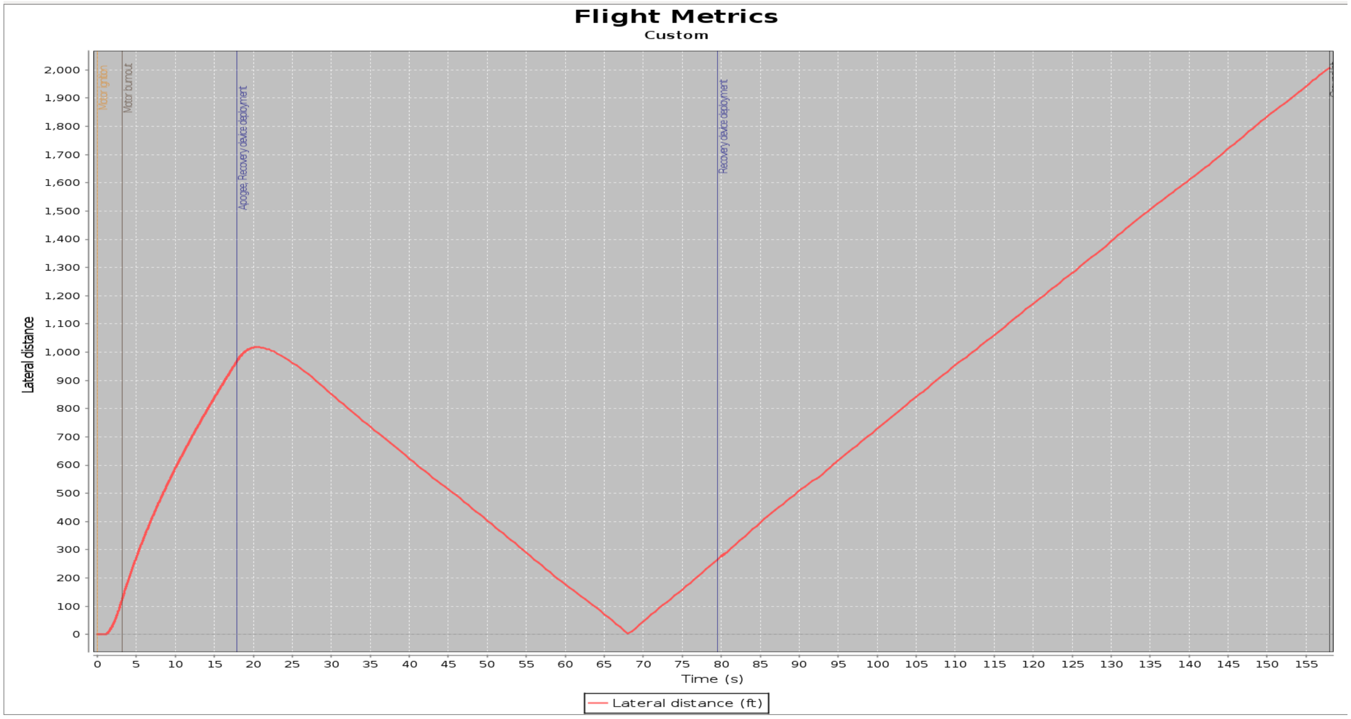
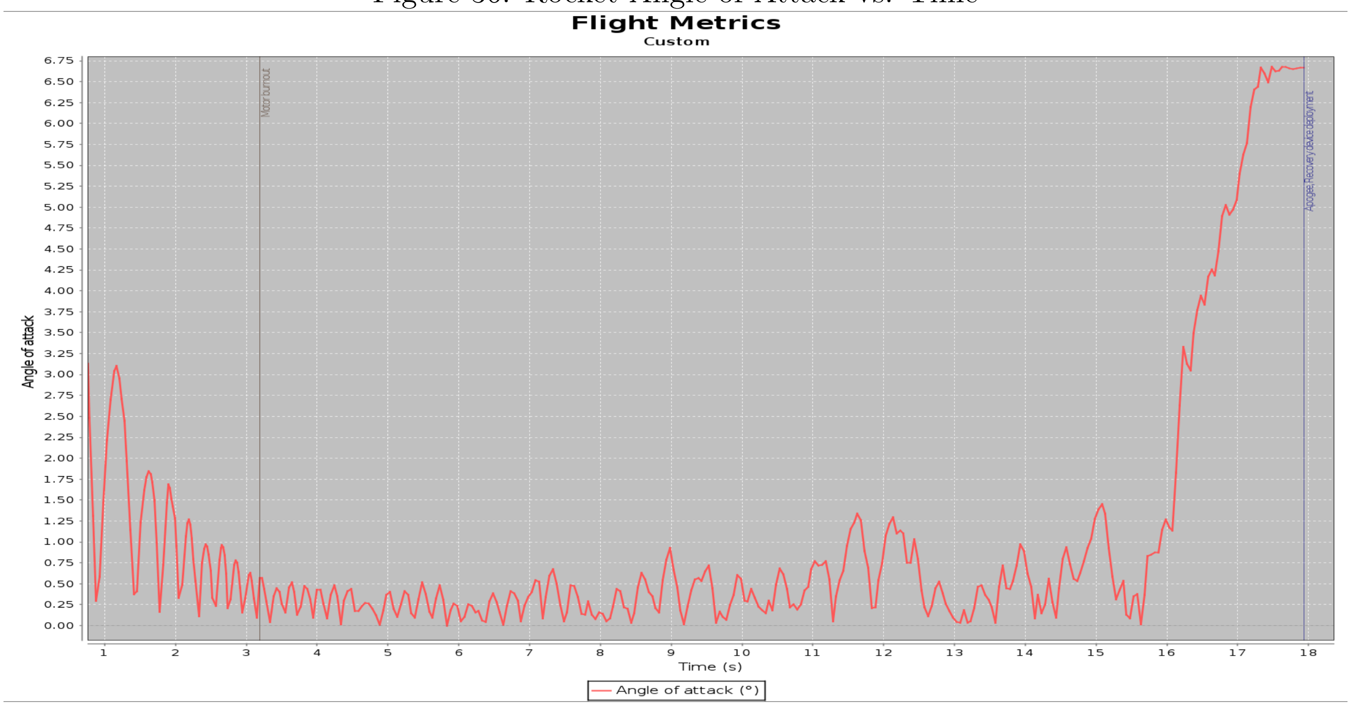


Figure 36 displays the rocket's angle of attack in 15 mph wind vs. time. The results are similar to the previous two cases, but here, the oscillations have more variance both in amplitude and in frequency. The maximum angle of attack before apogee is approximately 3 degrees, and the angle sharply increases as the rocket approaches apogee. However, in this case, the increase in angle just before apogee is much smaller than in 10 and 5 mph winds.

Figure 36: Rocket Angle of Attack vs. Time



20 mph Wind

Simulation results for 20 mph wind are shown in the following table.

Apogee	5168 ft
Velocity off Rod	78.7 ft/s
Velocity at Chute Deployment	61.1 ft/s
Maximum Velocity	680 ft/s (Mach 0.61)
Maximum Acceleration	273 ft/s^2
Ground Hit Velocity	18.5 ft/s
Time to Apogee	18 s
Flight Time	157 s

Apogee is reduced by another 45 feet from the 15 mph apogee. Figure 37 displays drift simulations for the 20 mph wind. The largest displacement occurs during descent, and the maximum distance is approximately 2820 feet from the launch site.

Figure 37: Rocket Lateral Distance vs. Time

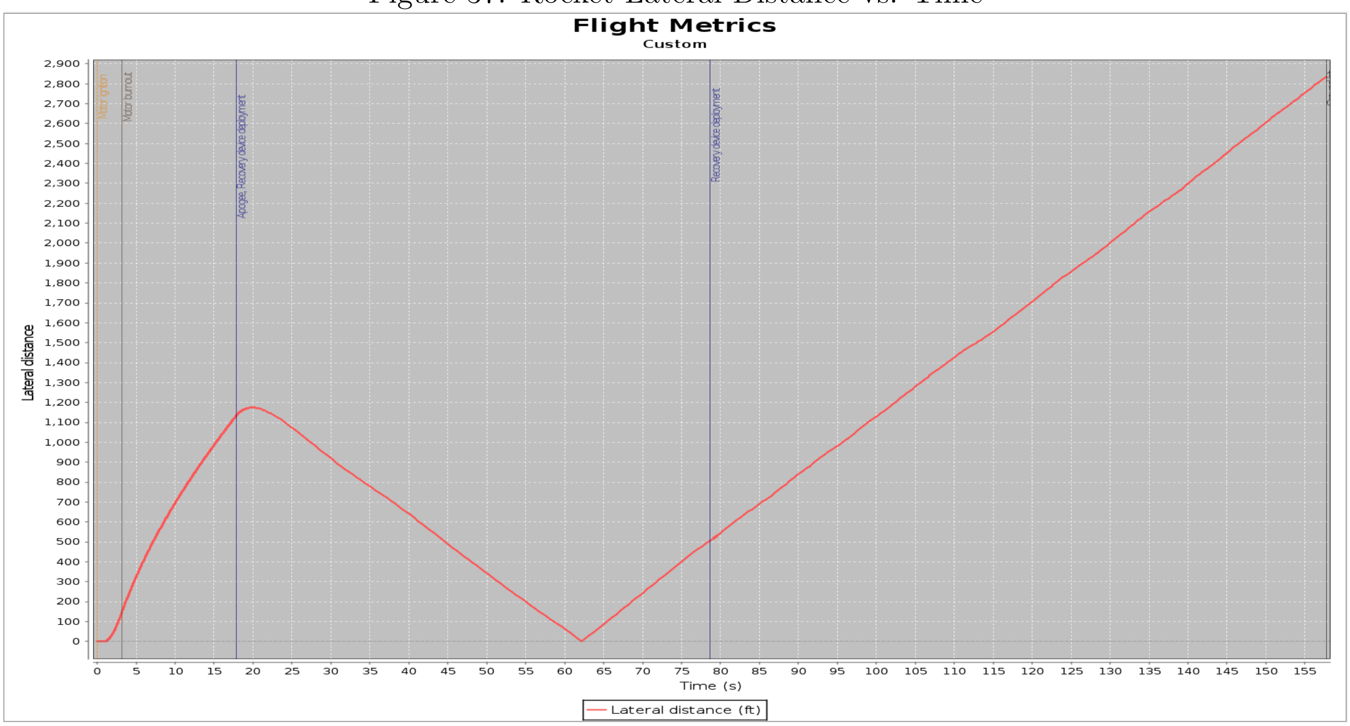
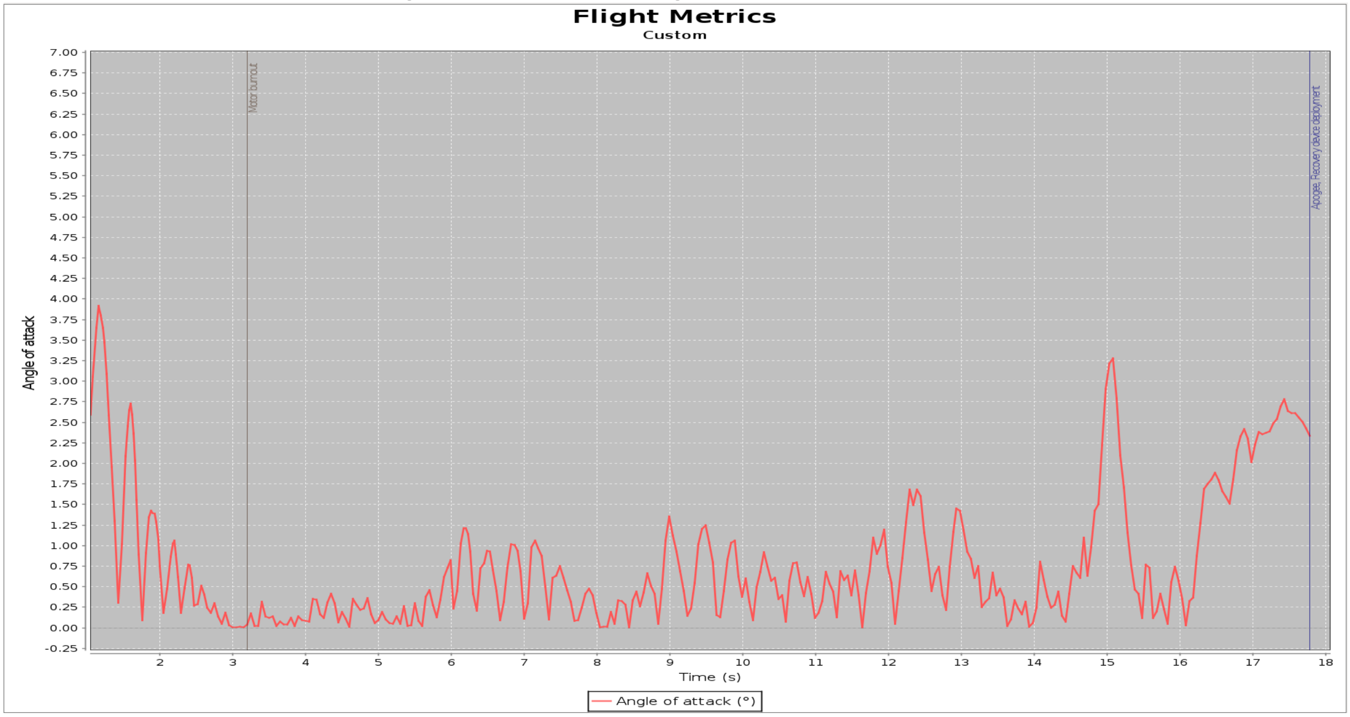


Figure 38 illustrates the rocket's angle of attack in 20 mph wind. The oscillations in angle vary between a maximum of 4 degrees and a minimum of 0.25 degrees. Like the 15 mph flight, the amplitudes are very irregular. However, in 20 mph winds, the variance is much larger than in the

15 mph flight. Additionally, the increase in angle just before apogee is much smaller in 20 mph winds than in lower wind speeds.

Figure 38: Rocket Angle of Attack vs. Time



3.7.5 Full-scale Flight Results

We flew our full scale rocket in Farmington, California on March 4th, 2017. It was 63° with 75% humidity and winds of 9 mph. The flight for the airframe was almost successful. There was no external nor internal structural damage. Furthermore, there was no interference between any of the sections. There was correct separation between the payload and the avionics section during deployment. The major issue with the airframe currently is the apogee. The full scale rocket flew with three altimeters reporting an apogee of 4541 feet. With an apogee of only 4541 feet, that is less than our predicted 5358 ft and is less than our mission success at 5200 ft. With 10 mph winds our rocket drifted a total of 2400 ft. This is approximately one-third our simulated 3500 ft. Most of these issues can be explained by our launch angle. After analyzing videos from our rocket, it was evident that we launched at 19 degrees from the vertical. This changes our apogee and drift simulations tremendously. Simulations in OpenRocket show that the projected altitude at a launch angle of 19 degrees from the vertical was 4746. This number is approximately 205 feet above our actual apogee. Our kinetic energy during ascent varied from a minimum of 2055.12 ft-lbf off the rail to a maximum of 192518.47 ft-lbf at max velocity.

