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

January 13, 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

- Length: **103"**
- Weight: **32.06 lbs**
- Final Motor Choice: **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 Summary of Changes made since PDR

2.1 Project Plan

A significant change to our project plan since the PDR is our amount of funding. Our application for $3,000 from the Student Opportunity Fund has been accepted. During UC Berkeley's annual fundraiser, The Big Give, CalSTAR won an award of $1,000.00. As a result we have increased our total funding from $4,505.33 to $8,505.33. This increase allows a larger budget for materials from $2785.50 to $3680.94. In regards to the timeline, we have completed our subscale launch as well as several subsystem tests. Also, we have added more tests to our future timeline. In regards to requirement verification, we have increased the amount of completed/verified requirements and continue to meet expected progress.

2.2 Launch Vehicle

Two major changes have been made since the PDR. The largest change is that the rocket will now utilize an Aerotech L1150 motor, which has a much higher impulse than the Aerotech K1050 motor selected in the PDR. This change was made due to increases in the projected weight of the rocket and increases in the projected drag coefficient.

Additionally, the length of the nosecone has been extended to 24", compared to 18" previously. This change was made due to the greater availability of 4:1 6" nose cones, as well as the fact that the longer nose cone offers a slight reduction in overall drag.

2.3 Payload

The payload section design has undergone three major changes: the couplers connecting the payload section to the avionics bay and the nose cone will no longer be slotted, and the length of each component has been modified to accommodate this change; the payload parachutes have been resized such that a single parachute can safely bring down the entire payload section; and, the deployment sequence has been changed to ensure that at least one parachute is deployed before ejection.

Instead of slotting the shoulder from the avionics bay, such that it consists of sections of varying lengths, the entire shoulder will be 3.5" long, and secured to the payload section using shear pins. As a result, the landing legs have been shortened to 10.25". The shoulder of the nose cone will also be 3.5" in length; this shoulder will be screwed to the payload tube.

The use of the Raspberry Pi presents a possibility of failure to deploy the legs by actuating the solenoid pins holding them in the airframe. As a result, if all pins fail, ejection of the payload section would cause the section to fall ballistically. To prevent this, one leg (and parachute) will be deployed before ejection. Furthermore, the altitude criteria for ejection will be activated by the altimeters, rather than the Raspberry Pi. As such, when the payload reaches the altitude criteria of 600 ft, the altimeters connected to a solenoid will cause it to retract, deploying one leg and parachute. The Raspberry Pi is then used to trigger ejection and subsequent leg deployments.

2.4 Recovery

The recovery subsection of the rocket has four primary changes since the PDR. The changes revolve primarily around the structural mechanisms of the avionics bay.

First and foremost, the wires leading out from the avionics bay and to the e-matches in the Tender Descenders will be improved with a detachable break-off design. The addition of these snappers would allow the wires to snap off from the Tender Descender after the e-match has been ignited. The reason this design is implemented is because the deployment of the main parachute would unchain the two Tender Descenders in series. As a result, the force of the main chute deployment would pull the wire leading to the e-match very far – to the extent that the wire would be pulled out, or it would snap, rendering it unusable. Furthermore, if the wire does not snap, it would significantly restrict the length of the shock cord connecting to the main chute, preventing the parachute from fully inflating and compromising the vehicle. Thus, having wires that will detach just outside the bulkhead of the avionics bay during main chute deployment would be the best solution to this issue.

Second, the door design will consist of a rubber sheet cushioning the door and the coupler tube that the door rests on. This will replace the silicone that was used for the subscale rocket, which, while convenient for the subscale launch, was not optimal for ensuring an air-tight door on the avionics bay. Furthermore, this gasket would be screwed on tightly with four screws on each corner of the door. However, the size and general structure of the door will remain constant.

Next, the parachutes used to recover the payload sections have been modified to increase safety and mitigate the risk of failure. As discussed in Section 2.3, the payload parachutes may fail to deploy; therefore, the three parachutes deployed from the payload section are calculated such that the section will land safely even if only one parachute deploys. A single parachute on the payload will provide enough drag to have the payload land with a kinetic energy of 75 ft-lbf. In the ideal case, where all three parachutes successfully deploy, the terminal velocity of the section will drastically decrease, giving a safety factor of three for the landing kinetic energy. The payload will contain 3 36” Iris Toroidal Parachutes from Fruity Chutes. In addition, the main parachute was calculated with a safety factor of 2, which allows the vehicle to land with 75 ft-lbf even if the payload fails to detach. The vehicle will contain an Iris Ultra 72” Compact Parachute for the main, and 24” Elliptical Parachute for the drogue. A Python program was developed to calculate the parachute sizes; see Appendix for the commented code.

Finally, both bulkheads of the avionics bay will be located at the outer end of the coupler/airframe tube rather than having one inside the coupler tube and the other located on the outside of the coupler tube. This would make it easier for on-field manipulation and wire organization, as it would eliminate the need to reach inside the tube. This would also reduce the amount of volume in the booster section for the parachutes, but would increase the volume inside the avionics bay.

3 Vehicle Criteria

3.1 Design and Verification 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 Design Alternatives

The following sections outline the alternatives discussed in the Preliminary Design Review as well as the final choices and the reasoning for each choice. A strength analysis of the various materials discussed in this section can be found in section 3.2.

Nosecone Design

The nose cone will consist of a 4:1 6" fiberglass ogive nose cone, with a tip made from PETG. The transparent tip is selected over alternatives, such as a fully transparent nose cone or a window in the side of the cone, as it balances manufacturability of the vacuum-formed plastic with optimizing visibility for the nose-mounted camera. PETG (polyethylene terephthalate glycol-modified) is selected over polycarbonate due to its low glass transition temperature and ease of vacuum-forming. A 4:1 aspect ratio (24" length) is selected over a 3:1 ratio due to its greater commercial availability.

Body Tube

Blue Tube is the final material choice for the body tube of the vehicle. Carbon fiber provides excellent strength, but its extreme brittleness poses too great a risk in the event of failure. Fiberglass also offers great strength and heat resistance, but poses safety risks in manufacturing. For both fiberglass and carbon fiber, monetary costs are also a concern. Quantum tubing offered a favorable combination of strength, low cost, and manufacturability, but Blue Tube provided similar properties with higher heat resistance. The manufacturing of our subscale vehicle additionally showed that Blue Tube was relatively easy to machine and suffered no structural damage during launch and upon recovery.

Kraft Phenolic Motor Mount

Kraft phenolic is our final choice for the motor mount material, largely due to its high heat resistance and reputation as a common motor mount material. Analysis of the subscale vehicle also revealed that kraft phenolic sufficiently insulated the heat from the motor, preventing any major warping or melting of the fins and airframe. As a result, kraft phenolic will remain the material of choice for the full scale motor mount.

G10 Fiberglass Fins

G10 Fiberglass will be used as the material for the fins. Previously, fiberglass reinforced plastic (FRP) was selected as the material of choice for the fins due to its excellent strength and reputation in structural applications. However, G10 fiberglass offers more tensile and impact strength than FRP for nearly the same density[1], so it was selected as the material of choice for the full scale launch.

Fin Attachment

Through the wall attachment will be used in the full scale vehicle, as it adds strength to the fins and decreases the risk of fin detachment from the airframe. A previous plan for attaching the fins to the airframe included Kevlar strips that would be epoxied onto the motor mount and up along the fins. Carbon fiber fillets would also be glued where the fin and the outside of the body tube come in contact. However, analysis of the subscale vehicle showed that high strength JB-Weld epoxy provided sufficient adhesion between the fins and the motor mount, so Kevlar strips will not be included along the motor mount and fins. Carbon fiber fillets will still be applied where the fin comes in contact with the body tube since large stress affects that joint upon impact with the ground.

Motor Choice

The Aerotech L1150 is the final motor choice for the vehicle. Previously, the Aerotech K1050 was the motor of choice for the launch vehicle; however, the increase in weight estimates since PDR resulted in the need for a more powerful motor. One critical factor in this choice is the projected apogee of 5322 feet. Although this estimate is above the goal of one mile, weights are predicted to be overestimated due to various manufacturing factors, allowing the launch vehicle to reach an apogee closer to 5280 feet. The higher projected apogee expected will also allow room for increases in the rocket's drag coefficient, making the Aerotech L1150 the motor of choice for these reasons.

[1] "More About Hard Fibre, Fiberglass, Garolite, and Carbon Fiber." McMaster-Carr. McMaster-Carr, n.d. Web. 07 Jan. 2017.

Epoxy

JB Weld Steel Reinforced Epoxy, as well as West System Epoxy Resin will be used in various components of the vehicle. The high strength and viscosity make JB Weld extremely useful for bonding large components. During the subscale launch, both JB Weld and West System 105/205 Epoxy Resin were used in different places. The JB Weld proved to be much easier to work with, and was much stronger than the West System epoxy resin. The West System epoxy resin was also difficult to apply to some objects due to its very low viscosity. However, the West System epoxy resin will be used with carbon fiber to create fillets along the fins.

3.1.3 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 3.2) 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 3.2). 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.

3.1.4 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. A full strength analysis of the various materials under simulated flight loads can be found in section 3.2.

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

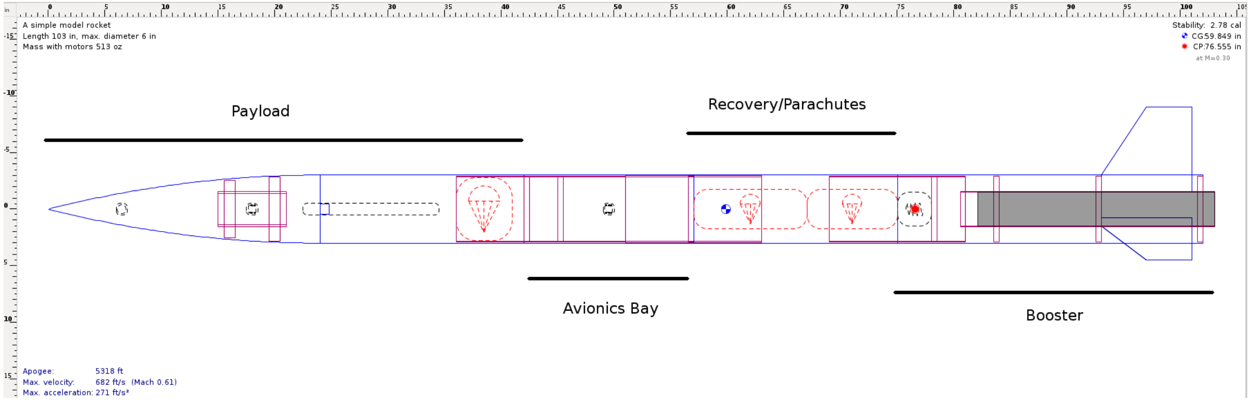
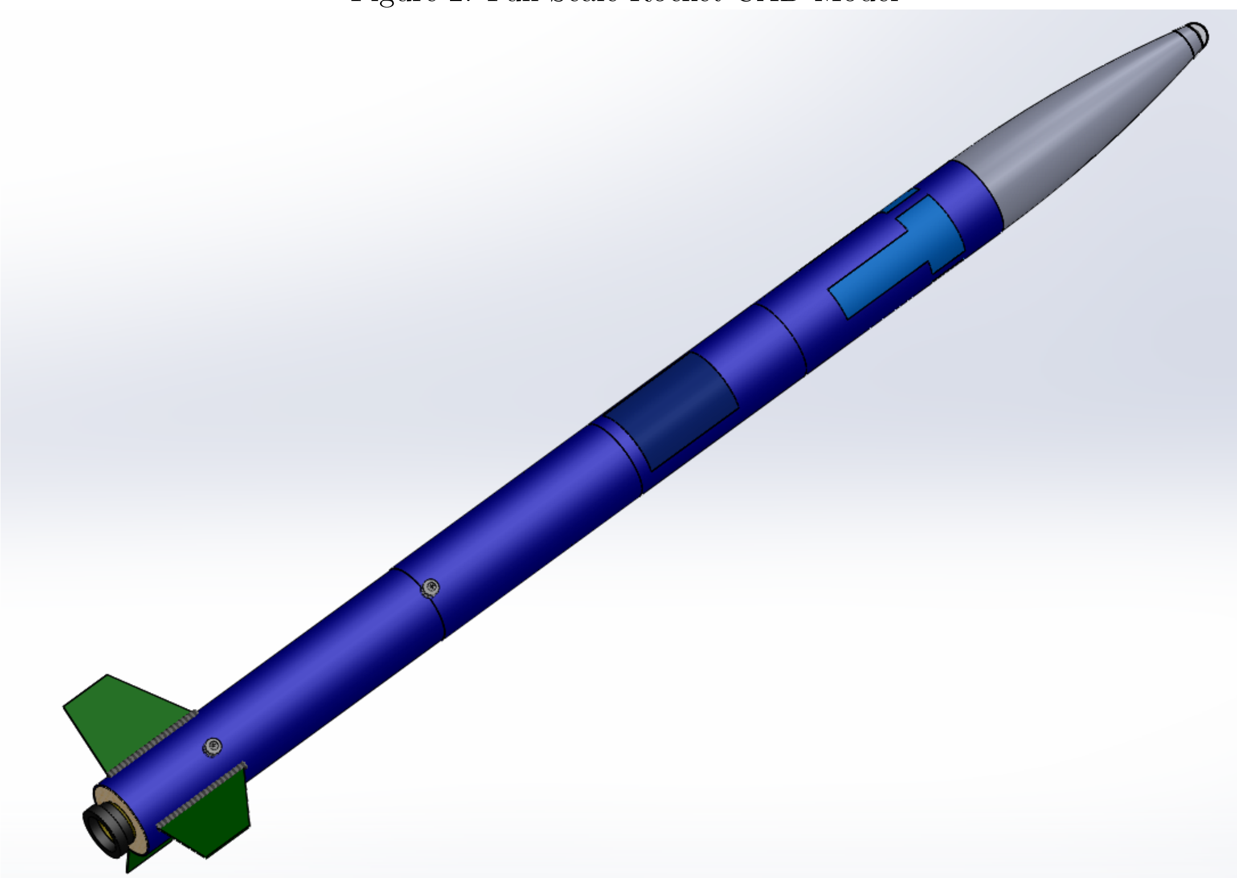
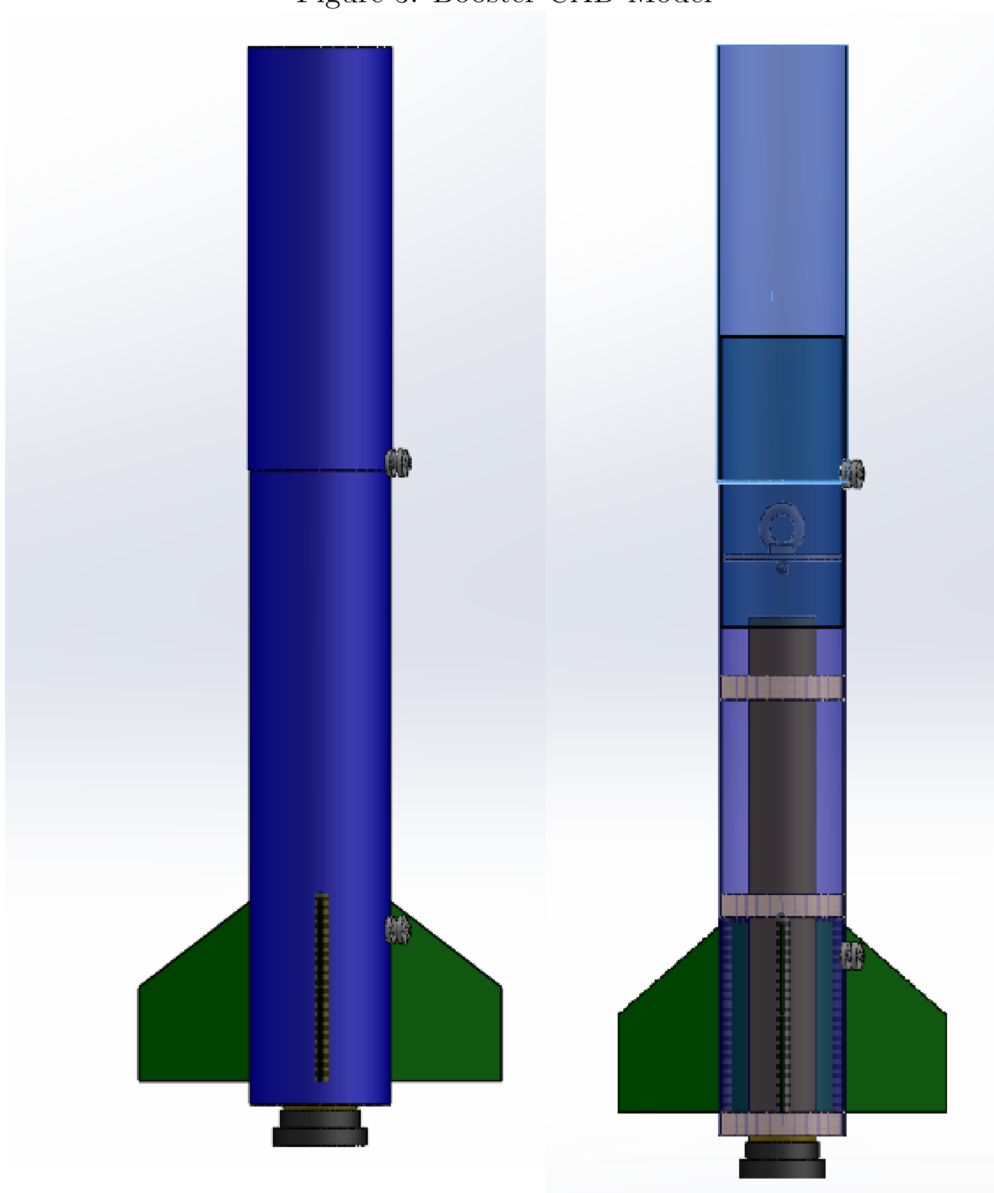


Figure 2: Full Scale Rocket CAD Model



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

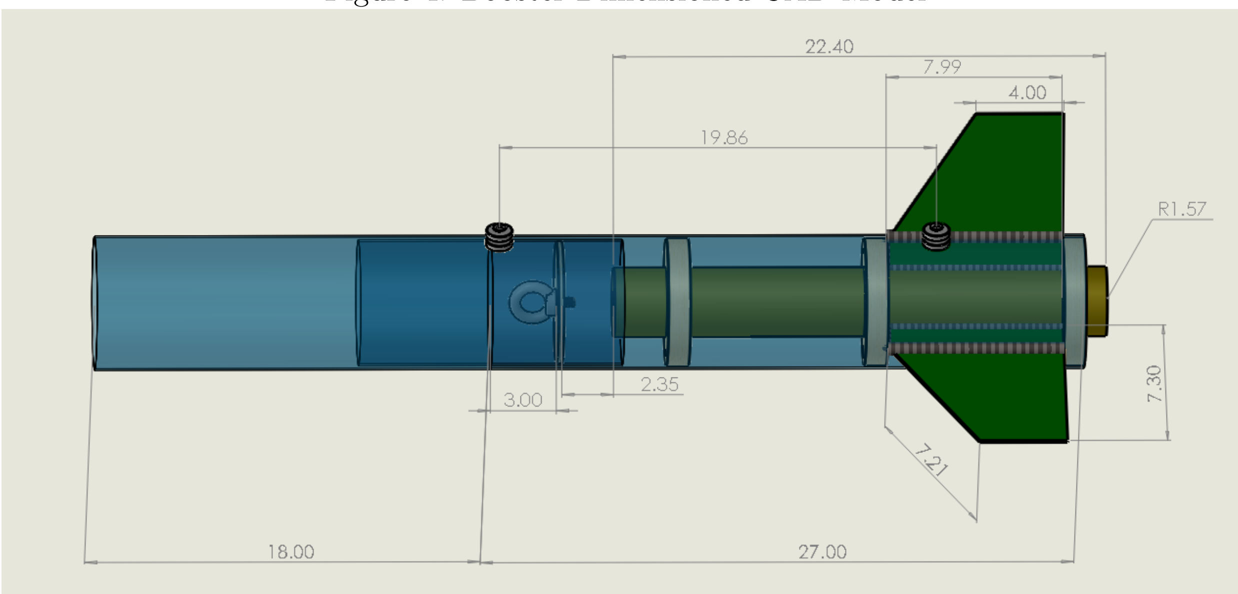


The estimated weights of the various sections of the rocket are displayed in the following table.

Section	**Weight (lb)**
Payload (including nosecone)	10.50

Avionics Bay	6.25
Parachute/Recovery	1.13
Booster	14.19
Total	**32.07**

Figure 4: Booster Dimensioned CAD Model



3.2 Airframe Strength Analysis

The strength properties of the various materials used in the airframe are discussed in the following sections. The properties illustrate the integrity of the design and prove it is robust enough to withstand the loads experienced during flight.

3.2.1 Blue Tube

The airframe is primarily composed of Blue Tube, a tough vulcanized fiber composite produced by Always Ready Rocketry. A table detailing the results of a compressive strength test conducted on three different three inch diameter and nine inch long lengths of blue tube is shown in Figure 5.

Figure 5: Blue Tube Strength Specifications[2]

Specimen #	Specimen Comment	Inner Diameter in	Outer Diameter in	Platen Separation in	Area in^2	Modulus ksi	Load At Yield lbf
1		3.002	3.128	9.00000	0.60662	559.60219	2974.13082
2		3.002	3.128	9.00000	0.60662	607.10291	3211.11207
3		3.002	3.128	9.00000	0.60662	574.09091	3052.63859
Mean		3.002	3.128	9.00000	0.60662	580.26534	**3079.29383**
Std. Dev.		0.000	0.000	0.00000	0.00000	24.34486	120.71828

Specimen #	Stress At Yield MPa	Peak Load lbf	Peak Stress psi	Energy To Peak ft*lbf	Break Load lbf	Elongation at Peak in	
1	33.80322	2974.13082	4902.72798	14.11096	1504.89966	0.11156	
2	36.49669	3211.11207	5293.38147	20.93077	1607.34466	0.13095	
3	34.69552	3052.63859	5032.14469	18.27847	1534.46427	0.11815	
Mean	34.99848	3079.29383	**5076.08472**	17.77340	1548.90286	0.12022	
Std. Dev.	1.37205	120.71828	198.99895	3.43785	52.72665	0.00986	

The mean Young's Modulus for the tube is approximately 580 ksi, or about 3.99 GPa. For reference, solid polystyrene has a modulus of approximately 3.5 GPa and medium density fiberboard has a modulus of approximately 4 GPa. Young's Modulus, or elastic modulus is a measure of the stiffness of a particular material. It is the ratio of stress to the strain of the material along the axis the stress is applied. Mathematically, Young's Modulus is defined by the following equation

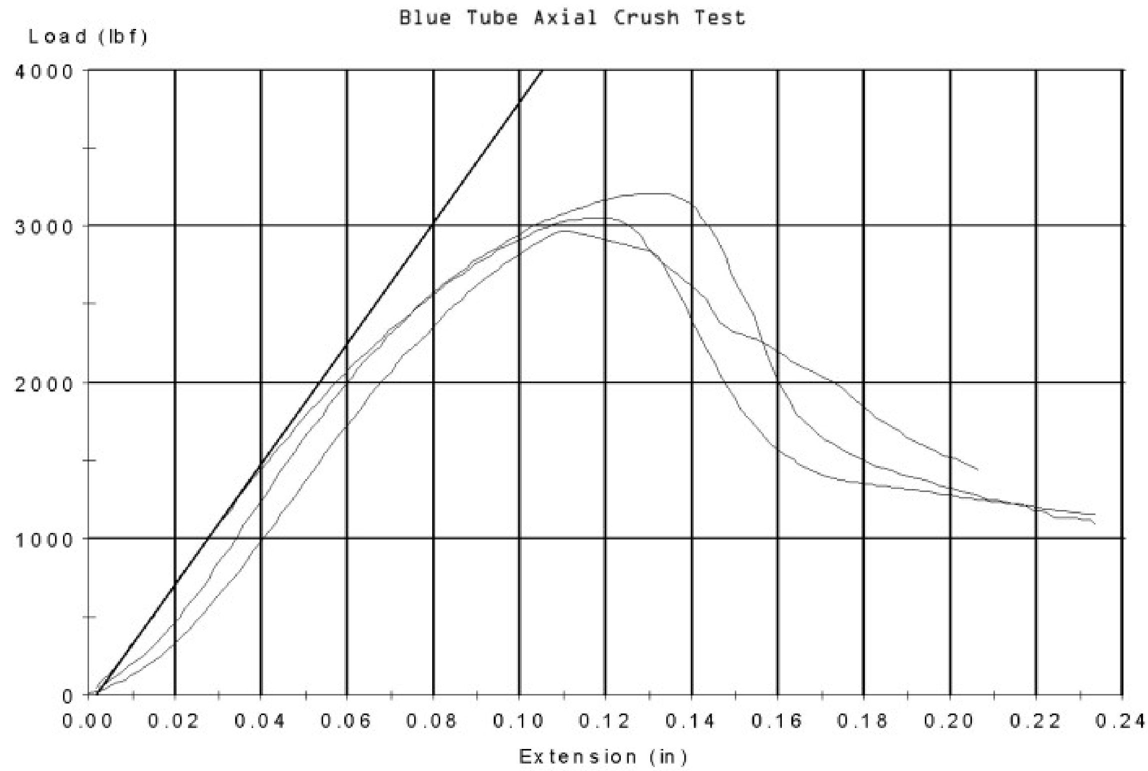
$$E = \frac{FL_0}{A_0 \Delta L}$$

where
E is Young's Modulus,
F is the applied force along a specific axis,
L_0 is the initial length of the object,
A_0 is the cross-sectional area through which the force is applied,
ΔL is the change in the length of the object across the axis the force was applied through.

The elastic modulus of blue tube describes the ability of the tube to deform under large stress loads. Such a characteristic is important during high speed flight. The tube's ability to deform reduces the risk that the tube will fracture or shatter completely during flight or during landing. The elastic deformation of the blue tube is illustrated in Figure 6. The loads experienced by the full scale rocket during flight are likely to not exceed 1000 lbf. Within that constraint, the extension of the blue tube is minimal and will likely not severely affect the integrity of the airframe.

[2] "What Is Blue Tube 2.0?" Always Ready Rocketry. AfterDark Creative, n.d. Web. 06 Jan. 2017. ⟨http://www.alwaysreadyrocketry.com/blue-tube-2-0/⟩.

Figure 6: Blue Tube Compressive Extension[3]



The mean yield strength of Blue Tube is approximately 5076 psi, or about 35 MPa. This is significantly larger than the compressive forces experienced by the Blue Tube during flight, namely drag forces and the force exerted by the motor on the airframe. Additionally, the airframe will have a relatively low kinetic energy upon landing, so the landing impact force will be significantly smaller than the yield strength. Due to this, the blue tube airframe is sufficiently strong enough to withstand the stress of flight and landing, allowing the rocket to be relaunched multiple times with minimal permanent damage.

3.2.2 Fiberglass

Both the nosecone base and the fins are constructed from G10 fiberglass epoxy laminate sheets. G10 fiberglass has extremely high strength and is a very good insulator. The following table describes various strength properties of G10 fiberglass[4].

Test	**Value**
Rockwell Hardness (M)	110

[3]"What Is Blue Tube 2.0?" Always Ready Rocketry. AfterDark Creative, n.d. Web. 06 Jan. 2017.

[4]"G10 Epoxy Fiberglass Laminate Sheet." MatWeb - The Online Materials Information Resource. MatWeb, LLC, n.d. Web. 06 Jan. 2017.

Crosswise Tensile Strength	38000 psi
Lengthwise Tensile Strength	45000 psi
Crosswise Flexural Strength	65000 psi
Lengthwise Flexural Strength	75000 psi
Crosswise Flexural Modulus	2400 ksi
Lengthwise Flexural Modulus	2700 ksi
Compressive Strength	65000 psi

The fiberglass nosecone base will mostly be under a compressive force. The compressive strength of G10 fiberglass is 65000 psi, which is a load much greater than what the nosecone will experience. Because of this, the fiberglass nosecone base is sufficiently strong enough to withstand flight. Additionally, The nosecone should experience very little stress upon landing due to the landing legs that will be deployed from the payload. The springs which connect the legs to the nosecone will absorb the vast majority of the impact upon landing.

The fiberglass fins will mostly experience a lengthwise tensile force due to the drag force exerted on the fins and the adhesive force between the fins and the motor mount. The lengthwise tensile strength of G10 fiberglass is 45000 psi. Again, this load is much greater than what will be experienced in flight. Due to this, G10 fiberglass is sufficiently strong enough to withstand loads experienced during flight.

3.2.3 PETG

The nosecone tip will be constructed out of PETG, a soft plastic composite. The tip of the nosecone will be experiencing the greatest drag force during flight, and as such, it is critical that the PETG is strong enough to withstand this force. The following table describes various strength properties of PETG[5].

Test	**Value**
Rockwell Hardness (R)	105
Tensile Strength at Break	7250 psi
Elongation at Break	54%
Tensile Modulus	319 ksi
Flexural Strength	10200 psi

[5]"Polycasa PETG." MatWeb - The Online Materials Information Resource. MatWeb, LLC, n.d. Web. 06 Jan. 2017.

Flexural Modulus	301 ksi

The nosecone tip will mostly experience a force causing flexing. The force will cause flexing because the edges of the tip are glued to the nosecone base and the drag force will mostly be experienced in the center region of the tip. The flexural strength of PETG is 10200 psi. This value is much greater than the pressure the tip will undergo during flight. Because of this, the PET-G is strong enough to withstand loads experienced during flight.

3.2.4 JB Weld Steel Reinforced Epoxy

JB Weld Steel Reinforced Epoxy is a two part epoxy that will be used to glue bulkheads, centering rings, and coupler tubes into the main body tubes. JB Weld was chosen due to its extremely high hardness and high strength characteristics. Additionally, the epoxy is very thick and has high viscosity when uncured, allowing it to be used to fill empty spaces between objects that are to be glued together. JB Weld epoxy has high heat resistance, allowing it to be used to attach motor retainers to the phenolic motor mount tube.

The following table lists the technical characteristics of JB Weld Steel Reinforced Epoxy[6].

Test	**Value**
Tensile Strength	3960 psi
Adhesion	1800 psi
Flex Strength	7320 psi
Shrinkage	0.0%
Heat Resistant up to	500°F
Set Time	4-6 hours
Cure Time	15-24 hours

The high tensile, flex, and adhesive strengths of JB Weld epoxy are good incentives for using it in the airframe. Additionally, the lack of shrinkage makes it very useful to epoxy objects together that have spaces between them.

[6] The Zen Cart Team and Others. "JB Weld - Technical Data and Instruction Sheet." JB Weld - Technical Data and Instruction Sheet : JB Weld It Australia, Dont Scrap It - JB Weld It. N.p., n.d. Web. 08 Jan. 2017.

3.3 Subscale Design and Flight Results

3.3.1 Scaling

Our subscale rocket, URSA Minor, was designed to be as similar as possible to the full scale rocket. The main scaling factors were the length and diameter of the rocket tubes. Both these variables were scaled by a factor of 2/3, resulting in a volume scale of approximately one third. The diameter of the airframe tubes was scaled down to 4". The length of the booster section was reduced from 27" in length to 18". The length of the parachute recovery section was reduced to 12". The avionics bay was reduced to 10" in length. The overall payload section, which included a 12" section of blue tube and a 12" nose cone, had a length of 24" total. The fins were also scaled by approximately two thirds. The trapezoidal fins were given a root chord length of 5.5", a tip chord of 3", and a height of 4".

The payload experiment was not conducted in the subscale vehicle. The Raspberry Pi camera was mounted in the nose cone and used to obtain video footage, in order to determine the quality of images obtained from the design of the clear window. The remainder of the payload mass was simulated using ballast.

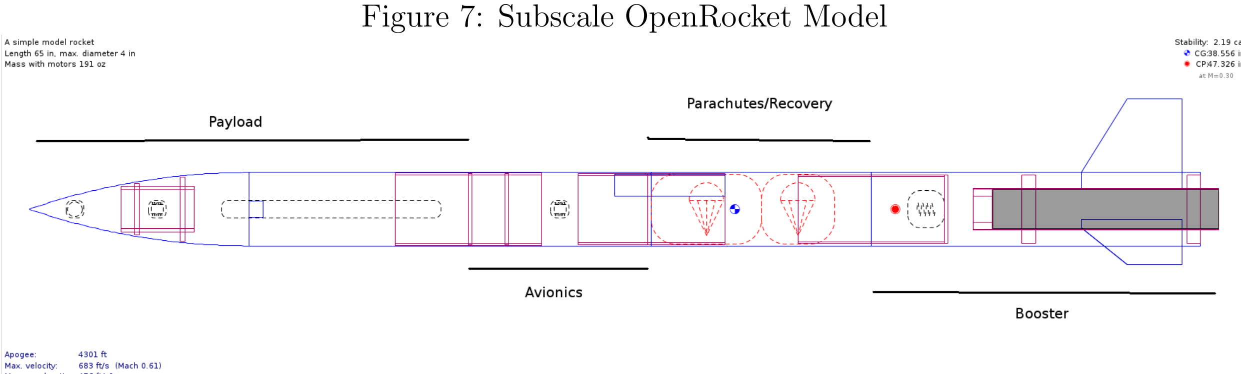
The motor was scaled down to an Aerotech J800. With this motor, the subscale was projected to reach an apogee of approximately 4600 feet AGL.

Many other factors were kept constant. The geometric shape of the rocket, including the shapes of the nose cone and fins was kept constant. The construction materials used in the subscale were the same materials that will be used in the full scale. The avionics hardware, including those associated with the Raspberry Pi, was mostly the same between the subscale and full scale. The size of all electronic components and mounts were kept constant, as these do not affect the flight dynamics of the rocket.

3.3.2 Design and Assembly

An OpenRocket model of the subscale design and the different rocket sections is shown in Figure 7.

Figure 7: Subscale OpenRocket Model



The final subscale rocket is shown in Figure 8.

Figure 8: Subscale Rocket

Nosecone

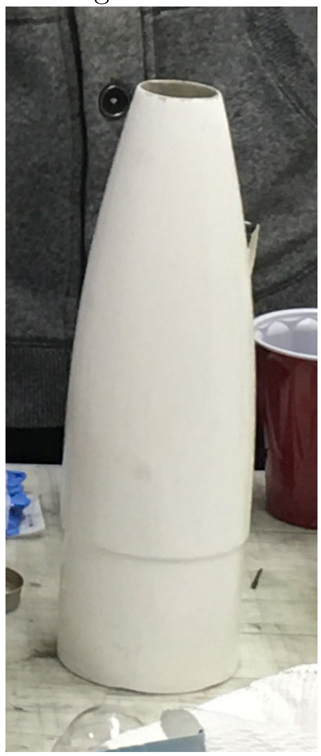
The nosecone was constructed from two separate pieces: a fiberglass base and a clear plastic tip.

The nosecone base was a 4” diameter ogive fiberglass nosecone with an exposed length of 12 inches. The cone was bought commercially rather than constructed. The tip of the nosecone was trimmed by approximately two inches in order to allow the clear tip to fit over it. The cut nosecone is shown in Figure 9. The nosecone was cut so that the outer diameter of the plastic tip was approximately 1.75”.

The nosecone tip was constructed from a 1/8” sheet of PETG. This specific material was chosen due to its low glass transition temperature of approximately 190 degrees Fahrenheit - allowing it to be used with a vacuum forming machine - as well as its transparency and its malleability.

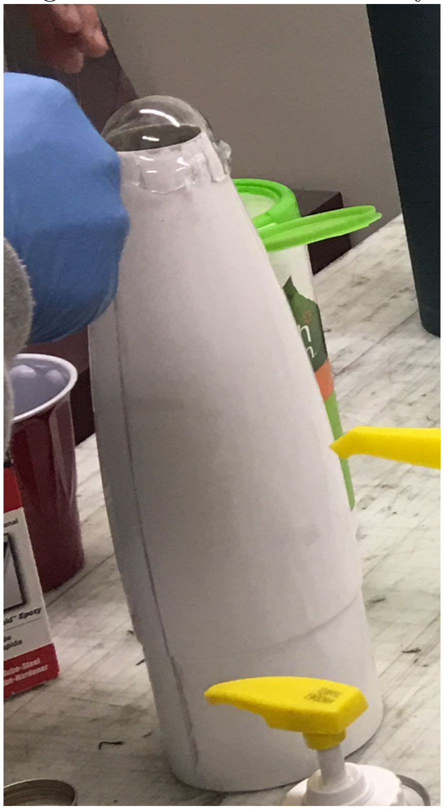
The tip was constructed by first 3D printing a mold. The mold was a hemisphere with a diameter of 1.75 inches. The PETG sheet was molded to the tip using a vacuum forming machine at UC Berkeley’s Jacobs Institute of Design. The molded piece of plastic was cut out of the sheet, along with a one inch lip.

Figure 9: Fiberglass Nosecone After Cut



The tip was placed over the end of the nosecone, and the lip was heated with a heat gun and bent to fit flush against the outer surface of the nosecone base. The tip was attached to the nosecone using a two part epoxy resin. The assembly is shown in Figure 10.

Figure 10: Nosecone Assembly



The edge of the PETG tip was sealed using a putty, which was sanded after curing, and covered in aluminum tape to reduce unwanted aerodynamic drag (see Figure 11).

Figure 11: Final Nosecone Assembly

The components inside the nosecone included a Raspberry Pi computer and a Raspberry Pi camera module. The computer was attached to the inside of the nosecone using tape. The camera module was attached to a centering ring (see Figure 12) which was glued to the inside of the nosecone, just below the tip (see Figure 13).

Figure 12: Camera Centering Ring

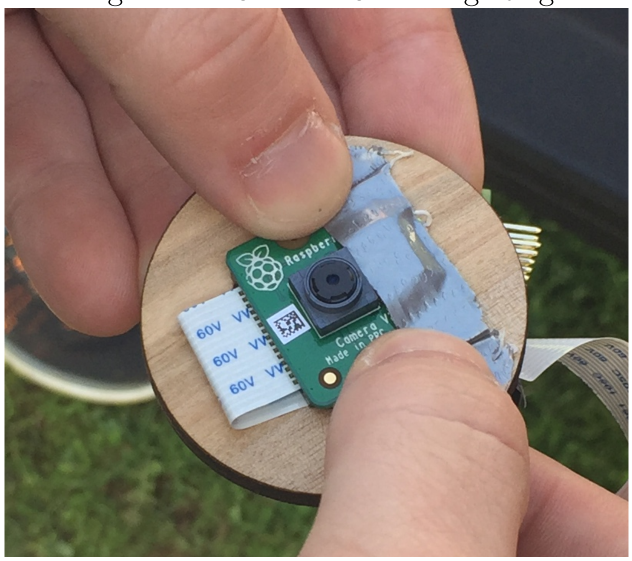
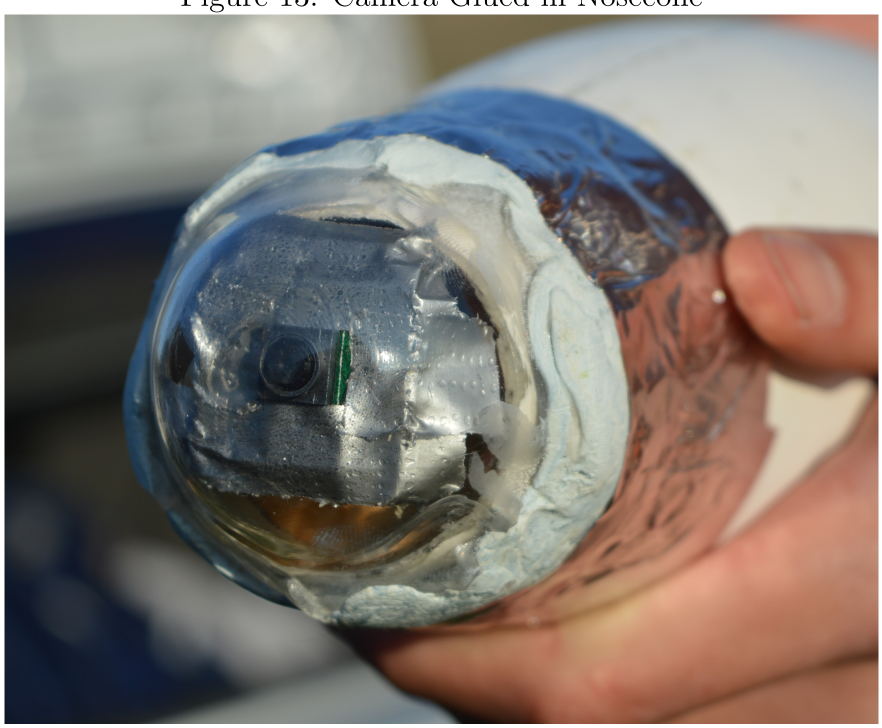


Figure 13: Camera Glued in Nosecone



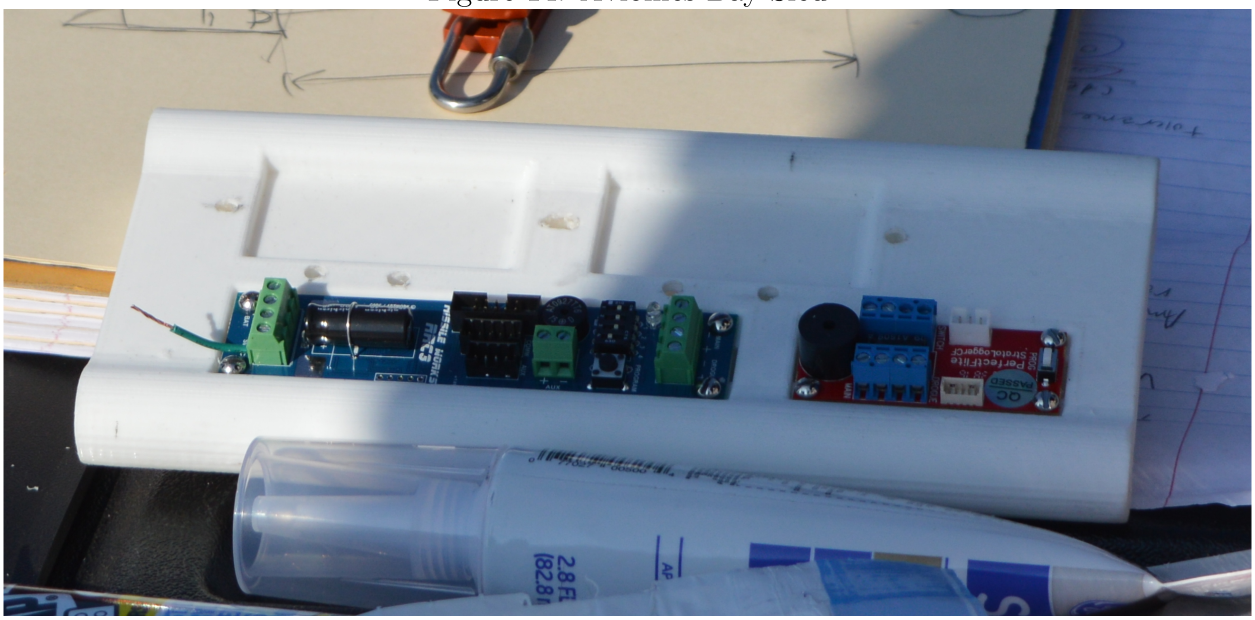
Payload

The payload section was a 12" length of blue tube. It contained a one pound ballast which was used to simulate the scaled weight of the payload internal components.

Avionics Bay

The avionics bay was a 10" length of Blue Tube. It contained a 3D printed sled (see Figure 14) which held the payload altimeters and electronics.

Figure 14: Avionics Bay Sled



Recovery/Parachutes

The recovery section was a 12" length of tube. It contained the black powder charges, which were ignited by the altimeters in the avionics bay. It also contained the drogue parachute, which had a diameter of 18", and the main parachute, which had a diameter of 60". Approximately 100 feet of Kevlar shock cord connected the parachutes to the booster section and the avionics bay.

Booster

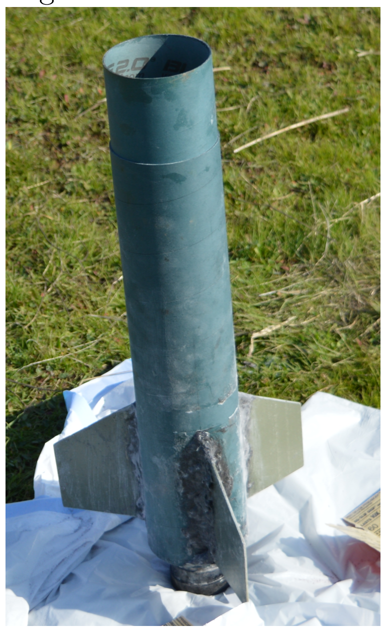
The booster section was constructed from several major pieces: the outer tube, the motor mount, and the fins. The outer tube was an 18" length of Blue Tube. The motor mount was an approximately 13" length of phenolic tubing. The fins were cut from a sheet of fiberglass.

Three centering rings were first glued onto the motor mount. One ring was glued approximately two inches from the aft end of the mount. The next centering ring was glued 5.5 inches forward of the first, and the third one was glued approximately two inches forward of the second. The positions of the first and second centering rings were chosen so that the surfaces of the rings would be in contact with the fins, which were glued to the motor mount. This allowed for additional surface area between the fins and the motor mount, increasing the strength of the glue joint. Figure 15 illustrates this process. A motor retainer was also glued to the end of the motor mount.

Figure 15: Motor Mount

Once the three fins were glued to the motor mount, the motor mount was inserted into the outer tube. Fin slots were first cut into the outer tube, and then the motor mount was glued into the outer tube. The strength of the fins were further reinforced by adding a fillet to the contact surface between the outer tube and the fins. The fillet was composed of an epoxy resin mixed with carbon fiber strips. The fillets were sanded down after they had dried, and resulted in an extremely strong connection between the fins and the outer tube. The fillets, along with the full booster section, can be viewed in Figure 16.

Figure 16: Booster Section



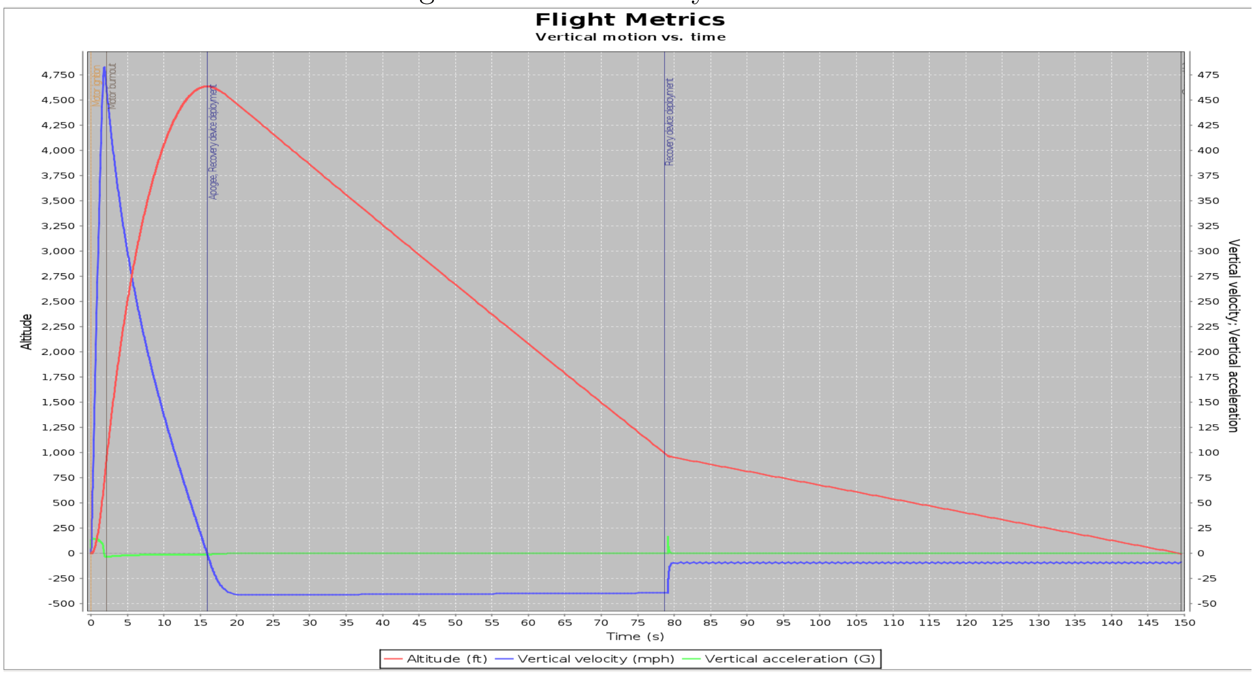
3.3.3 Launch Day Conditions

The subscale flight was conducted on December 4th, 2016 at approximately 3:55 P.M. PST. The temperature was approximately 56 degrees Fahrenheit. Barometric pressure was 30.2 inHg, and wind speed was approximately 0 mph. Cloud cover was minimal, and visibility extended to 6 miles.

3.3.4 Launch Day Simulation

OpenRocket simulations using launch day conditions result in an apogee of 4,633 feet AGL. A plot of the simulation can be viewed in Figure 17. The simulated velocity off the launch rod was 89.9 ft/s. The maximum velocity of the rocket was Mach 0.63, and the maximum acceleration was approximately 15.3 Gs.

Figure 17: Launch Day Simulation



3.3.5 Actual Subscale Results

The pre-launch weights of the separate sections are shown in the following table. The weight of the booster includes the motor and the motor casing.

Section	**Weight (lb)**
Nosecone	1.11
Payload (not including nosecone)	1.61
Avionics Bay	2.36
Parachute/Recovery	2.05
Booster	4.49
Total	**11.61**

The pre-launch CG is located 37.84 inches from the nosecone. The CP is located 47.33 inches from the nosecone. The pre-launch stability is 2.37 calibers.

The burnout weights of the separate sections are shown in the following table.

Section	**Weight (lb)**

Nosecone	1.11
Payload (not including nosecone)	1.61
Avionics Bay	2.36
Parachute/Recovery	2.05
Booster	3.17
Total	**10.30**

The burnout CG is located 35.34 inches from the nosecone. The burnout CP is the same as the pre-launch CP, resulting in a burnout stability of 2.9 calibers.

The subscale was launched with two altimeters which measured the apogee to be 4,574 feet. The simulated apogee of 4,633 feet was 59 feet above the actual apogee, a percent difference of 1.27. This difference may be accounted for by the rounded nosecone tip. The simulation assumed a perfectly ogival nosecone, and the tip may result in a higher drag coefficient. Additionally, the Blue Tube had spiral ridges on it, which could also increase the drag coefficient. Using OpenRocket and the actual flight data, the drag coefficient is measured to be about 0.55.

3.3.6 Impact of Subscale on Final Design

The overall design of the rocket remains unchanged after the subscale launch. However, small changes to individual parts and to the build procedure resulted from the subscale.

Nosecone

The design and manufacture of the nosecone tip presented various challenges. For the subscale, the tip was designed to be a simple hemispherical shell. This caused great difficulty when deciding how the tip was to be attached to the nosecone base. The tip had to be melted and reshaped to fit the profile of the base, and the two were then epoxied together. This process proved to be extremely messy and resulted in large protrusions on the nosecone that reduced aerodynamic efficiency. On the full-scale vehicle, the PETG is to be molded such that the bottom of the tip flares outwards to match the profile of the ogival nosecone (see Figure 18). The tip would then fit snugly over the base and could easily be glued (see Figure 19).

Additionally, the images captured by the camera during the subscale flight were affected by blur and glare. The blur was caused by smudges and scratches on the PETG nosecone tip. This can be solved by covering the tip with a transparent film during construction that would be removed just before flight. Also, an abrasion resistant spray could be applied to the tip to prevent scratches from forming. The glare can be averted by placing an opaque material, such as aluminum tape, on the areas outside the field of view of the camera. This would reduce the amount of light entering through the nosecone tip without affecting the camera's field of view.

Figure 18: Nosecone Tip

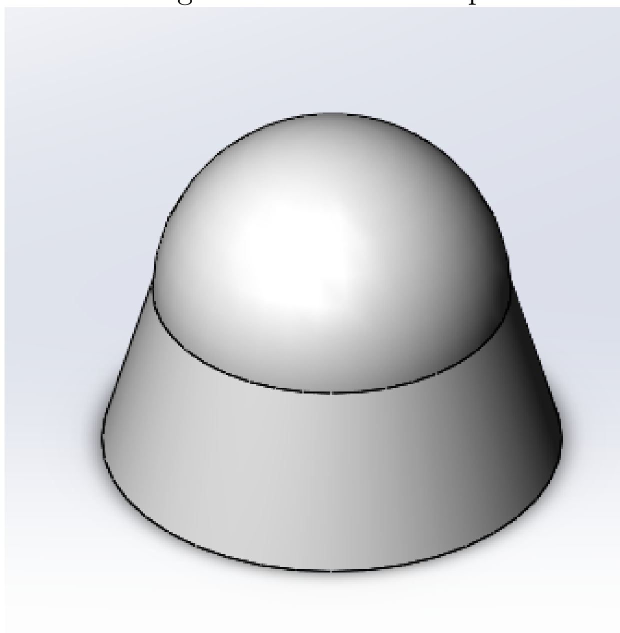
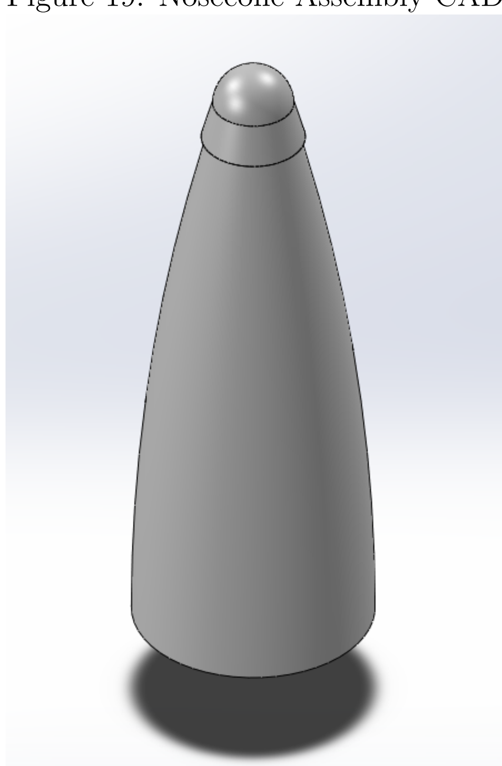


Figure 19: Nosecone Assembly CAD



Motor Mount/Fins

The method for attaching the fins and the motor mount for the subscale rocket was imprecise, resulting in imperfect alignment of the fins. Severe misalignment has various aerodynamic effects, including induced spin of the rocket and unequal lift forces generated by each fin. To align the fins properly, a step by step procedure will be followed during the full scale build.