Figure 39: Rocket Altitude vs. Time

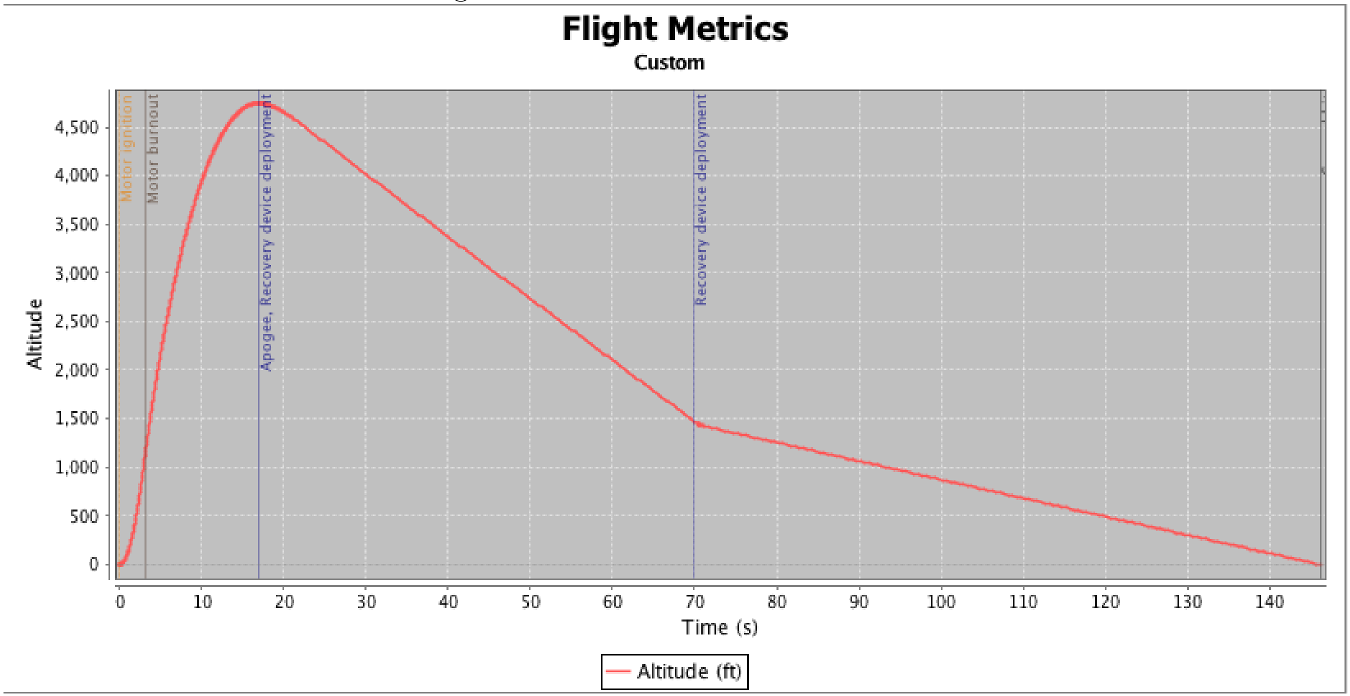


Figure 40: Rocket Velocity vs. Time

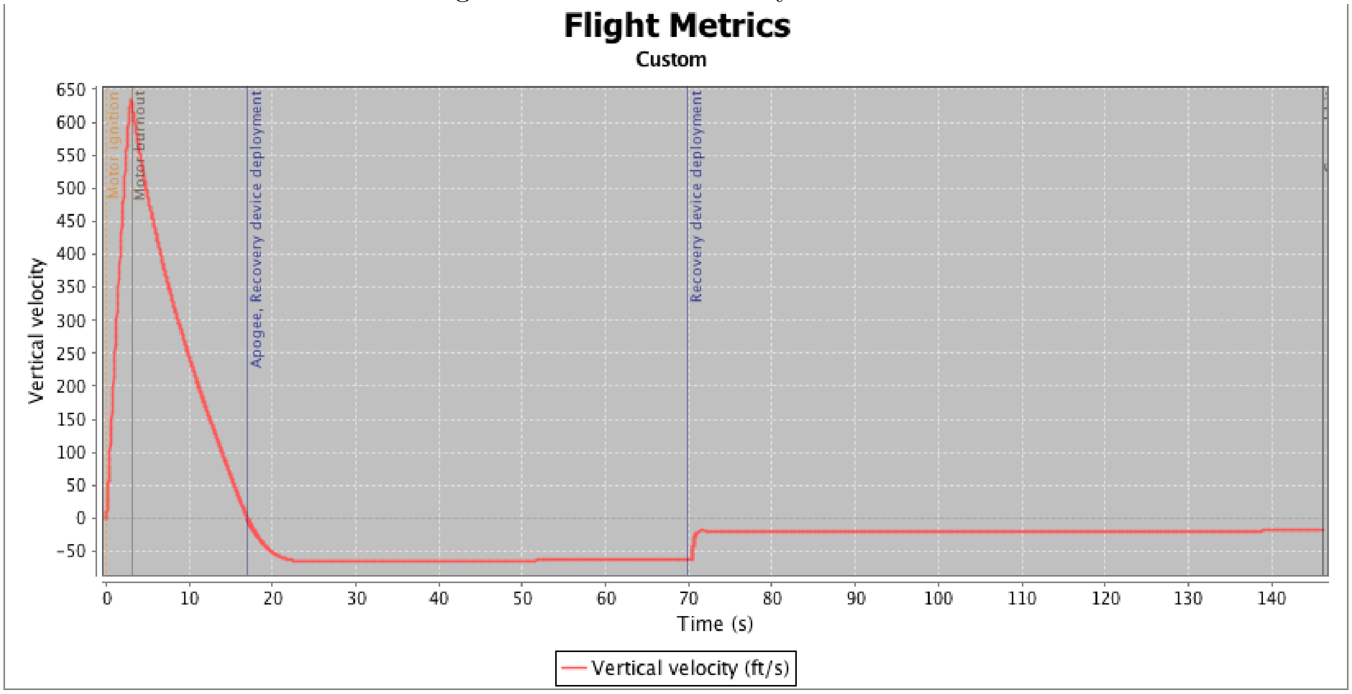


Figure 41: Rocket Acceleration vs. Time

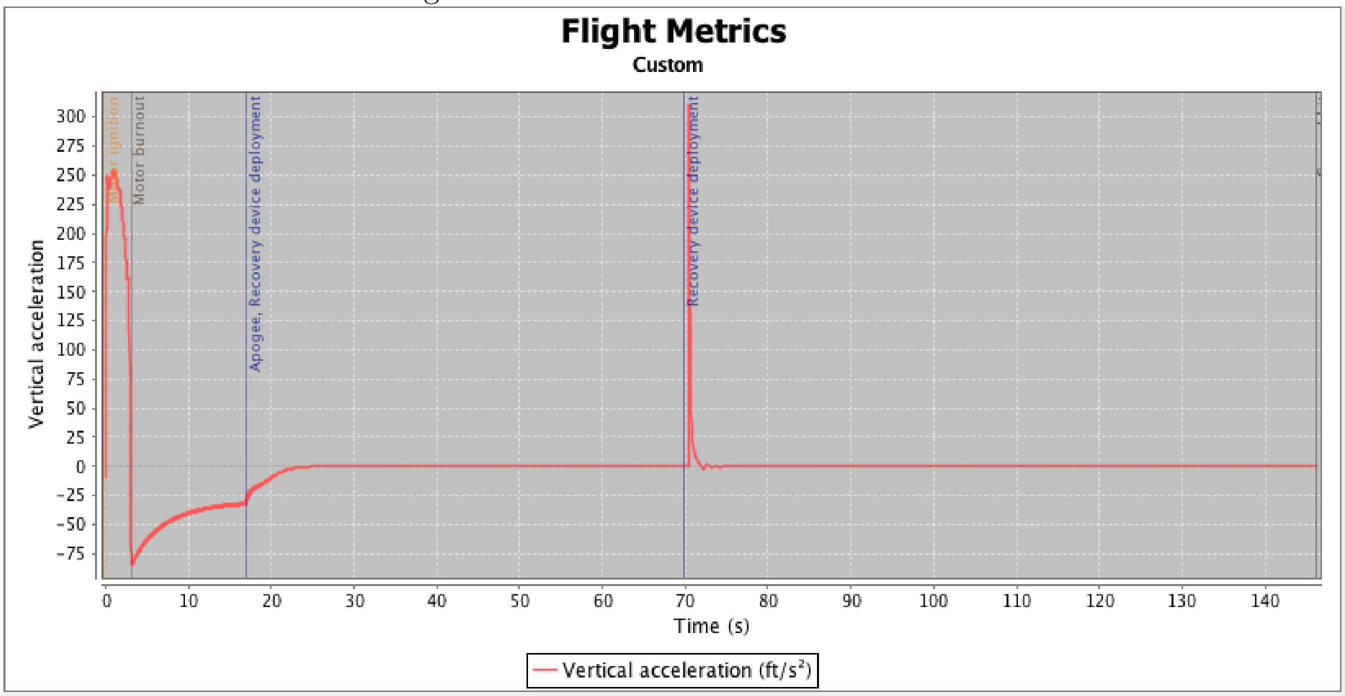
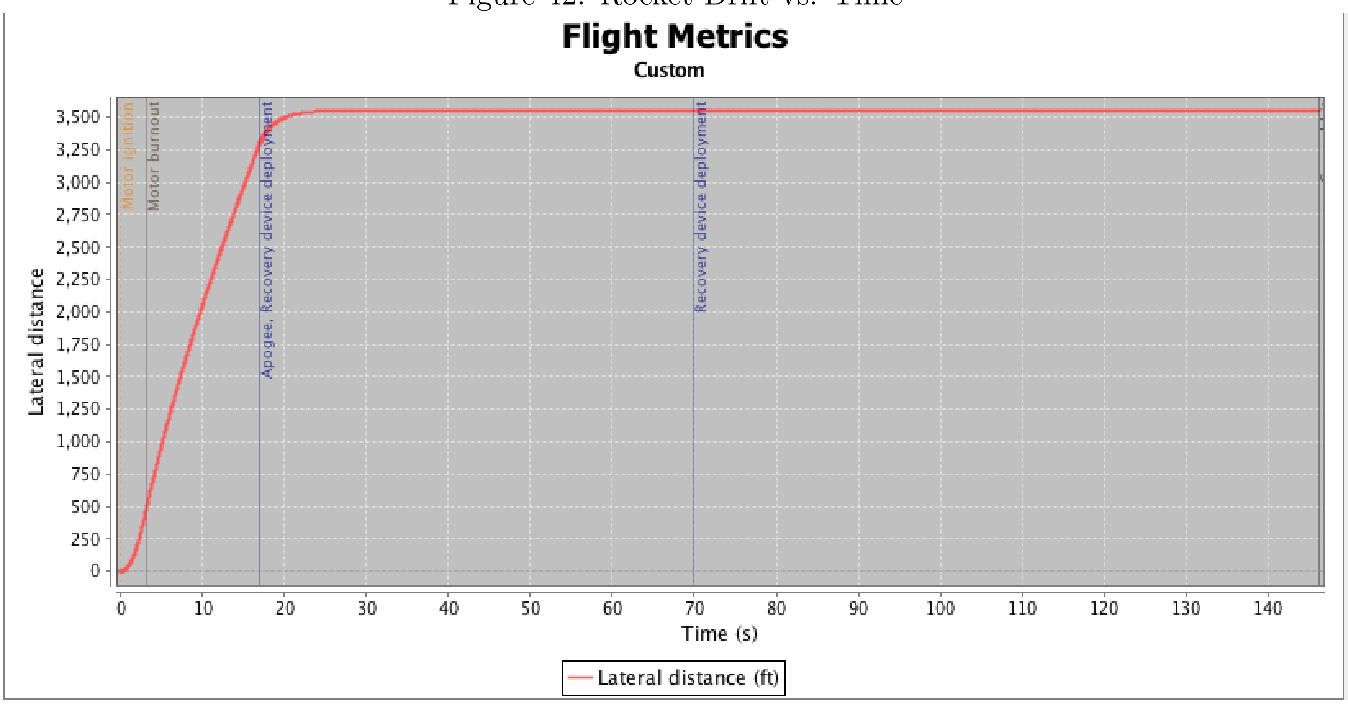


Figure 42: Rocket Drift vs. Time



4 Payload Criteria

4.1 Mission Statement

The objective of our vehicle's payload experiment is to fulfill the Target Detection and Upright Landing challenge, which an onboard camera system identifies ground targets, and the section housing the cameras lands upright. Our payload, SAGITTA-VL, uses an onboard camera mounted inside the nose cone viewing through a clear tip. A custom software package, operated using a Raspberry Pi camera, is used to view the ground during descent, and identify the three ground targets by color. This sequence of operations constitutes **"Target Detection"**. After Target Detection has been completed, or after an altitude threshold has been reached, the payload section will be ejected from the vehicle to be recovered independently. The payload deploys three parachutes via the deployment of three landing legs. The positioning of the payload center of gravity below the parachutes causes the section to turn upright during its descent, allowing the payload to land upright. This sequence of operations constitutes **"Upright Landing"**.

4.2 Payload Overview

The payload section consists of an 18" section of tubing and a 21" nose cone. This acts as the upper section of the main vehicle airframe. A camera is mounted in the top of the nose cone, and views through a clear PETG tip. The tubing section contains three landing legs, which deploy out in order to assist Upright Landing. During "launch configuration," the legs are folded in so as to be flush against the airframe. During "landing configuration," the legs are extended, and the inner assembly is exposed. The payload parachutes are deployed via springs that push the parachutes out when they are exposed (i.e. when the legs are deployed). The legs are held in place using steel pins, which are released using linear solenoid actuators.

4.2.1 Payload Flight Plan

The payload operations take place primarily after the deployment of the main paracute. At this time, the payload section is attached to the avionics bay, and faces the ground. During this phase, the camera views the ground, and the Target Detection algorithm is used to find and identify the three ground targets.

When Target Detection has concluded, the onboard computer is used to actuate one of the three legs, thus releasing one parachute. After a set delay, the payload section is ejected from the vehicle. A photoresistor is placed behind the leg as a safety feature: if the leg does not successfully deploy, the photoresistor will indicate darkness, and the computer will not activate ejection, thus ensuring that the payload does not fall without a recovery system. After ejection, a second leg and parachute are deployed, and a third leg and parachute are deployed after a delay. The delays, of approximately 3 seconds each, are to ensure that the parachutes do not tangle as they unravel and inflate. If Target Detection does not complete by the time the vehicle falls to 650 ft, the payload altimeter will signal the actuation of the first leg - this is to ensure that in case Target Detection becomes impossible (e.g. the vehicle has drifted too far from the targets), Upright Landing will still be attempted.

4.3 Design and Construction

The payload consists of several subsystems. These are distributed between the payload section (consisting of an 18” section of tubing) and the nose cone. The three major systems of the payload section include: the landing subsystem; the parachute deployment subsystem; and the payload electronics subsystem.

4.3.1 Subsystem: Upright Landing

The upright landing subsystem resides within an 18” section of blue tube. The internal payload assembly consists of the following components and sub-assemblies:

- A central ”support tower” consisting of a 10.25” PVC tube, and three 8.75” aluminum rails screwed onto the PVC at 120° apart.
- A rail carriage sliding on each rail, consisting of a 3/8” hex head bolt, a steel L-bracket, and an aluminum ”support leg” attached to the bracket and to the landing leg frame.
- Three landing legs, each consisting of a 3D printed ABS “landing leg frame” glued to a T-shaped blue tube cut-out, the “landing leg shell”. This is described in Figure 43.

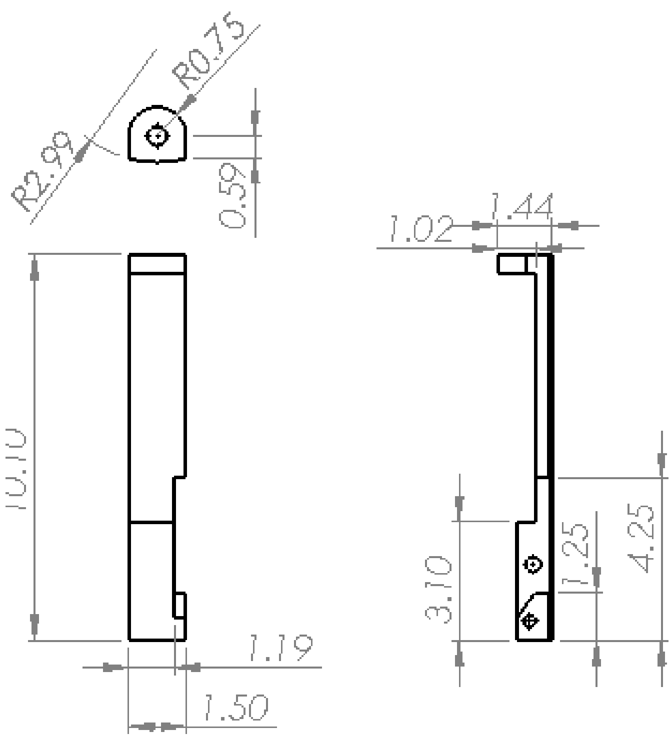


Figure 43: Dimensioned drawing of the landing leg frame

- A “payload bulkhead,” consisting of a 1/2” plywood bulkhead, modified to provide clearance for the landing legs to swing through as they open.

- Three “hinges,” consisting of 3” high wood posts mounted on the payload bulkhead. Each hinge consists of two posts with a steel dowel between them at 1/2” above the bulkhead, around which the landing leg rotates. Each dowel is fitted with two 120° torsion springs; for each torsion spring, one arm is placed against the wood post, and the other arm is laid against the landing leg frame, pushing them apart.

- A ”parachute container”, consisting of three ”parachute cells” arranged at 120° apart. Each cell is a 4” high by 2.5” deep cavity in which the payload parachutes are stored, and contains a U-bolt (to tie the parachute shock cords) and a ”spring board”: a 2” by 2” wood plate on a linear spring, which pushes the parachute out. Additionally, each cell contains a slot for a solenoid pin, which is used to hold the landing leg frame upright.

These components are illustrated in Figure 44

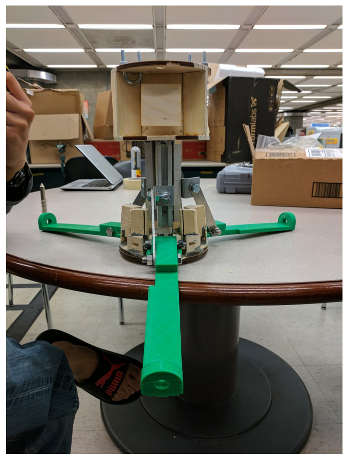


Figure 44: Constructed internal payload assembly

Note that the landing leg shells are not pictured in Figure 44.

4.3.2 Upright Landing: Construction

The Upright Landing assembly was constructed by first constructing the internal assembly, and then inserting it into the tubing section. The support tower was constructed by cutting PVC tube to length and using JB-Weld to glue it to the center of the payload bulkhead. The three rails were each affixed to the PVC by two 6-32 screws. The upper 4” of the rails were machined such that the support tower fits into a triangular slot in the center of the parachute box. This slot is illustrated in Figure 45.

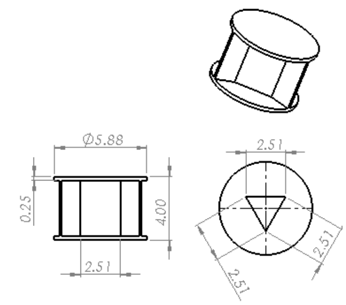


Figure 45: Parachute container dimensions

Each of the hinge posts was initially constructed as a 1" high post, with clearance holes drilled through each to insert the dowel. The printed landing leg frame contains a clearance hole placed 0.5" from its base for the dowel to pass through. The landing leg frame was attached by placing the leg between a pair of hinge posts with a torsion spring on either side, and inserting the dowel pin through all components. To ensure the dowel does not slide out, JB-weld was applied to the pin and hinge posts to permanently secure the hinge.

It should be noted that the initial design, as described in the Critical Design Review, called for a large torsion spring centered between the support tower and landing leg. This spring would have one arm glued to the side of the rail, and one arm glued to the inner face of the landing leg frame, in order to push the leg out. This system was assembled, as illustrated in Figure 46; however, the spring was excessively strong, causing failure of the JB-Weld joints. In addition, the geometry of this spring system caused severe warping of the spring, making it extremely difficult to assemble by hand and compress the legs for testing.

Figure 46: Construction of the original spring-loaded hinge design. The arms of the spring are glued to the rail and landing leg frame.

As a result, the decision was made to redesign the spring-loaded hinge system, using two smaller springs centered on the hinge itself. In order to accomplish this, the hinge posts had to be heightened, in order to provide a surface off of which the torsion springs could push. These consisted of 2" high wood blocks attached to the top of the original 1" hinge posts. In addition, the landing leg frame was redesigned with additional surfaces for the spring to push on. This redesign resulted in a spring-loaded hinge which did not require glue joints, and could be easily assembled by hand. The new hinge design is illustrated in Figure 47

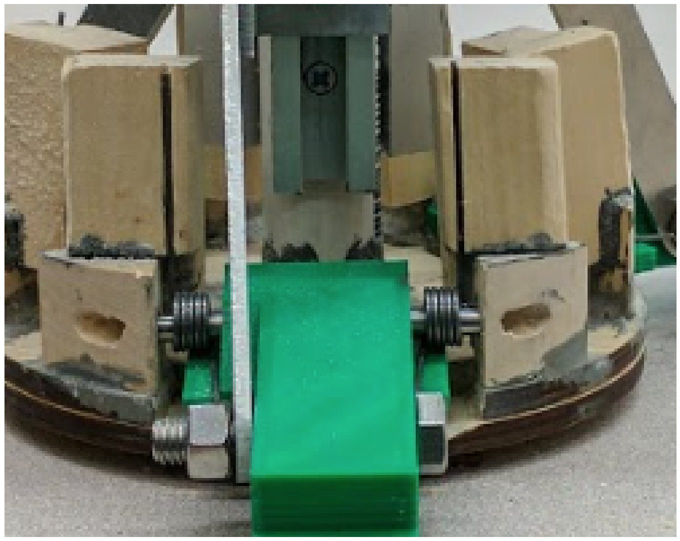


Figure 47: New spring-loaded hinge, consisting of two 120° torsion springs centered on the dowel pin

As seen in Figures 44 and 47, the rail support subassembly was assembled by hand by bolting the support leg to the landing leg frame, and to the L-bracket using 3/8-16 bolts and nuts. The L-bracket was attached to the rail using a 3/8-16 hex head bolt; the bolt head slides within the rail. This assembly, along with the spring-loaded hinge, allows the landing leg to be operated, rotating from upright (vertical) to approximately 112° from vertical - specifically, the landing leg extends to 3.5" below the payload bulkhead when fully extended. This is to accommodate the fact that the payload bulkhead is situated 3.5" from the base of the payload tubing section.

The parachute box was constructed using 1/4" laser-cut plywood pieces, attached together using epoxy. In each parachute cell, a 1/4-20 U-bolt was added, as well as a conical linear spring and spring board (the latter components were added with epoxy). The rear wall of each parachute cell was also drilled to allow a 8-32 screw to pass through. These screws (a total of three) were used to fix the parachute box to the support tower, which was placed in the center of the three cells. The use of screws for this fixture allows for the parachute box to be inserted and removed, allowing access to internal payload components.

The internal payload assembly was then inserted and glued into the payload section, such that the payload bulkhead lay 3.5" from the tube base. This is to accommodate the 3.5" shoulder for the coupling of the payload section and avionics bay. This process is illustrated in Figure 48.

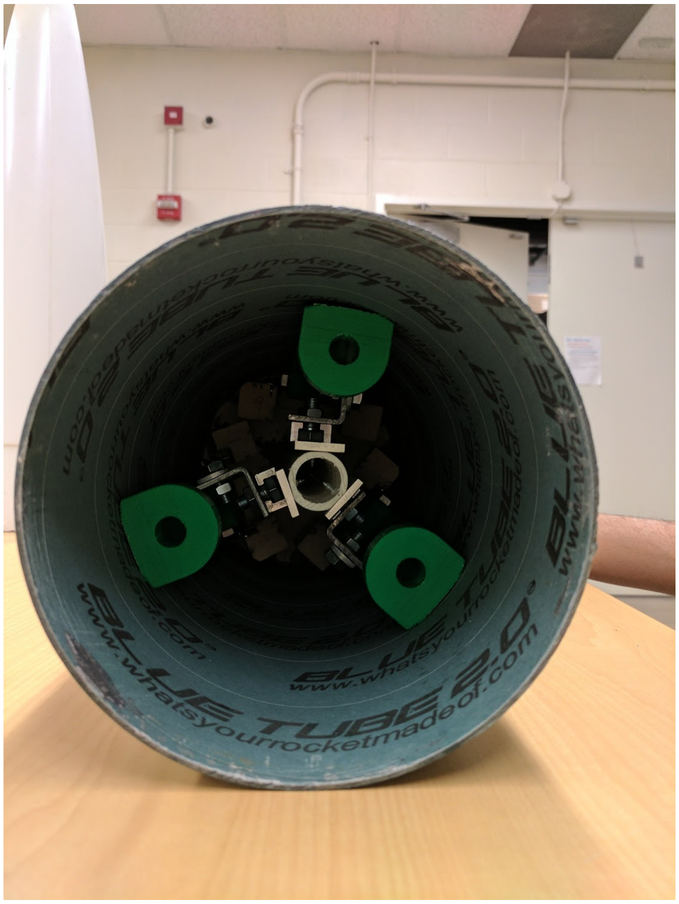


Figure 48: Inserting the payload internal assembly into the payload tubing section

The landing leg shells were then cut out, and then glued to the backs of the ABS frames such that the shells would be flush to the payload tube when the landing leg was folded up. A 10.5" coupler tube was inserted into the payload section, and cut out such that the leg frame could pass through it as the leg was folded. This provided a wall against which the leg shell would be in contact during the upright configuration, in order to minimize the possibility of air flowing into the vehicle. In order to provide clearance for the leg to pass through its entire arc, the bottom portion of the landing leg shell was cut away, leaving a gap. This gap is sealed in the launch configuration using tape, which will be scored to allow the leg to rotate outward. The final payload assembly is illustrated in Figure 49.

Figure 49: Complete landing leg assembly, in launch and landing configurations

4.3.3 Subsystem: Payload Recovery

The payload recovery system utilizes three 36" toroidal parachutes, positioned 120° apart. This is achieved using the parachute container, illustrated in Figure 44 and described in Figure 45. The 'floor' of each cell contains a cutout to allow clearance for the leg to reach a vertical position. Each parachute is attached to the U-bolt in its parachute cell via a 4 ft. long shock cord (1/4" tubular kevlar). In the launch configuration, the parachutes are folded and closed inside the parachute cells by the closure of the landing legs. The deployment of the landing legs opens the parachute cells, allowing the spring boards to push the parachutes out. This is illustrated in Figure 49. The construction of the parachute container is described in Section 4.3.2.

4.3.4 Subsystem: Solenoid Deployment

The landing legs and payload recovery system are deployed using linear solenoid actuators, mounted on top of the parachute container. Each actuator consists of a "pin" and a "housing." The pin consists of a 7/16" diameter steel rod, which is slotted through holes in the parachute cells and landing leg frames. This pins the landing legs in the launch configuration. The housings each contain a bolt and nut, which are used to fix the housing to a wood bracket that is glued to the top of the parachute container; this is illustrated in Figure **??**.

Figure 50: Bracket mounted to the top of the parachute container, used to mount the solenoid housings

The solenoid housing, when powered, pulls the pin toward it; a linear spring pushes the pin away from the housing when it is not being actuated. In the launch configuration, the pin is not actuated, and lies in the slots in the parachute cell and landing leg frame, holding the frame vertical. When the solenoid is actuated, the pin is pulled out of the landing leg frame, allowing the landing leg to be extended by the torsion springs.

4.3.5 Subsystem: Payload Electronics

The payload electronics are mounted in the nose cone. The nose cone consists of a 24" fiberglass ogive cone, with a 3.25" shoulder. This shoulder lies immediately above the parachute container, and is concurrent with the position of the solenoid housings. The upper 3" of the nose cone is cut off, and replaced with a PETG hemispherical tip of 1" radius. A bulkhead is placed 2.5" from the bottom of the shoulder, consisting of a 0.25" plywood ring (that is glued to the inner wall of the shoulder) and a 0.5" plywood plate that is screwed onto the ring. This bulkplate is the base of the electronics assembly, and can be screwed on and off to allow removal of the electronics. The electronic components, described in more detail in Section 4.7, are mounted to 3D printed sleds attached to the bulkplate and supported by 3/8" wooden dowels. This is illustrated in Figure 51.