1. Glue the centering rings to the motor mount. The rings should be glued so that the fins fit snugly between them.
2. Cut slots into the outer tube of the booster at 120 degree intervals.
3. Partially dry fit the motor mount into the outer tube.
4. Use the fin slots as guides to position the fins onto the motor mount.
5. Epoxy the fins onto the motor mount. Use hose clamps to keep the assembly together while the fins dry.
6. Once the fins have dried, epoxy the motor mount into the outer tube.
7. Create epoxy and carbon fiber fillets between the fins and the outer tube.

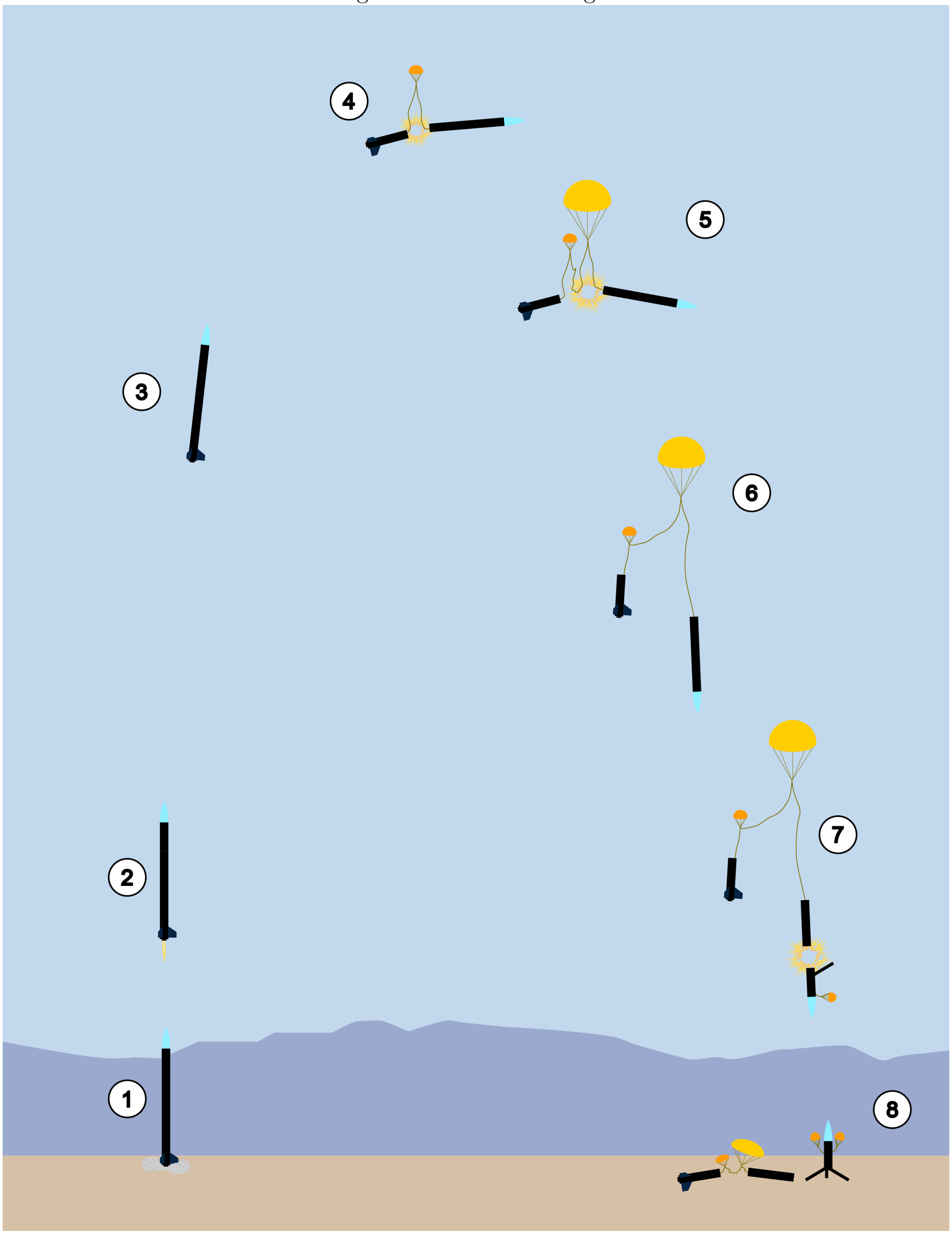
This plan deviates from our subscale manufacturing method at steps 3 and 4. For the subscale, the fins were glued onto the motor mount and then inserted into the outer tube. By inserting the motor mount into the outer tube before gluing the fins, issues with misalignment are greatly reduced. Additionally, the method for creating the carbon fiber fillets is different for the full scale rocket. Smaller carbon fiber strips will be used and the ratio of epoxy to carbon fiber will be increased, resulting in smaller, cleaner fillets.

3.4 Recovery Subsystem

3.4.1 Flight Plan

The flight plan is laid out below:

Figure 20: Phases of Flight



Phase	Event
1	Ignition.
2	Powered flight.
3	Coasting.
4	Drogue parachute deployed at an apogee of 5322 ft. AGL
5	Main parachute deployed at an altitude of 1000 ft. AGL
6	Camera in the nosecone of the rocket begins target spotting.
7	Payload section deploys itself from rocket and deploys its legs and parachutes.
8	All sections of the rocket land with a KE under 75 ft-lbf.

3.4.2 Parachutes

Description: This is the design choice for both parachutes (drogue and main) on the main system as well as the three deployed by the payload.

Designs	**Benefits**	**Costs**
Toroidal [Final Design]	1. Very high coefficient of drag	1. Much more expensive
Standard	1. Can be packed very tightly into rocket	1. Smaller coefficient of drag than toroidal parachute
Streamers	1. Can be packed very tightly into the rocket	1. Lower coefficient of drag 2. Over-tangling 3. Coefficient of drag can change over time
Tumbling	1. No drogue chute needed 2. Possible survival if main chute does not deploy	1. Camera will not face down until after main parachute deploys 2. Rocket has to be designed around stability that allows for tumbling

Table 9: Parachutes Analyses

Final Decision: Based on the costs and benefits of each option, toroidal is selected as the best option. A smaller parachute of this type can yield the same drag force, and thus can reduce the overall weight and be packed in a smaller volume. Streamer performance varies greatly across multiple uses, and will disrupt overall calculations. Toroidal also allows the rocket to point downwards so that the camera in payload can collect its data. The selected parachutes are a 24” drogue chute and a 72” toroidal main chute. Both the drogue chute and main chute are located in a tube connecting the avionics bay and the booster component. The main chute is attached to the L2 Tender Descender bottom quicklink, which is connected by shock cord to the U-bolt on the avionics bay. The drogue chute is tethered by shock cord to the U-bolt on the booster side and to the top quicklink on the Tender Descender. Furthermore, since both parachutes are wrapped in parachute covers, the drogue chute will be attached to the cover of the main chute such that when the drogue is deployed, it will remove the bag from the main chute. The code written to calculate the parachute sizes can be found in Section C.1.

3.4.3 Shock Cords

Description: This is an analysis on the type of shock cord to be used to tether the rocket and parachutes together.

Designs	**Benefits**	**Costs**
Tubular Kevlar [Final Design]	1. Very durable 2. Can hold high amounts of strain 3. Lighter than strap nylon	1. More expensive per length (4.34 Dollars/yard)
Strap Nylon	1. Cheaper per length (1.87 Dollars/yard)	1. Not as durable and more massive

Table 10: Shock Cord Analyses

Final Decision: Tubular kevlar will be used for the shock cord, because it has more durability and can handle higher amounts of strain relative to the strap nylon. Despite the higher price, it is worth the increased precaution.

3.4.4 Dual-Chute Deployment Mechanism

Description: The deployment device is used to deploy each of the parachutes.

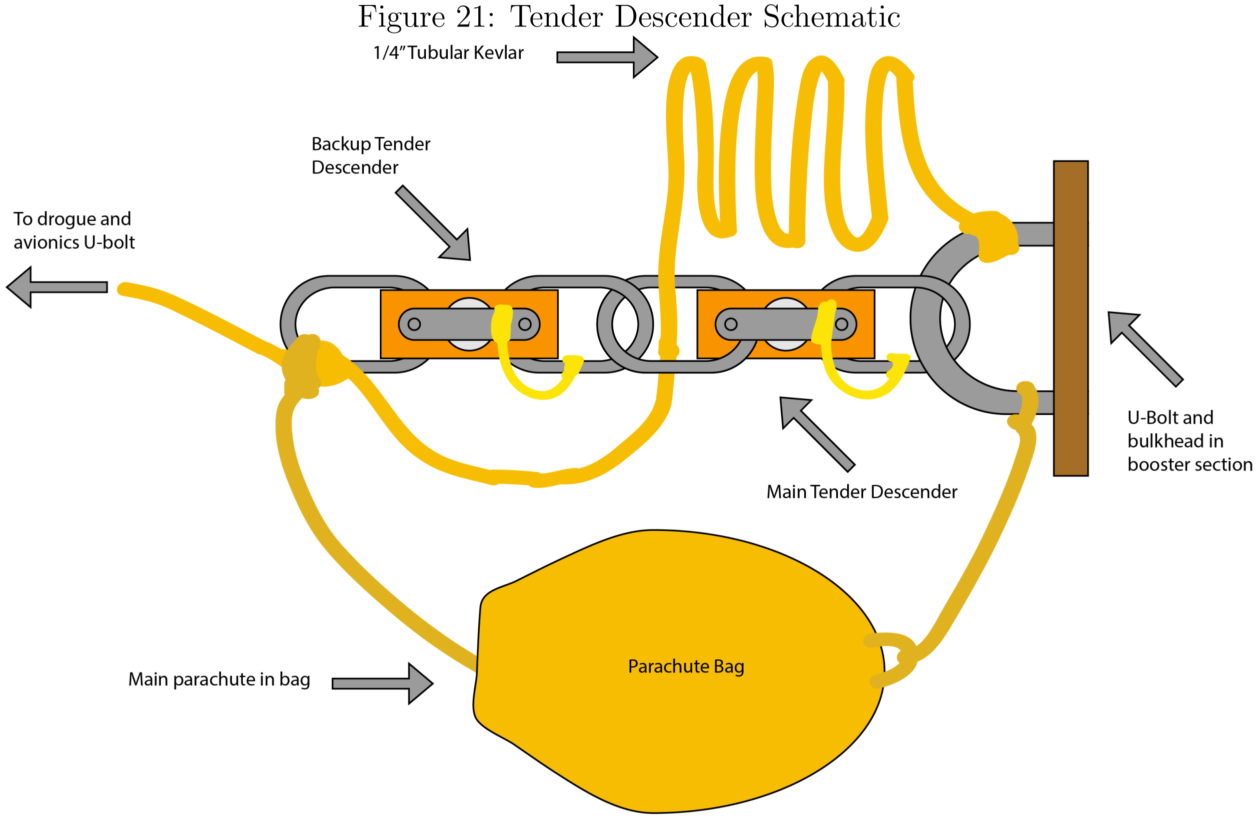
Designs	Benefits	Costs
Two L2 Tender Descenders [Final Design]	1. Has redundancy 2. Small but effective 3. Technique already practiced with sub-scale launch	1. Wiring interferes with parachute deployment 2. Might lose pieces 3. Black Powder explosions could damage parachutes
Jolly Logic Chute Release	1. Recommended by Mentor	1. 300 Dollar investment

Table 11: Dual Deployment Mechanism Analyses

Final Decision: In order to have dual-stage same-side deployment of the drogue and main chutes, two Tender Descenders will be used in series for our final deployment mechanism. Tender Descenders are used to stage our dual parachute deployment over other alternatives, such as the Jolly Logic Chute release, because it is very effective and space efficient. After testing the device on the subscale, the double Tender Descender method was found to be successful.

A diagram of the setup can be seen below:

Figure 21: Tender Descender Schematic



3.4.5 Deployment Device

Description: The deployment device is used to deploy each of the parachutes.

Designs	Benefits	Costs
Black Powder System [Final Design]	1. High energy can break strong shear pins (Using 4F class) 2. Extremely lightweight 3. Cost effective	1. Potential for damage to rocket from heat
CO2	1. Team is able to purchase, store, and handle CO2 devices without mentor supervision 2. No residue from charges 3. No need for heat blankets on parachutes	1. Potential for rupture of CO2 canisters 2. Higher weight 3. More expensive

Table 12: Deployment Device Analyses

Final Decision: Analyzing the cost and benefits of each option, 4F black powder housed in plastic vials will be used to deploy the parachutes. In efforts to reduce expenses, it was decided that the black powder will suffice over the CO2 canisters, though the team mentor will have to process the purchase. Logistically, black powder is lighter and will help with the maximum kinetic energy limitation.

3.4.6 Bulkheads

Description: The bulkhead will isolate the avionics bay from the parachute deployment devices.

Designs	Benefits	Costs
Plywood [Final Design]	1. Lightweight 2. Ease of manufacturing using laser cutters	1. Possibility of ply separation
Fiberglass reinforced plywood	1. Lightweight 2. A hybrid, incorporating the ease of manufacturing plywood and the durability of fiberglass	1. Would need to create the hybrid ourselves

Table 13: Bulkhead Analyses

Final Decision: The bulkheads will consist of two one-eigth in. pieces of plywood epoxied together to make a total thickness of one-quarter inch. One piece will be sized to fit tightly in the coupler while the other will be sized to fit the airframe. This staggered area will allow both bulkheads to be comfortably fitted into the ends of the tube of the avionics bay. The efficiency, cost-effectiveness, and convenience of this option outweigh the engineering benefits of the fiberglass/wood hybrid. Plywood is more readily accessible and easier to cut with a laser cutter.

3.4.7 Bolts

Description: To provide the maximize strength and stress distribution, U-Blts will be used on each bulkhead.

Designs	Benefits	Costs
U-Bolts [Final Design]	1. More durable 2. Greater stress distribution as a result of the two connections to the bulkhead	1. Requires two holes, which if not sealed properly, might increase risk of air pressure fluctuations mid-flight
Eye-Bolts	1. Lighter 2. Only need one hole per bulkhead	1. Not as strong as the U-Bolt 2. Most likely thinner than U-bolt

Table 14: Bolts Analyses

Final Decision: In order to distribute the stress and force of thrust during launch, U-Bolts will be used instead of Eye-Bolts. Attaching a U-Bolt to each bulkhead, positioned between the two protrusions from the two center rods, would provide for a much more sturdy avionics bay.

3.4.8 Centering Rods

Description: In order to optimize structural integrity, the dual-rod design will be adopted.

Designs	Benefits	Costs
Dual Rod [Final Design]	1. Double the structural integrity (each 1/4 in. diameter) 2. Distribution of stress 3. Better sled support	1. Two times as heavy
Single Rod	1. Allows for rotating altimeter platform 2. Lighter	1. Difficult to manufacture 2. Creates higher stress point in bulkhead

Table 15: Center Rod Analyses

Final Decision: The dual-rod design will be adopted in order ensure the avionics bay portion of the airframe is as structurally stable as possible. Each rod will be made out of aluminum or an aluminum-based alloy, because of the durable properties of aluminum. Each rod will be a quarter inch in diameter and threaded all the way through. Furthermore, the rods will be driven through the platform itself, in order to ensure that it doesn't move during flight.

3.4.9 Avionics Bay

Description: The avionics bay is a critical component of the recovery subsystem. The avionics bay is 6" in diameter and 15" in length, excluding the length of the shoulders extending out from both ends. The external frame is made out of Blue Tube, with three holes of 0.30" diameters to expose the altimeters to air pressure. Furthermore, there is a door around 1/3 the circumference of the avionics bay that can be removed and reattached with four screws to the inner frame. In addition, the bulkheads on each end are composed of 1/4" thick fiberglass coated plywood. Each bulkhead possesses a U-bolt screwed with nuts and washers to tether the shock cords. The bulkheads are also screwed into the edges of the airframe in order to ensure black powder from the explosions does not leak in. Inside, two 1/4" diameter aluminum rods run through the platform from bulkhead to bulkhead. This provides a solid structural foundation for the avionics bay. The platform itself will be 3D-printed to custom fit the two differently sized altimeters and two 9-V Duracell batteries. Wires run from each altimeter, through the bulkhead, and to the black powder charges on the parachute (aft) side. The avionics bay components can be seen in detail in the following figures.

Figure 22: Avionics Bay

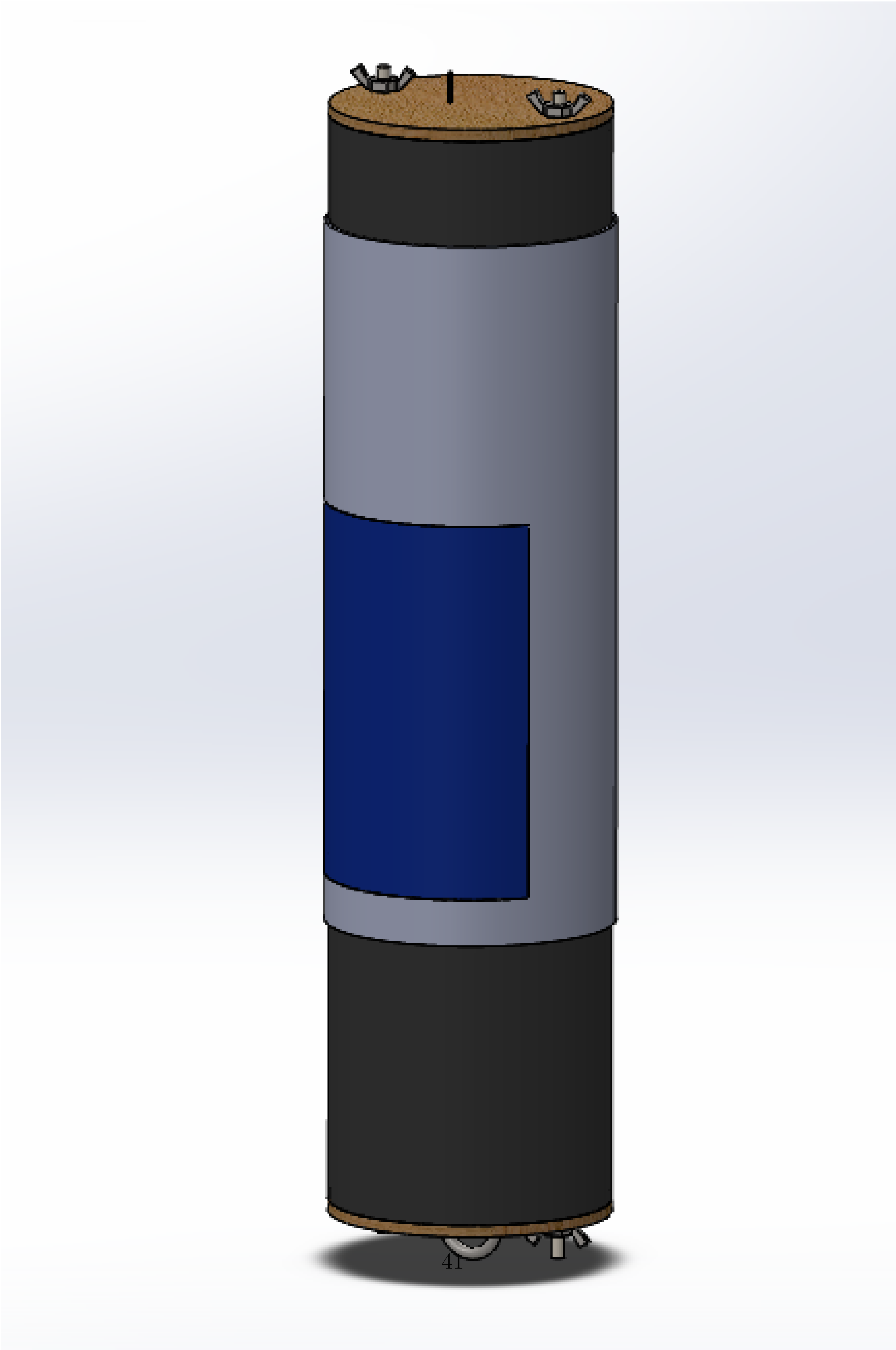


Figure 23: Avionics Bay Without Door

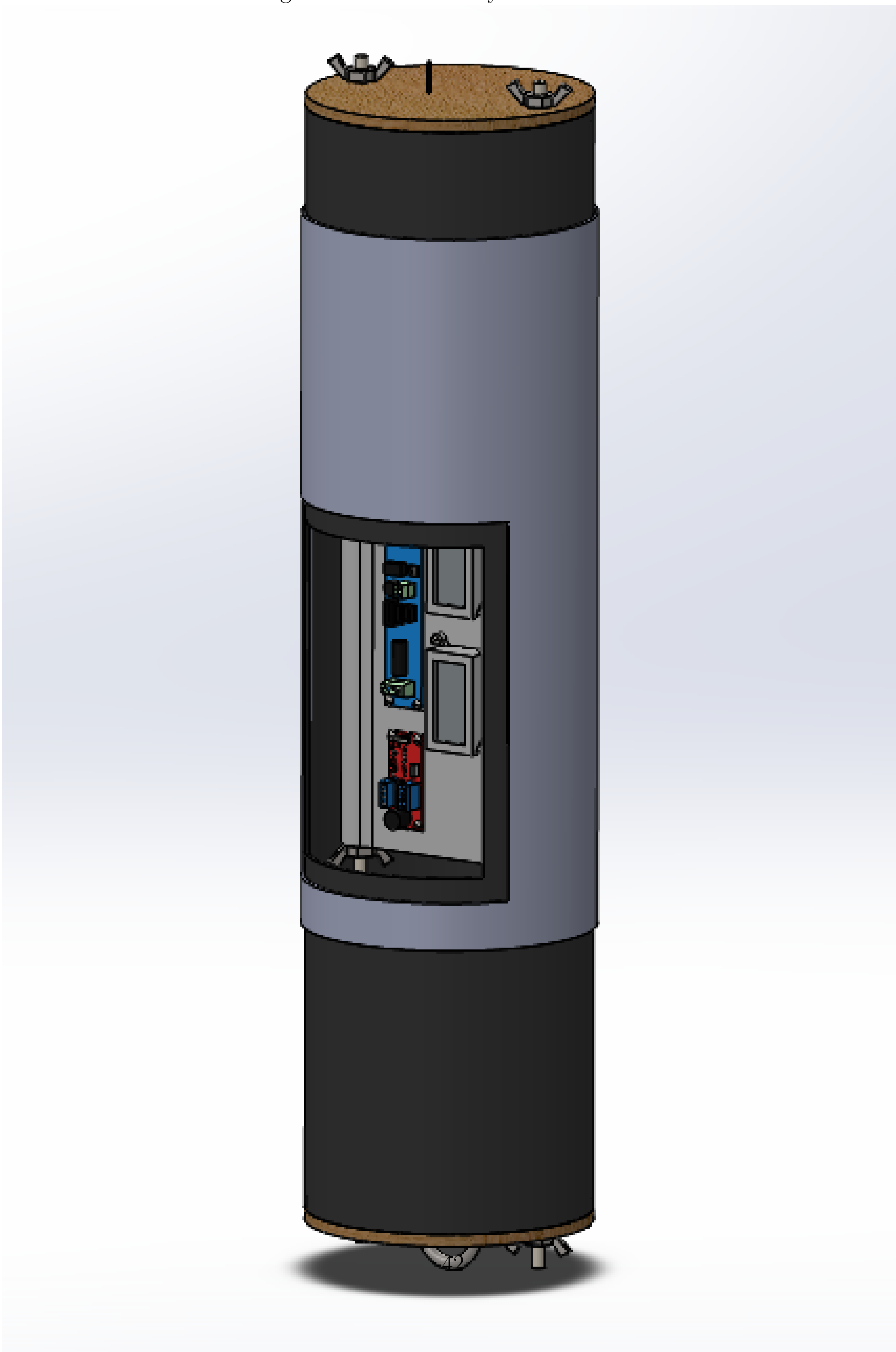


Figure 24: Avionics Bay Without Door - Close Up

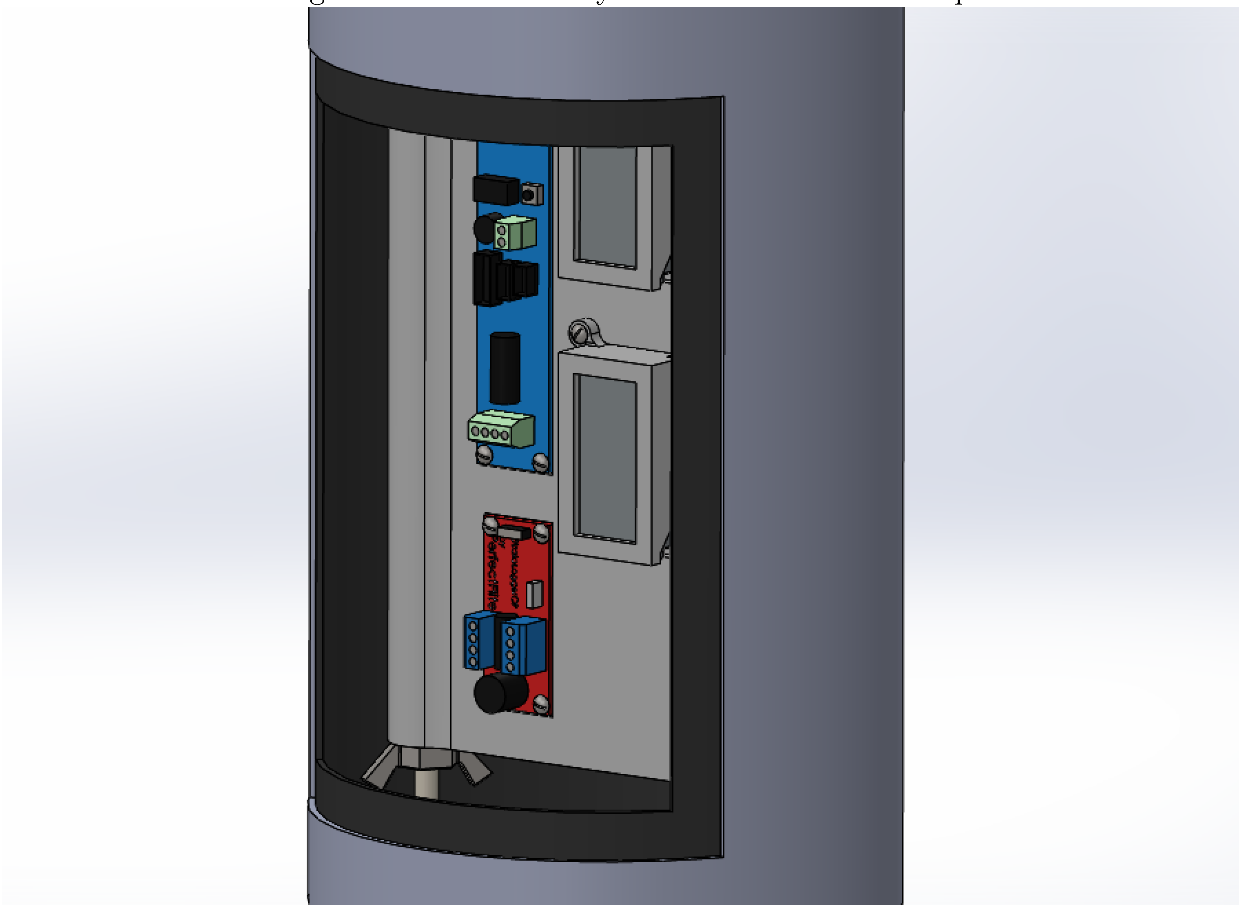


Figure 25: Avionics Bay Internals

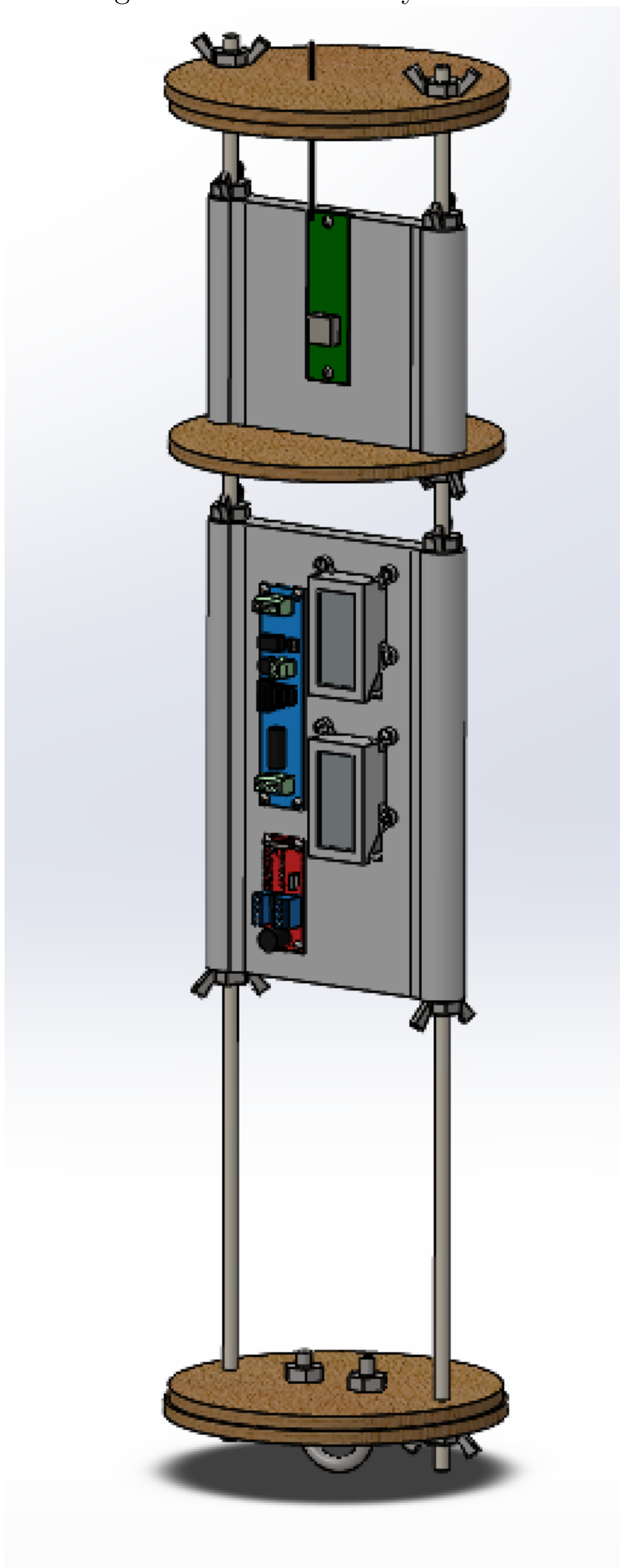


Figure 26: Altimeter Sled

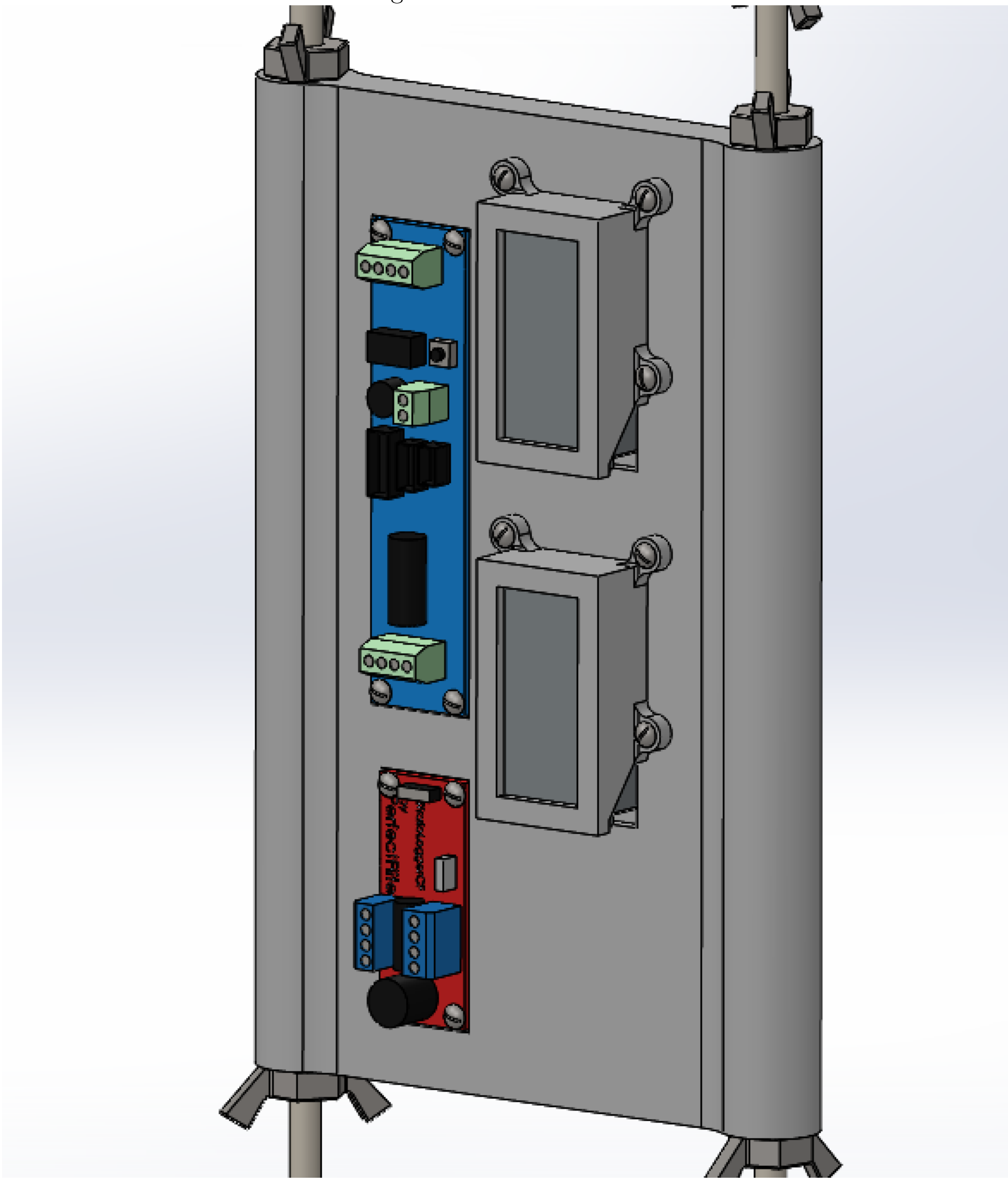


Figure 27: Avionics Bay Dimensioned

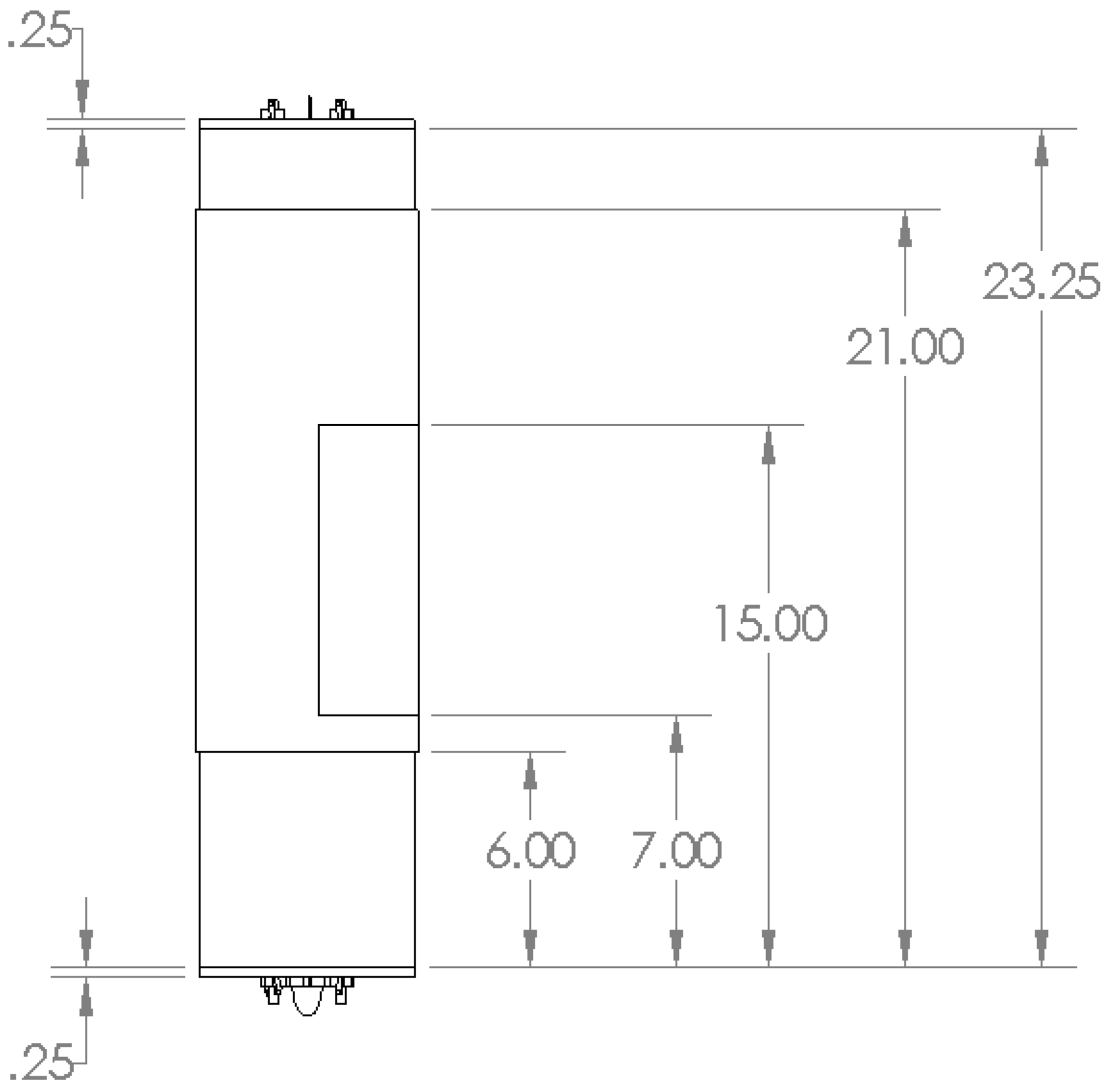


Figure 28: Avionics Bay Internals Dimensioned

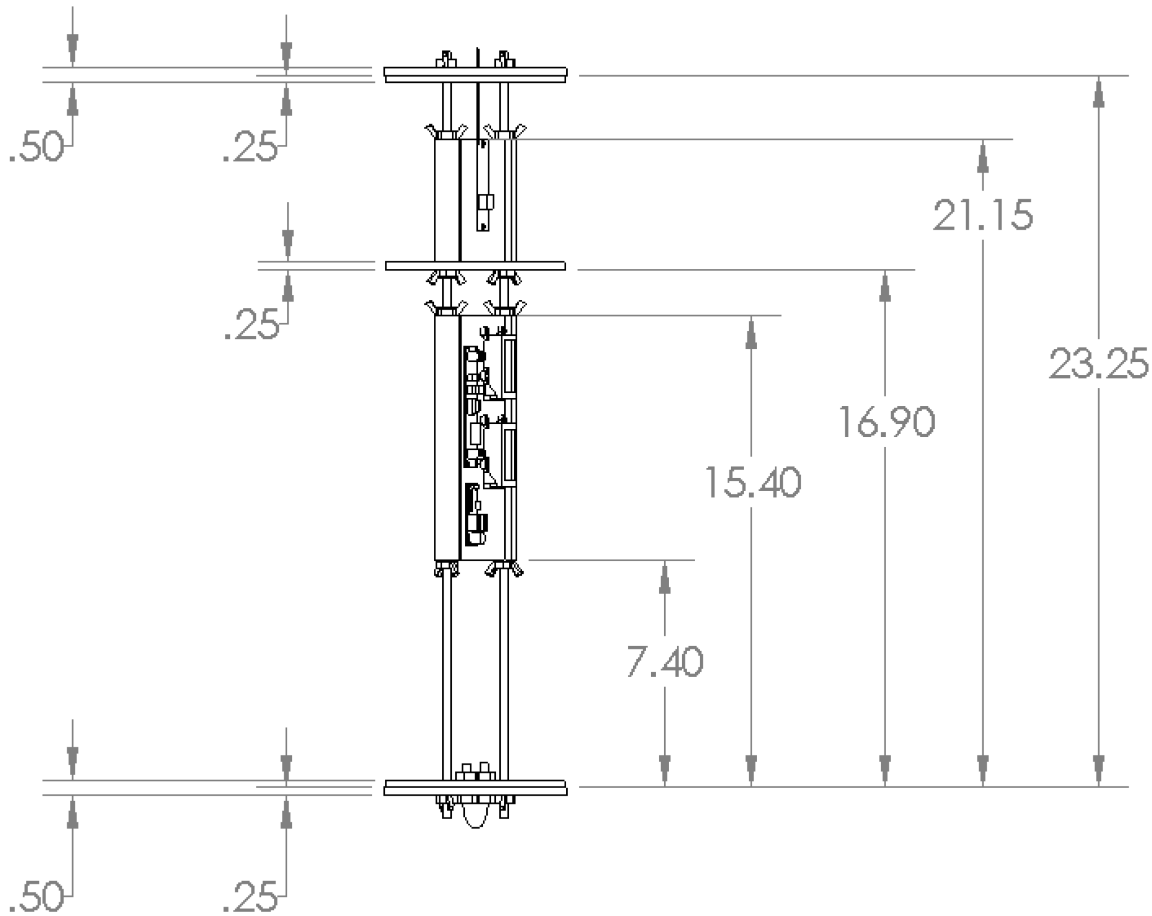


Figure 29: Altimeter Sled Dimensioned

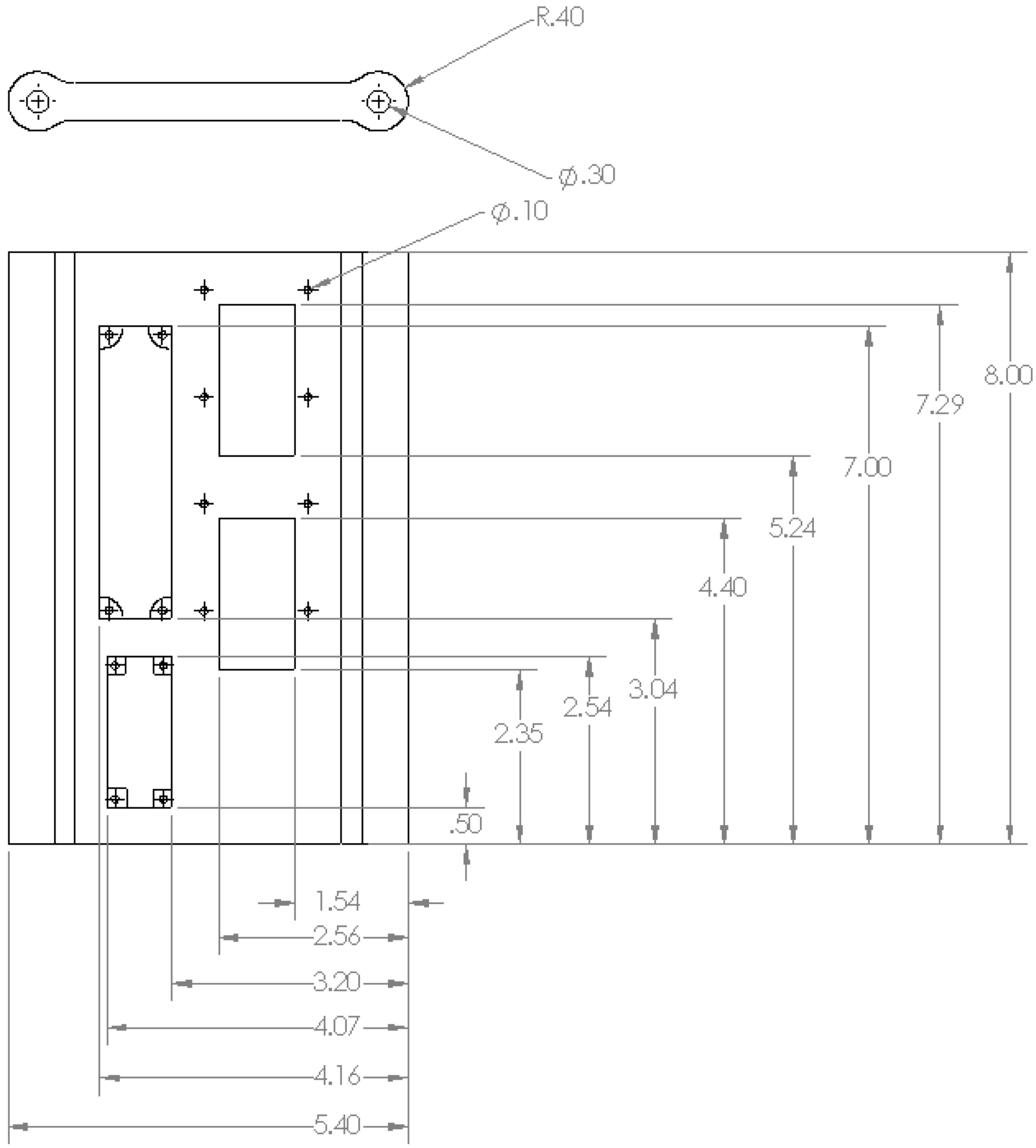
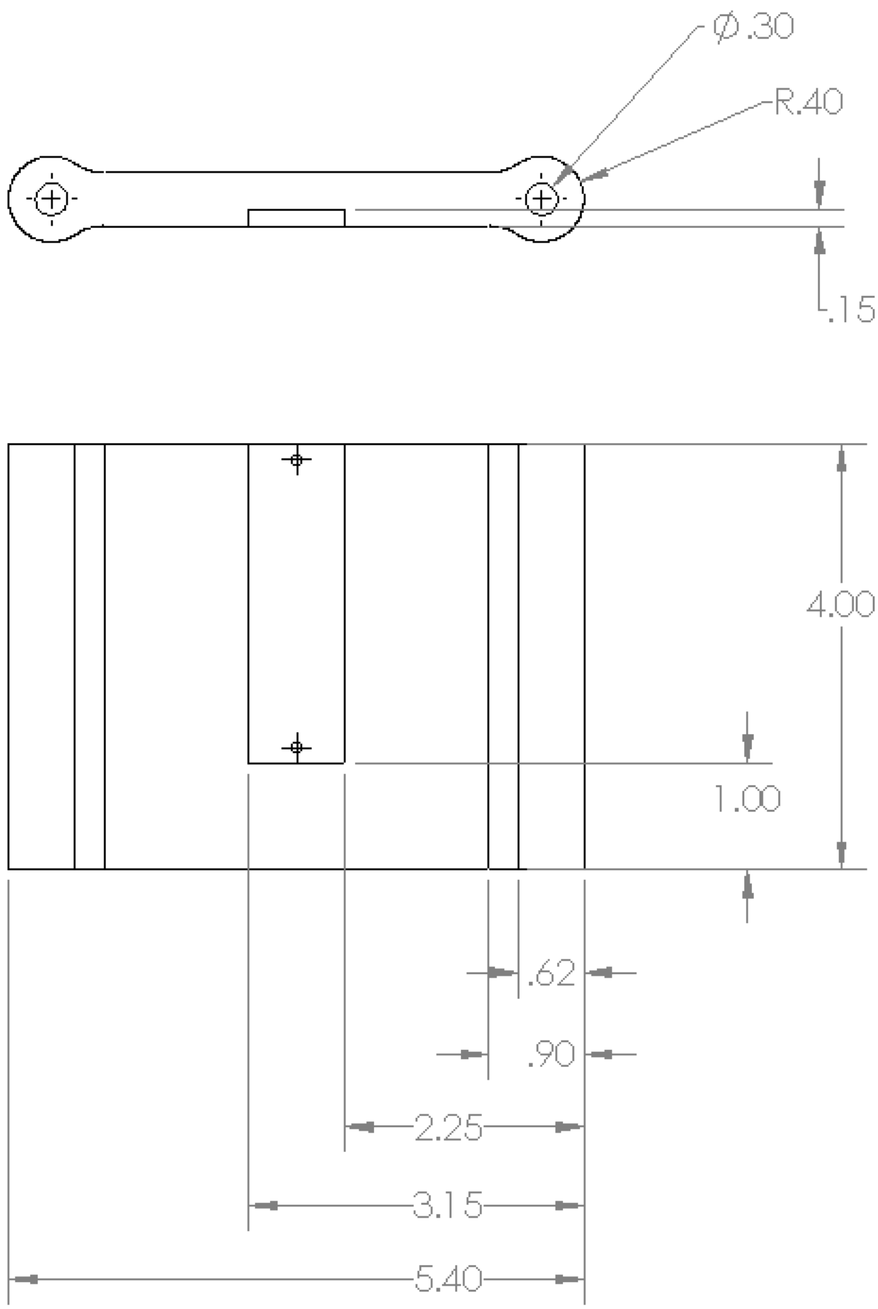


Figure 30: GPS Sled Dimensioned



Avionics Bay: INTERNAL

Description: For the internal components of our avionics bay, this chart compares the two options, a more traditional design and an additional alternative.

Designs	**Benefits**	**Costs**
Altimeter Sled [Final Design]	1. Provides more structural integrity 2. Can be customized to fit each altimeter tightly 3. Can be 3D-printed to be lightweight	1. Inconvenient; must take apart rocket to access 2. Wiring is unorganized 3. Could compromise mission if quick access to avionics bay is needed at launch site
Rotating Altimeter Platform (RAP)	1. Greater ease of access to altimeters and wiring 2. Can be customized to fit each altimeter tightly 3. Can be 3D-printed to be lightweight	1. Needs a structural mechanism to prevent it from rotating during flight 2. Would need to print back-ups in case of failure 3. Custom altimeter wells would allow for little flexibility if a last-minute exchange of altimeters is needed

Table 16: Avionics Bay: INTERNAL Analyses

Avionics Bay: EXTERNAL

Description: This section focuses on the method of reaching the avionics bay once the rocket is assembled, on and off the field.

Designs	Benefits	Costs
Detachable Door [Final Design]	1. Accessible; occupies 1/3 circumference	1. Can't access back of platform, unless using a rotating altimeter platform (RAP)
Removable Frame	1. Easy access to any component, regardless of the internal layout of the avionics bay	1. Have to take apart rocket to access 2. Huge loss of structural integrity
No Door; Completely sealed	1. More structural integrity	1. Could compromise mission if quick access to avionics bay is needed at launch site

Table 17: Avionics Bay: EXTERNAL Analyses

Final Decision: The final avionics bay will consist of both a removable door externally and a dual-rod sled design internally. The removable door will be made by laser cutting a rectangular portion with 1/3 the circumference of the entire airframe and putting it over the coupler tube, which has a laser-cut portion just partially smaller (approx. 3/4" width) to provide a border with which the door can rest on. The airframe and coupler itself will be made from Blue Tube. Furthermore, two 1/4" diameter aluminum rods will run through the length of the avionics bay, housing the altimeter sled. The ends of the avionics bay will be capped with two bulkheads, one of which will be glued on, and the other which will be removable. On the one that will be glued on, there will be a U-Bolt to attach to the shock cords. The decision to use this design of both the external and internal parts of the avionics bay was a result of the success of the subscale launch. This is better than using a Rotating Altimeter Platform, which would jeopardize too much of the structural integrity of the avionics bay. Finally, it was decided that the door will be retained rather than eliminated, since there still might be the need to access the altimeters quickly.

3.4.10 Avionics Bay Static Pressure Port Calculations

To equalize pressure within the avionics bay so that the altimeters can read the altitude, several holes will be drilled into the airframe. The code written to calculate this number can be found in Section C.2. The inputs into the program are 3 holes, an internal length of 16.65 inches, and an internal diameter of 5.837 inches. This yields an output of 0.3047 inches, meaning that to equalize pressure, three 0.3047 inch diameter holes must be drilled.

3.4.11 Black Powder Calculations

To deploy the parachutes two altimeters will be used. The main altimeter is the Perfectflite Stratologger CF Altimeter. The MissileWorks RRC3 Altimeter will be used as a backup.

Both altimeters are capable of deploying both the drogue and main chute. They will ignite an electronic match, which will then ignite black powder. The black powder will break the shear pins that hold the sections together and release the drogue parachute. The code written to calculate this number can be found in Section C.3. Two 4-40 shear pins will be used. The inputs into the program are 2 shear pins, a shear force of 40lbs, an internal length of 14.75 inches, and a multiplication factor of 2. This yields a black powder quantity of 1.2180 grams to deploy the drogue chute. The Tender Descenders used to deploy the main chute will each contain 0.5 grams of black powder.

3.4.12 Kinetic Energy

Even in the case that the payload fails to detach, the 72" toroidal main parachute and 24" drogue parachute ensures that each component of the vehicle will land with a kinetic energy less than 75 ft-lbf. The payload will also land with the appropriate kinetic energy even if only one of the three 36" toroidal parachutes deploys correctly. The following table has the landing Kinetic Energy of each section of the rocket (*'ed entries are scenarios where some part of the deployment of the payload fails).