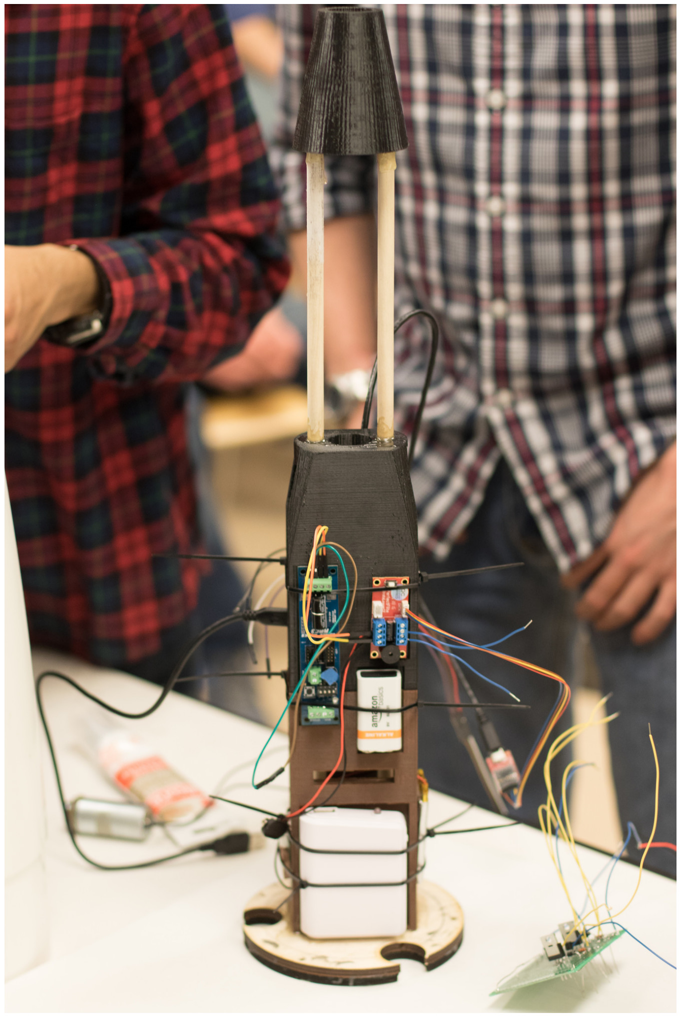


Figure 51: Payload electronics mounted to the electronics sled

The electronics sled includes a cone at the top, which fits against the inner wall of the nose cone near the location of the bottom of the plastic tip. This cone serves as the mount for the Raspberry Pi camera, allowing the camera to see out of the clear plastic tip with an uninhibited field of vision. The electronics package is connected to the solenoids (below the nose cone bulkhead), the photoresistor (in the parachute container), and the ejection charges to eject the payload (below the payload bulkhead). The wires for these connections are routed through holes drilled in the nose cone bulkhead, and holes in the parachute box. The wires for the ejection charges, in particular, run along the side of the support tower down to the payload bulkhead.

4.4 Test Outcomes: Upright Landing

4.4.1 Upright Landing: Manufacturing Outcomes

The manufacturing process for the upright landing system revealed several concerns not previously considered, requiring modifications to the payload design. The first and most severe of these modifications was the change in the spring-loaded hinge design, described more thoroughly in Section 4.3.2. The construction of the landing legs also posed difficulties: due to tolerances in the construction process, the built landing leg frames had difficulty reaching the ground. In order to extend the reach of the landing legs, the length of the landing leg shells was increased by 1", such that the top of the leg shell is concurrent with the lower 1" of the nose cone shoulder. Although this compromises the nose cone coupling, this was deemed safe as the nose cone is screwed to the tubing section using four M4 machine screws. Additionally, to provide clearance for the leg to extend, the bottom of the landing leg shell had to be removed, leaving a large gap in the airframe. In order to reduce drag and prevent air from entering the airframe during ascent, slitted tape was used to cover this gap while not obstructing the leg's movement.

4.4.2 Solenoid Subsystem: Manufacturing Outcomes

The manufacturing of the solenoid subsystem presented significant challenges that required several modifications to the payload. Initial testing of the solenoid system was done by hand; i.e., the electric actuation of the solenoid was replaced by pulling the pin out by hand. This yielded highly successful results, in which the landing legs were able to successfully spring out with no damage, and the parachutes were ejected forcefully from the parachute cells. This can be seen for the internal assembly at https://www.youtube.com/watch?v=s2IKCcYZDGA; similar tests were conducted once the payload was in the tube section.

However, the attempt to mount the solenoid housings presented several difficulties. The original design, as presented in the CDR, called for the housings to be mounted in the ring portion of the nose cone bulkhead. The housings would be aligned over the pins while the nose cone was coupled to the payload tube. This process, however, proved to be exceedingly difficult, as tolerances in the bulkhead manufacturing caused the housings and pins to be slightly misaligned - the housing would not fit over the pins if the alignment was not exact. This necessitated a redesign, in which the solenoids were mounted to the parachute box using the bracket illustrated in Figure 50. This way, they could be manually aligned before being fixed into place over the pins.

The pin actuation also presented several difficulties. The primary challenge faced once the solenoid system was assembled was binding, between the pin and the slots through which it slid up and down. This was largely due to the stress caused by the landing leg, which pulled outward on the pin, thus increasing friction as the pin attempted to lift out of the leg slot. Although in preliminary tests the pin could be pulled out by hand, the solenoids did not have sufficient power to reliably pull out the pins. In order to correct this issue, brass bushings were machined and placed inside the parachute cell slot and the landing leg slot, to ensure that the pin followed a straight path without being pulled. Furthermore, the pin (which is tapered on one side) was turned over such that the tapered end fit into a tapered bushing in the landing leg, making it easier for the leg to slip out once the pin had been raised. This, however, increased the risk of the leg prematurely deploying, which could cause severe damage to the vehicle if it occurred during ascent. As a result, the bushing was modified to make it harder for the pin to fully retract from the slot.

4.4.3 Upright Landing: Testing Outcomes

The upright landing system was tested primarily via "parachute tests" and "drop tests." The parachute tests, as described above, involved closing the landing legs using the solenoid pins, with parachutes folded into the parachute cells, and actuating the pins to allow the legs and parachutes to release. Success rate was 95% for parachute tests on the internal payload assembly and the full payload assembly; any failures were largely due to tangling of the parachute shroud lines on the spring board, and occasionally snagging on the coupler tube frame of the payload tubing. Both issues was solved by tighter packing of the parachutes. It should be noted, though, that these tests were conducted by 'hand actuation' of the solenoids. When the solenoid housings were used to

actuate these tests, the binding issue was encountered, as described above. Prior to including the brass bushings, success rate was only 5% when using the solenoid housings. After the bushings were inserted, success rate increased to approximately 50%; however, this was accompanied by a poorer flush fit between the landing leg and airframe wall.
The drop tests consisted of dropping the payload assembly from a height, with the goal of observing whether the parachutes could inflate. The primary goal of these tests was to verify that our choice of shock cord length was appropriate, and confirm that the payload lands safely under parachute. The assembly was dropped from a height of 40 ft, and caught with a 10x20 ft tarp, in three configurations:

- Upright, with all parachutes out: In this test, the assembly was dropped with all parachutes out and hanging at full length. Two parachutes inflated within one second; the third was observed to nearly inflate, but the assembly fell into a tree before this could be completed.

- Nose-down, with one parachute out: In this test, the assembly was dropped nose-first, to observe the uprighting effect, as well as packing two parachutes to observe the time necessary to unravel. Note that the legs were not closed - the parachutes were merely held in by hand. In this case, one parachute did inflate, and the assembly began to turn upright. However, the other two parachutes did not inflate.

- Nose-down, with two parachutes out: This test was similar to the previous test, with the exception that only one parachute was packed, in order to isolate the variable of the parachute unraveling. In this test, one parachute inflated within a second, beginning the uprighting process, and the second was observed to inflate just before the assembly landed. The third was observed to have just unraveled, but not inflated.

The drop tests verified that even under just one parachute, the payload could land without damage. It also verified that the deployment of parachutes could cause the payload to upright itself in mid-air. It was concluded that the parachutes would be expected to inflate if given more time; as the payload is meant to fall from at least 650 ft altitude, there should be enough time for parachutes to inflate.

4.4.4 Upright Landing: Full Scale Flight Outcomes

Our full-scale vehicle, URSA Major, contained the entire payload assembly as the upper section of the airframe. Due to the failure of certain electronic components, explained in further detail in Section 4.7.5, the payload experiment could not be entirely flown on the full-scale flight. Instead, the payload was modified such that only one leg would deploy, in order to observe whether the leg deployment and parachute deployment systems were functional. For reasons described below, the payload ejection, and two landing leg deployments were disabled; ejection charges were not present, and the landing legs were rigidly pinned in place and taped over. During full-scale flight, the payload leg did not deploy. It was found upon recovery that the solenoid pin had not moved; however, the software indicated that the solenoid pin had been actuated. This indicates that the pin was obstructed due to friction. Although charges were not included, the software indicated that the charges would not have been set off, due to the fact that parachutes had not been deployed - this indicates the success of our safety measure using a photoresistor to detect the deployment of the landing leg.

4.5 Instrumentation Precision

Measurement precision of the StratoLogger CF (according to the specification) is 0.01% of the reading plus 1 foot. With the measured apogee of 4541 feet, that gives a precision of $\pm$ 5.5 feet.

As enumerated in 4.6.4, the precision of the target detection is shown graphically. A 5% variance on the color allows for repeatability of target detection given different light conditions.

4.6 Payload Software

4.6.1 Deployment Software

The software used for deployment on the full scale test flight was a Python script that monitored the payload altimeter to decide if and when to execute leg deployment. Upon exceeding an altitude of 200', the leg is considered "armed" - no deployment would be considered until this happened. Then, after descending below 700', the Raspberry Pi sent a "high" signal to the switching system, allowing the solenoid to retract and the leg to deploy. All altitudes were determined by ensuring 30 consecutive samples met the altitude criteria, to ensure no premature deployment.

This software was limited by several component failures in the twelve hours leading up to launch. The final version of the software will act according to the following logic:

1. The legs will be armed, as in the previous version, at 200'.
2. At 650' or upon successful target identification (whichever happens first), the Raspberry Pi will signal to deploy the first leg.
3. For a period of 15 seconds, the Raspberry Pi will be in a loop, sampling the photoresistor voltage to ensure leg deployment was successful. If after this time period no deployment is verified, ejection procedures will be aborted.
4. If deployment is verified, the Raspberry Pi signals the second leg to deploy, also triggering the charges that eject the payload from the body.
5. Approximately 5 seconds later, the Raspberry Pi deploys the third leg.

4.6.2 Detection Software

The software used for detection designed for the full scale test flight was not used on the full scale test flight on March 4, 2017 due to broken hardware which could not be replaced in time. However, it was improved significantly over the prototype we had by CDR. The detection software is run continuously from prior to launch to after landing. The Python-based capture program takes pictures at 1 second intervals through the Raspberry Pi camera. As the photos are being taken, the Mathematica-based analysis program searches the images for the colors of the ground targets with a 5% variance to adjust for lighting conditions. Any targets locations found are superimposed on the original photo and saved to the Raspberry Pi filesystem. The timestamp of the original photo and of the analyzed photo prove that the target detection is occurring while SAGITTA-VL is in flight.

4.6.3 Target Detection: Full Scale Flight Testing Outcomes

The software launched on the full scale rocket consists of two parts–that concerned with deployment and that concerned with target detection. The target detection software was tested with the target detection hardware prior to launch, and the payload camera was verified as operational approximately 24 hours before launch. About 12 hours before launch, an error was detected in the payload camera. Multiple test suites were run and hardware swaps to determine the source of failure. The source turned out to be a hardware failure, detailed in 4.7.5. No spares were available to run and there were no purchasing options available to us that would allow us to fly in our launch window. As such, the target detection software was not running on the full scale test flight; however, pre-flight static tests were run.

4.6.4 Target Detection: Static Testing Outcomes from Sub-scale Flight Images

The software has been validated on images captured from the payload camera while running on the Raspberry Pi. These static tests confirm that the analysis does detect specific colors at altitude, that images captured through the PETG nosecone are viable for target detection, that taking images at the specified rate of capture is possible, and that the hardware-constrained flight platform can still run the software despite processor limitations.

Displayed below is an image captured during the sub-scale flight of URSA Minor. The land features in the bottom right are slightly whiter than the features in the center, which are more gray.

Figure 52: Image captured during URSA Minor sub-scale launch at altitude

After running this image through the Mathematica analysis software on the payload's Raspberry Pi using a color value close to the lower left set of features, it successfully detected the features using a variance of 5%. A variance of 5% will be selected for the final software to allow for more diverse lighting conditions while reducing the signal-to-noise ratio. The highlighted image is shown below.

Figure 53: Image from sub-scale launch highlighted by analysis program

The second set of ground features (darker, more centralized) were closer in color to the ground, so some false positives occurred but the software was robust enough to not highlight the other color ground features, as shown.

Figure 54: Central ground features highlighted by analysis program

4.6.5 Deployment: Full Scale Flight Testing Outcomes

The deployment software was active during the full scale test flight. As designed, it attempted to deploy the first landing leg. The leg did not open, as detailed in 4.4.4—and the photoresistor detected this state. As such, there was no signal sent to the ejection charge wires (see 4.7.5), and the rest of the payload deployment was aborted. The payload came down safely under the main parachute.

The full scale test demonstrates that under flight conditions, the deployment software can properly detect anomalous conditions and react accordingly. The proper signals were sent (or not sent) at the correct times and the log successfully recorded events for post-launch analysis.

4.7 Payload Electronics

The payload electronics section consists of eight main components:

- A Raspberry Pi microprocessor. This contains the payload software and can be thought of as the main "base of operations" of the electronics. It is powered by a 5V USB power bank that contains four AA batteries. It is connected to the Stratologger CF, the RRC3, the prototype board, the photoresistor, and the camera.

- A Stratologger CF altimeter. This is one of the two altimeters used in case of Raspberry Pi failure. Its main ejection port is connected to one of the solenoids, so that at least one leg will be deployed in all launch situations. It is powered by a 9V Duracell battery. Its serial port is connected via a serial-to-miniUSB dongle and a miniUSB-to-USB cable that connects to a USB port on the Raspberry Pi. This allows the Raspberry Pi to receive and process altitude data.

- An RRC3 altimeter. This is the other altimeter used in case of Raspberry Pi failure. Its main ejection port is connected to the same solenoid that the Stratologger CF is connected to. It is powered by a 9V Duracell battery.

- A prototype board with three solenoid switches, each of which is a transistor circuit that has a Raspberry Pi GPIO pin as input, and activates the corresponding solenoid based on the input.

- Three solenoids. Each of these is connected to a solenoid switch so that they can be activated and deactivated by the Raspberry Pi. All three are powered by the same 9V Duracell battery. To prevent current overdraw on the battery, during flight two or more solenoids are never activated at the same time.

  The first solenoid activated is also connected to the main ejection ports of both altimeters. The second solenoid activated is also connected to the two ejection charges. The third solenoid has no extra connections.

- A photoresistor component that measures the light present in the parachute box for the first leg deployed. It is powered by the Raspberry Pi and is connected to a GPIO pin on the Pi for processing by the payload software.

  It is used to check if the first leg deployed, so that if the leg does not deploy, the ejection charges will not be activated.

- A camera to be placed in the tip of the nosecone. It is connected to and powered by the Raspberry Pi, and its data output is extremely important to the payload experiment.

- A TeleGPS transmitter module. It is powered by a 3.7V LiPo battery.

All electronics, except for the solenoids, are contained within a sled in the nosecone that allows for easy assembly and removal.

4.7.1 Drawings and Schematics

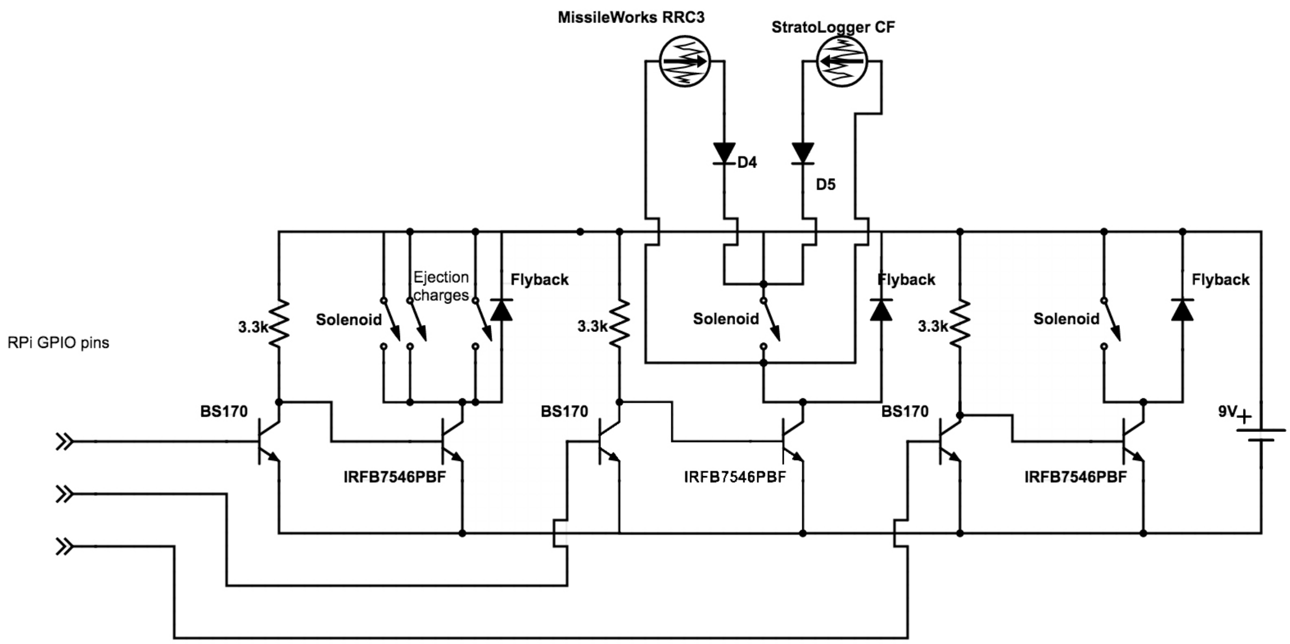


Figure 55: Prototype board schematic – Solenoid switches

4.7.2 Block Diagrams

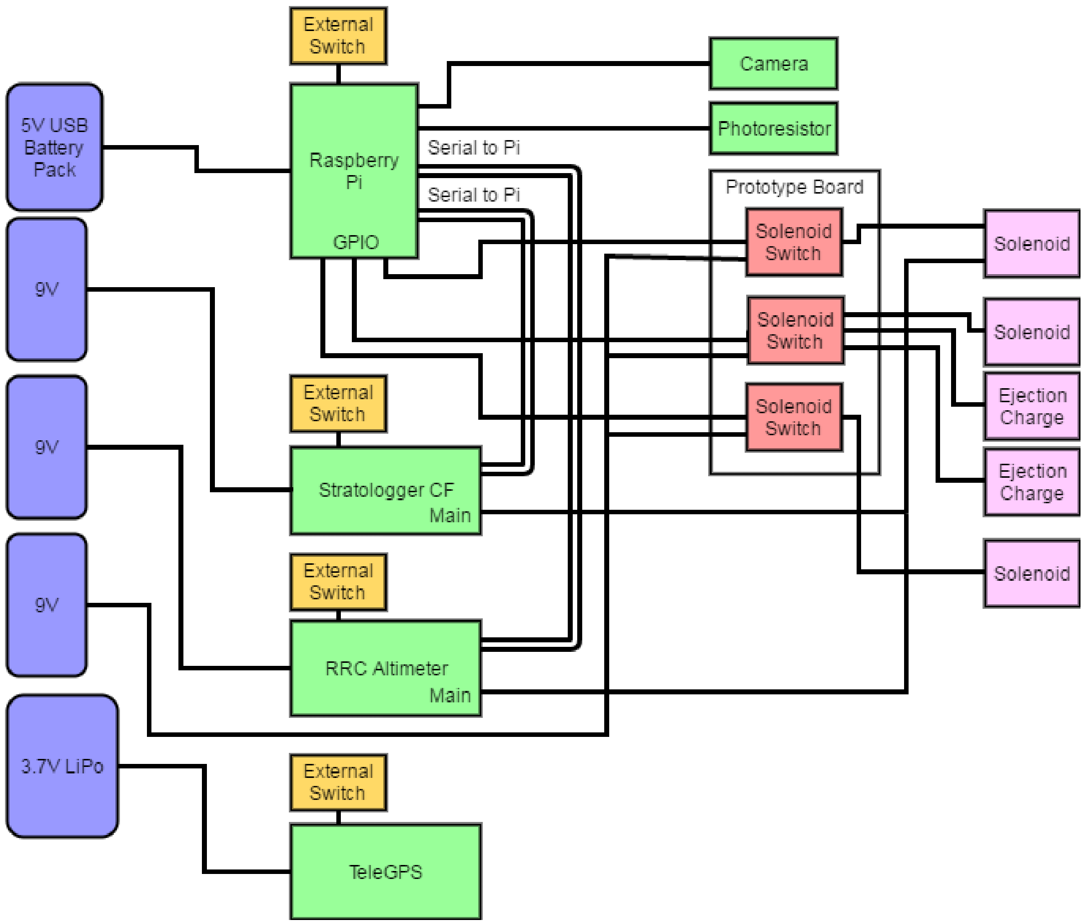


Figure 56: Payload electronics block diagram/overview

4.7.3 Batteries/Power

There are five batteries:

- A 5V USB power bank powered by four AA batteries, for the Raspberry Pi. There will be an external switch connected to the Pi's reset switch, so that the Pi can be externally turned on and off.
- A 9V Duracell battery for the Stratologger CF altimeter. There will be an external switch connected to the altimeter's switch port.
- A 9V Duracell battery for the RRC3 altimeter. There will be an external switch connected to the altimeter's switch port.
- A 9V Duracell battery for the solenoids. This can be connected early, since there is minimal power drain when the solenoids are not in use. There will be an external switch connected to the prototype board, so that this battery (which controls the ejection charges as well) cannot be activated early and potentially cause hazardous conditions with the ejection charges.
- A 3.7V, 2000mA-hour LiPo battery for the GPS.

4.7.4 Switch and indicator wattage and location

There will be five external switches for the payload electronics, all of which will be on the side of the nosecone.

- A switch connected to the Raspberry Pi's reset switch, so that the Pi can be turned on at the launchpad.
- A switch connected to the Stratologger CF altimeter.
- A switch connected to the RRC3 altimeter.
- A switch connected to the TeleGPS.
- A switch connected to the solenoids' 9V power source.

These switches are meant for rocketry applications and are rated for 6.3A / 250V, both of which are significantly higher than any power source in the payload can supply.