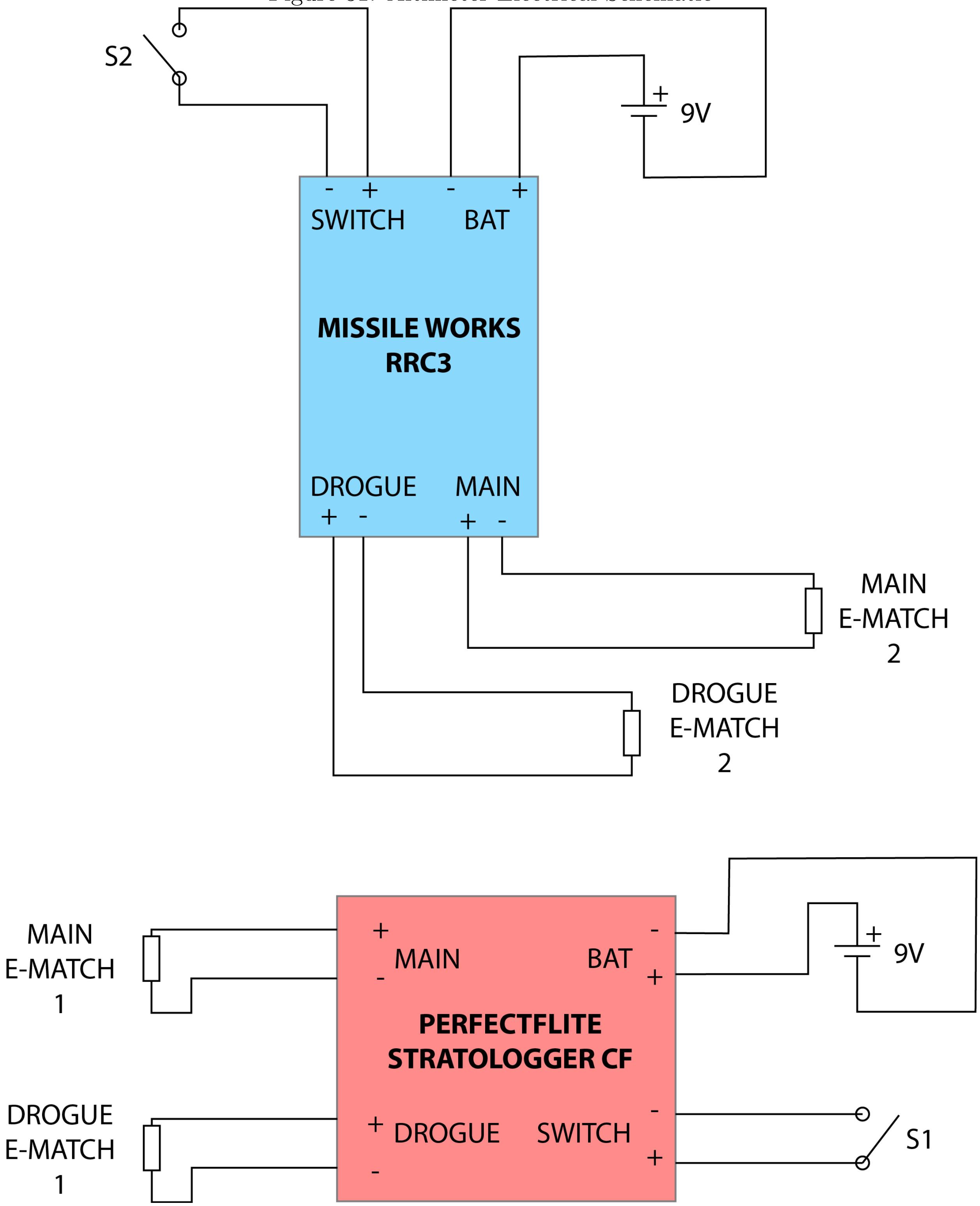
Section	**Scenario**	**Kinetic Energy (ft-lbf)**
Avionics Bay	Payload Detaches	12.42
Booster	Payload Detaches	34.91
Payload	Payload Detaches and 3 parachutes deploy	23.97
*Avionics and Payload (attached)	Payload does NOT detach	64.64
*Booster	Payload does NOT detach	55.67
*Payload	Payload Detaches and 1 parachute deploys	71.92

3.4.13 Altimeter System

In order to maximize the chances of successfully deploying the drogue and main parachutes, two different altimeters will be used in the avionics bay (Missileworks RRC3 and Perfectflite Stratologger CF). The purpose of having at least two different altimeters is to provide redundancy in the case that if one brand of altimeter fails in a given environment, the other might work. Each altimeter will be connected to a corresponding 9V battery on the same side of the platform. The main altimeter, the Perfectflite Stratologger CF, has the ability to read out the last flight via a series of beeps even after it has been turned off. This is important, as both altimeters will be shut off immediately after landing in order to prevent any injuries from possibly live black powder charges.

The electrical schematic for the two altimeters can be seen below:

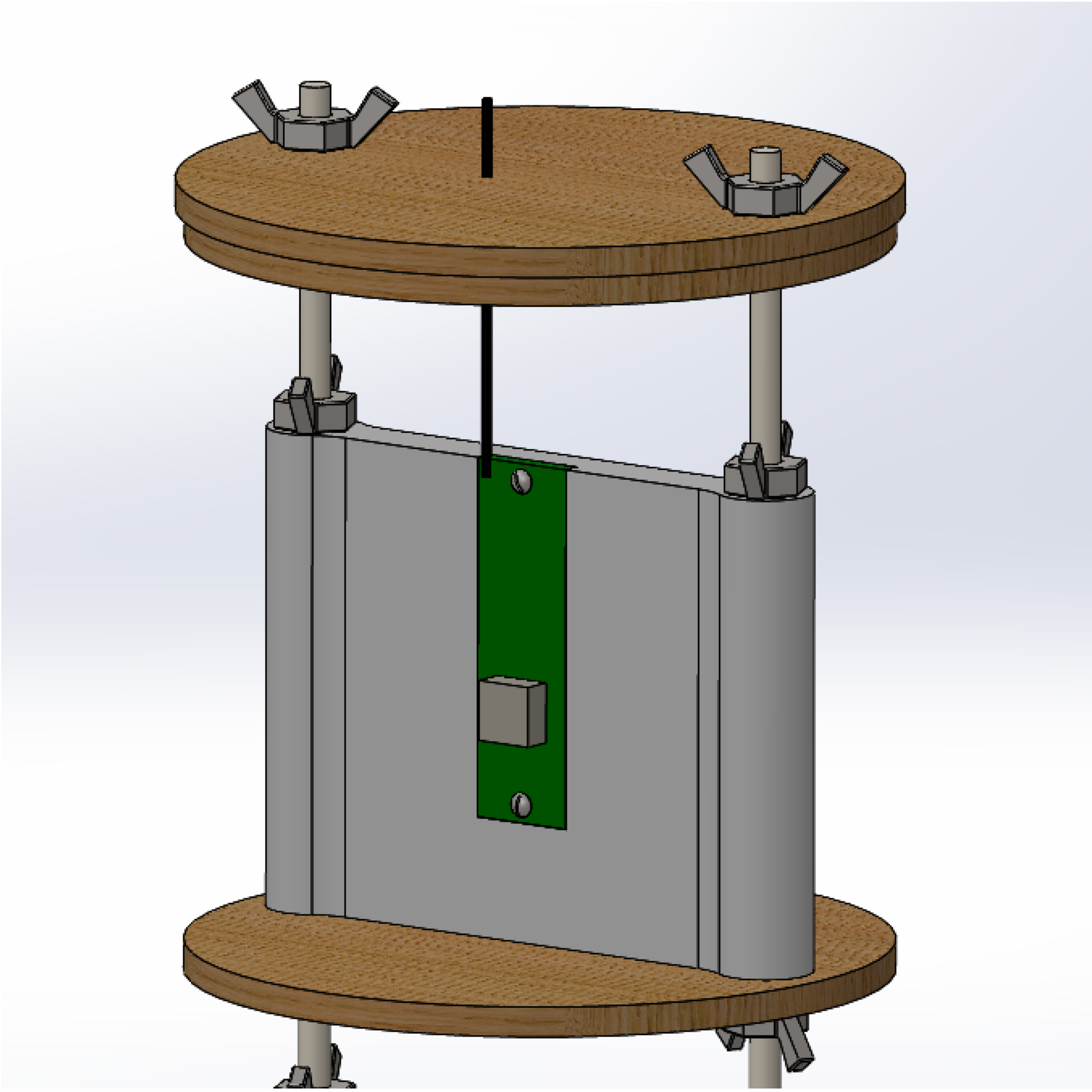
Figure 31: Altimeter Electrical Schematic



3.4.14 GPS System

To provide consistency in both the payload and the rest of the rocket, the avionics bay and the payload will use the same GPS tracker. The GPS for the booster and avionics bay is the Eggfinder GPS Tracking System. The system will operate at 923.000 MHz. It will be placed in the same section of tubing as the altimeters, but it will be seperated from the altimeters with a bulkhead, in order to prevent interference.

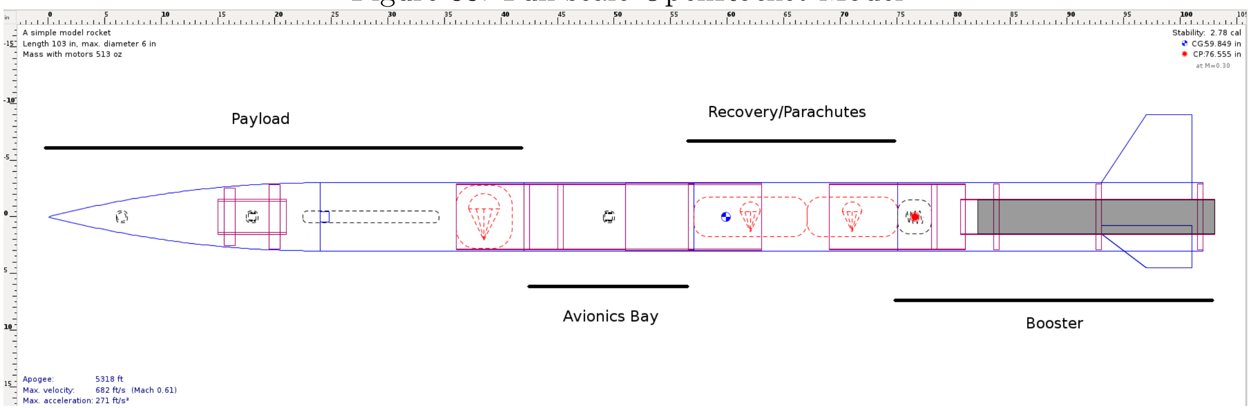
Figure 32: GPS Sled



3.5 Mission Performance Predictions

Full scale flight data is simulated using the OpenRocket software. Figure 33 shows the design in OpenRocket with each section labeled.

Figure 33: Full scale OpenRocket Model



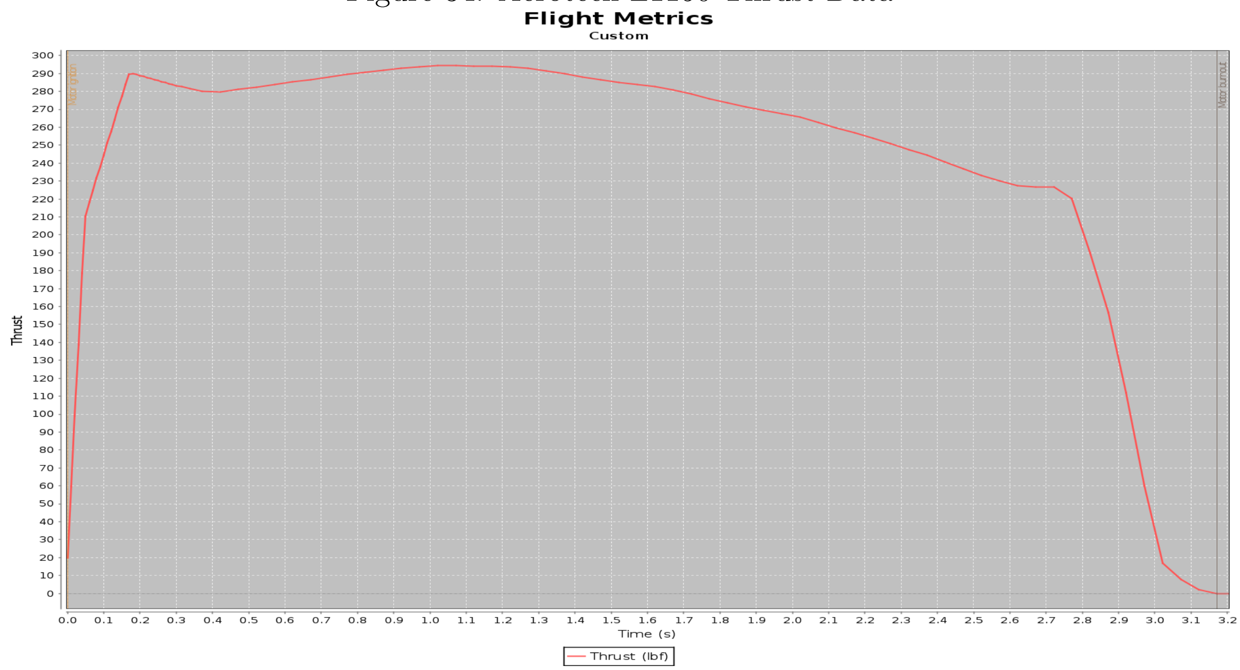
3.5.1 Motor

The full scale motor is an Aerotech L1150, which utilizes a solid ammonium perchlorate composite propellant. The simulated thrust curve is illustrated in Figure 34. 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[7].

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

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

Figure 34: Aerotech L1150 Thrust Data



3.5.2 Pre-Flight Data

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

Section	**Weight (lb)**
Payload (including nosecone)	10.50
Avionics Bay	6.25
Parachute/Recovery	1.13
Booster	14.19
Total	**32.07**

OpenRocket simulations show the center of gravity to be 59.85 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.

3.5.3 Flight Profile Simulations

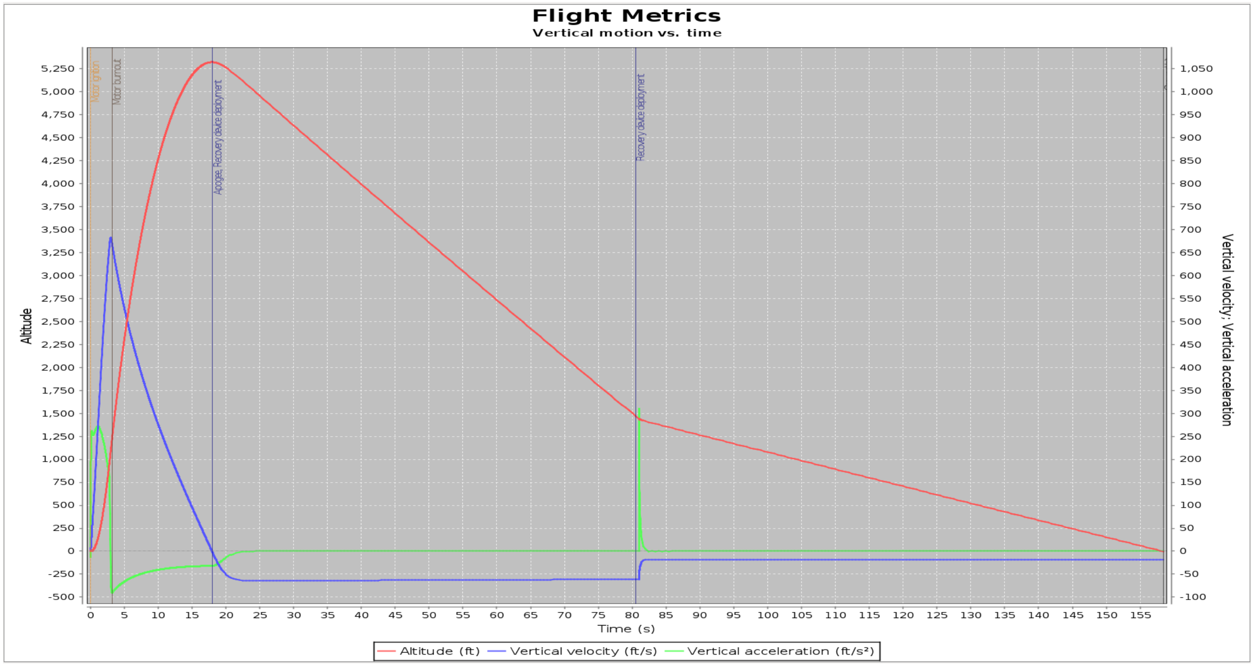
Flight profile simulations were conducted with zero wind and International Standard Atmospheric conditions. The simulated rocket is launched at a vertical angle off of a 12 foot rod. The OpenRocket simulation uses the extended Barrowman method for calculations. The simulation is conducted using a 6-DOF 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	5322 ft
Velocity off Rod	78.7 ft/s
Velocity at Chute Deployment	61.2 ft/s
Maximum Velocity	683 ft/s (Mach 0.61)
Maximum Acceleration	271 ft/s^2
Ground Hit Velocity	18.3 ft/s
Time to Apogee	18 s
Flight Time	158 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 35.

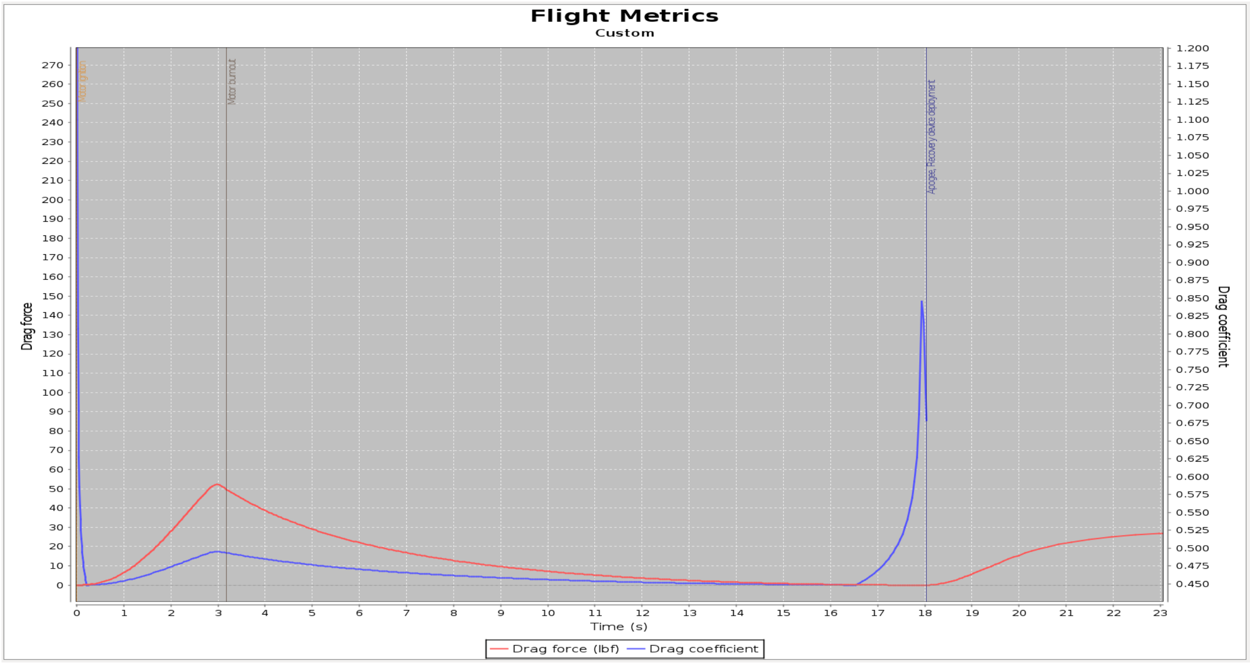
Figure 35: Rocket Flight Profile



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.

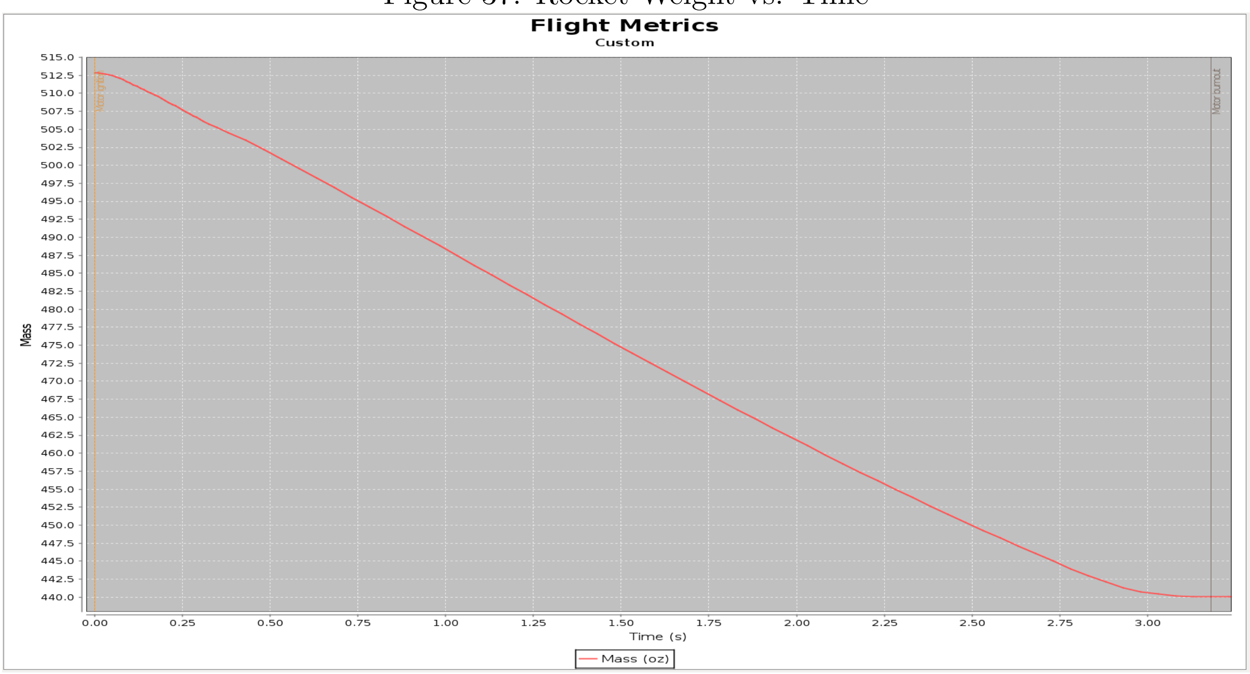
Drag simulation data is illustrated in Figure 36. The maximum drag coefficient during flight occurs just before apogee, and is approximately 0.85. The drag coefficient at motor burnout is about 0.49. The drag force steadily increases from motor ignition and peaks at a value of about 52 lbf just before 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 36: Flight Drag Data



The rocket's weight vs. time is displayed in Figure 37.

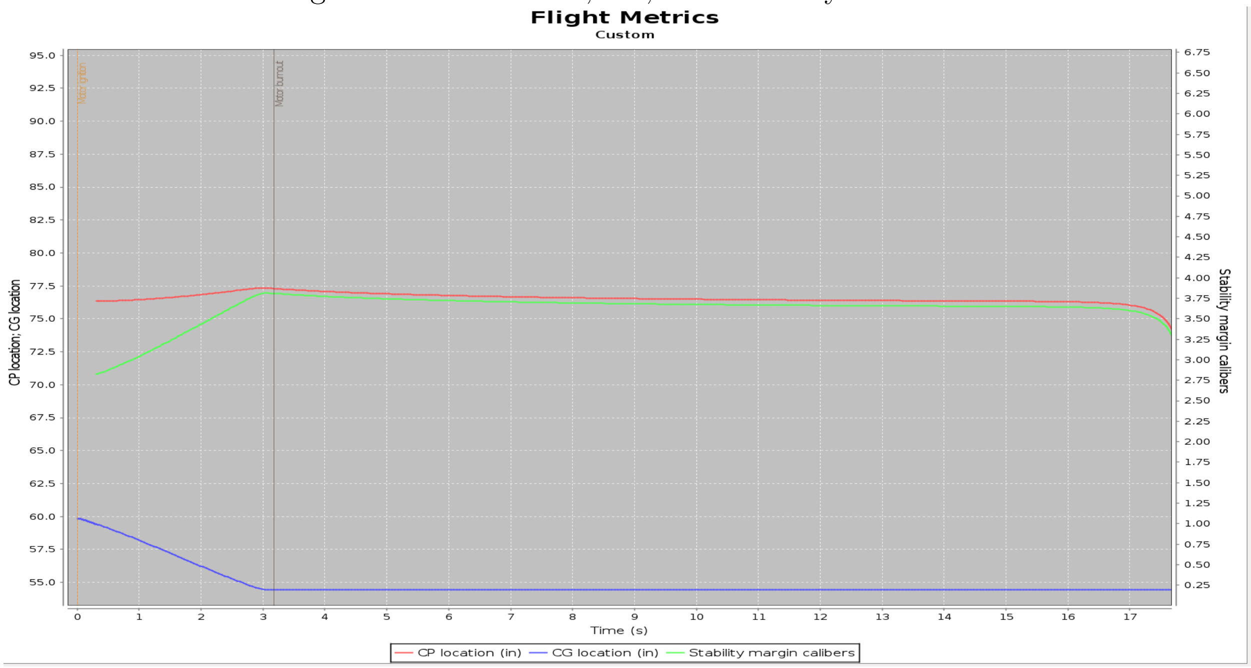
Figure 37: Rocket Weight vs. Time



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

Figure 38 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.

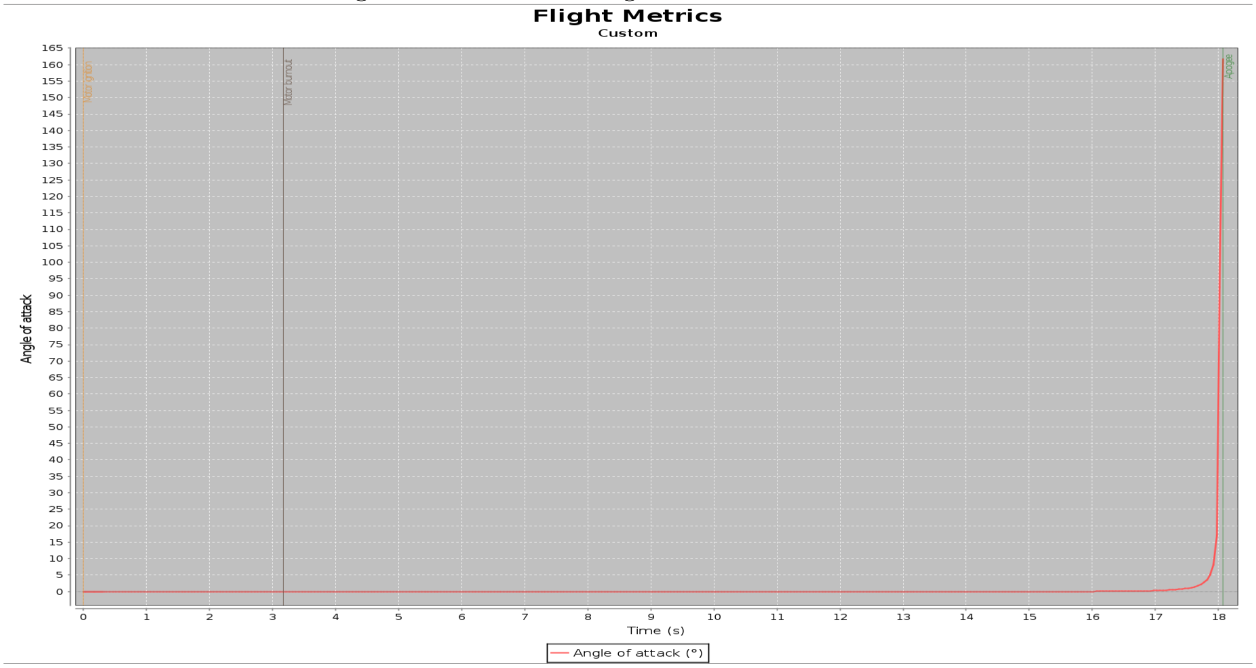
Figure 38: Rocket CG, CP, and Stability vs. Time



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 39 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 39: Rocket Angle of Attack vs. Time

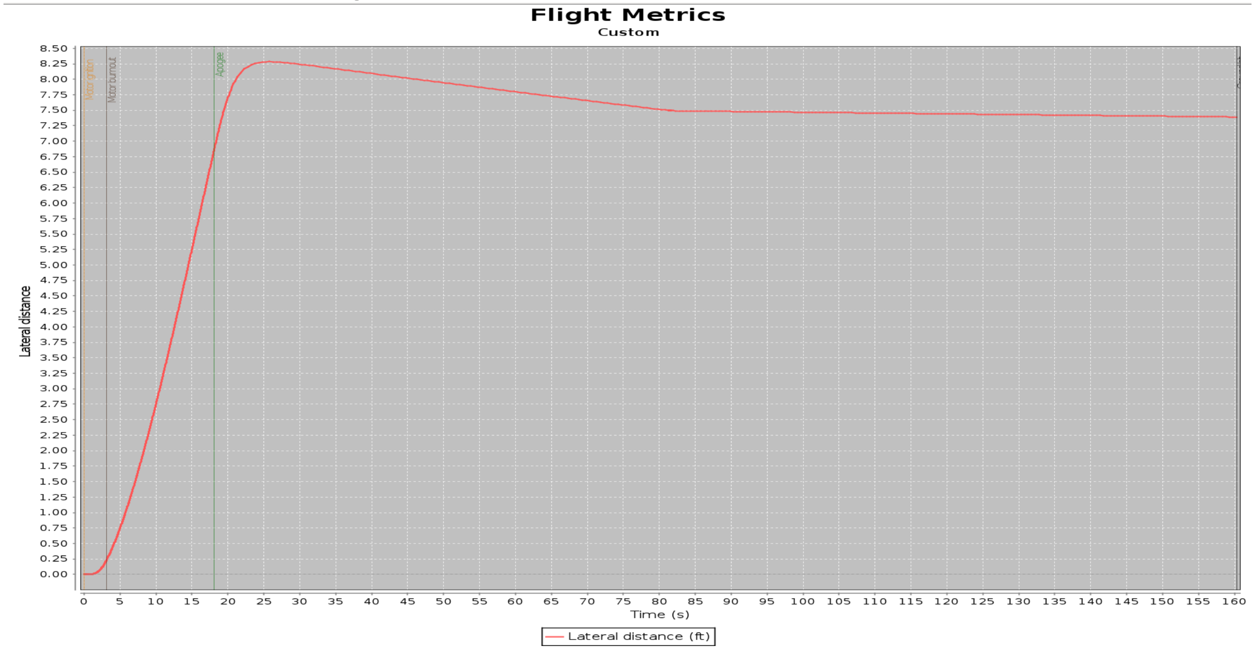


3.5.4 Simulated Drift

Zero Wind

Figure 40 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 40: 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 41. 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 41: Rocket Lateral Distance vs. Time

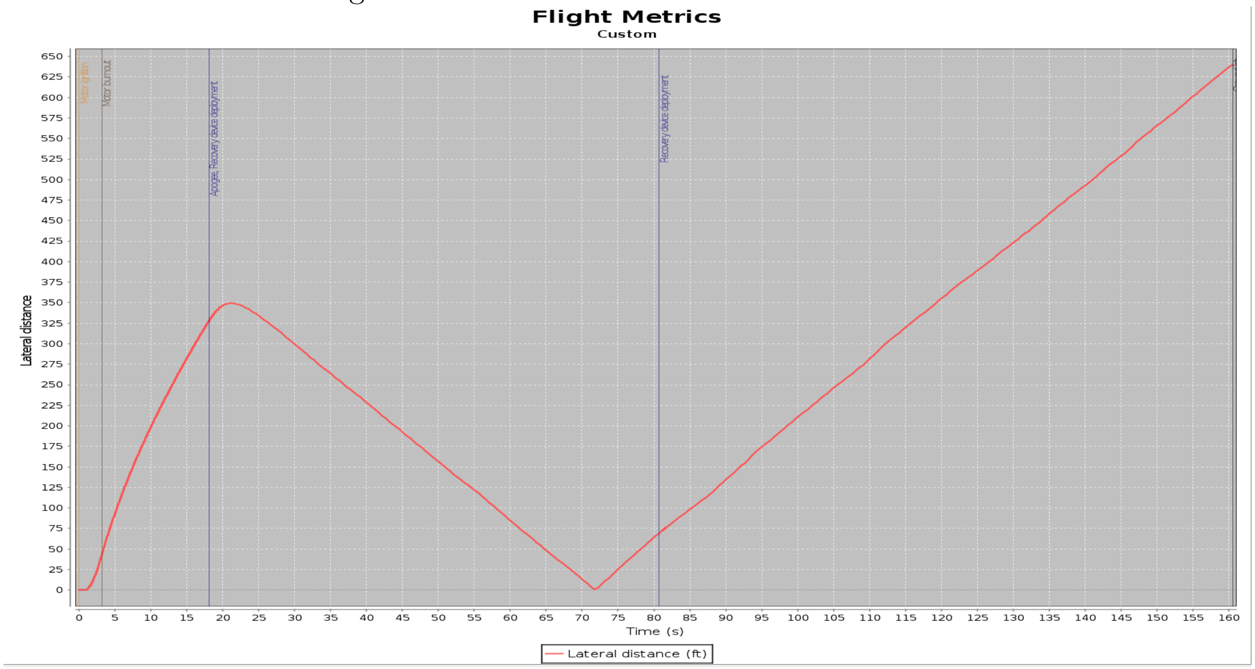
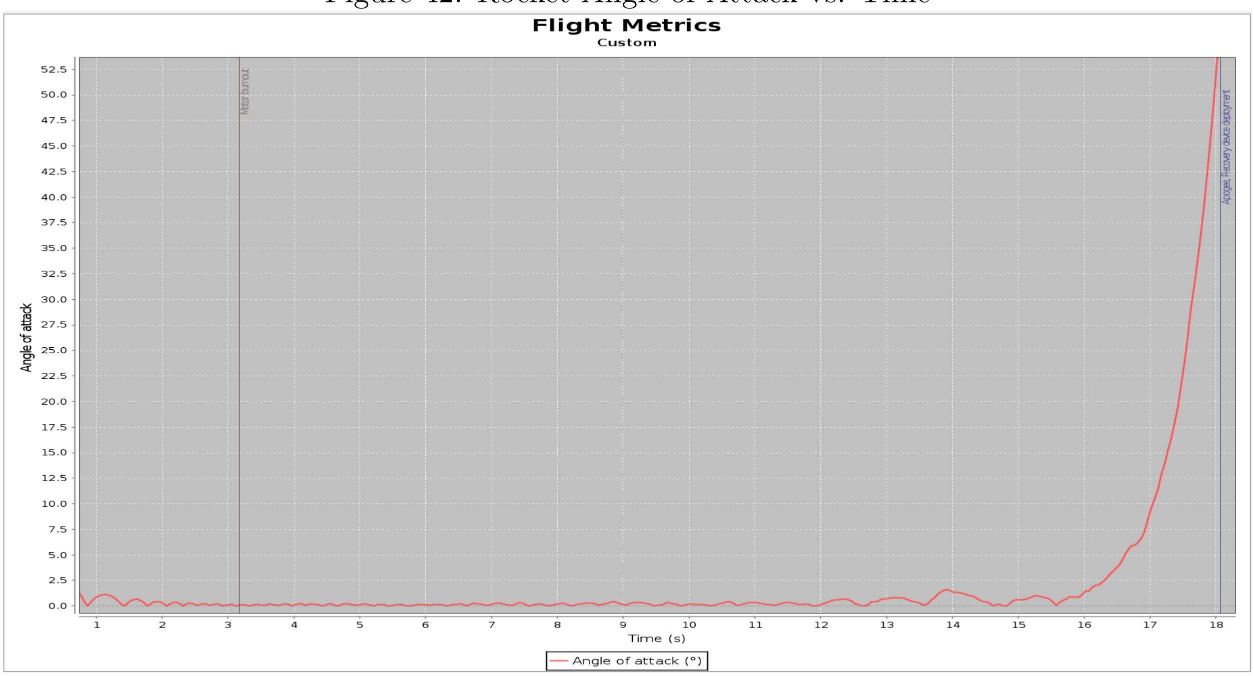


Figure 42 graphs the rocket's angle of attack in 5 mph wind vs. time. During ascent, the angle of attack oscillates with an amplitude of approximately 1 degree. As the rocket approaches apogee, its speed is greatly reduced, and the angle of attack sharply increases until apogee.

Figure 42: 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 43. The greatest displacement also occurs during descent, and the maximum lateral distance is about 1340 feet from the launch location.

Figure 43: Rocket Lateral Distance vs. Time

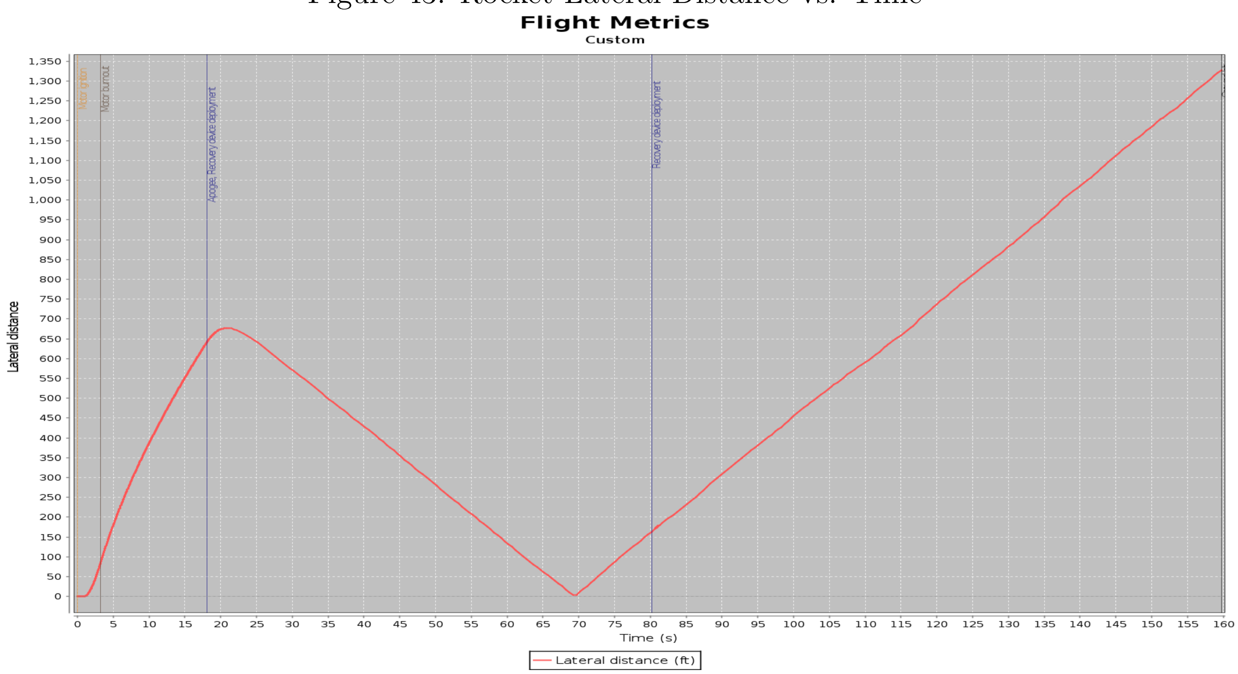
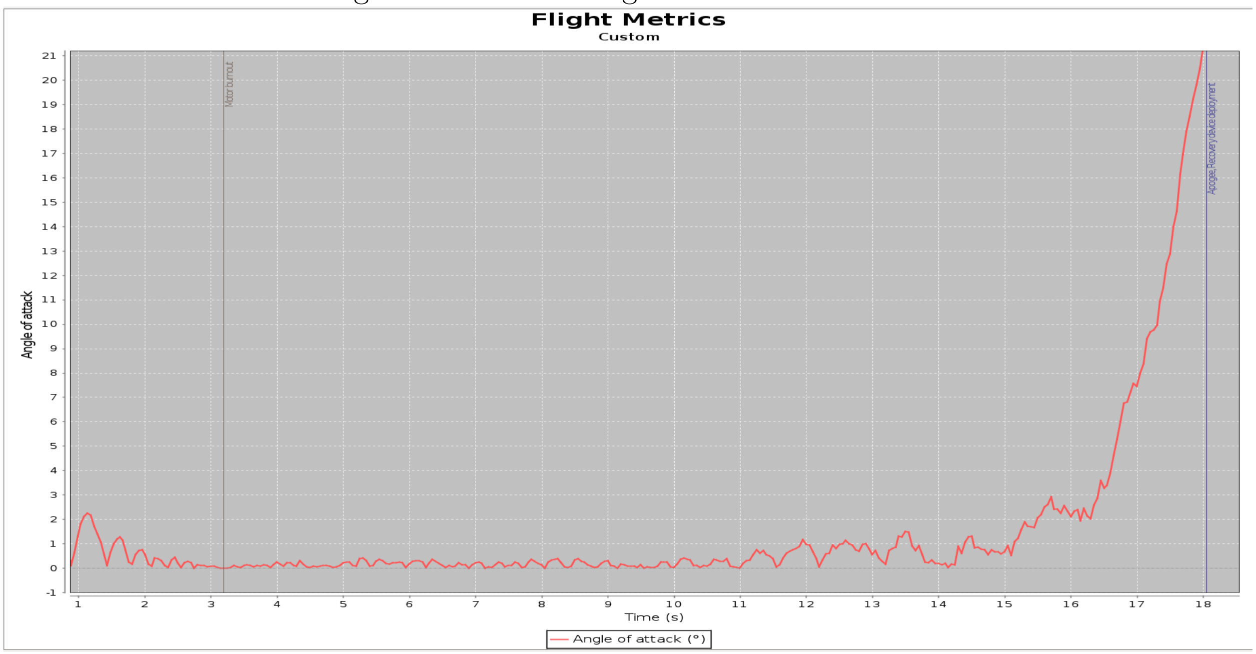


Figure 44 plots the rocket's angle of attack in 10 mph wind vs. time. The results are very similar to the 5 mph wind case. The angle of attack oscillates at a similar frequency and amplitude. However, the maximum angle of attack is greater in 10 mph wind than in 5 mph wind. Much like in 5 mph wind, the angle of attack sharply increases as the rocket approaches apogee.

Figure 44: 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 45 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 45: Rocket Lateral Distance vs. Time

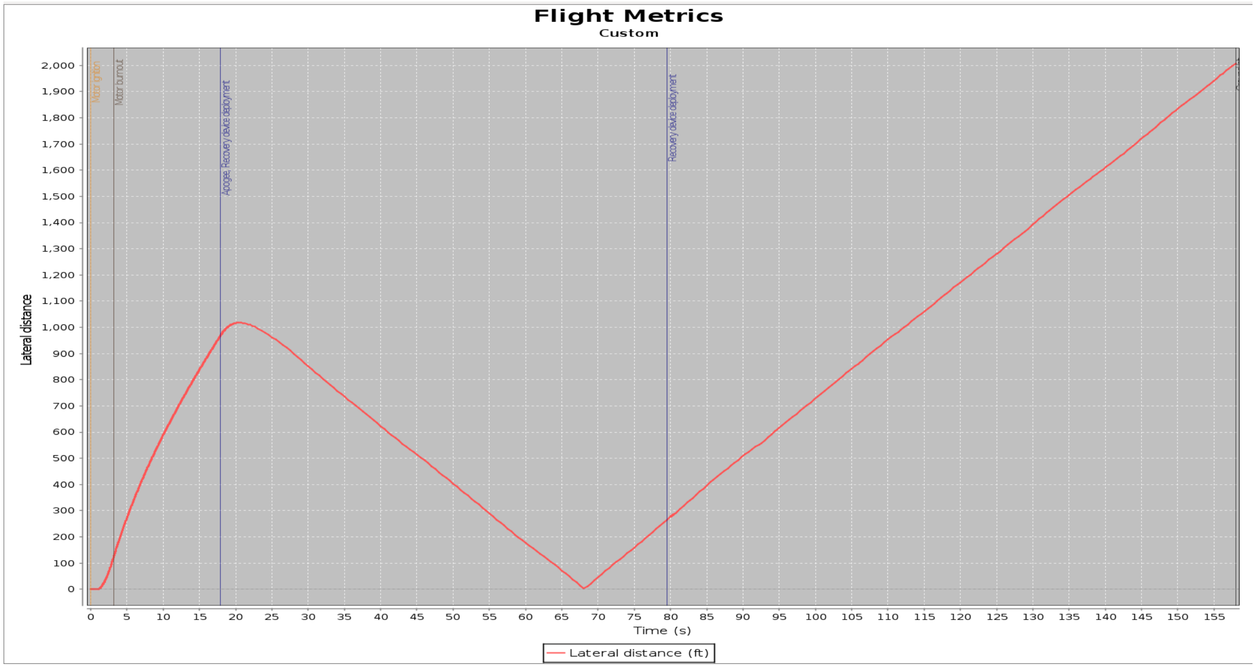
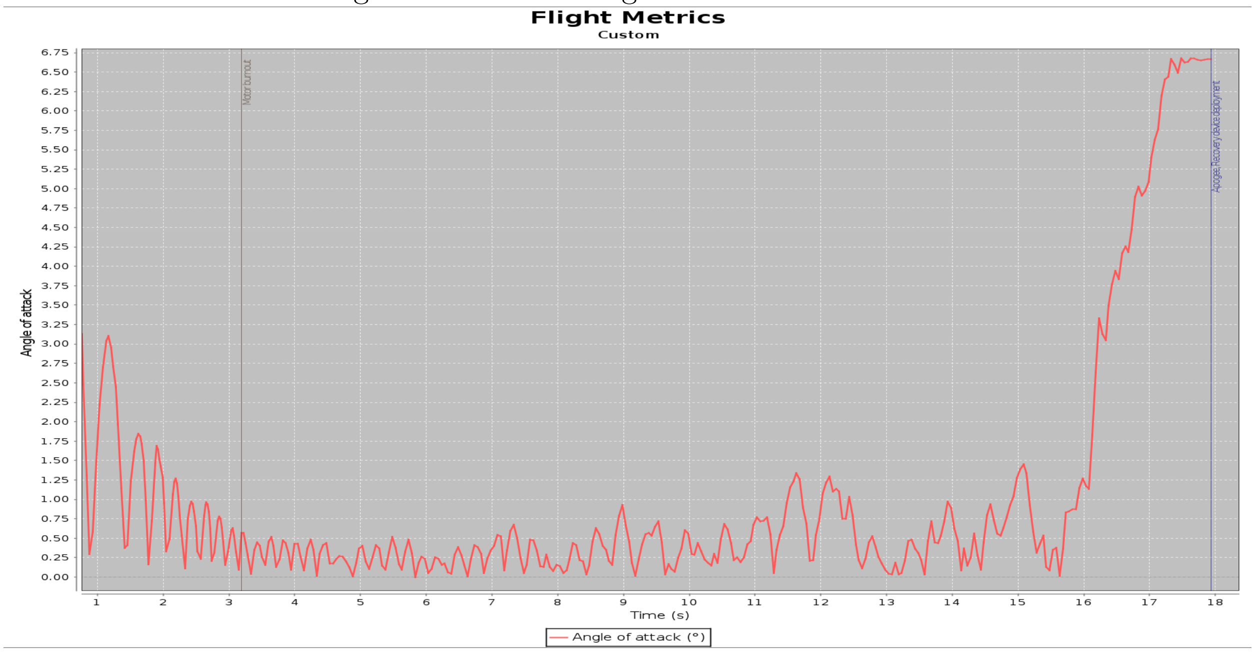


Figure 46 displays the rocket's angle of attack in 15 mph wind vs. time. The results are similar to the previous two cases, but here, the oscillations have more variance both in amplitude and in frequency. The maximum angle of attack before apogee is approximately 3 degrees, and the angle sharply increases 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 46: 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 47 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 47: Rocket Lateral Distance vs. Time

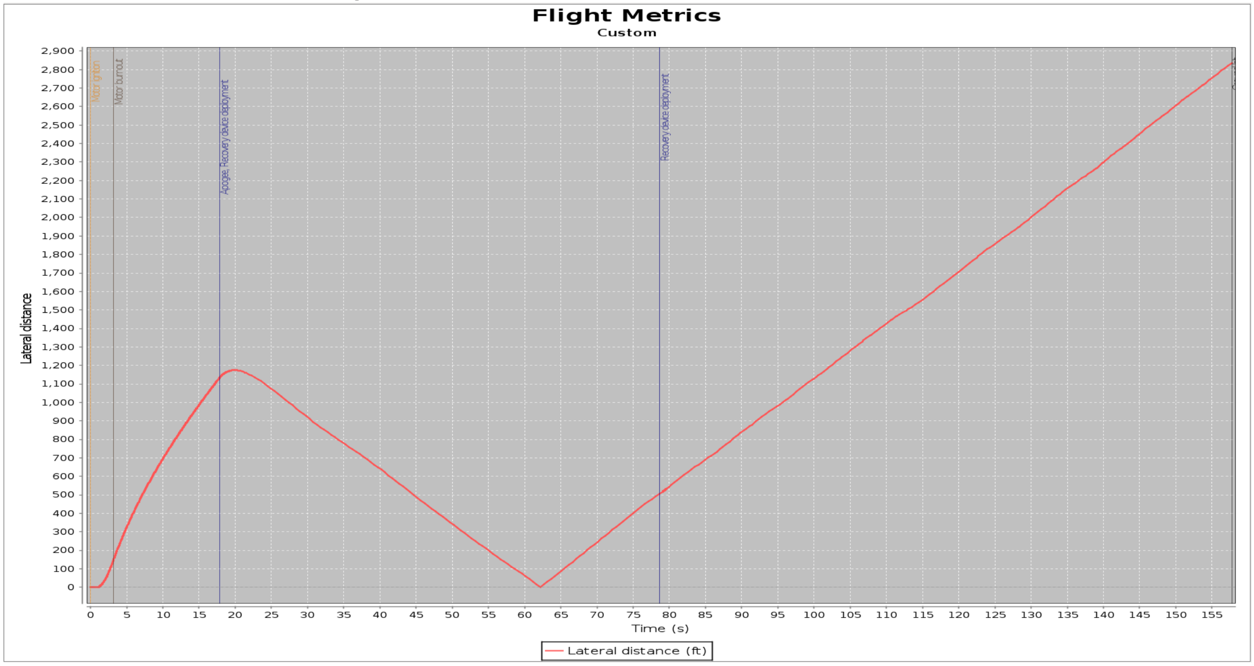
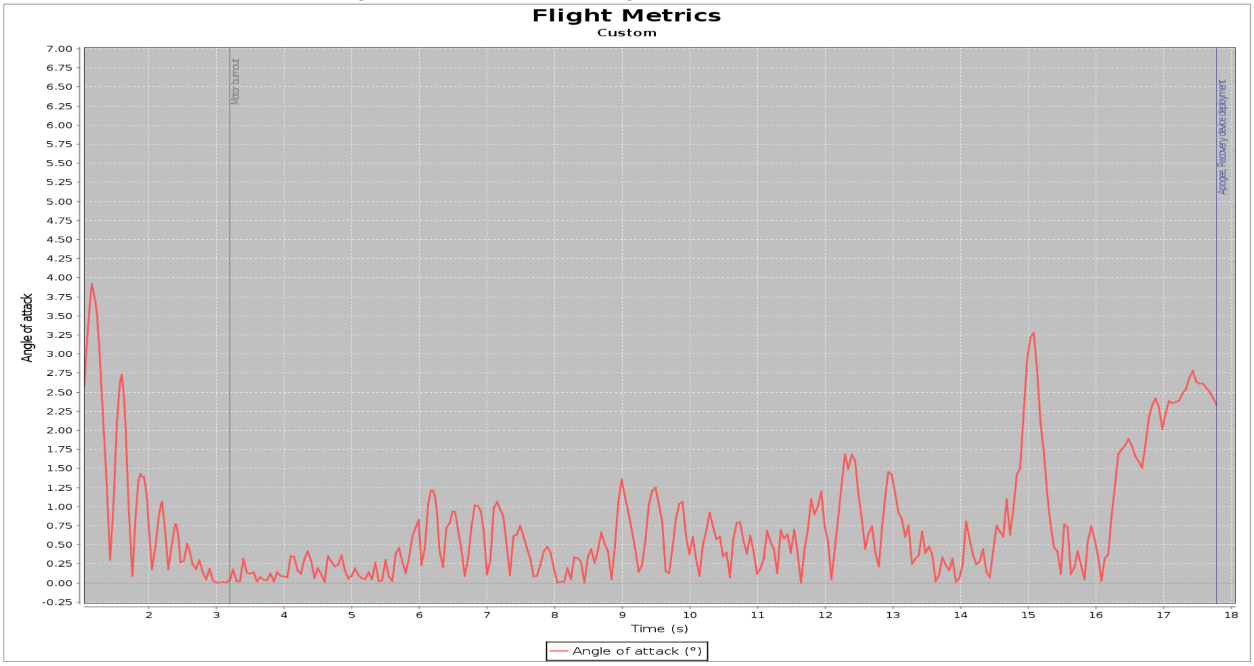


Figure 48 illustrates the rocket's angle of attack in 20 mph wind. The oscillations in angle vary between a maximum of 4 degrees and a minimum of 0.25 degrees. Like the 15 mph flight, the amplitudes are very irregular. However, in 20 mph winds, the variance is much larger than in the 15 mph flight. Additionally, the increase in angle just before apogee is much smaller in 20 mph winds than in lower wind speeds.

Figure 48: Rocket Angle of Attack vs. Time



3.5.5 Kinetic Energy Simulations

See section 3.4.12 for kinetic energy calculations and simulations.

4 Safety

4.1 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, instruction, and team agreement to the Appendix D. 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.

4.2 Checklists

4.2.1 Assembly

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 may be useful for adjustments or repairs.

1. Screwdrivers and allen wrenches
2. Pliers

3. A soldering iron and extra solder
4. Extra wire for electronics
5. Wire strippers and wire cutters
6. Screws, bolts, and nuts
7. Extra batteries (9V Duracell and 12V)

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
   (f) Motor retainer
2. Payload components:
   (a) Landing leg (x3)
   (b) Parachute (x3)
   (c) Raspberry Pi
   (d) Raspberry Pi Camera Board v2
   (e) Missile Works RRC3 Altimeter System
   (f) Eggfinder GPS System
   (g) SparkFun Triple-Axis Digital-Output Gyro Breakout - ITG-3200
   (h) SparkFun Triple Axis Accelerometer Breakout - LIS331
   (i) Fully charged batteries
   (j) 2-3 foot rope
3. Recovery components:
   (a) Main parachute
   (b) Drogue parachute
   (c) Two new, fully charged 9V Duracell batteries
   (d) Black powder
   (e) Perfectflite Stratologger CF Altimeter
   (f) Missile Works RRC3 Altimeter

Assembly

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

1. Airframe:
   The airframe team is responsible for the assembly of the 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) Fins are secure, don't flex/bend.