4.7.5 Test Outcomes for Payload Electronics

The original full-scale test was planned to have the Raspberry Pi deploying the three legs and ejecting the payload section by using the three solenoid switches on the prototype board.

However, due to unforeseen circumstances despite mitigation testing procedures, two of the three switches did not work directly prior to our launch window, with no replacements available on the field, while in tests several hours previous they were shown successful. This contributed largely to our decision to fly with a single leg activated. To avoid launching the payload section with no parachutes, we did not want to have ejection on the only leg now available. We still used this "test leg" with the photoresistor to confirm deployment prior to what would be an ejection event.

The solution to this problem was to connect the leg with the photoresistor to the working switch, and to not install ejection charges for the aforementioned safety reasons. During the full scale launch test, the photoresistor accurately reported to the deployment software on the Raspberry Pi that the leg failed to deploy, so it did not attempt to activate the ejection process.

5 Safety

5.1 Review of Responsibilities

The Safety Officer for CalSTAR is Grant Posner. The Safety Officer's responsibilities include:

- Ensuring that construction is carried out safely. In particular, the Safety Officer will maintain MSDS documentation for various chemicals and materials that team members may be working with, will ensure that the relevant team members understand the risks and procedures involved in these materials, will identify construction risks, and will design and implement procedures for minimizing these risks.
- Ensuring that all tests and launches abide by relevant codes and regulations. In particular, the Safety Officer will design and implement procedures to abide by the NAR High Power Rocket Safety Code; NFPA 1127; FAR 14 CFR, Subchapter F, Part 101, Subpart C; and CFR 27 Part 55; and verify team compliance through observation and instruction. Furthermore,

the Safety Officer will ensure compliance with all relevant local codes and regulations, and compliance of every team member with the commands of the Range Safety Officer at any launch site.

- Maintaining hazard analyses, team procedures, and safety protocols.
- Conducting pre-launch briefings and hazard recognition and accident avoidance briefings.

The utmost concern of the entire team during all team operations is safety. The primary duties and responsibilities of the Safety Officer and the members of the Safety Team are therefore intended to maximize team safety and minimize hazards and risks.

5.2 Personnel Hazard Analysis

Table 12: Personnel Hazards Analysis

Risk	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Black powder fails to explode, or explodes at an undesignated time	This could result in the parachutes not being able to deploy, creating a dangerous falling projectile. Furthermore, upon examining the rocket after it lands, it could explode and hurt a student	3E	Tape the E-match to the Tender Descenders to ensure that it will light the black powder; make sure all electronics are connected	Double-check all wiring before launch to verify electronic connections. Test the E-match attachment by verifying that the attachment is secure.
Short-circuiting of wires	Could potentially create a fire inside the rocket	2E	Tape and label each wire to ensure that they would are connected to the intended locations	Double-check labels to verify correct wiring, and tape any un-taped wires as soon as noticed.

continued. . .

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Risk	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Inadvertent launch before rocket is at launch pad and site is clear	Possibility of major injury to team members or bystanders from physical contact with the rocket or its exhaust	2E	The motor will be installed only when required, and the launch system will be armed only when the rocket is at the launch pad. There will be minimal time between the rocket being ready to launch and the launch itself.	Team safety officer and team mentor will verify that motor is installed only when required, and that launch system is armed only when safe.
Improper use of machining tools	Damage or wear to equipment, minor personal injury; possibly major damage to construction components.	2D	Workshop training is always required before personnel are allowed to use machines and equipment for construction. UC Berkeley machine shops only admit personnel once training and a test are completed.	University workshops allow access only after training and the test are completed, which automatically verifies that team members understand proper equipment use.

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Risk	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Touching a hot soldering iron	Minor personal injury to due localized burns	C3	Electronics team members should be particularly careful around any soldering iron, and all soldering irons should always be assumed to be on and hot unless directly verified otherwise. Team members should never touch any part other than the handle of a soldering iron.	Team safety officer will observe that soldering iron is placed in its holder before and after use.

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Risk	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Improper handling of hazardous materials/chemicals	Explosion or fire, personal injury (burns, loss of eyesight, cuts, etc.); possible damage to rocket components.	2C	Experienced team members/team mentor should supervise all handling of hazardous materials, or the team mentor should handle materials himself. Also, use of Personal Protective Equipment and applying lab safety standards can help: wearing safety goggles, lab coats, closed-toed shoes, having minimal exposed skin, wearing gloves, etc.	Team members are required to understand MSDS and wear proper personal protective equipment before working with hazardous materials and/or chemicals, and furthermore university workshop supervisor and/or the team safety officer observe mitigations.

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Risk	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Exposure to hazardous materials/chemicals (in particular fiberglass, epoxy, spray paints)	Skin, eye, and/or respiratory irritation; coughing or, in severe cases, lung damage and reduced respiratory capability	2C	Clothing that covers the arms, along with safety goggles and either a respirator or a dusk mask, should be worn when machining materials that may release dust or fibers into the air, and if possible work should be done outside or in an otherwise ventilated area (especially when spray-painting components). MSDS for particular materials have more information, which team members should be aware of before construction.	Team members are required to understand MSDS before working with hazardous materials and/or chemicals, and furthermore university workshop supervisor and/or the team safety officer observe mitigations.

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Risk	Effects	Severity and Likeli-hood	Mitigations	Verification of Mitigations
Electric shock while working with electronic components	Tingling, minor muscle contractions	2B	Batteries will not be installed except when testing or launch requires their installation. Rubber-encased wires primarily should be used in construction. Before touching bare wires, team members should ensure that batteries or power sources are disconnected.	Visual observation of wires leading to any particular component may verify that power sources are disconnected.
Rocket lands in spectator area	Rocket may strike and injure persons or property	2C	Tilt rod at a slight angle away from spectator and prohibited areas before launch	Visual observation will verify that launch rod is tilted appropriately
Rocket is launched too close to people or property	Possible burns, hearing damage, and failure to abide by regulations	2D	Ensure that nobody is within the minimum allowed distance to the pad, specified in the NAR High Power Rocket Safety Code	Visual observation that launch area is clear

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Risk	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Motor mishandling	Possible ignition	3D	Only the allowed personnel (David Raimondi, other LUNAR personnel) will be allowed to handle the motor. Igniter will not be installed until the rocket is at the launch pad.	When motor is placed into the rocket, visual observation will verify that there is no igniter, and of course verification that the proper person is handling the motor can be visual as well (i.e. does the person handling the motor look and act like David Raimondi?)
Payload ejection without leg deployment	Ballistic trajectory of payload section to the ground; injury to bystanders	2B	Onboard computer will use data from photo-resistor sensors to determine that legs have deployed before ejection commands are executed	Ground testing: for example, by manually deploying legs and verifying that the rocket's computer correctly detects deployment, and manually raising legs and verifying that the computer correct detects non-deployment

5.3 Failure Modes and Effects Analysis

5.3.1 Airframe Failure Modes

Table 13: Airframe Failure Modes

Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Blue Tube airframe breaks in flight	Stress during launch. High wind speeds/G-Forces causing stress/fractures in airframe.	Airframe breaks in midair, booster section may come loose while motor is still burning. Payload and avionics components may break free and lose functionality.	C2	All structurally weakened portions of the airframe will be reinforced with centering rings, bulkheads, or additional tubes. All internal components will be secured using screws, epoxy, or zip ties. No friction fitting will be used to secure components.	We have pulled and jostled the airframe and run a jiggly test. It has not come apart.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Nose cone tip comes loose during flight	Weak glue joint between the tip and the nose cone base. High drag forces may break the glue joint.	Payload internal components are exposed to the outside atmosphere, may compromise/break some components.	E2	Nose cone tip will be securely fastened to the nose cone base using high temperature, high strength, high viscosity epoxy. The glue joint will utilize as much contact surface area as possible to further reinforce the joint.	The nose cone has been pulled and twisted more than the expected amount of force during flight. It did not come off.
Fins are damaged on landing	Impact of rocket with ground	Rocket loses launch capability and is no longer reusable	E3	Use 3/16 fiberglass fins to ensure strength; fillet with West Systems epoxy and small carbon fiber strips.	There have been drop tests where the fins do not come loose.
Recovery System does not deploy	Inadequate setup during launch	Extreme hazard to bystanders; extreme risk of damage to rocket	D2	Have thorough pre-launch and launch checklists; practice during sub-scale and full scale launches.	Ground tests are conducted before flight and all electronics are checked.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Motor failure	Motor fails to ignite; faulty motor; improper storage/installation of motor	Rocket will not take off	D3	Double check out igniter; research company and motor for any faulty motors; use manufacturer's instruction to properly store motor.	Motor is checked thoroughly before being placed in rocket.
Rocket becomes unstable; loss of height and possible loss of camera for sight acquisition	Thrust to weight ratio does not meet minimum requirements to stabilize against wind speed	Nose cone deforms during flight	C2	Perform a series of test that determine the conditions the rocket might be exposed to during flight to ensure no deformations.	Camera tests are conducted before placing the camera in the nose cone.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Motor tube failure during flight	Weak adhesive bonds between motor tube, centering rings, and body tube	Complete loss of flight vehicle; likely payload damage	E1	Take extra care to ensure epoxy is affixed to centering rings, as well as checking that centering rings are properly attached to the body tube; double check that motor tube is not damaged before constructing	Intensive material testing is conducted prior to use of materials for manufacturing purposes.
Launch rail fails to maintain vertical	Improper setup	Launch vehicle launches at an angle, potential danger posed to life and property	D1	Use structural analysis and ensure launch rail is constructed properly; check security of fasteners and components	Prior to rocket placement of rail, there will be an alignment test for the rail buttons in order to ensure parallelity.
Nose cone detaches	Weak fit between nose cone in body tube	Loss of stability; hazard to nearby onlookers	D1	Ensure that nose cone is constructed properly and fits tightly within the body tube	Conduct pull tests prior to launch.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Fin flutter damages fins during flight	Due to wind turbulence and vibrations of the rocket	Loss of stability; hazard to nearby onlookers if parts break off	C2	Take extra care to reinforce epoxy bond with carbon fiber fillets; use through-the-wall bonding for extra strength	Conduct flex tests on the fins prior to launch.
Coupler failure	Weak fit between coupler and body section; weak adhesive bond with frame	Loss of stability and structural integrity; hazard to people on the ground; compromised internal systems	E2	Inspect rocket components thoroughly before launch; ensure sections are properly fitted together. Ensure that the couplers are tight enough to hold the weight of the sections below it.	Conduct slide tests in order to ensure that the couplers do not slide off.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Motor Explodes	Propellant outside of the casing or defective motor lining, nozzle, casing, or o-ring	Complete mission failure	E1	Properly manufacture the motor.	Do not hook up igniter to motor until ready for launch and follow these steps when building motor: 1) spray inside of casing and outside of lining and forward closure with teflon 2) grease orings 3) put orings and on closures 4) cap the nozzle 5) insert propellant grains/delay grain 6) cap forward closure 7) oversee installation of motor.

5.3.2 Payload Failure Modes

Table 14: Payload Failure Modes

Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Solenoid pin actuation failure	Software error	No landing leg deployment or chute ejection, potentially severely damaging the payload section.	E2	To avoid possible software errors from the Raspberry Pi affecting the landing leg deployment, one solenoid is wired directly to the altimeters (See section 5.5) Further, only one landing leg deployment is needed for a safe landing since a single parachute can effectively land the payload below 75 ft lbf. Also, introduction of a photoresistor to the leg that will be deployed first will give data about whether or not the leg successfully deployed. Only after a successful first leg deployment will the payload be ejected from the rest of the rocket. This ensures that even if the leg doesnt deploy, the payload will descend under a parachute.	Redundant altimeters for solenoid activation will be tested under the following lab conditions: using the altimeters' test mode, individually activate the electric pulse from each altimeter one at a time and ensure that the solenoids deploy as configured in a flight-ready circuit. Also test the effects of both altimeters firing to prevent electrical malfunctions that may lead to solenoid activation failure. Confirmation of solenoid deployment will be done visually and confirmed by using a multimeter to check that each part of the circuit is receiving the expected currents and voltages.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Hinge connecting support leg and landing leg frame breaks	As landing legs deploy then stop at full extension, excessive force from air flow might cause that abrupt stop to send a shock through the landing leg that breaks the hinge.	Possible upright landing failure.	C3	Use strong hinges and bolts which can withstand more force than anticipated from our stress analysis of the system. Torsion spring will aid in absorbing possible damaging shock.	The landing leg system for a single leg will be built. Performing drop tests from a height of approximately 40', the hinge connection will be tested. If during leg deployment, it breaks within 5 tests, another analysis will be ran to determine the next highest strength hinge or bolt to use. This process will continue until 5 consecutive successful tests are completed.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Parachute snags	Unsmooth parachute chamber or poor packaging of parachute.	1) Delayed parachute deployment 2) Parachute tear 3) Partial or Incomplete parachute deployment - Individual or combination of these effects could result in violent spinning of payload and/ or too high of a descent speed damaging the rocket and potentially bystanders.	E2	Manufacture a smooth parachute chamber. Work with recovery team to properly package each parachute.	The payload will be loaded with only one leg and parachute will be properly loaded with a 36" toroidal parachute. With the payload nose cone down, a test will be performed where the payload body is fixed and the leg is deployed such that the parachute can fall out properly. Until 10 consecutive successful tests are completed, the packaging method or parachute chamber design will be altered.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Parachute lines tangle	Payload tumbling due to the uneven load distribution (until all parachutes are fully deployed) from staggered parachute deployment and close proximity of the three parachutes may result in the lines tangling.	Parachutes lose effectiveness and rocket lands with greater than 75 ft lbf.	D3	Determine the optimum time interval between each parachute deployment that will lead to the lowest chance of tangling.	Drop tests from approximately 40' will be performed. Tests will continue until 5 consecutive successful (parachute lines dont tangle) tests are completed. That successful time interval will then be implemented into the full scale payload design.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Incomplete Uprighting	Particularly uneven terrain or a strong crosswind	Upright landing failure	B4	The three payload parachutes will land the payload at an approximate 23.97 ft lbf which will provide the best opportunity of upright landing.	Using a payload full scale test model where all three legs and parachutes are already deployed, a drop test from a height of approximately 40' will be performed. This test will be performed over different terrains. If the payload falls over after 1 minute, the test is unsuccessful. The test will be repeated 25 times to determine the probability of an incomplete uprighting. If the probability is high, then design changes will follow.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Sliding rails get stuck	Misaligned or dirty leg rail system	Landing legs can't fully extend, resulting in upright landing failure and possible damage to bottom of payload section.	B2	During build and at launch site, perform ground tests consisting of manually sliding the support leg along the rail to ensure legs are capable of full and smooth extension (aided by application of WD-40 if necessary).	First, for each landing leg system the support leg will manually be slid along the support leg to ensure a full and smooth extension. Then drop tests of all three landing legs will be performed from a height of 40' to confirm a full and smooth extension during descent. WD-40 will be incrementally applied until 5 consecutive successful tests are completed.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Incomplete retraction of solenoid pin	Too much friction on solenoid pin from torsion springs on landing legs and compression springs in parachute box	No landing leg deployment or chute ejection, potentially severely damaging the payload section	E3	Introduction of a photoresistor to the leg that will be deployed first will give data about whether or not the leg successfully deployed. Only after a successful first leg deployment will the payload be ejected from the rest of the rocket. This ensures that even if the leg doesnt deploy, the payload will descend under a parachute.	Install the photoresistor to the leg and electronics. Pack up a single leg including the parachute and run the electronics to release the leg. Check that the photoresistor detects that the leg successfully deployed. Also run some tests where the leg isnt allowed to deploy and check that the photoresistor correctly detected that. Fix or modify electronics if needed until 10 successful tests are completed.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
One or more landing leg pulled open during ascent or before ejection from the rest of the rocket during descent	Too large of a gap between the top and sides of the landing legs with the body of the payload.	Leg and payload parachute deploys causing an immense increase in drag, unstable rocket trajectory, possible loss of leg, and possible danger to bystanders.	E2	During pre-launch setup, load the legs into the correct position so they are as flush as possible with the payload body. If there are still gaps, liquid silicon gasket can be added to fill the gaps.	Load the legs into the upright position, including the parachute in the parachute box, and agitate the whole payload to simulate agitation felt during flight. Repeat this test multiple times (10 minimum), each time correctly loading the legs to ensure that that isnt the issue. If a gap consistently occurs, fill the gaps with silicon gasket.

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**
Shock cords snap at deployment	Minor cut to begin with; force of descending payload section too much for kevlar shock cords to hold	If only one or two shock cords snap, payload descends at a safe speed but fails to land upright. If all three shock cords snap, payload descends without a parachute, damaging the payload and potentially injuring bystanders.	E1	Perform force analysis and tensile test on shock cords.	Drop testing from the roof of a 4 story building will give a good idea of the validity of the shock cords. Given the height, there isnt sufficient time for all three parachutes to deploy from a tightly wrapped position. Therefore, only one parachute will be unwrapped during the drop test. This will be repeated for each parachute. This will test the strength of each shock cord under the full weight of the payload.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations
Black powder residue enters payload section	Bulkhead of payload not secure/air-tight enough	Residue potentially comes in contact with the sliding leg mechanism hindering the leg from full extension. This would result in upright landing failure and possible damage to bottom of payload.	B2	Make sure payload section is completely sealed off from ejection charges using rubber gaskets.	An air canister will be used to check for any leaks around the bulkhead.

5.3.3 Recovery Failure Modes

Table 15: Recovery Failure Modes

Risk	Causes	Effects	Severity and Likelihood	Mitigations

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Risk	Causes	Effects	Severity and Likelihood	Mitigations
Drogue chute fails to deploy	Rocket travels at too high of speed when main chute is deployed, potentially severely damaging the rocket	Altimeters fail to recognize air pressure change, causing the black powder charges to not fire	E3	Use of two, redundant altimeters; perform several ground tests to be sure that charges will deploy chutes.
Main chute fails to deploy	Rocket lands at kinetic energy higher than 75 ft-lbf, damaging the rocket and potentially injuring bystanders	Altimeters fail to recognize air pressure change, causing the black powder charges to not fire; Tender L2 Descender fails	E3	Use of two, redundant altimeters; perform several ground tests to be sure that charges will deploy chutes
Altimeters shut off during flight, causing deployment system to malfunction	Parachutes either deploy too early or not at all, damaging the rocket and potentially injuring bystanders	Forgetting to turn on before flight; batteries run out	E3	Use new 9V Duracell batteries, check batteries before flight, and tightly secure all power supplies before flight
Parachutes Melt	Rocket is not ready for launch after landing; rocket potentially lands at kinetic energy higher than 75 ft-lbf, damaging the rocket and potentially injuring bystanders	Black powder deployment charges explode, creating too much heat inside parachute chamber	E2	Properly wrap parachutes in heat blankets

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Risk	Causes	Effects	Severity and Likelihood	Mitigations
Deployment charges are not sized properly	Rocket is either damaged from too large of ejection charge or parachutes are not deployed from too small of ejection charge	Black powder was not accurately allocated for each charge region	E2	Perform several ground tests to be sure that charges will deploy chutes
Shock cords snap at deployment	Sections of the rocket descend without parachute, damaging the rocket and potentially injuring bystanders	Minor cut to begin with; force of rocket too much to hold for kevlar shock cords	E1	Perform force analysis and tensile test on shock cords
Black powder residue enters avionics bay	Potential damage to electronic devices; heavy cleaning needed after flight	Bulkhead of avionics bay not secure/airtight enough	C2	Make sure avionics bay is completely sealed off from ejection charges using rubber gaskets

5.3.4 Electronics Failure Modes

Table 16: Electronics Failure Modes

Risk	Causes	Effects	Severity and Likelihood	Mitigations

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**
Connection failures between electronic components	Launch trauma, failure to properly test electronics	Payload will fail to eject and deploy.	E4	Minimize push-pull connections. Use PCB in place of breadboard. Ensure soldered joints are solid. Ensure wire lengths are appropriate (not taut).
Batteries are too low	Not double-checking batteries before launch, and not putting enough battery power in the rocket	Payload will never eject and deploy	E3	Pre-flight testing before setup and on launchpad. Include enough battery power to last two hours. Have full replacement batteries available.
Altimeter failure or miscalibration	Launch trauma, failure to properly test electronics on launchpad	If payload does not detect targets, the payload will not eject or deploy.	E3	Include comprehensive testing process in launch procedure. Secure altimeter to payload, and ensure connections are solid.
Camera fails to work	Launch trauma, failure to properly test electronics	Payload will not detect targets and will deploy at a certain threshold altitude instead	D3	Solidly secure camera to the payload body. Test in subscale launches.

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Risk	Causes	Effects	Severity and Likelihood	Mitigations
Camera is out of focus	Miscalibration, failure to properly test electronics	Payload will not detect targets and will deploy at a certain threshold altitude instead	D3	Launchpad testing to verify images. Calibrate/focus before launch.
Accelerometer failure or miscalibration	Launch trauma, failure to properly test electronics	Payload data will be incorrect.	A3	Include comprehensive testing process in launch procedure. Secure accelerometer to payload, and ensure connections are solid.
Gyroscope failure or miscalibration	Launch trauma, failure to properly test electronics	Payload data will be incorrect.	A3	Include comprehensive testing in launch procedure. Solidly secure gyroscope to payload body.

5.4 Environmental Risks Analysis

Overview:

CalSTAR's safety team will prepare and observe all environmental and safety issues. These guidelines will be followed completely throughout all tests and deployments, including any competitions. All team members will be instructed on these procedures and be required to sign off that they understand and will comply with these safety procedures. Monitoring of compliance will be performed and documented by the safety team.

Safety Issues:

At all times, any possible procedures that involve chemicals, explosive devices, electricity, waste or runoff, shall be contained to all local, university, state, federal and national rocketry and contest regulations. This includes contemplating complete failure of any liquids, solids, devices, or any exhaust or by-products of any part of the experiments. As such, this contemplates containing any negative impacts with barriers, shields, liquid containment, and exhaust containment. In addition, site preparation and post-experiment cleanup and waste issues will be contained.

Environmental Issues:

The following are the contemplated areas of environmental concern:

- Shore/water hazard
- Soil impact (chemical changes)
- Air impact (unwanted gas emission)
- Waste disposal
- Drainage/runoff
- Fire/explosion

Monitoring:

The safety team will monitor these concerns at all tests and deployments.

Documentation:

The safety team shall document these procedures are followed at all tests and deployments.

This includes monitoring and gathering all sensor, blast, and payload data for the launch and comparing it to expected values.

In addition, we shall video tape the complete setup and deployment of any launch in order to document the success or failure of any and all procedures and activities connected to the launch and to enable a post-mortem after the launch if necessary.

Specific Concerns:

- **Rocket motors:** While we do not know precisely the exact contents of the L-type rocket motor that we plan to use, solid rocket motors are likely to give off harmful gases, such as: hydrogen chloride (HCl), alumina particle (Al2O3), Chloro-fluoro-carbons (CFCs) and chlorine gas (Cl(g)). Although level 2 rockets aren't comparable in emissions to (sub-orbital) rockets, they still have an impact on the local environment and the deployment envelope. The concern is not in the manufacturing because the rocket engines are manufactured under government license and control. The main issue of concern is leaving behind any ammonium perchlorate residue or harmful air contamination for bystanders to breathe in.
- **Launch area:** Before doing any rocket launch, it is critical to inspect the site of launch for potential fire risks, ecological environments and nearby water sources. Rocket launches can damage local ecological environments by affecting soil quality, and local ecosystems.

  A site survey shall be performed to note any nearby areas that may be impacted by the launch, such as any water, streams, or lakes, as well as flammable structures or objects, such as buildings, bushes, or trees. It is devastating to the ecosystem of a water environment to expose it to such inorganic chemicals. It may destroy chemical properties of the water as well as affecting the rest of the water surroundings. Such ecosystems including any organisms and microorganisms will be affected by the contaminants.

There also should be an animal impact assessment to consider any negative impacts to animals in the blast or deployment area. (The launch site shall not be near any animal habitats.)

- **Electrical systems and batteries:** The performance characteristics of any electrical systems, including batteries shall be documented, per their manufacturers, in order to contain any malfunction. In addition, any electrical systems should be protected against human contact, even in a malfunction. Any chemical runoff from a malfunction of an electric system will have serious negative impacts to the local environment. The chemical runoff shall be immediately picked up and contained, and disposed of in an appropriate waste bin. Because there are no liquid chemicals in the rocket, and the electrical system is powered strictly by over-the-counter consumer grade batteries, these risks are extremely minimal.

- **Hazardous disposal:** Any identified hazardous parts, needs to be picked up, contained, and disposed of in accordance with applicable laws and safety considerations. This includes any chemicals typically used to construct the rocket, such as glues or resins. This also includes any malfunctioning parts, or parts that may have exploded. This also includes any used or malfunctioning rocket engines, chemicals and batteries. Rocket engines shall be neutralized chemically, per manufacturer's instructions, before being bagged. The main concern of hazardous waste is primarily the rocket motor and to a lesser degree, any paint, glue or batteries, and black powder remnants that may fall off the rocket during flight. Rocket engine and uncharged black powder remains shall be properly disposed of by manufacturer's recommendations, should be buried in the ground and burned. The remaining propellant holder is non-hazardous after flight. Post-flight, the motor casing shall be properly cleaned for reuse.

- **Waste disposal:** All other non-hazardous waste from the launch area shall be accumulated and disposed of appropriately so that the launch area is completely clean after the launch.

Table 17: Environmental Risks Analysis

Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**	**Remediation**

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
Rocket may land in standing water	The rocket or any parts of the rocket may land, drift off course, or otherwise end up in a standing water area, such as a puddle or a water basin	Chemical runoff from the motor, paint, electrical parts contaminates the water.	2E	Survey the competition site for any standing water. Itemize these spots as potential standing water risk areas based on launch site and possible trajectory errors	Teammates confirm that rocket has not landed in any standing water	Retrieve rocket or parts from water as soon as safely possible.
Rocket lands in running water	Rocket or any parts of the rocket lands, or drifts off course, landing in running water, like a stream	Chemical runoff from the motor, paint, glue, batteries or electrical parts contaminates water in a downstream area from where the rocket landed	2E	Survey the competition site for any water sources and ensure that launch site and trajectory errors are outside the area of possible water landing	Teammates confirm that rocket has not landed in any running water	Retrieve rocket or parts from water as soon as safely possible

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**	**Remediation**
Rocket landing in water destroys sensors and other electrical components	Rocket lands in water	Sensors, RPi, batteries, wiring and other electrical components get damaged or ruined	3D	Survey the competition site for any standing water. Itemize these spots as potential standing water risk areas based on launch site and possible trajectory errors. Design installation of internal rocket components to withstand water for a designated amount of time	Teammates confirm that rocket has not landed in any running water	Retrieve rocket or parts from water as soon as safely possible
Rocket exhaust contaminates the ground soil at launch site	The chemical exhaust from the motor at launch contaminates the ground below the launch site	The ground at the launch site gets contaminated	3B	Launch to be on the assigned launch pad	Verify the rocket is set up on the correct launch pad	If remediation is necessary, dig up dirt and dispose of as hazardous material

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
Rocket ignition starts a fire at launch site, contaminating the ground soil	Flames from the motor at launch causes a fire, due the rocket motor igniting with the rocket still on the launch rail/pad	A fire is started at the launch site	2C	Launch to be on the assigned launch pad	Verify the rocket is set up on the correct launch pad	If remediation is necessary, dig up dirt and dispose of as hazardous material
Rocket ignition starts a fire away from launch site, due to residual heat or flames at landing, contaminating the ground soil	Heat or flames from the motor at launch causes a fire	A fire is started away from the launch site	2D	Launch to be on the assigned launch pad	Verify the rocket is set up on the correct launch pad	If remediation is necessary, dig up dirt and dispose of as hazardous material
Rocket comes apart upon crash landing, contaminating the ground soil	Heat or flames from the motor at landing contaminates the ground	The ground away from the launch site gets contaminated	2D	Launch to be on the assigned launch pad	Verify the rocket is set up on the correct launch pad	If remediation is necessary, dig up dirt and dispose of as hazardous material

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**	**Remediation**
Chemical exhaust from the rocket engine pollutes the air	The chemical exhaust from the rocket engine is released along the whole trajectory path, from the ground to the target apogee	Air becomes polluted with inorganic chemicals, thus hurting the atmosphere, and cause people to breathe the exhaust fumes	3A	Launch in the competition assigned area, and everyone hold their breath as the fumes dissipate	Verify the rocket is on the correct launch pad, and remind members to hold their breath during launch	There is no remediation
People are negatively impacted from breathing chemical exhaust from the rocket motor	Burning of the motor	Chemical exhaust is harmful to nearby people breathing in the polluted air	3B	Have team members hold their breath until fumes quickly dissipate	Remind team members to hold their breath	There is no remediation

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
Extreme temperatures affects the rocket's target apogee	The chemistry of the rocket engine is affected by extreme temperatures	The rocket doesn't meet mission altitude objectives	4C	If possible, don't launch until temperatures are within expected parameters. Assemble rocket engine just before launch	Double check weather reports far in advanced	There is no remediation since this is unknown until after launch
Extreme temperatures may affect the rocket motor performance	The chemistry of the rocket engine is affected by extreme temperatures, giving the engine an unknown power curve	The rocket doesn't perform to design parameters	2D	If possible, don't launch until temperatures are within expected parameters. Assemble rocket engine just before launch	Double check weather reports far in advanced	There is no remediation since this is unknown until after launch
Unexpected wind gust can push the rocket at an angle, making it fly off trajectory	The wind changes the launch or mission trajectory	The rocket trajectory becomes unknown	2C	If possible, don't launch until wind is within expected parameters	Constantly check the wind conditions to see if it is safe to fly	There is no remediation since this is unknown until after launch

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**	**Remediation**
Prolonged sun exposure/high temperatures may over-heat the interior of the rocket beyond design parameters	The components and sensors are outside design parameters	The components and sensors inside the rocket perform unexpectedly or not at all	2D	If possible, don't launch until temperatures are within expected parameters. Assemble rocket engine just before launch	Double check weather reports far in advanced	There is no remediation since this is unknown until after launch
Rocket hits and injures an animal during flight	A flying animal unexpectedly flies into the path of the rocket moving at mach .66	A flying animal is injured	2E	The competition area provides enough human activity, warning alerts, noise from launches and the smell of exhaust to keep away most animals	Verify the rocket is set up on the correct launch pad	Any animals affected should be immediately gathered up and remediated by a qualified veterinarian

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
Rocket hits and injures an animal on landing	The rocket unexpectedly lands on an animal	An animal is injured on the ground	2E	The competition area provides enough human activity, warning alerts, noise from launches and the smell of exhaust to keep away most animals	Verify the rocket is set up on the correct launch pad	Any animals affected should be immediately gathered up and remediated by a qualified veterinarian
Misfire of rocket causes the rocket fly into the crowd	Rocket misfires	Rocket flies into the crowd of people	1D	Team constantly reviewing competition guidelines. There are alerts at launch. Several people are monitoring sequence of launch procedures	Double check guidelines and parameters at the launch time	Anyone affected should immediately be attended to by an on-site doctor. Call 911 if necessary
Unexpected rocket landing in a nearby fire	There is a nearby fire, which should have prevented the launch	Rocket lands in a fire	3E	If possible, don't launch rocket if there is a nearby fire	Check with organizers about site conditions	Rocket can only be retrieved after fire department approves

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
An unexpected nearby fire may create unsafe conditions to fly the rocket (such as smoke or air changes)	The chemistry of the air affects the rocket engine performance	The rocket performs unexpectedly	4D	If possible, don't launch rocket if there is a nearby fire	Check with organizers about site conditions	There is no remediation since this is unknown until after launch
Unexpected chemical spill near the launch pad may cause the motor to explode, due to changes in the ignition chemistry	The chemistry of the launch area atmosphere affects the rocket engine performance	The rocket performs unexpectedly	2E	If possible, don't launch rocket if there is a known chemical spill	Check with organizers about site conditions	There is no remediation since this is unknown until after launch
Rocket take-off disrupts the soil/dirt surface causing a change in evenness	The rocket engine blast disturbs the soil surface geometry	The ground is disturbed in terms of its evenness	2D	If possible, don't launch rocket if there is a soil disturbance	Check with organizers about site conditions	There is no remediation since this is unknown until after launch

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Risk	**Causes**	**Effects**	**Severity and Likelihood**	**Mitigations**	**Verification of Mitigations**	**Remediation**
Prior rain changes the atmosphere density and chemistry in the air and soil, affecting the flight of the rocket	The chemistry of the rocket engine is affected by changes in the expected air parameters, giving the engine an unknown power curve	The rocket performs unexpectedly	3D	The rocket performs unexpectedly	If possible, don't launch rocket if there are atmospheric disturbances outside design parameters	There is no remediation since this is unknown until after launch
Prior rain changed the launch site for the rocket	The changes in the ground parameters provide an unknown base from which to launch the rocket, giving the engine an unknown trajectory	The rocket trajectory is outside the design parameters	3D	If possible, don't launch rocket if there are atmospheric disturbances outside design parameters	Check with organizers about site conditions	There is no remediation since this is unknown until after launch

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
Rocket lands on a building or other structure, outside the target landing area	Rocket goes off-course, outside the pre-determined trajectory plus safety envelope	A building or structure may be damaged or catch fire	2D	Calculate the launch trajectory plus a safety margin to prevent an accidental landing outside a safe landing envelope	Double check the calculations	Competition organization and team should have fire extinguishers available for immediate attention to a possible fire
Rocket produces noise pollution at ground level upon launch	A rocket launch is expected to have a certain amount of noise above ambient for a very small period of time. (1-2 seconds at ground level, but throughout flight until engine expires)	Loud noise on launch is well above ambient noise levels	4A	Every effort should be made to ensure that the launch area is sufficiently far away from any residents or businesses	Double check guidelines and parameters at the launch time	Follow-up coordination with neighbors and city government to ensure better cooperation and notice in the future

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Risk	Causes	Effects	Severity and Likelihood	Mitigations	Verification of Mitigations	Remediation
Neighbors to the launch area are negatively affected	Residential or business housing is too close to competition launch area. In addition, prior mitigation efforts by the organizers may not have been entirely successful	Neighbors to the launch area are negatively affected by the launches	4C	Launch organizers should ensure that the launch area is sufficiently far away from any residents or businesses	This is a competition level issue, outside the Team's control	Follow-up coordination with neighbors and city government to ensure better cooperation and notice in the future
The rocket launch leaves rocket parts, or debris residue on the ground	Debris from a rocket launch is to be expected, including parts flying off rocket and related launch items	There are rocket parts, or debris, on the ground after launch	2B	Complete cleanup plans and personnel assignments should completely mitigate this	Visual inspection by team after launch completed	Completely review launch area after launch to ensure complete and proper disposal of all debris

6 Launch Operations Procedures

6.1 Assembly

6.1.1 Materials & Components

Before traveling to any launch site, ensure that all of the following items are brought to the launch.

Tooling

The following extra tools and minor components are needed for adjustments or repairs.

1. Screwdrivers and allen wrenches
2. Cordless drill and drill bits
3. Pliers
4. A soldering iron and extra solder + flux
5. Extra wires for electronics
6. Wire strippers and wire cutters
7. Screws, bolts, and nuts
8. Extra batteries (9V Duracell, 12V, 3.7V LiPo with JST plug, and AA)
9. Glue (JB Weld and 5 min epoxy)
10. WD-40 and other lubricants
11. Scissors
12. Electrical and duct tape
13. Voltage meter
14. Cables
15. Respirator mask
16. Safety glasses
17. Trash bags
18. Tarp

Rocket Components:

The following items are essential, and cannot be left behind.

1. Airframe components:
   (a) Nose cone
   (b) Payload section (top)
   (c) Avionics section (middle)
   (d) Booster section (bottom)
   (e) Motor casing (David will have this)
   (f) Motor retainer
2. Payload components:
   (a) Landing leg (3x)
      i. L-brackets (3x)
      ii. 3/8" nuts (9x)
      iii. 3/8" bolts (9x)
      iv. Aluminum Supports (3x)
   (b) Raspberry Pi
   (c) Raspberry Pi Camera Board v2
   (d) Missile Works RRC3 Altimeter System
   (e) Eggfinder GPS System
   (f) Fully charged batteries
   (g) Shock cord
   (h) Solenoid (3x)
      i. Solenoid Pin (3x)

ii. Solenoid Springs (3x)
(i) Hose clamp
3. Recovery components:
(a) Materials
i. Drogue (24 in.) and Main (72 in.) chutes
ii. Bulkheads (both the same diameter and the different diameter bulkheads)
iii. 1/4 inch alum. threaded rod (2x)
iv. 1/4 -20 wing nuts (4x)
v. 1/4-20 nuts (6x)
vi. 2-56 screws for altimeters and batteries (16x)
vii. 2-56 nuts for corresponding screws (16x)
viii. 3D Printed altimeter sled
ix. 3D Printed battery cases (2x)
x. Shock Cord with quick links attached
xi. Fresh 9-volt Duracell batteries (2x)
xii. 9 volt terminal connectors (2x)
xiii. Quick links (4x)
xiv. L2 Tender descenders (2x)
xv. 4 gram black powder charges for Av-Bay and Booster+ separation (2x)
xvi. 1/2 gram black powder charges for Tender Descenders (2x)
xvii. 2 gram black powder charges for Payload (2x)
xviii. E-Matches (6x)
xix. Large Olive Green Heat Blanket
xx. Small Orange Heat Blanket
xxi. Stingray parachute bag for main chute
xxii. Door Screws
xxiii. Detachable Door (with two switches already attached)
xxiv. Micro Deans Wire Disconnects (4x)
xxv. 36 in. Payload parachutes (3x)
xxvi. 4ft shock cords for payload (3x)
xxvii. Extra 20 gauge wire
(b) Tools
i. Small flathead Screwdriver for screwing altimeter screws
ii. Philips Screw Driver
iii. Wire stripper
iv. Pliers
v. Pen
vi. Electrical tape
vii. Silicone
viii. 5-min. Epoxy
ix. Sand Paper
x. Heat shrink tubes and lighter
xi. Razor blade
xii. Drill and bits
4. Electronics
(a) Raspberry Pi
(b) Back-up Raspberry Pi

   (c) Many extra batteries

Assembly

These steps should be followed in order with a call-and-response system to ensure that no step is skipped.

1. Airframe:
   Warning: Failure to follow ANY of the following steps may result in the failure of the rocket to fly. Specific examples include: launch misfire due to unattached or unsmoothed parts.
   (a) No cracks, dents, etc. in any airframe components (tubing, nose cone, fins, etc.).
   (b) Make sure the airframe components are properly sanded.
   (c) Add filler to cracks and holes.
   (d) Fins are secure, don't flex/bend
   (e) Examine glue joints and U-bolts on all bulkheads, including eyebolt shock cord mount.
   (f) Inspect gaskets on avionics bay door for damage.
2. Recovery: Assembly of Avionics Bay
   Warning: Failure to follow ANY of the following steps may result in the failure of the recovery system. Specific examples include: Parachute will not deploy correctly and thus result in a crash landing of the rocket.
   (a) Verify that both altimeters (Missileworks RRC3 and Perfectflite Stratologger CF) are secured onto the altimeter sled with four 2-56 screws each. Also verify that both 9V batteries are secured in their respective battery casings, and confirm that it is secured onto the altimeter sled with four 2-56 screws each.
   (b) Connect wires to altimeters on altimeter sled. After connecting, VERIFY that they are the correct wires that correspond to the tape labels.
   (c) Slide the altimeter sled onto the dual aluminum rods and fasten them such that the sled is accessible with the door opening.
   (d) Attach dual rods to the top bulkhead (The same diameter bulkhead) using nuts, washers, and an o-ring. The order is as follows: o-ring, washer, and the nut on top.
   (e) Secure the top bulkhead onto the payload facing portion of the Av-Bay. Ensure that the connection is air-tight.
   (f) Close the aft end of the avionics bay with the bottom bulkhead (the one that has two different diameters) and secure with o-rings and wing nuts. O-rings precede the wing nuts when adding them onto the altimeter sled.
   (g) Attach switches to altimeters.
      i. Attach the wires labeled switch 1 to the switch ports on the red, StratoLogger CF altimeter
      ii. Attach the wires labeled switch 2 to the switch ports on the blue, RRC3 altimeter
   (h) Check altimeters for functionality.
      i. Check main parachute altitude on both.
         A. For the RRC3 set the 4 switches to (ON, OFF, OFF, OFF), turn it on, tap the PROGRAM button during the init 5 second tone, and ensure it beeps out 1000 (ft) (beeps out each digit (x number of beeps for the digit x) with a long beep representing 0)
         B. For the StratoLoggerCF switch it on (ensure there is no siren indicating error codes) wait for it to sound off the 1 digit preset, 2 second pause, and then ensure that the 4 digit number representing the main parachute deployment altitude is

1000 (ft) this number is read off through the beeps on the altimeter (1 long beep to signal a number, pause, then it will beep out each digit, 10 beeps represent 0)

ii. Check drogue delays on both.

A. For the RRC3 set the 4 switches to (ON, ON, ON, OFF), turn it on, tap the PROGRAM button during the init 5 second tone, and ensure it beeps twice (set to 2 second delay)

B. For the StratoLoggerCF switch it on (ensure there is no siren indicating error codes) wait for it to sound off the 1 digit preset, 2 second pause, 3-4 digit number representing the main parachute deployment alititude, then ensure that after 2 seconds there is NO 5 second continuous tone indicating the drogue deployment delay (set to 0 second delay)

iii. Perform continuity check.

A. For the RRC3, turn on, wait for the 5 second long init beep, 10 second init time of silence, 10 second launch commit test time of silence, and then it will start the Launch Detect mode showing continuity. First connect the + and - terminal for drogue parachute 2 on the terminal block. It should repeatedly give one short beep (showing continuity for the drogue terminal). Then connect the + and - terminal for main parachute 2 (keep drogue connected). It should repeatedly give 3 short beeps (showing continuity for the main terminal AND drogue terminal).

B. For the StratoLoggerCF switch it on and wait for the preset number to be beeped out, a 2 second pause, the main parachute deployment altitude to be beeped out, a 2 second pause, another number representing the apogee of the last flight, 2 second pause, the battery voltage, 2 second pause, and then it will start giving out continuity beeps. First connect the + and - terminal for drogue parachute 1 and make sure the StratoLogger gives out single beeps repeatedly (this shows drogue ematch continuity). Then connect the + and - terminal for the main parachute 1 (keep drogue connected) and make sure the StatoLogger gives out 3 beeps at a time (this shows both drogue and main parachute continuity).

(i) Door placed on gently. Ensure that the coils of the blue tube line up with the door.

(j) Screw down all six screws with screwdriver. Tighten them all of the way before fully tightening them. The order of screwing them on is not important, but it might be easier to screw the corner ones first, and the middle two later.

3. Recovery: Deployment Systems Assembly

(a) Verify that bulkheads and doors are airtight by looking for cracks of light/air.

(b) Turn altimeters on to ensure they are functioning.

(c) Attach parachutes to corresponding quicklinks:

i. Main chute to QL2

ii. Drogue Chute to QL3

(d) Verify Dual Deployment Orientation.