   (c) Examine glue joints and U-bolts on all bulkheads.
   (d) Inspect gaskets on avionics bay door for damage.
2. Recovery:
   The recovery team is responsible for the assembly of the recovery system. The team lead, Adam, shall be present during the assembly.
   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) Inspect parachutes for holes.
   (b) Untangle shock cords and check integrity.
   (c) Make sure both altimeters are working properly and that set altitudes are correct.
   (d) Measure the voltage on all batteries, and verify that they are at full or nearly full charge.
   (e) Place and secure both batteries onto avionics platform.
   (f) Secure altimeters onto avionics platform.
   (g) Carefully roll up parachutes.
   (h) Neatly fold shock cords into zig-zag pattern - secure with masking tape.
   (i) Wrap parachutes tightly in heat blankets.
   (j) Wrap parachutes tightly in heat blankets.
   (k) Tuck parachutes into the parachute section.
   (l) Connect parachute section to the booster section.
3. Payload:
   The payload team is responsible for the assembly of the payload. The team lead, Avyay, shall be present during the assembly.
   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) Landing legs are attached securely to hinge/pin.
   (b) Mount camera in nose cone:
      i. Not loose.
      ii. Good physical connection.
      iii. Connect wiring.
   (c) Attach nose cone to tube:
      i. Not scratched/damaged.
      ii. Attached securely.
   (d) Verify that electronics are securely attached to the rocket.
   (e) Test landing leg pin actuation: smooth, not obstructed.
   (f) Raise pins (released position).
   (g) Stuff parachutes into payload section.
   (h) For each leg:
      i. Fold the leg up while wrapping string around corresponding parachute and compressing the spring behind the parachute.
      ii. Drop the corresponding pin, so the landing leg is held in position.
   (i) Tie the 3-foot rope around the landing legs in case of pin failure.
4. 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, and can hold the entire weight of the rocket.

5. 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) Launch Device Manager on the connected laptop, and search for "USB Serial Port" under Ports. Note the number of this port.
   (c) Launch PuTTY on the laptop, and set up a connection to the above noted port with connection type "Serial" and speed 115200.
   (d) Click "Open" to launch the Raspberry Pi terminal.
   (e) Execute the following commands to begin recording:
      i. cd Desktop/
      ii. rm stop
      iii. python camera.py
6. 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) 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

4.2.2 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 Appendix E.
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.

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.
4. Check that both altimeters are off.
5. Connect black powder containers to deployment terminals.
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 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.
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.
5. Turn both altimeters on once the rocket is in place on the launch rail.
6. Test igniter continuity.
7. Ensure no person is closer to the launch pad than the distance specified in field (3): minimum personnel distance.
8. Install electrical motor igniters.
    Igniter installation should only be handled by our mentor, David, followed by an experienced member at the site.
    (a) Make sure the bent end 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.
9. "Ensure that no person is at the pad except safety personnel and those required for arming and disarming operations." [NAR HPRSC]
10. Count down at least 5 seconds, and then launch the rocket.
11. 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. Check rocket for hot charges.
2. Turn off both altimeters.

3. Open avionics bay door and disconnect altimeters from charges.
4. Read out altitude.
5. Inspect all parts for damage.
6. To stop recording, execute the following (after reconnecting to Raspberry Pi via serial):
   (a) cd Desktop/
   (b) touch stop
7. 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>

4.3 Personnel Hazard Analysis

Risk	**Effects**	**Severity and Likelihood**	**Mitigations**
Black Powder Fails to Explode/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	E3	Tape the E-match to the Tender Descenders to ensure that it will light the black powder; make sure all electronics are connected
Shortcircuiting of Wires	Could potentially create a fire inside the rocket	E2	Taped and Labeled each wire to ensure that they would be connected to the intended locations

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	E2	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.
Improper use of machining tools	Damage or wear to equipment, minor personal injury; possibly major damage to construction components.	D2	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.
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.

Improper handling of hazardous materials/chemicals	Explosion or fire, personal injury (burns, loss of eyesight, cuts, etc.); possible damage to rocket components.	C2	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.
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	C2	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.

Electric shock while working with electronic components	Tingling, minor muscle contractions	B2	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.

Table 25: Personnel Hazards Analysis

4.4 Failure Modes and Effects Analysis

4.4.1 Airframe Failure Modes

Risk	**Causes**	**Effects**	**Severity and Likelihood**	**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.

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.
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.
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
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

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
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
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
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

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
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; compromise 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.

Table 26: Airframe Failure Analyses

4.4.2 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.	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.

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.	Perform stress analysis calculations to determine potential hinges and bolts. Once specific hinges and bolts are decided upon, a test landing leg system for a single leg will be built. Performing drop tests from a height of approximately 50', 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.

Wire connecting landing leg and parachute breaks	Due to force of air flow on landing leg during deployment, landing leg quickly opens before parachute has sufficient time to exit chamber, snapping the wire.	Parachute deployment reliant solely on linear spring resulting in possible single parachute ejection failure.	A3	Use high impact nylon wire. Additionally, staggered deployment of the landing legs will lower the payload speed after each leg deployment. Meaning, if the linear spring is successful in deploying the parachute despite the broken wire, this identified risk lowers after each consecutive landing leg deployment.	Using a payload test model, a dummy weight also approximate in size will be used in place of the parachute. After correctly packaging the dummy weight with the high impact nylon wire wrapped around and connected to the landing leg, drop tests from 50' will be performed. If the wire breaks within 5 tests, different aspects of the design will be changed. Different wire wrapping methods will be tested. Varying lengths of wire will be tested. Possibly different connection points with the landing leg may need to be tested. This will continue until 5 consecutive successful drop tests are completed. Since a drop test will not replicate extreme conditions, an additional test will be conducted where, in the descent orientation, the landing leg is rapidly deployed via a team member pulling a wire connected to the landing leg. Similarly, this test will continue until 5 consecutive successful tests are completed.

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. Redundancy in parachute deployment system (wire and linear spring) will safeguard against a partial or incomplete deployment.	A payload test model of 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. First tests will be performed with only the linear spring to aid in parachute deployment. This is to ensure the parachute can still deploy successfully without the wire. Second tests will use both linear springs and nylon wire. Until 5 consecutive successful tests are completed, the packaging method or parachute chamber design will be altered.

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.	Subscale payload models will be built and used to test all three parachutes at once. Drop tests from approximately 50' will be performed with varying time intervals between each parachute deployment. Tests will continue until 5 consecutive successful (parachute lines don't tangle) tests are completed. That successful time interval will then be implemented into the full scale payload design.
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 are already deployed, a drop test from a height calculated to provide approximately 35 ft lbf (so as to not test only best case scenario) will be performed. This test will be performed over different terrains. If the 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.

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 50' to confirm a full and smooth extension during descent. WD-40 will be incrementally applied until 5 consecutive successful tests are completed.

Table 27: Payload Failure Analyses

4.4.3 Recovery Failure Modes

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
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

Table 28: Recovery Failure Analyses

4.4.4 Electronics Failure Mode

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.
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.

Table 29: Electronics Failure Analyses

4.5 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-fluorocarbons (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.

- **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.

- **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.

- **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.

Environmental risk matrix key:

RISK POSSIBILITY SCORE (1-4) 1=High
1 = Extremely Likely
2 = Very Likely
3 = Possible
4 = Very Unlikely

RISK SEVERITY SCORE (1-4) 1=High
1 = Extremely Bad if this occurred
2 = Very Bad if this occurred
3 = Somewhat Bad if this occurred
4 = Not Bad - a minor problem

FINANCIAL SEVERITY SCORE (1-4) 1=High
1 = Extreme financial cost to remediate - More than $10,000
2 = High financial cost to remediate - Under $10,000
3 = Some financial cost to remediate - Under $1,000
4 = Very low Extreme financial cost to remediate - Under $100

REPUTATIONAL SEVERITY SCORE (1-4) 1=High
1 = Devastating - severely impacting future of program, severe negative press in journals and TV
2 = Very Bad - definite write-up in newspapers and journals, TV coverage possible
3 = Somewhat Bad - possible write-up in newspaper or journals
4 = Not Bad, not newsworthy

FINAL RISK RATING SCORE (1-4) 1=High
1 = Extremely Likely to cause total risk concerns - very serious concern should be applied to this risk area
2 = Very Likely to cause total risk concerns - serious concern should be applied to this risk area
3 = Possible to cause total risk concerns - some concern should be applied to this risk area
4 = Very Unlikely to cause total risk concerns - acceptable overall risk

RISK #	RISK ITEM	RISK DESCRIPTION	CAUSE	RISK POSSIBILITY	RISK SEVERITY	FINANCIAL SEVERITY	REPUTATIONAL SEVERITY	FINAL RISK RATING Possibility x Severity	MITIGATION	REMEDIATION	Calculation Notes
1	Water Contamination	Any water in the area may be affected. This includes lakes, ponds, rivers, streams, oceans, or any standing or running water. Rocket may land in water or parts of rocket may come apart and land in water.	Rocket or any parts of the rocket may land, drift off course, or otherwise end up in a water area.	4	2	3	2	4	Survey the Competition site for any water sources and ensure that launch site and trajectory errors are outside the area of possible water landing.	Retrieve rocket or parts from water as soon as safely possible.	Based on small commercially built rocket engine and 1-off occurance.
2	Ground Contamination	The ground may become contaminated from the launch of the rocket due to the chemical exhaust from the engine.	The chemical exhaust from the rocket engine launch is directed straight down into the ground.	1	4	4	4	4	Launch in the Competition assigned area. Place a non-flammable sheet directly under the launch site for later disposal.	Dispose of non-flammable sheet in accordance with hazardous waste rules. If further remediation is necessary, dig up dirt asnd dispose of as hazardous material.	Using a commercially available and certified rocket engine minimizes contamination. Also this is a 1-off occurance
3	Air Contamination	The air at launch and throughout the complete trajectory route may become contaminated from the chemical exhaust of the rocket engine.	The chemical exhaust from the rocket engine is released along the whole trajectory path, from the ground to the target apogee at 5,400 feet.	1	4	4	4	4	Launch in the Competition assigned area.	There is no remediation available.	The dissapation of the exhaust is distributed over the complete trajectory route, expected to be about 5,400 feet.
4	Ecosystem Contamination	Disruption and pollution of the total microenvironment.	The hazardous chemicals and pollutants exhasted from the rocket engine output.	3	2	3	3	4	By placing a non-flammable mat under the launch area, we should minimize contamination of the immediate ecosystem area.	Dig up the ground underneath the launch area and dispose of it properly.	This is a very localized problem to the immediate launch area.
5	Animal Risk	Animals may be injured from contact with the rocket at high speed, or from the heat of the rocket engine at launch or shortly after landing.	Animals may enter the Competition area during the active launch window.	4	2	3	2	4	The Competition area provides enough human activity, warning alerts, noise from launches and the smell of exhaust to keep away most animals.	Any animals affected should be immediately gathered up and remediated by a qualified veteranarian.	This is not very likely, but a bird may enter the flight area at altitude.
6	Human Risk	People may be injured from the launch.	Someone may not be following all Competition procedures.	3	2	2	2	3	Team constantly reviewing Competion guidelines. There are alerts at launch. Several people are monitoring sequene of launch procedures.	Anyone affected should immediately be attended to by a doctor.	This should be mitigated by the Competition atmosphere and because everyone will have been coached.
6	Building or Structure Risk	Any buildings in the area may be accidently landed on and affected by the hot rocket engine, causing damage or fire.	A rocket may land on a building primarily due to a rocket going off-course, outside the pre-determined trajectory plus safety envelope.	4	2	2	2	4	Calculate the launch trajectory plus a safety margin to prevent an accidental landing outside a safe landing envelope.	Competition organization and Team should have fire extinguishers available for immediate attention to a possible fire.	This should not occur because of Competition area calculations putting the launch area well outside any radius that would include buildings.
7	Noise Contamination	Loud noise well above typically ambient noise for the area.	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)	1	4	4	4	4	Every effort should be made to ensure that the launch area is sufficiently far away from any reisdents or businesses.	Followup coordination with neighbors and city government to ensure better cooperation and notice in the future.	This is a Competition level issues, outside the Team's control.
8	Community Risk	This activity causes concerns in the local area by residents or local government.	Residential or business housing is too close to Competition launch area. In addition, prior mitgation efforts may not have been untirely successful.	3	3	4	4	4	Every effort should be made to ensure that the launch area is sufficiently far away from any reisdents or businesses.	Followup coordination with neighbors and city government to ensure better cooperation and notice in the future.	This is a Competition level issues, outside the Team's control.

9	Debris	Debris, trash or parts from the launch are left on the Competition filed after launch.	Incomplete attention to proper cleanup and hazardous remediation after a launch. May include unexpected parts flying off rocket from launch.	3	3	4	3	3	Complete cleanup plans and personnel assignments should completely mitigate this.	Completely review launch area after launch to ensure complete and proper disposal of all debris.	This is the most controllable risk meaning that it is 100% controllable by the team via proper planning and personnel assigments.
10	Legal or Compliance Risk	Compliance with all laws, and School and Competition regulations	Either not aware or not following laws or regulations	3	2	2	2	3	Review all available laws and Schools and Competition regulations in prepapration for Competition	Pay any fines, post Competion team review and add to future team book of knowledge fro continuous improvement of process.	The entire process is monitored by several entities to ensure compliance. In addition, the Competition organization and launch site is very used to this activity.

5 Payload

5.1 Payload Mission Statement

Our payload experiment, SAGITTA-VL, is designed to demonstrate the ability to identify various ground objects during descent, and land a section of the vehicle upright under an independent recovery system for reusability. The objective of our experiment is to use our onboard computer package to analyze images viewed through the vehicle nose cone, in order to identify and differentiate three ground targets by color in real time. Once this has been achieved, the vehicle section housing the viewing components will be deployed as an upright landing vehicle, using legs built into the airframe. The extension of the legs, and subsequent deployment of an independent recovery system, are to rotate the section during its fall and cause it to descend in an upright configuration, such that our ground target identification package lands upright, undamaged, and fully recoverable for repeated use.

5.2 System Design Selections

The following design alternatives were selected for each of the subsystems of the payload experiment, as outlined in the Preliminary Design Review.

Recovery: The recovery system will consist of *three parachutes, ejected from the landing leg slots (via linear springs).* This removes the need to open the nosecone to release a parachute, and will bring the payload down under a passive recovery system. The release of the parachutes will be staged by sequential deployment of the landing legs, in order to prevent tangling.

Nosecone: The nosecone will consist of an *opaque ogive (fiberglass) nosecone, with the tip replaced by clear PETG plastic.* This facilitates the placement of a camera in the top of the nosecone, providing an uninhibited field of vision while viewing the ground during descent. As the parachutes are deployed by the legs, the nosecone remains rigidly attached to the payload section, allowing the coupling to be strengthened by permanent fixtures (i.e. steel screws).

Camera: The camera will be *nose-facing, placed in the clear tip of the nosecone.* Using a sufficiently large clear tip, this allows the camera's field of view to be uninhibited; additionally, the electronics associated with the camera and Raspberry Pi can be stored in the nosecone, creating more space in the payload tubing section. The camera is nose-facing, rather than booster-facing, to allow Target Detection to occur primarily during descent, when the payload section hangs from the vehicle facing the ground - this allows more time for Target Detection than a booster-facing camera, which would view primarily after the payload section has been deployed.

Landing Legs: The landing legs will consist of *three legs, integrated into the airframe, hinged near the base of the payload section.* This allows the leg length to be maximized before the use of any additional lengthening mechanisms. The legs are deployed by a compressed spring near the hinge, and held in place during launch by solenoid pins mounted near the top of the legs. The payload tube is strengthened by the use of an inner coupler tube as reinforcement - this tube also extends to partially cover the slots cut for the landing legs, thus sealing the leg slots in launch configuration.

Deployment: Deployment of the landing legs (which facilitates deployment of the payload parachutes) will utilize *linear solenoid actuators* to release the legs, *base-mounted torsion springs* to push the legs into landing configuration, with the landing legs supported by *sliding aluminum 'support legs.'* The use of solenoid actuators allows for the simple design of a pin and slot to keep the legs in place prior to deployment. In comparison to linear gas springs, torsion springs were found to be significantly easier to compress and package, as the gas springs exert much more force - the torsion springs, however, still provide enough force to extend the the legs. A support member to connect the leg to a central rail system is used in place of the gas spring, and is constructed from aluminum to withstand the compressive force it would experience upon landing.

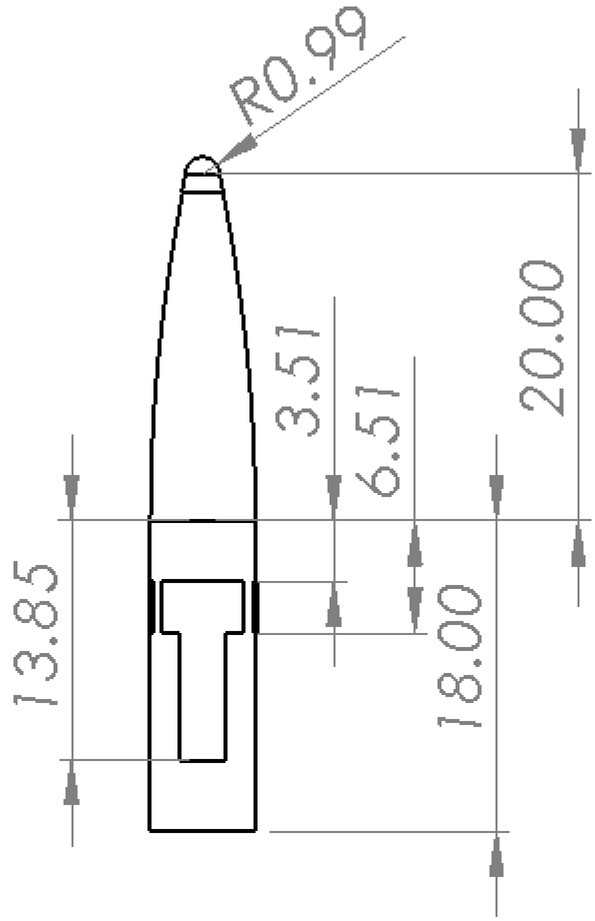
Post-landing Stability: *No post-landing stability mechanism* will be implemented on the final payload vehicle. While telescoping legs and other mechanisms would offer assistance in keeping the vehicle upright after landing, such mechanisms also introduce an additional degree of complexity in the leg design and pose additional failure modes (e.g. telescoping legs could interfere with the deployment of the legs and parachutes). These mechanisms also reduce the already limited space in the payload section. These complexity and packaging concerns were deemed to outweigh the potential benefits of post-landing stability mechanisms.

5.3 System Design Review

5.3.1 Payload System Overview

The payload subsystem consists of the upper 18" of the vehicle body tube, and the nose cone. The nose cone houses the Target Detection subsystem, i.e. the camera and computer hardware used to identify and differentiate ground targets in real time. The body tube houses the Upright Landing and Recovery subsystems, which use three landing legs integrated into the airframe to deploy three parachutes and descend in an upright orientation. The dimensioned payload section is shown in Figure 49

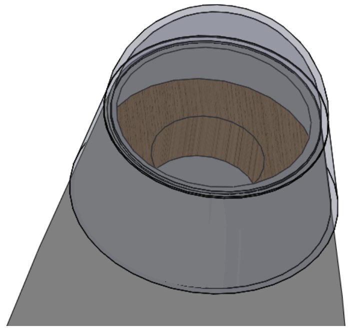
Figure 49: Dimensions for Payload section



5.3.2 Target Detection Subsystem

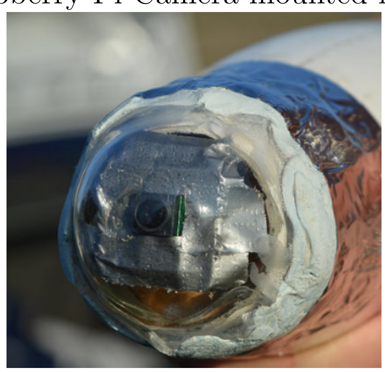
The Target Detection subsystem consists of a 24” fiberglass nosecone, a PETG vacuum-formed nosecone tip, and all electronics and hardware associated with a Raspberry Pi camera and onboard computer. The nosecone is a fully fiberglass ogive nosecone with a 6” base and 24” of length above the shoulder. The upper 4” of the cone is cut off and replaced with a hemispherical transparent tip, vacuum-formed from a 1/16” thick PETG plastic sheet. The tip consists of a 1.86” diameter hemisphere, and a 1” long flange that extends down the side of the nose cone, as illustrated in Figure 50. This flange is bonded to the nose cone using thickened epoxy.

Figure 50: Clear Nose cone Tip



A ring-shaped plywood bulkhead (with an inner diameter of 1") is glued inside the nose cone below the transparent tip - this bulkhead is used to mount a Raspberry Pi camera used for Target Detection. This setup is illustrated in Figure 51, on our subscale vehicle URSA Minor.

Figure 51: Raspberry Pi Camera mounted in the nose cone



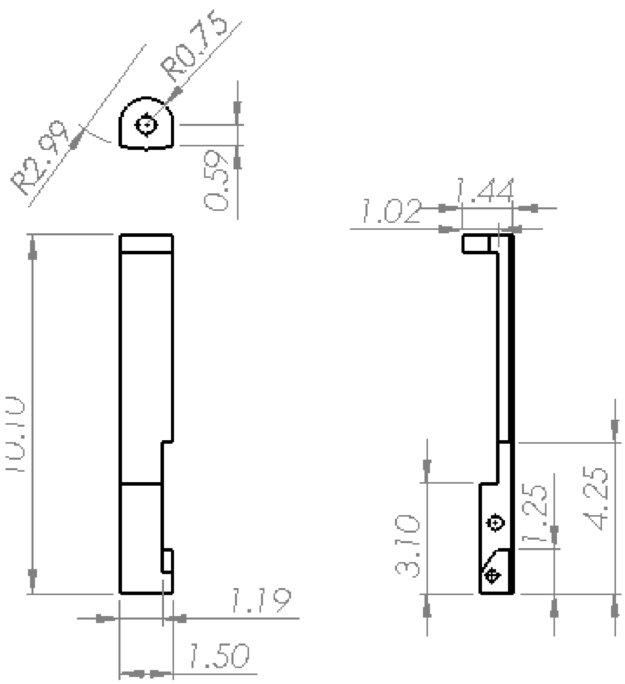
The Raspberry Pi, and associated electronics used to operate the camera, are mounted in the lower part of the nose cone, on a bulkhead located in the shoulder. This bulkhead consists of a ring glued into the shoulder (3" from the base), and a disk that is screwed onto the ring (Figure 52). This allows the bulkhead and electronics to be removed from the nose cone for analysis and modification between launches. All plywood bulkheads within the nose cone are 1/2" in thickness.

Figure 52: Nose cone cross-section, illustrating bulkhead locations

5.3.3 Upright Landing Subsystem

The Upright Landing subsystem consists of all components required to facilitate the deployment of three "landing legs" onto which the payload falls. The landing legs themselves consist of T-shaped sections cut out of the body tube. Attached to the inside of each leg is a 3D printed "landing leg frame," which contains mounting points for various elements of the Upright Landing subsystem. Each landing leg is 10.4" long, with the base of each leg at 4.15" from the base of the body tube. The cut body tube is reinforced by the addition of coupler tubing along the length of the payload section; this coupler tubing extends into the slots left by the landing legs, providing a frame which seals the gap between the leg and body tube. The body tube is a total of 18" long, while the coupler tube is 13.9" long. The dimensions of the landing leg frame are shown in Figure 53.

Figure 53: Landing Leg Dimensions



During ascent and the initial phase of descent, the legs will be flush with the body tube to form a closed airframe (Figure 54a). After the rocket begins to descend under the main parachute, the payload will execute the Target Detection operation, with the nose-mounted camera viewing the ground to detect the ground targets. The payload section will be ejected from the main vehicle upon the completion of one of the following criteria:

- The Raspberry Pi indicates that **Target Detection has been completed**
- The payload altimeter detects an altitude of **600 ft**.

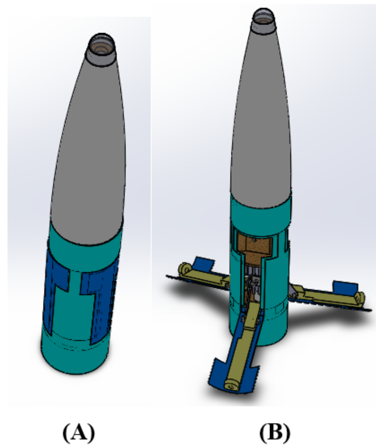
The payload flight plan is designed such that it executes the Target Detection experiment during descent under the drogue and main parachutes, and executes Upright Landing once Target Detection is completed. However, in the event that Target Detection cannot be completed, the Upright Landing experiment will be executed at a threshold altitude. The deployment will occur in the following steps:

- One of the legs will be extended, releasing a parachute.

- The payload section will be ejected from the main vehicle.
- The remaining two legs will be extended, releasing the remaining parachutes.

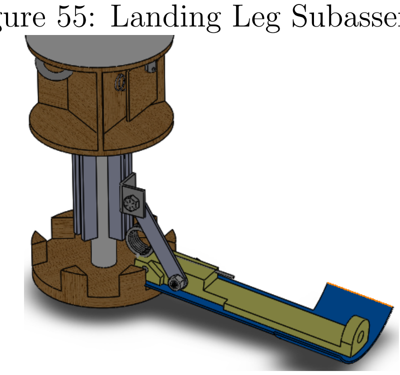
This will leave the rocket in an upright "landing configuration" (as described in Section 5.3.4), with legs extended (Figure 54b).

Figure 54: (A) Launch configuration; (B) Landing configuration



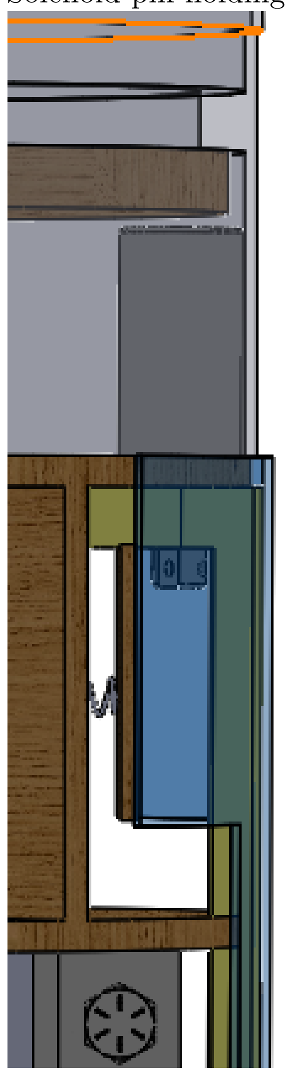
The landing leg frame is connected to the vehicle at two points: a rotating hinge, consisting of a steel dowel attached to a bulkhead at the base of the payload section; and an aluminum "support leg", attached to a rail in the center of the payload section. Figure 55 displays the landing leg subsystem for a single leg.