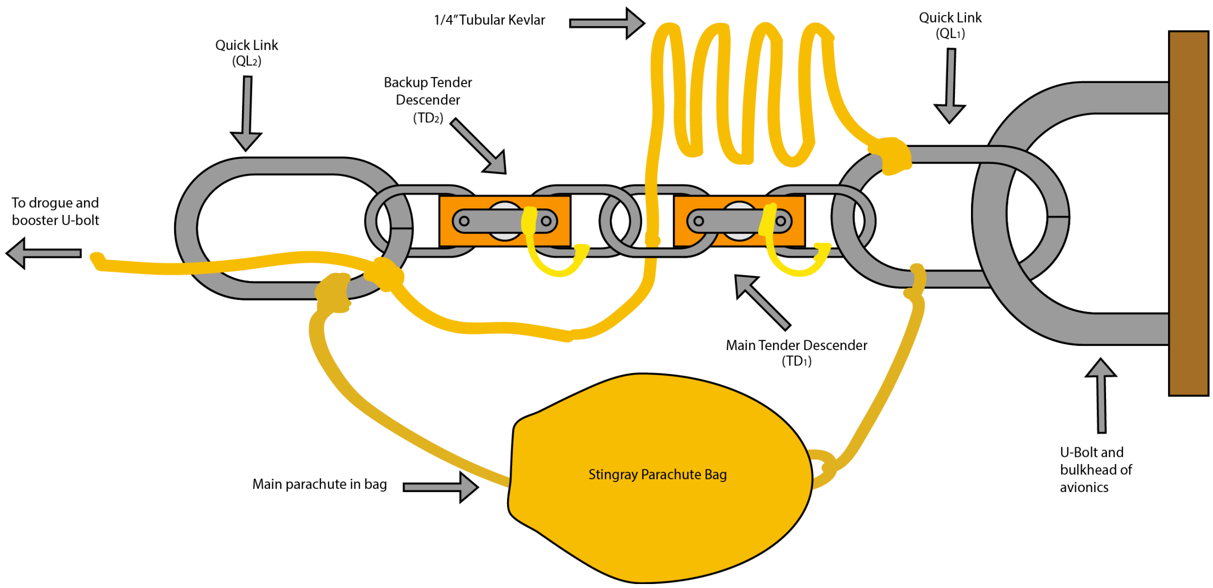


Figure 57: Dual Deployment Orientation

Figure 58: Tender Descender 1

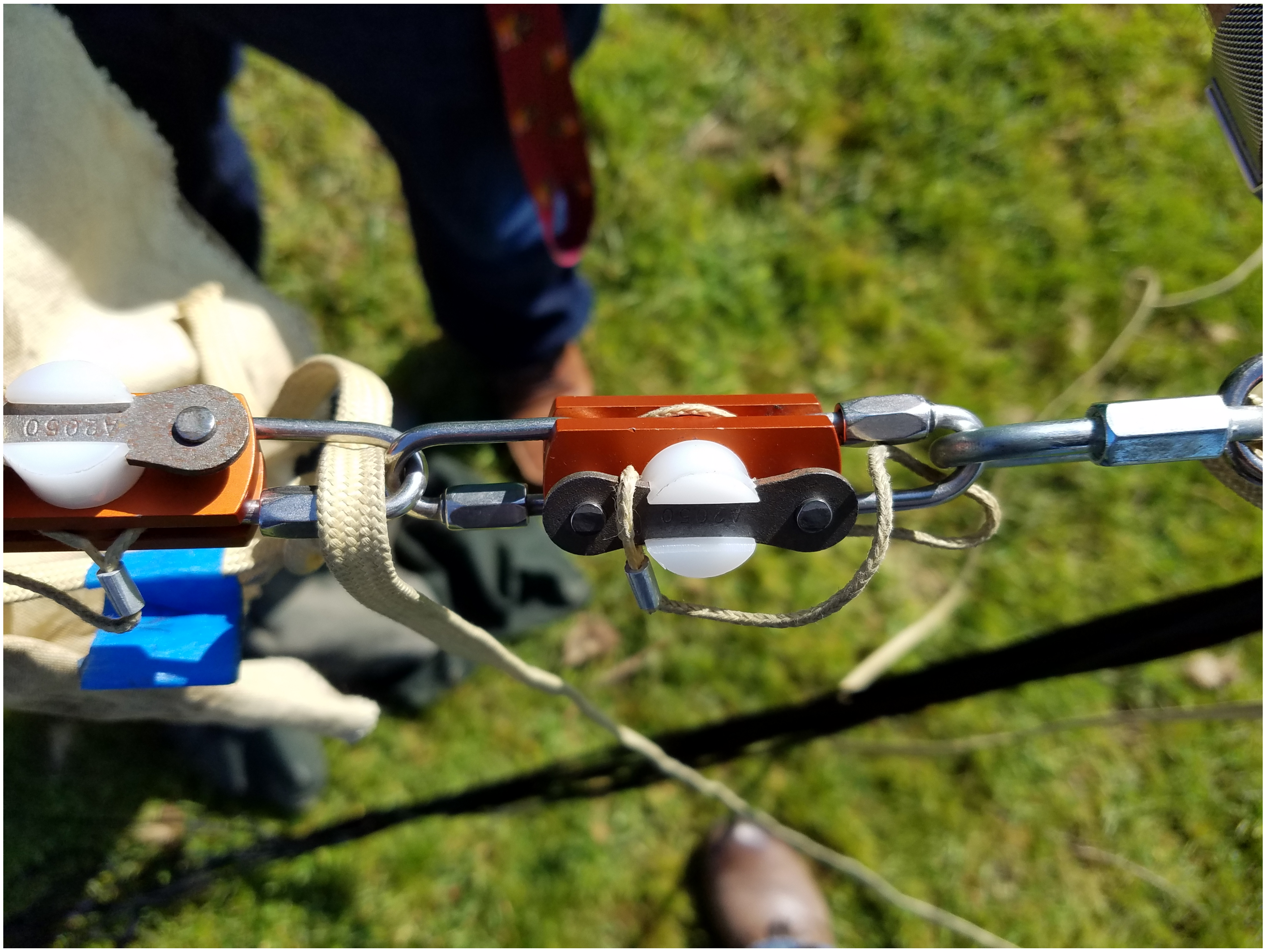


Figure 59: Tender Descender 2

Figure 60: Quicklink 2

i. The following orientation will be described in order beginning from the Av-Bay section to the Booster.

ii. Two L2 Tender Descenders (TD) linked together in series

   A. Will be designated as TD1 for the TD located closest to the Av-Bay and TD2 for the TD located after the TD2

   B. Contains two small quick links on each side of the quick link

   C. Will eventually contain an E-Match in each

   D. Contains g of Black Powder in each

iii. Shock Cords

   A. Use one very long length of shock cord, knotted at various distances and attached with quicklinks.

   B. BAY-to-MAIN (B2M): This is the shock cord length between QL1, which is attached to the Av-Bay, and the main chute. This is stored as a closed loop and will not be extended until after the Tender Descender Charges are released. Its length is 48.75 ft.

   C. MAIN-to-DROGUE (M2D): This refers to the length of shock cord between the Main Chute and the Drogue Chute. It is pulled out during the first Av-Bay and

Booster section separation stage when the drogue chute catches air. Its length is 24.58 ft.

D. DROGUE-to-BOOSTER (D2B): This refers to the length of shock cord between the Drogue Chute and QL3, which is directly attached to the Booster section of the rocket. Like the M2B, it is also pulled out during the first two stage separation. Its length is 12.00 ft.

iv. Quicklinks

A. QL1 - the one closest to the avionics bay; is connected to the following: 1) U-Bolt connected to Av-Bay, 2) Stingray Main Chute Bag, 3) B2M, 4) TD1

B. QL2 - the one connected to the main chute; connected to the following: 1) TD2, 2) Shock Cord to QL1, 3) Main Chute, 4) M2D

C. QL3 - the one connected to the drogue chute; connected to the following: 1) M2D, 2) Drogue chute, 3), D2B

D. QL4 - the one connected to the booster; connected to the following: 1) D2B, 2) U-Bolt on the Booster Section Bulkhead

v. Parachutes

A. Drogue Chute: 24 Elliptical parachute from Fruity Chutes; the red and white one

B. Main Chute: 72 Toroidal parachute from Fruity Chutes; the orange and black one

vi. Parachute Bag

A. Stingray: beige/off-white Kevlar bag with a custom fit pocket to protect the main chute during the black powder ejection charges. This is connected to QL1. The main chute is going to be pulled out of the Stingray when the Tender Descenders release the charges.

vii. Parachute Blankets

A. Drogue Chute Blanket: Orange blanket that will cover the wrapped drogue chute

B. Complete Chute Blanket: Olive-green/gray blanket that will cover the stingray, drogue chute blanket, both tender descenders, and all shock cords excluding the D2B

viii. Procedure

A. Attach stingray to QL1

B. Attach QL1 to the U-Bolt on the Av-Bay side

C. Check QL1 to see that it is connected to the following four components: 1) U-Bolt connected to Av-Bay, 2) Stingray Main Chute Bag, 3) B2M, 4) TD1

D. Verify that TD1 is connected to TD2 and that the B2M is looped through the aft-end smaller quicklink on TD1

E. Verify that TD2 is connected to QL2

F. Verify that QL2 is connected to the following four components: 1) TD2, 2) B2M, 3) Main Chute, 4) M2D

G. Verify that Main Chute is not tangled

H. Verify that Drogue chute is not tangled

I. Verify that QL3 is attached to the following components: 1) M2D, 2) U-Bolt on the Booster Section Bulkhead

J. Verify everything once more.

(e) Fold Parachutes

i. Main Chute

A. Starts flat folded in half in front of you

B. Fold in left and right 1/4 parts towards the center

C. Fold in shroud lines neatly

D. Repeat left and right folds to fit desired size (based on parachute deployment bag)

E. Roll parachute up

F. Stuff gently into the Stingray parachute bag

ii. Drogue Chute

A. Starts flat folded in half in front of you

B. Fold in left and right 1/4 parts towards the center

C. Fold in shroud lines neatly

D. Repeat left and right folds to fit desired size (based on parachute deployment bag)

E. Roll parachute up

F. Wrap carefully in orange parachute cloth

(f) Fold shock cords

i. B2M: Take full length, and fold in half. Repeat until the bundle is in 10-12 in. loops, but still neat, tape for now, but will be REMOVED later.

ii. M2D: Neatly zig zagged into 10-12 in. loops and taped

iii. D2B: Neatly zig zagged into 10-12 in. loops and taped

(g) Turn altimeters to the OFF position. This IS VERY IMPORTANT. Verify that they are off.

4. Payload:

Warning: Failure to follow ANY of the structural steps may result in disruption of the aerodynamics throughout the launch. This may cause the rocket to misfire or crash the rocket.

(a) Check solenoid positioning.

i. Place solenoid pin into the bushing located at the top of the parachute box.

ii. Place springs around the solenoid pin. The smaller diameter end of the spring should be closest to the parachute box.

iii. Place solenoid housing over pin and screw the housing into the mounting fixture.

iv. Connect the solenoid wires to a new battery to actuate solenoid. Check pin retraction height. If the pin doesn't fully retract such that it clears the bottom of the top plate of the parachute box, then the height of the solenoid will need to be adjusted.

v. Once its confirmed that the pin fully retracts upon actuation, test the system with the payload leg.

vi. Use a battery to retract the pin. Fold the payload leg into the launch position, with a parachute packed into the parachute box. While holding the leg flush to the payload tube, disconnect the solenoid from the battery to release the pin such that it lowers into the bushing in the landing leg frame.

vii. Ensure that with the solenoid pin down, the landing leg stays in the launch position. If it doesn't, either the pin isn't fully extended or it isn't sitting properly in the bushing. If those two things aren't true, then the solenoid height will need to change in order to properly hold the leg.

viii. Finally, fold the leg up into the launch position, use the battery to retract the solenoid, push the leg flush with the payload tube, then drop the pin such that it holds the leg.

(b) Adjust solenoid alignment to make sure leg can correctly deploy.

(c) Dremel out left over or unnecessary brackets, so that they don't interfere with any new brackets or the solenoid.

(d) Assemble sliding landing leg mechanism.

i. For each landing leg, first connect the two bolts and nuts to the L-bracket, including the aluminum support.

ii. Then slide the 3/8" bolt not connected to the aluminum support into the T-track rail. Note that the bolt only slides into the rail in a specific configuration.

(e) Check that the sliding rail component of the landing leg slides smoothly. If not, then check for any scratched/damaged parts that may be hindering the system. If possible, fix or remove the problem part. Application of WD-40 maybe become necessary if the problem persists.

(f) Make sure the correct strength spring is in the solenoid.

(g) Check for gaps between the landing leg and the payload tube. If there are gaps, use silicon gasket to fill them.

(h) Ensure ballast is properly secured. If not, use either 5 min epoxy or duct tape to secure the ballast.

(i) Make sure holes are drilled in correct places for wires to pass through.

i. Ejection charge wires located near the bottom of the payload section

ii. Wire for laptop connection to Raspberry Pi located in the nosecone

iii. External switch for the Raspberry Pi

(j) Connect solenoid wires to battery and check if the leg deploys.

(k) Continually check that the leg deployment works consistently.

(l) Connect wires to the terminal.

(m) Connect wires to altimeter.

(n) Check that all three U-bolts are secured.

(o) Check that the shock cord connection to the shroud lines are sufficient.

(p) Check that the connection from the shock cord to the U-bolt is secured.

(q) Fold and Pack Parachute

i. Starts flat folded in half in front of you

ii. Fold in left and right 1/4 parts towards the center. Repeat until desired size.

iii. Roll parachute up. At this point, it should be approximately the size of the parachute box it will go into.

iv. Tightly wrap the shroud lines in one directly around the parachute. This should slightly decrease the size of the parachute.

v. Tightly wrap the shock cord in the perpendicular direction of the shroud lines. Again, this should slightly decrease the size of the parachute.

        vi. Continue to wrap the shock cord all the way until the parachute is in the parachute box.
        vii. Ensure that the lines are not free to possible snag on anything. Also, ensure that the parachute is small enough that the edges won't catch on the sides of the parachute box.
    (r) Tighten all nuts on the sliding leg system. They must be tightened such that the nuts don't have the chance to twist loose but also tight enough so that the leg is still allowed to move freely. NOTE: After this step, the leg should not be repeatedly slid up and down since this will cause the nuts to loosen.
    (s) Slide the leg into the launch position. While doing so, ensure the parachute is packed correctly and that the leg is flush with the payload.
    (t) Lower the pin down such that it holds the leg in the launch position.
    (u) Correctly wire electronics and payload
    (v) Fit the wiring through the correct holes
    (w) Screw the electronics sled bulkhead into position using 3 bolts.
    (x) Screw nose cone to tube using a drill:
        i. Not scratched/damaged.
        ii. Attached securely.
    (y) Verify electronics are securely attached to the rocket.

5. Airframe:
   Warning: Failure to follow these steps will result in the failure of the rocket to fly. This may lead to launch misfire due to unattached or unsmoothed parts.
    (a) Connect payload section to avionics and booster sections.
    (b) Verify couplers are sufficiently tight (don't bind), and can hold the entire weight of the rocket.
    (c) Verify that the motor is sufficiently tight, and retainer is fastened securely once motor is in place.

6. Electronics:
   The electronics team is responsible for the assembly of the electronics bay. The team lead, Jacob, shall be present during the assembly.
    (a) Connect the FT232R USB-to-serial cable to the Raspberry Pi's GPIO pins (VCC, GND, TXD).
    (b) Connections
        i. External switches connected to Pi, Stratologger CF, RRC3, GPS, and prototype board.
        ii. Ensure Pi is connected to battery pack.
        iii. RRC3 connected to 9V battery, serial connected to Pi.
        iv. Stratologger CF connected to 9V battery, serial connected to Pi.
        v. Photodiode connected to Pi (check code for pin assignment).
    (c) Verify connections
        i. Stratologger CF activate switch, check for beeping.
        ii. RRC3 activate switch, check for beeping.
        iii. Connect Pi serial to laptop
    (d) Reboot Pi and/or laptop.
    (e) Verify SD card connection on Pi.
    (f) Switch Tx/Rx wires.
        i. Turn on Stratologger with test battery.

ii. Connect solenoid to prototype board.
iii. Run solenoid testing program on Pi.

(g) Run launch program on Pi and verify altitude/light sensor output.
(h) Connect solenoid to prototype board.
(i) Run solenoid testing program on Pi.
  i. Run ejection wires through payload tube.
  ii. Thread photodiode wiring into payload tube
  iii. Connect Stratologger CF and RRC3 to solenoid.
  iv. Tape off unused wires.
(j) Ground Testing:
  i. Nose cone on sled, batteries not connected.
  ii. Be careful sliding nose cone down dont crush/pinch wires.
  iii. After testing, verify electronics are not broken, wires are still connected.
(k) Connect wires between payload and sled, double-check.
(l) Put the serial cable in the nose cone, and attach it to the sled.
(m) Slide the nose cone onto the sled as before.
(n) Slide nose cone and electronics assembly into payload.
(o) Test the Pi, and then start the launch program before moving the rocket to the pad.

7. Motor:
When our mentor, David Raimondi, is present, he has the authority to handle and prepare the motor. Otherwise, any adult supervisor at the site that has experience in preparing a rocket motor before will be of next priority, followed by an experienced member of our team.
(a) Bring required materials to the motor prep. Such materials include: grease, gloves, Teflon, safety glasses and protective clothing.
(b) Check if motor casing fits into the motor tube.
(c) Once the rocket is fully put together and ready to fly, prepare motor by following the packaged instructions that come with the motor of use.

Important safety tips to follow when preparing the motor:
- Grease shall be handled with protective gloves to avoid contact with skin
- Do not get grease on either side of the delay grain or propellant grains
- Keep greased items away from everything else to avoid accidental greasing of other parts
- When applying Teflon to the liner and inside of the casing, make sure to spray it away from face and in an open area. Use protective gloves and clothing to avoid skin and face contact
- Do not touch the fuel grains with bare hands, use protective gloves
- Forward closure must be screwed in very tight, screwed in all the way until it touches the casing
- Do not install the igniter

6.2 Launch

The following fields will be filled in during the pre-launch checklist:

1	Total installed impulse (N-sec)	
2	Minimum diameter of cleared area (ft)	
3	Minimum personnel distance (ft)	
4	Minimum launch site diameter(ft)	

Pre-Launch Checklist

1. Determine total installed impulse, and fill in field (1): Total installed impulse.
2. Fill in fields (2) and (3) with data from the accompanying Minimum Distance Table in **??**.
3. Fill in field (4):
   (a) If the rocket has "a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 ft.)," [NAR HPRSC] then the minimum launch site diameter is 1000 feet.
   (b) Otherwise, the minimum launch site diameter is the greater value of the following: 1500 ft., or "one-half of the maximum altitude to which rockets are allowed to be flown at that site" [NAR HPRSC].
4. Launch site is at least the minimum launch site diameter (field 4) in its smallest dimension.
5. Launcher is 1500 ft. away from any occupied building and from any public highway with more than 10 vehicles passing per hour (except for vehicles related to the launch).
6. The distance from the launcher to every part of the launch site boundary is at least the minimum personnel distance (field 3).
7. Wind speeds are at most 20 mph.
8. Rocket will not exceed any applicable altitude limits (whether from the FAA or otherwise) at the launch site.
9. The planned rocket trajectory does not go
   (a) towards any target
   (b) into any cloud
   (c) near any aircraft
   (d) over spectators' heads
   (e) beyond the launch site boundaries
10. Launcher device is stable and guides rocket to stable flight, even if there is wind.
11. Launcher device is pointed within 20 degrees of vertical.
12. Launcher device has a blast deflector.
13. There is no dry grass or combustible material within an area around the launch pad of which the diameter is field (2): minimum distance of cleared area.Launch system has a safety interlock in series with the launch switch.
14. Launch switch "returns to the "off" position when released." [NAR HPRSC]
15. Pre-launch briefing is complete. This includes discussion of any risks involved with the launch, as well as recovery information and safety rules.

Recovery Pre-Launch Checklist

1. Verify with mentor on current setup before obtaining black powder charges. Then, obtain them.
2. E-matches
   (a) Strip ends and pull through back first through tender descender hole
   (b) Repeat for second tender descender

3. Add 1/2 g BP to each tender descender and secure tightly, ensuring quick links are inserted around each pin of the TD.
4. Wire orientation:
   (a) Connect wire with micro dean to M2+ on terminal block
   (b) Connect wire with micro dean to M2- on terminal block
   (c) Connect the e-match connected to TD2 to the two wires with micro deans
   (d) Connect e-match connected to TD1 to M1+ and M1- on terminal block
   (e) Connect e-match with 4g charge to D1+ and D1- on terminal block
   (f) Connect e-match with 4g charge to D2+ and D2- on terminal block
5. Attach drogue-release BP charges to the terminal block on the Av-Bay bulkhead.
6. Untape B2M shock cords, but keep them neat to prevent them from tangling.
7. Wrap all (main chute and stingray, M2D, B2M, drogue chute and cover) in heat blanket. Leave D2B shock cord outside of the bag.
8. Stick wrapped blanket into the Booster+ section carefully.
9. Gently connect the Av-Bay to Booster+ section. Ensure that no wires are protruding.
10. Orient the Av-Bay correctly such that the holes for the shear pin line up. Use the four marked lines for reference.
11. Add 4-40 shear pin using a small screwdriver. Ensure that it is securely fastened.
12. At the launch pad, turn on both altimeter switches
    (a) First turn on switch 1 and wait for startup sequence to complete. The altimeter will emit a sequence of 3 quick beeps if is continuity on both charges
    (b) Turn on switch 2 and wait for startup sequence to complete. The altimeter will emit a sequence of 3 beeps if there is continuity on both charges

Ground Test for Main and Drogue Chute

1. Set up rocket following all pre-launch checklists - electronics do not need to be armed.
2. Instead of connecting internal wires to altimeters, disconnect them and run them through the static pressure ports.
3. Attach 10ft of additional wiring to the wire labeled M1+, M1-, D1+, and D1-
4. Connect one 4g charge to D1+ and D1- on terminal block.
5. Connect live TD1 with 0.5g of black powder to M1+ and M1- on terminal block.
6. Assemble rocket and attach 4-40 shear pins.
7. Make sure all team members are not directly in front of or behind rocket and over 10ft away.
8. Have mentor connect power to D1+ and D1-
9. Once the avionics bay and booster+ have separated, have mentor connect power to M1+ and M1-
10. Ensure that tender descender system works as planned.
11. Inspect bulkheads, airframe, and parachutes for damage.

Final Assembly Checklist

1. Install the motor into the motor mount.
2. Screw on the motor retainer, and verify that the motor is secure.
3. Verify that altimeters are wired correctly.
   (a) Connect altimeters to deployment charge terminals.
   (b) Connect altimeters to activation switches.
   (c) Connect altimeters to battery terminals.
      - Warning: Failure to do this step WILL result in the failure of the recovery chute system to deploy.

4. Check that both altimeters are off.
5. Connect black powder containers to deployment terminals.
   - Warning: Failure to do this step WILL result in the failure of the recovery chute system to deploy.
6. Insert shear pins.
7. Close avionics bay door and secure screws.
8. Verify payload electronics settings and test data (view serial connection readout).
   (a) Altimeter (listen to beeps after initiating test mode)
   (b) GPS (verify data is accurate)
   (c) Gyroscope (calibrate and verify readout)
   (d) Accelerometer (laptop initiates test mode)
   (e) Camera connection (verify clarity and quality of images)
9. Seal the payload bulkhead.

Final Launch Set-Up Checklist

1. Verify the stability of the rocket: is it safe to fly?
2. Once all doors on the rocket are closed, and motor is installed, carefully carry the rocket to the launch pad.
   - Warning: If the rocket is dropped or heavily shaken, parts may break or be moved around. In this case, it is not safe to fly and requires immediate inspection.
3. Lower the launch rod, slide the rocket onto the rod, and raise the rod.
4. Verify that the launch rod is nearly vertical, then **tilt rod at a slight angle away from the crowd** so it will not aim the rocket towards any people or prohibited areas.
   - Warning: Failure to do this step may result in angled trajectory (towards the crowd of people) or misfire may result in the rocket heading towards the crowd.

Final Launch Procedure Checklist

1. Turn both altimeters on once the rocket is in place on the launch rail.
2. Test igniter continuity.
   - Igniter should only be handled by our mentor, David, followed by an experienced member at the site.
   - Igniter should be handled with protective clothing (safety glasses, heavy gloves, and no skin contact).
   - All other personnel not involved with the igniter should be away from the launch pad at this time.
   - Warning: If igniter is not reliable, there is risk of pre-ignition of the rocket, or spontaneous combustion of the motor.
3. Ensure no person is closer to the launch pad than the distance specified in field (3): minimum personnel distance.
4. Install electrical motor igniters.
   Igniter installation should only be handled by our mentor, David, followed by an experienced member at the site.
   Warning: Once igniter has been installed to the rocket motor, there is a dangerous risk of pre-ignition.
   (a) Make sure the tip of the wire does not touch together.
   (b) Put the head of the tip into the nozzle.
   (c) Put the plug into the nozzle.
   (d) Hook up the igniter.

5. “Ensure that no person is at the pad except safety personnel and those required for arming and disarming operations.” [NAR HPRSC]
   - Warning: Failure of this step results in serious risk of danger if the rocket were to pre-ignite or misfire.
6. Count down at least 5 seconds, and then launch the rocket.
7. In case of misfire, remove the launcher’s safety interlock and wait at least 60 seconds before approaching the rocket. (Also wait until the range is clear.)

Post-Launch & Recovery Checklist

1. First person to reach landed rocket must CAREFULLY turn off both altimeter switches.
2. Carefully inspect all powder charges have been deployed (drogue chute x2, and both Tender Descender charges).
3. Open avionics bay door and disconnect altimeters from charges.
4. If and ONLY if all charges are deployed and clear and the altimeters are disconnected, one can turn on altimeter for altimeter readings.
5. Read out altitude.
6. Assess CONDITION: all components, is there damage? If so, how bad?
7. Quick links can be detached from Main Chute to Av-Bay and Drogue to Booster.
8. Return to prep site/base.
9. Remove bottom bulkhead.
10. Remove sled.
11. Disconnect switches.
12. To stop recording, execute the following (after reconnecting to Raspberry Pi via serial):
    (a) cd Desktop/
    (b) touch stop
13. Upload video
    (a) Verify FTP server running
    (b) cd Desktop/
    (c) python upload.py video.h264 <IP address of FTP server> <username on server> <password on server>
14. Analyze data from altimeter readings.
15. Put away and clean hardware.

7 Project Plan

7.1 Testing

Below are the Vehicle Component Test Plans and Statuses. The Payload Component Test Plans and Statuses are found in the payload section of the report. (section 4)

7.1.1 Fin Durability

In order to comply with Req. 1.4 we want to test the durability of our fins and their response to impact upon landing.

Procedure:

1. Given calculated impact velocity of booster section, determine how high the sub-scale booster section will need to be dropped from in order to achieve the same impact velocity. Instead of a factor of safety, the fact that we are dropping this on a hard surface and not a softer surface likely to be found at launch sites accounts for the factor of safety.

2. Drop booster section from calculated height.

3. Record any damage to fins

4. Repeat as deemed necessary to gain further information.

Results: The fins showed very little damage or weakening from impact.
Verdict: Successful.
Effects: No further action needs to be taken to improve durability of our fins.

7.1.2 PET-G Nosecone Tip Durability

Similar to the previous test. We want to verify compliance with Req. 1.4.

Procedure:

1. We are using individual tips instead of the one on the sub-scale rocket, in the case that we want to fly it again. Calculate the height from which a 1-lb mass need be dropped on the PET-G tip in order to simulate impact from landing.

2. Secure tip to the ground with tape

3. Drop mass from calculated height.

4. Record any damage to the tip, including scratches or anything that may hinder vision.

5. Repeat as deemed necessary to gain further information.

Results: PET-G nosecone tip damaged beyond use when worst case scenarios are considered and simulated.
Verdict: Successful in gaging nosecone tip durability. Unsuccessful in that it was determined the tip is not sufficiently strong.
Effects: Redesign for nosecone tip necessary. This will like simply be vacuum forming a thicker piece of PET-G.

7.1.3 Effects of Water on Bluetube

Since Bluetube is similar in composition to cardboard, we want to determine whether the rocket would still be flyable if the rocket was to land in water (there is a small creek immediately along the LUNAR launch site).

Procedure:

1. Obtain a piece of scrap Bluetube

2. Inspect the appearance and properties of the Bluetube (how does it flex, are there any frays between the layers). This state will be compared with the final states.

3. Splash the Bluetube with a small amount of water and observe/record the effects.

4. Submerse the Bluetube in water for about 10 seconds. Observe/record the effects.

5. Repeat Step 3 until Bluetube is deemed 'unusable.'

Results: Splashing, while to be avoided when necessary, has negligible effects on the Bluetube. When submerged for 10 seconds the Bluetube displays wrinkles on the surface, has clearly absorbed some water, and is less stiff when flexed/bent.
Verdict: Successfully allowed us to gauge Bluetube properties.
Effects: At a launch site, we will identify any water hazards and ensure that we are in the position to remove the rocket from any water as quickly as possible. This is something we likely would have wanted to do anyways due to potential water damage to electronics.

7.2 Requirements Compliance

7.2.1 Student Launch Requirements Compliance

Requirement	Verification Plan	Status
The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level.	OpenRocket simulations and our Perfectflite Stratologger CF Altimeter will verify that the design and an Aerotech L1150 motor meets the altitude requirement.	In Progress. OpenRocket simulations have given an apogee estimate that matches the requirement for the motor we have selected. Will be verified by test launch.
The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	A Perfectflite Stratologger altimeter was purchased and received and will be used to record the official attitude.	Completed. Altimeters have been purchased and attachment has been determined.
All recovery electronics shall be powered by commercially available batteries.	Verification by inspection of design.	Completed. All recovery electronics powered by commercially available Duracell batteries.
The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Verification by testing (REF) and by demonstration at test flights.	The only component not yet deemed durable enough to be reusable is the PET-G nosecone tip.
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.	Verified through inspection of design.	Completed. Our vehicle only has 3 independent sections.
The launch vehicle shall be limited to a single stage.	Verified through inspection of design.	Completed. Our vehicle has one motor and one stage.
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.	Assembly and pre-launch checklists will be made to make sure preparations takes within 4 hours. Will be verified by a test launch.	Completed. Checklists have been finalized.

Requirement	Verification Plan	Status
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.	Verified through inspection of design.	Completed. No part of the functionality of our design will be affected by the passing of 1 hour.
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.	Verified through inspection of design and test launch.	Completed. The motor we selected is ignitable by standard systems.
The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	Verified through inspection of design and test launch.	Completed. Nothing in our design requires any additional or unique circuitry or equipment in order to initiate launch.
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).	Verified by inspection of design and motor selection.	Completed. The Aerotech L1150 motor satisfies these requirements.
The total impulse provided by a College and/or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	Verified through inspection of design and motor selection. An Aerotech L1150 motor will be used.	Completed. The Aerotech L1150 motor has an impulse of 3589 N-s.
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Will be verified using OpenRocket to determine center of pressure and gravity.	Completed. Our rocket has a minimum static stability margin during ascent of 2.98, as calculated by OpenRocket.

Requirement	Verification Plan	Status
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Will be verified by OpenRocket simulations of rocket.	Completed. Our rocket has a velocity at rail exit of 62.9 fps off an 8 foot rail, as calculated by OpenRocket.
All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	Sub-scale launch took place December 3rd at LUNAR launch site.	Completed. Sub-scale rocket was successfully launched and recovered.
All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	Will be verified by a test launch.	In progress. Our full-scale rocket was successfully and safely flown and recovered. However, due to complications, it was deemed unsafe to fully test the payload. Payload will be fully tested March 12th.
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.	Verified by inspection/weighing.	Complete. Full payload flown in full-scale test flight.
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).	Verified by demonstration. Team safety officer will ensure nothing is modified following completion of a successful full-scale demonstration launch without proper authority.	Not Completed. We will re-fly our full-scale rocket March 12th. Afterwards, all modifications will be done only with the concurrence of the NASA RSO.
Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	Verified through inspection of design.	Completed. No protuberance on the rocket is located aft of the burnout center of gravity in our design.
Vehicle Prohibitions	Verified through inspection of design.	Completed. Our rocket does not utilize any of the materials or features explicitly prohibited in section 1.19 of the NSL Handbook.
The launch vehicle shall not exceed Mach 1 at any point during flight.	Verified through testing and OpenRocket simulations.	Completed. Our rocket reaches a maximum velocity of Mach 0.59 during flight, as calculated by OpenRocket.

Requirement	Verification Plan	Status
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.	Will be verified through demonstration and a test launch. The drogue chute is set to be deployed at apogee, while the main chute is set to be deployed at 1000 ft. agl.	Completed. The dual deployment recovery conducted at the March 4th full-scale launch was successful.
Each team must perform a successful ground ejection test for both the drogue and main parachutes prior to the initial sub-scale and full scale launches.	Will be verified through demonstration before test launch. At the test, the rocket will be tethered down, and the black powder charges between the avionics bay and the booster portions will be ejected to ensure the charge explosion will be strong enough to eject the drogue and main chutes.	Completed for sub-scale and full-scale launch.
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Verified through OpenRocket simulations, hand calculations, and test launch. Calculations for the impact of the payload upon landing can be viewed in section 3.2.	Completed. OpenRocket simulations and calculations have been completed. Full scale test flight has confirmed results.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Verification through inspection by design. The recovery system electronics will be housed in the avionics bay, which will be between the booster and payload sections of the rocket, while the payload electronics will be housed specifically in the payload section. Upon inspection, the independence should be self-evident.	Completed. The avionics bay and the payload electronics have been designed to be completely independent.
The recovery system shall contain redundant, commercially available altimeters.	Verification through inspection of design. Upon inspection, the two different altimeters (Perfectflite Stratologger CF and Missileworks RRC3) will be clearly visible.	Completed. We have designed our avionics bay platform to house both the different altimeters.

Requirement	Verification Plan	Status
Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad, and is capable of being locked in the ON position for launch.	Verification by inspection and demonstration. Our avionics bay will have rotary switches on the outside that can arm and disarm our altimeters.	Partially complete. The avionics section altimeters have rotary switches. However, they have not yet been implemented for the payload section.
Each altimeter shall have a dedicated power supply.	Verification by inspection. Each altimeter will be connected to a 9V Duracell battery, which will be attached to the platform inside the avionics bay.	Completed. The Duracell batteries are obtained and will be connected to the altimeters.
Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Verification through inspection. Shear pins and key connection points/coupler joints will be checked before launch.	Completed. The removable shear pins will be used to separate the compartments housing both parachutes.
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.	Verified by inspection. One Eggfinder GPS system will be installed in payload section and another Eggfinder GPS system will be installed in a section of the tethered components of the rocket. We will ensure that the GPS systems are on and working before launch.	Completed.
The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight.	Verification upon inspection. During the design and build stages, we will ensure that the avionics bay is completely independent from any of the other electronics. Before flight, we will check all inputs and outputs to verify that this is true.	Completed. Full-scale flight confirmed this.
Teams shall design an on-board camera system capable of identifying and differentiating between 3 randomly placed targets.	Verification by testing and demonstration at March 12th full-scale test launch. Testing process described in full detail in REF.	In Progress.

Requirement	Verification Plan	Status
After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.	Verification by demonstration at March 12th full-scale test launch. Nosecone facing camera will provide proof of upright landing.	In Progress.
Data from the camera system shall be analyzed in real time by a custom designed onboard software package that shall identify and differentiate between the three targets.	Verification by demonstration during final launch and proved by saved camera images.	Not Started. To be verified at launch.
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.	Demonstration by creation of checklists.	Completed. Final checklists have been completed and included in this report.
Each team must identify a student safety officer who shall be responsible for all items in section 4.3.	Demonstration by identification in Proposal.	Completed. Safety Lead/Officer selected in the beginning of the school year.
Each team shall identify a mentor.	Demonstration by identification in Proposal & PDR.	Completed. Mentor identified in all reports.
During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO.	Demonstration during launches.	Completed. Team safety officer informed team of rocketry club rules and ensured all rules were complied with for both test launches.
Teams shall abide by all rules set forth by the FAA.	Verified Through Inspection.	In progress. We have taken measures to ensure that we and our rocket will be able to comply with the FAA. Team safety officer will be responsible for ensuring all rules are complied with.
Students on the team shall do 100% of the project.	Inspection to ensure that aide of our mentor is limited to that of advice and guidance, not any specific designing.	Complied with thus far in the competition and our work on URSA.

Requirement	Verification Plan	Status
The team shall provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Demonstration. Continue to maintain, and update when necessary.	Complied with thus far in the competition. We have been maintaining a project plan since the submission of our Proposal.
Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR).	Verify with all team members that none are Foreign Nationals.	Completed. No foreign nationals on team.
The team shall identify all team members attending launch week activities by the Critical Design Review (CDR).	Inspection/checking off that this is listed in CDR.	Completed.
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.	Demonstration/Careful Documentation. Process for team outreach describe in length in our proposal.	In progress. Engaged 111 participants thus far in outreach events. We strongly expect to exceed 200 with our final two scheduled outreach events.
The team shall develop and host a Web site for project documentation.	N/A	Completed.
All report submission related requirements.	Will be verified by checklist upon submission.	N/A
The team shall provide any computer equipment necessary to perform a video teleconference with the review board.	Demonstration. Test video equipment with software to ensure no technical or connection issues.	Completed for PDR and CDR. Once date & time is finalized, we will book same or similar on-campus room for the FRR teleconference.

7.2.2 Team Requirements

- **D.1** The vehicle shall be limited to a maximum altitude of 5400 ft in order to challenge the team to a more accurate design.
- **D.2** Mission success shall be achieved without using an excess of propulsion (energy) and other resources. For this reason the vehicle is limited to a maximum weight of 40 lbs.

- **D.3** Extending upon requirement 1.4 (reusable launch vehicle), the vehicle shall not exceed the maximum damage criteria in all of the categories. Broken is defined as not reusable. The criteria is the following:
  - **D.3.1** Zero fins are broken.
  - **D.3.2** Zero pieces of the Nose Cone are broken.
  - **D.3.3** Zero sections of the rocket are broken.
  - **D.3.4** Camera, Avionics altimeters, and GPS are functioning
  - **D.3.5** Parachutes have no tears.
- **D.4** Airframe profile is sufficiently aerodynamic
  - **D.4.1** PET-G tip is not excessively protruding
  - **D.4.2** Carbon fiber fillets are even/sanded down
  - **D.4.3** Cuts in airframe for landing legs are sealed
  - **D.4.4** No significant burs in payload section
  - **D.4.5** Landing legs do not extend more than a certain amount out of the airframe in flight
- **D.5** Fins aligned within +/-5 degrees of 120. In order for the rocket to go up as straight as possible during flight, we are imposing a tolerance on our fin angles.
- **D.6** The booster fins shall be at no more than a 5 degree angle from perpendicular with respect to airframe. This is, like Requirement **D.5**, for the purpose of ensuring straight flight.
- **D.7** The vehicle shall have clear vision out of the nosecone.
- **D.8** Vision out of the nosecone, as previously noted, is vital to mission success. As a result, if any scratches, dents, etc. will possibly affect vision, we must replace it with a new tip given at least 2 days time for manufacturing and epoxying.
- **D.9** All scenarios of parachute deployment must result in all rocket components landing under 75ft-lbf. This is done so that the rocket lands safely even if all separations and payload parachute deployments do not take place.
- **D.10** Parachutes are not damaged by black powder charges - there are no holes or burn marks.
- **D.11** Wires to tender descenders are broken upon successful deployment of main parachute.
- **D.12** The vehicle shall use a removable door on avionics bay that allows for easy access and adjustment of altimeters on the launch pad if necessary.
- **D.13** All 3 legs must unfold in order to expect mission success. Even if the vehicle manages to land upright without all 3 legs deploying, this will be considered a mission failure.
- **D.14** The payload is designed to land at a safe velocity under only 1/3 chutes. However, chute release is critical to upright landing, so at least 2/3 parachutes must be released and unfolded successfully.

- **D.15** It is acknowledged that aberrations in the launch site ground are to be expected and it is therefore recognized that it is highly unlikely we will be exactly perpendicular to the ground at landing. Still, the design and suspension must allow the payload to be within 20 degrees of perpendicular at upright landing.
- **D.16** Payload will be able to remain upright when on a slope of up to 20 degrees. The March 4th full scale flight was recovered on the slope of a hill. This led to the realization that the payload must be able to land upright on such hills.
- **D.17** Payload be able to right itself within 15 degrees of perpendicular. We will not rely on the payload landing optimally. As such, we want the payload section to be able to right itself using the force of the torsional springs from a range of angles.
- **D.18** Partially thinned bulkheads hold up to charge. Sections of the lower payload bulkhead we selectively sanded away in order to increase vertical reach of our landing legs. We want to ensure this does not compromise the ability of the bulkhead to withstand the black powder explosion during separation.
- **D.19** In order to mitigate the increase in our drag coefficient, there must be no significant direct openings in the payload section.
- **D.20** We do not want to rely on the payload being in a certain state/orientation for the landing legs to deploy. As such, the legs must be able to deploy from any orientation (upside down, etc.)
- **D.21** Payload will right itself from any orientation to face (generally) up after the first parachute is released.
- **D.22** Altitude data and camera recordings will be saved.
- **D.23** Target detection will occur at least once per second (during the applicable time period)
- **D.24** Payload parachute deployments must be staggered. This is done to prevent current overdraw.
- **D.25 A** Checklists must be detailed to the point where it is possible for any team member to correctly follow the steps.
- **D.25 B** Troubleshooting steps in the checklist allow any team member to diagnose and fix any expected problems.
- **D.26** Personnel hazards analysis are comprehensive enough to include every expected hazard and useful mitigation.
- **D.27** Workshop safety advice is clear enough and adhered to so that there are no injuries during construction.
- **D.28** At least 15 members must attend all video teleconferences so that there is sufficient representation, and the team will more fully be able to gather and synthesize advice/criticisms from NASA.
- **D.29** FINAL edits to all report documents must be made no later than 45 minutes prior to deadline. This is done to ensure the report is not submitted late.

- **D.30** Any necessary report edits must be made to documents and re-uploaded to the team website, even if after NASA deadline.

Requirement	Verification Plan	Status
D.1 Upper-altitude limit of 5400 ft AGL.	OpenRocket simulations and our Perfectflite Stratologger CF Altimeter will verify that the design and an Aerotech L1150 motor meets the altitude requirement.	In Progress. OpenRocket simulations have given an apogee estimate that matches the requirement for the motor we have selected. March 4th test launch altitude significantly below this limit. Another test flight desired.
D.2 Maximum vehicle weight of 40 lbs.	Verified through inspection of design	Complete. Total vehicle weight of 33 lbs.
D.3 Maximum damage criteria (outlined above) are not exceeded.	Verified by inspection upon landing. And tests (SEE 7.1)	In Progress. The only remaining feature with durability concerns is the nosecone tip.
D.4 Airframe sufficiently aerodynamic.	Verified through inspection of design and estimated drag coefficient based on test launch results.	In Progress. March 4th flight revealed that payload section needs to made more aerodynamic.
D.5 Fins at 120 +/- 5 degrees with each other.	Verification by use of laser-cut jig to test fit. Jig will have 3 fin slots cut out at exactly 120 degrees and with a tolerance in thickness.	Completed. The fins fit within the laser cut jig.
D.6 Fins at 90 +/- 5 degrees relative to tubing.	Verification by use of laser-cut jig to test fit.	Completed.
D.7 Clear Nosecone	Verification by Demonstration at test launch.	Completed.
D.8 Nosecone replaced when damaged.	Verification by Inspection. We will inspect the nosecone tip regularly and proceed to manufacturing and epoxying on a new one as soon as possible whenever scratched.	Complied with up to this point. Our recent nosecone gradually reduced in quality over the course of many weeks and tests, so we are now manufacturing a new one.
D.9 Safe recovery for all possibilities of payload separation and chute deployment.	Verification by analysis. Simulating possible scenarios in OpenRocket and the resulting landing kinetic energy for each.	Complete. See subsubsection 3.6.5

Requirement	Verification Plan	Status
D.10 Parachutes not damaged by black powder charges.	Verified by demonstration at full scale ground tests and full scale test flight.	Completed.
D.11 Wires to tender descenders are broken.	Verified by demonstration at full scale test flight.	Completed.
D.12 Removable door on avionics bay.	Verified through inspection of design.	Completed.
D.13 All 3 landing legs unfold.	Verification by Demonstration at test launch.	In Progress. Has yet to be demonstrated during flight.
D.14 At least 2/3 payload parachutes fully deploy.	Verified by Demonstration	In Progress. Due to late complications, we did not fully fly the payload and did not have an opportunity to test launch. We will fully test the payload recovery at a test launch on March 12th.
D.15 Payload within 20 degrees of perpendicular to ground.	Verification by inspection.	In Progress.
D.16 Payload able to remain upright on slope of up to 20 degrees.	Verification by testing.	Not Started.
D.17 Payload can right itself in any direction from within 15 degrees of perfectly upright.	Verification by testing. Full process detailed in section 4.	In Progress. Completed testing has not given us desired results. Further testing to be done after design modifications.
D.18 Selectively thinned bulkhead able to withstand black powder charges.	Verification by Demonstration during ground black powder charge testing.	Completed.
D.19 No openings/gaps in payload section.	Verification by Inspection of vehicle.	Completed.
D.20 Landing legs able to deploy from any orientation.	Verification by testing. Drop test process described in detail in section 4.	In progress.
D.21 Payload points nosecone up when descending and under parachutes.	Verification by testing. Process described in detail in section 4.	Completed.
D.22 Altitude data and camera recordings must be saved.	Verified by Demonstration.	In Progress.

Requirement	Verification Plan	Status
D.23 Target detection at least once per second.	Verification by Inspection of saved camera recordings (see **D.22**)	In Progress.
D.24 Staggered payload parachute deployments.	Verified by solenoid testing.	In Progress.
D.25 A Any team member able to correctly follow checklists.	Verified by demonstration at test launch(es). Safety team members will oversee assembly and launch operations and ensure there is no confusion with checklists.	Complied with thus far in the competition.
D.25 B Any team member able to use troubleshooting steps to diagnose and fix expected problems.	Verified by demonstration at test launch(es). Safety team members will oversee assembly and launch operations and ensure troubleshooting is aided by the listed steps.	Complied with thus far in the competition.
D.26 Personal hazards analysis include every expected hazard and useful mitigation.	Verification by critical and thorough inspection of Personal Hazards Analysis.	Completed.
D.27 Workshop safety advice clear. No sever injuries occur.	Verification by demonstration. Safety officer will ensure this is complied with and that no injuries during construction occur.	Complied with thus far in the competition.
D.28 At least 15 team members attend each video teleconference.	Verification by Inspection.	Complied with thus far in the competition.
D.29 Final report edits made prior to 45 minutes before submission deadline.	Verification by Demonstration. The Report Compiling team lead will ensure this is complied with.	Complied with thus far in the competition.
D.30 Reports re-uploaded to website with any necessary edits.	Verification by Demonstration. The Report Compiling team lead will ensure this is complied with.	Complied with thus far in the competition.

7.3 Budgeting and Timeline

7.3.1 Budget

Items	Sub-items	Quantity	Unit price	Anticipated Cost		Subtotal
2016-17 NASA SLI Rocket						
Airframe						
	Polymer Nose Cone	1	$119.00	$119.00		
	Airframe Body	1	$220.00	$220.00		
	Glue/Epoxy	9	$18.00	$162.00		
	Motor Mount	1	$18.99	$17.09		
	Motor Retainer	1	$50.00	$50.00		
	Sub-scale Rocket Materials	1	$425.99	$425.99		
	3D Printed Prototypes	1	$7.00	$15.00		
	Motor	2	$199.00	$400.00		
	Motor Shipping	2	$80.00	$160.00		
	Fiberglass Fins	5	$25.07	$127.77		
	J-B Weld	5	$14.87	$81.25		
	75mm Motor Retainer	1	$47.08	$47.08		
	Rail Buttons	2	$4.65	$14.56		
	Blue Tube Couplers (12") [ApogeeRocketry]	2	$29.95	$39.99		
	Blue Tube Couplers (48") [ApogeeRocketry]	1	$66.95	$66.95		
	Blue Tube Couplers (12") [AlwaysReadyRocketry]	1	$19.95	$19.95		
	Blue Tube Couplers (16") [AlwaysReadyRocketry]	2	$27.95	$55.90		
					$ 2,022.53	
Recovery system						
	Perfect Flight Stratologger CF Altimeter	2	$60.00	$ 120.00		
	Missile Works RRC3 Altimeter	1	$70.00	$ 70.00		
	24" Elliptical Parachute from Fruity Chutes™	1	$60.00	$ 60.00		
	Main Parachute	1	$265.00	$ 265.00		
	Drogue Parachute Protector	1	$11.00	$ 11.00		
	Main Parachute Protector	1	$11.00	$ 11.00		
	Shock Cord (20-30 yds.)	1	$85.00	$ 85.00		
	U-Bolts	5	$5.00	$ 25.00		
	Batteries	1	$4.00	$ 4.00		
	Misc. Hardware	1	$50.00	$ 50.00		
	3D Printed Components	1	$50.00	$ 50.00		
	L2 Tender Descender	2	$85.00	$ 170.00		
	Subscale Recovery Components	1	$300.00	$ 300.00		

	GPS - Eggfinder GPS System	1	$100.00	$ 100.00		
					$ 1,321.00	
Electrical						
	GPS - Eggfinder GPS System	1	$ 100.00	$ 100.00		
	Gyro - Sparkfun Triple-Axis Digital-Output Gyro ITG-3200 Breakout	1	$ 24.95	$ 24.95		
	Accelerometer - SparkFun Triple Axis Accelerometer Breakout - LIS331	1	$ 9.95	$ 9.95		
	Microprocessor - Raspberry Pi	1	$ 35.00	$ 35.00		
	Camera - 8MP Raspberry Pi Camera Module	1	$ 24.99	$ 24.99		
	Altimeter - Missile Works RRC3	1	$ 70.00	$ 70.00		
	3.7V LiPo Battery	1	$ 9.98	$ 9.98		
	LiPo Battery Charger	1	$ 15.51	$ 15.51		
	Terminal Blocks (5 count)	1	$ 7.66	$ 7.66		
	Missile Works USB-IO Dongle	1	$ 31.95	$ 31.95		
	Diodes (10 count)	1	$ 1.60	$ 1.60		
	AA Batteries (20 count)	1	$ 12.99	$ 12.99		
	Prototype Boards (5 count)	1	$ 5.17	$ 5.17		
	Zip Ties (250 count)	1	$ 4.99	$ 4.99		
	GPS - Apogee Components TeleGPS	1	$ 214.00	$ 214.00		
	9V Battery Clips (5 count)	1	$ 5.19	$ 5.19		
	9V Batteries (8 count)	1	$ 9.99	$ 9.99		
	Rasberry Pi USB-Serial Cable	2	$ 6.99	$ 13.98		
	Various Shipping/Handling/Tax	1	$ 67.60	$ 67.60		
	IRFB7546PBF MOSFET (package of 10)	1	$11.34	$11.34		
	PerfectFlite USB Data Transfer Kit	1	$26.85	$26.85		
					$ 703.69	
Payload system						
	Music Wire Torsion Spring - Left Hand (6 count)	1	$ 6.47	$ 6.47		
	Music Wire Torsion Spring - Right Hand (6 count)	1	$ 6.47	$ 6.47		
	Dowel Pins (5 count)	1	$ 8.03	$ 8.03		
	48" T-Track	1	$ 30.98	$ 30.98		
	Confined-Space Conical Compression Springs - 4 lb load	3	$ 3.16	$ 9.48		
	L-Bracket	1	$ 9.22	$ 9.22		
	PVC Pipe 3/4" x 2'	1	$ 1.43	$ 1.43		
	1.5" x 1.5" x 3' Wood Square	1	$ 5.34	$ 5.34		
	Wooden Dowel 3/8" x 48"	1	$ 1.50	$ 1.50		
	Linear Solenoids	3	$ 36.87	$ 110.61		

	Misc. Hardware	1	$ 20.00	$ 20.00		
	36" Iris Torodial Parachutes	3	$ 150.00	$ 450.00		
	Lead Weights (Package of 24 7 gram pieces)	4	$ 7.81	$ 31.24		
	5 Minute Epoxy	2	$ 4.49	$ 8.98		
	Silicone Gasket	1	$ 7.99	$ 7.99		
	WD-40	1	$ 5.99	$ 5.99		
					$ 713.73	
Outreach						
	Printed Materials	1	$ 100.00	$ 100.00		
	Giveaways	1	$ 50.00	$ 50.00		
					$ 150.00	
Safety						
	NFPA 1127 Code for Higher Power Rocketry 2013 Ed	1	$39.50	$39.50		
					$ 39.50	
						$ 4,950.45
Transportation to launch site						
	Equipments shipping	1	$ 417.23	$ 417.23		
	Accomodation	4	$ 376.20	$ 1,504.80		
	Travel budget	18	$ 600.00	$ 10,800.00		
						$ 12,722.03
Misc.				$ 500.00		
GRAND TOTAL						**$ 17,672.48**

7.3.2 Current Funding

Received	Amount
Student Opportunity Fund	$1,401.01
Engineering Student Council	$1,604.32
Northrop Grumman	$1,500.00
The Big Give, ASUC Student Union	$750.00
Student Opportunity Fund	$3,000.00
Total	**$8,255.33**
Materials Budget	$4,950.45
Balance	$3,304.88

Note: We have sufficient funding for all manufacturing-related purchases. Remainder of funds will be put towards travel expenses to the competition.

7.3.3 Future Funding Plan

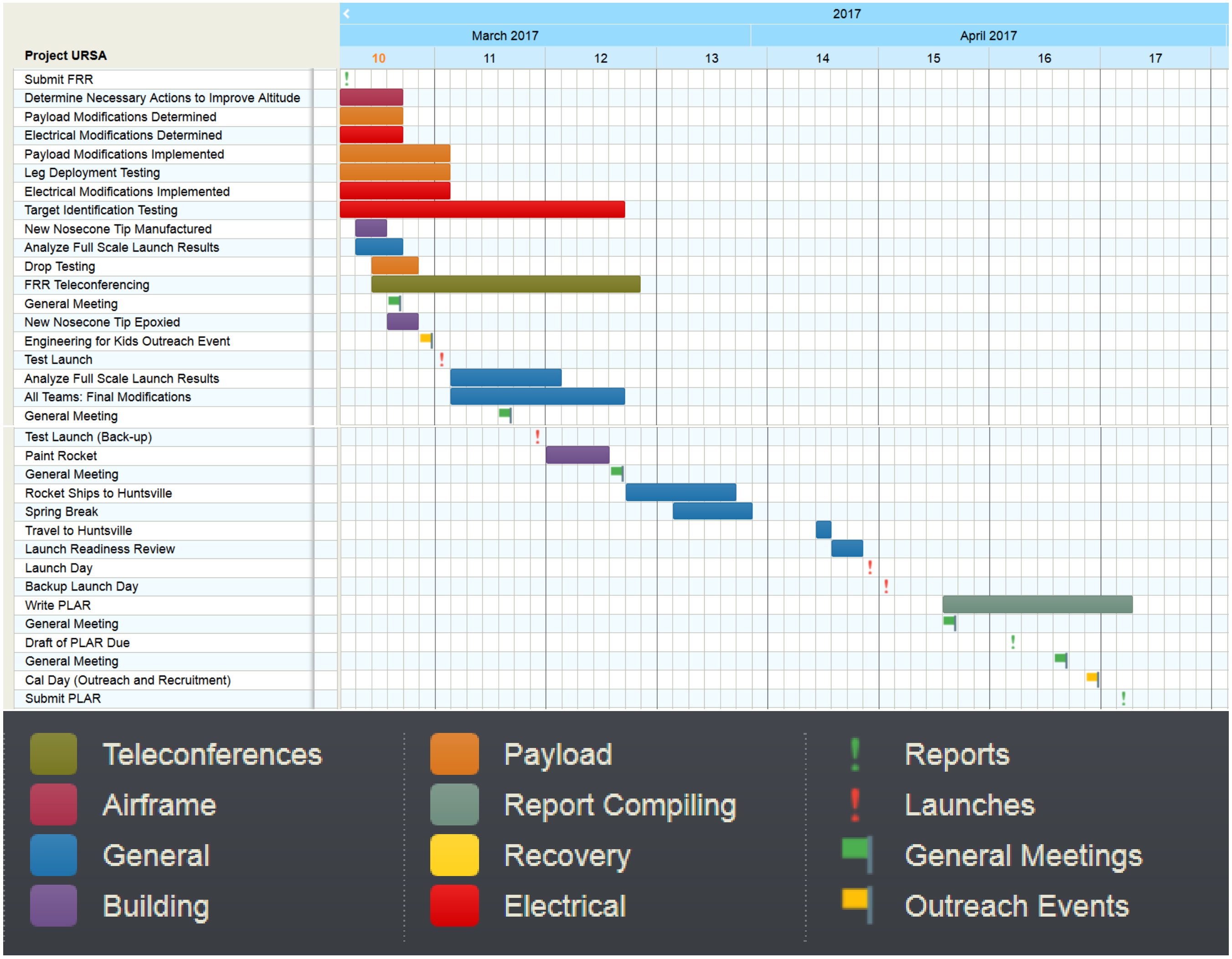
Private Corporations:

1. We have submitted an application to Northrop Grumman for $1500.

7.3.4 Timeline

Overview of Important Upcoming Events/Dates:

- March 11th - Engineering for Kids (E4K) Outreach Event
- March 12th - Full-scale test flight
- March 27th-31st - Spring Break
- April 5th - Travel to Huntsville, Alabama
- April 5th-6th - Launch Readiness Review (LRR)
- April 8th - Competition Launch Date
- April 24th - Submit PLAR



Appendix A Recovery Computer Programs

A.1 Parachute Calculation: Python Code

To calculate the parachute sizes the following python code was used. It uses the readline module for user input on an interactive python shell.

```
import readline, math

rho = 0.0765
g = 32.174 #ft/s^2
ftlbf_to_lbmft2persec2 = 32.174049 #conversion factor of ft-lbf

def para_area_v_cd(mass, vmax, cd):
    ''' takes mass, velocity, and coefficient of drag to calculate the
    necessary parachute area (in ft^2)'''
    return ((mass * g) / (.5 * (vmax ** 2) * rho * cd)) #returns ft^2

def KEmax_to_vmax(KEmax, mass):
```

```
    ''' for a given mass, returns the landing velocity (ft/s) to land
    with a given Kinetic Energy'''
    return math.sqrt((2*(KEmax)*ftlbf_to_lbmft2persec2)/mass)

def terminal_v(m, cd1, a1, cd2, a2): #lbm, cd, ft^2, cd, ft^2
    return (math.sqrt((m*g)/(.5*rho*(cd1*a1 + cd2*a2))))

def ke(m, cd1, a1, cd2, a2, mass):
    return .5*mass*(terminal_v(m, cd1, a1, cd2,
            a2)**2)/ftlbf_to_lbmft2persec2

def v_fts_to_ke_ft_lbf(v_ft, m_lbm):
    return ((.5 * m_lbm) * (v_ft ** 2))/ftlbf_to_lbmft2persec2

def ke_to_v(ke, m):
    return math.sqrt(ke*ftlbf_to_lbmft2persec2*2/m)

def payload_para(pl): #pl = mass of the payload
    print("\nPayload Parachute(s)\n")
    Cd3 = 2.2
    print("payload parachute coefficient of drag is " + str(Cd3))
    #float(input('KE(ft-lbf) (for whole payload):'))
    maxKE = 75 #ft-lbf
    parachute_area_ft2 = para_area_v_cd(pl, KEmax_to_vmax(maxKE, pl),
                                                                Cd3)
    parachute_radius_ft = math.sqrt(parachute_area_ft2 / math.pi)
    parachute_diameter_in = parachute_radius_ft* 12 * 2
    print("The diameter of 1 parachute for the whole payload to land"
    + "\n    with 75 ft-lb must be at least " +
    str(parachute_diameter_in) + " in")

    parachute_diameter_in = float(input("FINAL payload parachute"
            + " diameter -->"))
    parachute_radius_ft = parachute_diameter_in / (12 * 2)
    parachute_area_ft2 = (parachute_radius_ft ** 2) * math.pi

    one_para_v_ft_s = terminal_v(pl, Cd3, parachute_area_ft2, 0 , 0)
            #last two are zero becasue only 1 parachute
    print("Payload landing velcocity (for ONE successful payload"
            + "parachute) is " + str(one_para_v_ft_s) + " ft/s")
    print("Payload landing KE (for ONE successful payload parachute)"
            + "is "
            + str(v_fts_to_ke_ft_lbf(one_para_v_ft_s, pl)) + "ft_lbf")

    three_para_v_ft_s = terminal_v(pl, Cd3, parachute_area_ft2 * 3,
        0 , 0) #last two are zero becasue only 1 parachute
    print("Payload landing velcocity (for THREE successful payload"
```

```
            + "parachute) is " + str(three_para_v_ft_s) + " ft/s")
    print("Payload landing KE (for THREE successful payload"
            + "parachute) is "
            + str(v_fts_to_ke_ft_lbf(three_para_v_ft_s, pl)) + "ft_lbf")




def drogue_main():
    # pl = float(eval(input('payload weight (lbm) -->')))
    # av = float(eval(input('avionics bay weight (lbm) -->')))
    # btr = float(eval(input('booster weight (lbm) -->')))
    # pl = 9.489 #CDR
    # av = 4.083 #CDR
    # btr = 11.483 #CDR
    # cords_parachute_weights = 0
    pl = 10.1 #FRR
    av = 4.68 #FRR (this is avionics + the shock cords + the parachutes)
    btr = 7.86 #FRR
    cords_parachute_weights = 2.54 #FRR
    total = pl + av + btr + cords_parachute_weights
    print("WEIGHTS: payload " + str(pl) + " lbm | avionics "
            + str(av) + " lbm | booster " + str(btr) + " lbm")
    print("WEIGHT: cords and parachutes "
            + str(cords_parachute_weights) + " lbm")
    print("TOTAL WEIGHT: " + str(total) + " lbm")
    print("————————————————————————————————————————")



    ##########################################################
    #drogue parachute########################################

    Cd1 = 1.5 #coefficient of drag for Drogue
    print("drogue coefficient of drag is " + str(Cd1))
    drogue_vmax = 73 + (1 / 3)

    drogue_area = para_area_v_cd(total, drogue_vmax, Cd1)
    drogue_radius = math.sqrt(drogue_area/math.pi) #given in ft
    print("drogue is designed to slow the rocket to "
        + str(drogue_vmax) + " ft/s")
    print("drogue's diameter must be at least "
        + str(drogue_radius * 12 * 2) + " inches")
    final_drogue_diameter_in = float(input('decide on final drogue'
        + 'parachute size (diameter inches)-->')) #inches
    #final_drogue_diameter_in = 24
```

```
final_drogue_area_ft = ((final_drogue_diameter_in /
        (12 * 2)) ** 2) * math.pi
#####################################################################
#vmax for landing with a KE less than 75 ft-lbf with detaching
#payload
KEmax = 75 #ft-lbf
print("Max landing KE is " + str(KEmax) + " ft-lbf")
safety_factor = float(input('safety factor of (should be between'
        + '0 and 1) -->'))
KEmax = safety_factor * KEmax


hv = float(eval(input('HEAVIEST SECTION put "btr", "av", "pl" '
    + '(no quotes) or a number -->')))
vmax = math.sqrt((2*(KEmax)*ftlbf_to_lbmft2persec2)/hv)

print("vmax: " + str(vmax))
#####################################################################
Cd2 = 2.2
print("main coefficient of drag is " + str(Cd2))



#--------------------------------------------------------
#asks user if the payload will detach or will not detach
while True:
    yn = input("does the payload detach? ('y' or 'n') -->")
    if yn == "y":
        m = total - pl
        detach_payload = True
        break
    elif yn == "n":
        m = total
        detach_payload = False
        break
    else:
        print("invalid response")
#--------------------------------------------------------
print("PAYLOAD DOESN'T DETACH") if m == total else print("PAYLOAD"
        + "DETACHES")


main_area = (((m * g)/(.5 * (vmax ** 2) * rho)) - (Cd1
        * final_drogue_area_ft)) / Cd2
main_radius = math.sqrt(main_area/math.pi)
main_diameter_in = main_radius * 2 * 12
```

```
    print("main's diameter must be at least " + str(main_diameter_in)
            + " inches")
    print("decided on drogue of " + str(final_drogue_diameter_in)
            + " inches")

    main_radius_ft = float(eval(input("main diameter "
            + "(inches) --> "))) / (2 * 12)
    main_area_ft2 = ((main_radius_ft) ** 2) * math.pi

    t_velocity = terminal_v(m, Cd1, final_drogue_area_ft, Cd2,
            main_area_ft2)


    if detach_payload:
        print("The final terminal velcocity is " + str(t_velocity)
                + " ft/s")
        print("The final KE for the booster is "
                + str(v_fts_to_ke_ft_lbf(t_velocity, btr)) + "ft_lbf")
        print("The final KE for the avionics is "
                + str(v_fts_to_ke_ft_lbf(t_velocity, av)) + "ft_lbf")
        payload_para(pl)
    else:
        print("The final terminal velcocity is " + str(t_velocity)
                + " ft/s")
        print("The final KE for the booster is "
                + str(v_fts_to_ke_ft_lbf(t_velocity, btr)) + "ft_lbf")
        print("The final KE for the avionics & payload is "
                + str(v_fts_to_ke_ft_lbf(t_velocity, av+pl)) + "ft_lbf")

drogue_main()
```

A.2 Static Pressure Ports: Matlab Code

To calculate the sizes of the static pressure ports the following matlab code was used.

```
function [D_hole] = Static_Pressure_Ports(N,L,D)
% This function calculates the size of the static pressure ports needed for
% our avionics bay. N is the number of desired holes, L is the internal
% length of the avionics bay in inches, and D is the internal diameter of
% the avionics bay in inches. D_hole is the diameter of one static pressure
% port. In order to equalize pressure within the avionics bay so that the
% altimeters can read the altitude, we will need a 1/4 in diameter hole cut
% out the airframe for every 100 in^3 of volume.
R=D/2;
A = pi*(R^2)*L*(4.9087*10^(-4)); % A is the area that we need to cut out of
% the airframe, and the constant 4.9087*10^(-4) is a reference determined
% by dividing 1/4 in^2 by 100 in^3.
A_hole = A/N; % This is the area of one static pressure port hole.
```

```
D_hole = 2*sqrt(A_hole/pi);
```

A.3 Black Powder: Matlab Code

To calculate the sizes of black powder charges the following matlab code was used.

```
function [Powder_quantity] = Black_Powder(N,F,L,K)
% This function calculates the amount of black powder necessary to deploy
% our parachutes. N is the number of shear pins, F is the force required to
% break one shear pin, L is the internal length between bulkheads, and K is
% the factor the amount of blackpowder will be scaled by to be sure all
% parachutes will deploy. Powder_quantity is the amount of black powder
% necessary in grams.
Powder_quantity = (5.161*10^(-4))*N*F*L*K; % where 5.161*10^(-4) is a
% constant derived from the ideal gas law.
```