Figure 55: Landing Leg Subassembly



Three aluminum rails, one corresponding to each landing leg, are bolted to a PVC pipe that runs from the base of the payload section to the top, and is slotted into bulkplates at both ends. The top of each rail is additionally screwed into the upper bulkplate, as described in Section 5.3.4. The central PVC tower has a 1" diameter and is 10.25" in length. Each rail extends from the top of the PVC tower, to a length of 8.75". The support leg is 4.55" long, and is bolted to an L-bracket which moves along the rail on a 3/8" bolt. This carriage slides up the rail when the legs are in launch configuration, and falls down the rail as the legs open. The hinge is attached to the landing leg frame 1/2" from its base, and is secured between two posts on the lower payload bulkhead. This bulkhead is glued around its circumference to the rigid payload body tube. The landing leg rotates about the hinge as it opens, driven by a torsion spring mounted between the rail system and the landing leg frame. The arms of the torsion spring are attached to the leg frame and the rail, and are designed to open to 180°. However, the bulkhead prevents the leg from extending beyond 110°, which is the final landing configuration. In launch configuration, the landing leg is kept flush with the body tube using a linear-actuated pin located at the top of the payload section. As seen in Figure 56, this pin rests in a slot in the top of the landing leg frame. To deploy the legs, an electric pulse is sent to the actuator (either from the Raspberry Pi or the altimeter, based on the deployment criteria met) and the pin is retracted, allowing the leg to spring out into its landing configuration.

Figure 56: Solenoid pin holding in the landing leg



5.3.4 Payload Recovery Subsystem

The payload recovery system consists of three 36" toroidal parachutes, arranged at 120°apart, suspended from the base of the nose cone. When the payload center of mass is situated below the nose cone, the deployment of these parachutes causes the payload to fall in an upright configuration; the use of three symmetrically arranged parachutes ensures that the section does not fall at an angle. The recovery subsystem consists of a set of open parachute containers, residing in the upper payload section below the nose cone shoulder. The three parachute containers are made from 1/8" plywood, and fixed together as a single unit under a 1/4" bulkplate, as illustrated in Figure 57. The dimensions of the parachute container are given in Figure 58. Each parachute is attached to an eyebolt in the bulkplate. Each compartment additionally contains a solenoid actuator, glued into the bulkplate, and a linear spring attached to a plywood board (Figure 57). The bulkplate is screwed into the payload tubing around its circumference, as well as being screwed onto the tops of the three aluminum rails. This provides additional structural support for both the parachute containers and the rail system. The assembly process is shown in Figure 59 as an exploded view.

Figure 57: Parachute Container

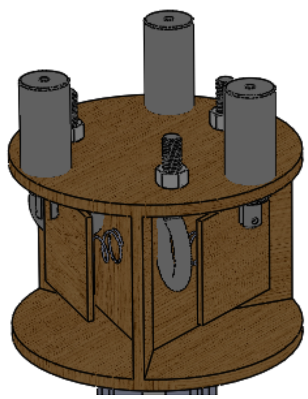


Figure 58: Parachute Container Dimensions

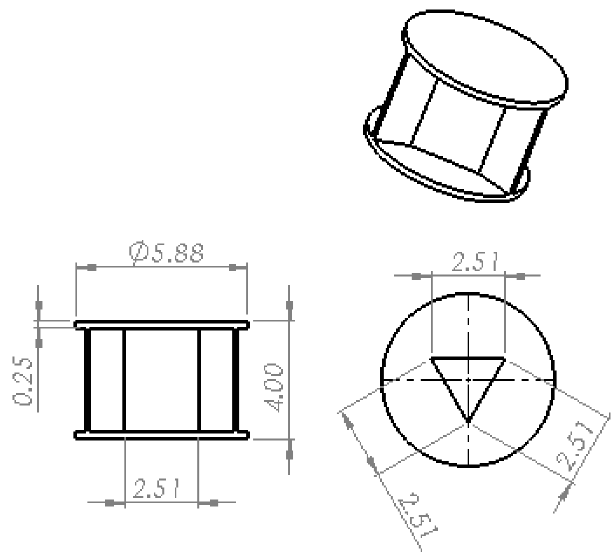
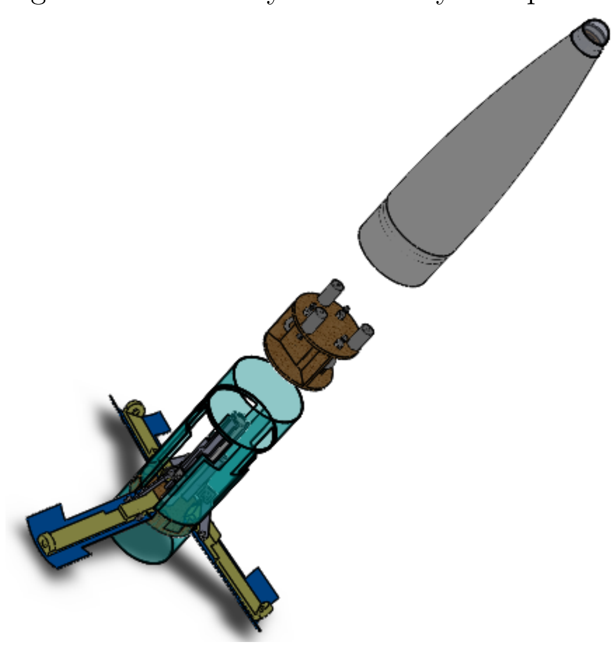


Figure 59: Assembly of Recovery Components



In launch configuration, the parachutes are folded and stored in the compartments, held in by the closed landing legs. Deployment of the parachutes occurs by two independent mechanisms, creating redundancy in the recovery system. When the legs open (by the actuation of the solenoid pins), the parachutes are exposed, and the linear springs push the parachutes out of the vehicle. Independently, each parachute is loosely wrapped with nylon cord, which is tied to the landing leg. When the leg opens, it pulls the parachute out of the vehicle, allowing the parachute to open as the cord unravels. Prior to the deployment of the parachutes, the payload section falls with its nose facing downward, as it hangs from the main vehicle shock cord. When the parachutes deploy and the payload section is ejected from the main vehicle, the center of mass falls below the nose cone, and the parachutes pull the section into its upright configuration.

5.3.5 Vehicle Interfaces

During launch configuration, the payload section acts as a part of the main vehicle airframe. The nose cone is attached to the payload body tube by a 3.5” shoulder, which is screwed directly to the body tube. The payload section is coupled to the avionics bay section by a 3.5” shoulder; as this section separates, the coupling is reinforced by shear pins. During descent, the payload is ejected from the avionics bay section by an ejection charge between the avionics bay and the lower payload bulkhead. The payload section, including the nose cone, is then recovered separately from the main vehicle.

5.4 Mission Success Criteria

SAGITTA-VL is designed to execute the Target Detection and Upright Landing experiment and perform successfully as a component of the launch vehicle airframe. Success of the mission will be defined by the following functional requirements:

- **Identifying and differentiating ground targets**
  The Raspberry Pi camera subsystem program will search captured frames for the RGB values near or at the provided values for the ground targets. The computer will save images containing any of the three targets; this criteria can be evaluated by inspection of the data after recovery. To maximize the time for this process to occur, the camera will operate primarily during descent under drogue and main parachutes, while the nose cone faces the ground.

- **Real time image analysis**
  The camera subsystem will obtain and analyze images of the ground during descent at a rate of 30 images per second. Saved images will be timestamped, such that the time of successful detection of all three targets can be identified upon analysis of the data after recovery. During descent, successful identification of the targets will trigger a signal from the Raspberry Pi to execute deployment procedures for the Upright Landing subsystem. To mitigate the risk of this confirmation not arriving in time to perform Upright Landing, the Upright Landing procedures will also occur via an altimeter pulse at an altitude of 600 ft.

- **Proof of a successful controlled upright landing**
  A successful upright landing will be defined by the landing vehicle being stable (standing with the nose cone not touching the ground) for at least 5 minutes without human interference. This can be determine by visual inspection prior to recovery, as well as by inspection of camera data after recovery (for a successful upright landing, camera data will indicate viewing away from the ground). This has been designed for by the

optimization of landing leg length. The leg lengths are maximized, occupying the entire length between the nose cone shoulder and avionics bay shoulder; the shoulders themselves are shortened and reinforced to provide greater length for the legs. The landing legs, which are 10.25" long and extend to a 110°angle, provide a total landing base radius of approximately 12.1". If the center of gravity of the payload section is kept below 10" from the base, the payload can land at angles up to 47°without tipping over, increasing the likelihood of a successful upright landing even in wind conditions.

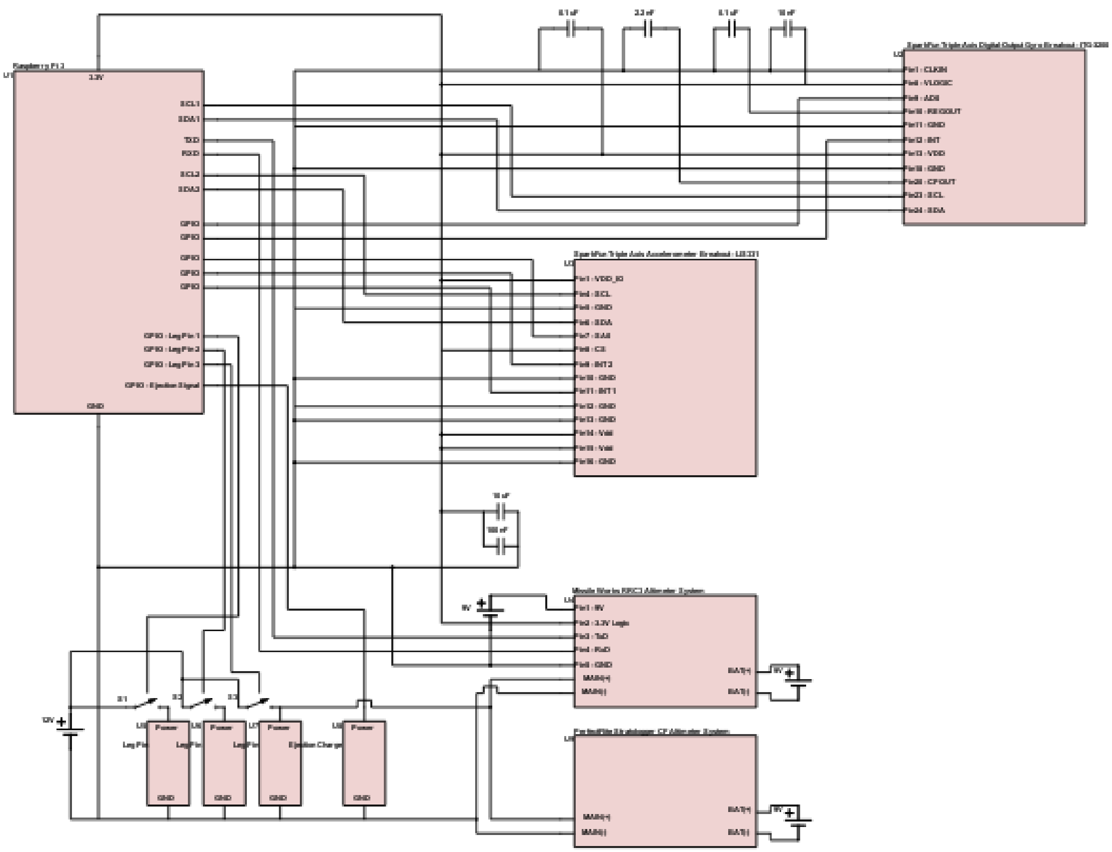
- **Telemetry for flight analysis**
  In addition to the equipment associated with Target Detection and Upright Landing, the payload includes a gyroscope and altimeter, operated by the Raspberry Pi, to gather data about the vehicle's flight and descent. The accelerometer will provide data about the rate of acceleration during ascent, which can be used to verify future flight simulations against real-world information. The gyroscope will provide information about the angular motion of the vehicle, which can be used to analyze deviations from ideal flight path, such as roll during ascent and precession during descent.

5.5 Payload Electronics Summary

The payload electronics package consists of:

- A Raspberry Pi3 computer
- A Raspberry Pi 8MP camera module
- An Eggfinder GPS transmitter
- A Missileworks RRC3 altimeter
- A Stratologger CF altimeter
- An Invensense ITG-3200 gyroscope
- An STMicroelectronics LIS331 accelerometer

Figure 60: Payload Electronics Schematic



Apart from the GPS unit (which is paired with an independent handheld receiver) and the altimeters (which are wired directly to the payload chute deployment solenoids), all sensors' data will be stored and processed by the Raspberry Pi. The gyroscope and accelerometer use I2C protocols, while the camera has a dedicated port on the Pi.

The primary indicator of payload status is audio confirmation from the altimeters, which enter a pattern of beeping out the current altitude when in flight-ready configuration. Each altimeter will have a switch in the battery loop positioned four inches from the base of the payload section. Each altimeter will run off a 9V battery, while the Raspberry Pi will be powered by a 5V battery.

During descent, the Pi will also execute the target detection algorithm and control payload separation. One of its GPIO pins will be connected to one of the three chute deployment solenoids, in parallel with the two altimeters. As a result, that solenoid will be triggered either upon successful target detection or upon reaching an altitude of 600 ft, whichever comes first. At this point, that single parachute will deploy, followed by ejection of the payload from the rocket body and deployment of the other two parachutes.

5.5.1 Target Detection Algorithm

The Target Detection Algorithm will follow these steps for each image taken:

1. Capture an image using the camera.

2. Search the image captured for three contiguous regions of color, one of each target color. This is done by sampling pixels at regular intervals in the image, and testing the color of the pixel to see whether it falls within bounds centered on each color. Some exceptions do apply - under conditions that would cause undue glare, such as the camera being pointed at the sun, the algorithm will skip an image so as not to generate a false positive.

3. If the image contains at least one of the three necessary regions of color, and the regions are of a sufficient size in the image, then targets have been identified. Save the image to the file system, along with a file noting the position(s) in the image of the region(s) of color identified, as well as a timestamp. If no regions of color are found, do not save anything to the file system.

5.6 Pre-Launch Procedure

1. Connect the FT232R USB-to-serial cable to the Raspberry Pi's GPIO pins (VCC, GND, TXD).

2. Launch Device Manager on the connected laptop, and search for "USB Serial Port" under Ports. Note the number of this port.

3. Launch PuTTY on the laptop, and set up a connection to the above noted port with connection type "Serial" and speed 115200.

4. Click "Open" to launch the Raspberry Pi terminal.

5. Execute the following commands to begin recording:

   (a) cd Desktop\

   (b) rm stop

   (c) python camera.py

6 Launch Procedures

6.1 Assembly

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 may be useful for adjustments or repairs.

1. Screwdrivers and allen wrenches
2. Pliers
3. A soldering iron and extra solder
4. Extra wire for electronics
5. Wire strippers and wire cutters
6. Screws, bolts, and nuts
7. Extra batteries (9V Duracell and 12V)

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
   (f) Motor retainer
2. Payload components:
   (a) Landing leg (x3)
   (b) Parachute (x3)
   (c) Raspberry Pi
   (d) Raspberry Pi Camera Board v2
   (e) Missile Works RRC3 Altimeter System
   (f) Eggfinder GPS System
   (g) SparkFun Triple-Axis Digital-Output Gyro Breakout - ITG-3200
   (h) SparkFun Triple Axis Accelerometer Breakout - LIS331
   (i) Fully charged batteries
   (j) 2-3 foot rope
3. Recovery components:
   (a) Main parachute
   (b) Drogue parachute
   (c) Two new, fully charged 9V Duracell batteries
   (d) Black powder
   (e) Perfectflite Stratologger CF Altimeter
   (f) Missile Works RRC3 Altimeter

Assembly

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

1. Airframe:
   The airframe team is responsible for the assembly of the 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) Fins are secure, don't flex/bend.
(c) Examine glue joints and U-bolts on all bulkheads.
(d) Inspect gaskets on avionics bay door for damage.

2. Recovery:

The recovery team is responsible for the assembly of the recovery system. The team lead, Adam, shall be present during the assembly.

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) Inspect parachutes for holes.
(b) Untangle shock cords and check integrity.
(c) Make sure both altimeters are working properly and that set altitudes are correct.
(d) Measure the voltage on all batteries, and verify that they are at full or nearly full charge.
(e) Place and secure both batteries onto avionics platform.
(f) Secure altimeters onto avionics platform.
(g) Carefully roll up parachutes.
(h) Neatly fold shock cords into zig-zag pattern - secure with masking tape.
(i) Wrap parachutes tightly in heat blankets.
(j) Tuck parachutes into the parachute section.
(k) Connect parachute section to the booster section.

3. Payload:

The payload team is responsible for the assembly of the payload. The team lead, Avyay, shall be present during the assembly.

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) Landing legs are attached securely to hinge/pin.
(b) Mount camera in nose cone:
    i. Not loose.
    ii. Good physical connection.
    iii. Connect wiring.
(c) Attach nose cone to tube:
    i. Not scratched/damaged.
    ii. Attached securely.
(d) Verify that electronics are securely attached to the rocket.
(e) Test landing leg pin actuation: smooth, not obstructed.
(f) Raise pins (released position).
(g) Stuff parachutes into payload section.
(h) For each leg:
    i. Fold the leg up while wrapping string around corresponding parachute and

compressing the spring behind the parachute.

   ii. Drop the corresponding pin, so the landing leg is held in position.

(i) Tie the 3-foot rope around the landing legs in case of pin failure.

4. 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, and can hold the entire weight of the rocket.
5. 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) Launch Device Manager on the connected laptop, and search for "USB Serial Port" under Ports. Note the number of this port.
   (c) Launch PuTTY on the laptop, and set up a connection to the above noted port with connection type "Serial" and speed 115200.
   (d) Click "Open" to launch the Raspberry Pi terminal.
   (e) Execute the following commands to begin recording:
      i. cd Desktop/
      ii. rm stop
      iii. python camera.py
6. 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) 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 Appendix E.
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.

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. Check rocket for hot charges.
2. Turn off both altimeters.
3. Open avionics bay door and disconnect altimeters from charges.
4. Read out altitude.
5. Inspect all parts for damage.
6. To stop recording, execute the following (after reconnecting to Raspberry Pi via serial):
   (a) cd Desktop/
   (b) touch stop
7. 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>

7 Project Plan

7.1 Testing

7.1.1 Camera Testing

We were able to make many observations from the video footage provided by the nosecone camera during our sub-scale launch. Primarily there was significant glare in the video captured by the camera, with a variety of colored flashes. Additionally, the nose cone was swinging rapidly at times. The purpose of this test is to determine if either of these occurrences will hinder our ability to identify the colored tarps and *only* the colored tarps. The testing variable will be having the camera stationary, swinging, etc. and at varying distances from our tarp simulator.

Procedure:

1. Buy at least one piece of tarp or similar material that closely resembles at least one of the three selected colors.
2. Take video of the tarp simulator with the Raspberry Pi camera in the sub-scale nose cone. (various motions and distances as mentioned above)
3. Check if computer successfully identified the tarp simulator and *only* the tarp simulator.

7.1.2 Payload Drop Testing

In order to conserve time and money, we desire to test our payload upright landing without having to launch the rocket. Success will be defined as it is in our team derived requirement **D.8** below in section 7.2.2.

Since we are dropping our 10.5 lb payload from a relatively significant height, ensuring this is done safely, and without endangering anyone on or not on the team, is critical. To eliminate risk of injury, we will identify and secure a location on private property that **a.** allows us to completely close off the area from the public during testing and **b.** has a sufficient drop.

Procedure:

1. Deploy landing legs and unfold parachutes. In order to increase safety, deployment of these will not be tested during the fall.
2. Once area is designated as clear and there are no potential hazards, release the payload.
3. Note and record landing orientation of payload and any damage induced.
4. Repeat from a variety of different orientations (this is the testing variable) to test durability of design.

7.1.3 Payload Parachute Deployment Testing

While the previous test will test the landing of the payload, this test will serve to isolate and test the deployment of the payload parachutes. For this test a prototype (possibly scaled down) will be made of *one* landing leg and parachute packing area. Success will be defined as the parachute properly being pulled out by the motion of the landing leg. The testing variable will be the amount of nylon cord used and, if necessary, alternative materials to nylon cord.

Procedure:

1. Deploy the landing leg.
2. Record whether the parachute was properly pulled out and any other notable occurrences.

7.1.4 Epoxy Strength Testing

The purpose of this test is to determine the strength of JB Weld epoxy, which we are using for fins, centering rings, and bulkheads. We are especially interested in assuring that it is strong enough (to a factor of safety) to ensure there is no risk of mission failure.

Tensile Strength Procedure:

1. Create a piece of fiberglass/wood 6x4x0.125 inches
2. Cut a section of Blue Tube about 7 inches long
3. Using epoxy, attach the fiberglass/wood to the Blue Tube
4. Wedge the Blue Tube + fin combo between two tables, with the fin facing downward
5. Attach empty bucket underneath the table to the fin Use a bolt attached straight to the fins Use a super strong clamp and maybe some sandpaper in between to increase friction
6. Pour sand into bucket until glue fails
7. Measure weight of the bucket to determine force required for glue failure

Shear Strength Procedure: ***Repeat tensile test except Step 4***: Wedge the Blue Tube + fin combo upright between two tables, with the fins facing upward

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.	Complete. Altimeters have been purchased and attachment has been determined.
All recovery electronics shall be powered by commercially available batteries.	Verification by inspection of design.	Complete. 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.	Structural analysis both in simulation and testing will be performed to make sure the vehicle can withstand recovery at descent velocities.	In Progress. Test procedures for structural analysis has been designed. Finite Element Analysis using SolidWorks is in progress. BlueTube will be tested for durability.
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.	Complete. Our vehicle only has 3 independent sections.
The launch vehicle shall be limited to a single stage.	Verified through inspection of design.	Complete. 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.	In Progress. Checklists have been made. We will have a practice set-up prior to the full-scale flight in order to prepare.

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.	In Progress. 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.	Complete. 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.	Complete. 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.	Complete. The Aerotech L1150 motor has an impulse of 3589 N-s.

Requirement	Verification Plan	Status
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.	Complete. Our rocket has a minimum static stability margin during ascent of 2.34, as calculated by OpenRocket.
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Will be verified by OpenRocket simulations of rocket.	Complete. Our rocket has a velocity at rail exit of 67.9 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.	Complete. 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. We plan to launch the full-scale rocket at LUNAR on February 4th.
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.	Not Started. To be verified at launch.
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 Started.
Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	Verified through inspection of design.	Complete. No protuberance on the rocket is located aft of the burnout center of gravity in our design.

Requirement	Verification Plan	Status
Vehicle Prohibitions	Verified through inspection of design.	Complete. 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.	Complete. Our rocket reaches a maximum velocity of Mach 0.66 during flight, as calculated by OpenRocket.
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 approximately 5280 ft above ground level (agl), while the main chute is set to be deployed at 1000 ft. agl.	In Progress.
Each team must perform a successful ground ejection test for both the drogue and main parachutes prior to the initial subscale 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 launch. Not started for 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 below.?	In Progress. OpenRocket simulations and calculations have already been completed, but a full scale test has yet to be completed.

Requirement	Verification Plan	Status
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.	Complete. 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.	Complete. We have designed our avionics bay platform to house both the different altimeters.
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.	Design complete. Yet to be manufactured and tested.
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.	Complete. 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.	Complete. The removable shear pins will be used to separate the compartments housing both parachutes.

Requirement	Verification Plan	Status
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.	In Progress. We will ensure that the GPS allows us to pinpoint the location of each untethered portion of the rocket.
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.	In Progress. We are currently in the design and build phase. We will ensure that the recovery electronics will not interfere/be interfered by other electronics.
Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.	Demonstration. Data from Raspberry Pi will be read to verify targets had been identified and differentiated.	In Progress. Initial onboard camera testing done during sub-scale flight.
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.	Visual inspection upon recovery. Data from gyroscope will be able to tell us orientation of payload section upon landing.	Not Started. To be verified at launch.
Data from the camera system shall be analyzed in real time by a custom designed on-board software package that shall identify and differentiate between the three targets.	Demonstration. Payload section will be deployed/ejected once targets are identified in real time. If deployed before 500 feet, this will demonstrate data has been successfully analyzed.	Not Started. To be verified at launch.

Requirement	Verification Plan	Status
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.	In progress. Draft of final checklists have been completed and included in this report. Will be updated up to the FRR report as necessary.
Each team must identify a student safety officer who shall be responsible for all items in section 4.3.	Demonstration by identification in Proposal.	Complete. Safety Lead/Officer selected in the beginning of the school year.
Each team shall identify a mentor.	Demonstration by identification in Proposal & PDR.	Complete. Mentor identified in Proposal and PDR.
During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO.	Demonstration during launches.	Partially Completed. Team safety officer will inform team of rocketry club rules and will ensure all rules are complied with.
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.	In progress. Have met this requirement so far in our work on URSA.
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.	In progress. We have been maintaining a project plan since the submission of our Proposal.

Requirement	Verification Plan	Status
Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR).	Verify with all team members that none are Foreign Nationals.	Complete. 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.	Complete.
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 62 participants in first outreach event. In communication with local Charter school group.
The team shall develop and host a Web site for project documentation.	N/A	Complete.
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. Once date & time is finalized, we will book same or similar on-campus room for CDR & FRR teleconferences as we did for PDR 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** 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.5** The vehicle shall have clear vision out of the nosecone.

- **D.6** 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.7** 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.8** 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.9** A safety factor of 2 will be used on the descent of the rocket, allowing it to land under 75ft-lbf in the case that the payload does not deploy and the drogue parachute is tangled.

- **D.10** Draft for reports shall be completed 1 week before given deadline. In order to provide sufficient time to ensure high quality and professionalism of reports.

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. Will be verified by test launch.
D.2 Maximum vehicle weight of 40 lbs.	Verified through inspection of design	Complete. Total vehicle weight of 32 lbs.

Requirement	Verification Plan	Status
D.3 Maximum damage criteria (outlined above) are not exceeded.	Verified by inspection upon landing.	In Progress. Test launches and payload prototype tests will be used to identify any damage resulting from flight and impact.
D.4 Removable door on avionics bay.	Verified through inspection of design.	Complete.
D.5 Clear vision out of our nosecone.	Verification by inspection and by testing camera identification through the nosecone.	In Progress. Footage from sub-scale flight has been analyzed. Upcoming tests planed using sub-scale nosecone to further study target identification.
D.6 All 3 legs must unfold.	Verified through demonstration at launch/test launch.	Not Started. Payload prototype to be completed ASAP and tested.
D.7 All payload parachutes are successfully released and unfolded.	Verified through demonstration at launch/test launch.	Not Started. Payload prototype to be completed ASAP and tested.
D.8 Payolad lands within 20 degrees of perpendicular to the ground.	Verified through visual inspection upon recovery.	Not Started. Payload prototype to be completed ASAP and tested.
D.9 Factor of safety of 2 for kinetic energy of vehicle upon landing.	Verified through OpenRocket simulations, hand calculations, and test launch. Calculations for the impact of the payload upon landing can be viewed below.	In Progress. OpenRocket simulations and calculations have already been completed, but a full scale test has yet to be completed.
D.10 Draft for documents completed 1 week prior to deadline.	Verified through demonstration. Report Compiling lead will be responsible for ensuring all sub-teams are on schedule and meet this deadline.	In progress, updated timelines and updated report compiling processes have been made to reflect these deadlines.

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	$0.00	$0.00		
	Motor	2	$188.00	$376.00		
	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		
					$ 1,530.08	
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		
					$ 1,221.00	
Electrical						
	GPS - Eggfinder GPS System	2	$ 100.00	$ 200.00		
	Gyro - Sparkfun Triple-Axis Digital-Output Gyro ITG-3200 Breakout	2	$ 25.00	$ 50.00		
	Accelerometer - SparkFun Triple Axis Accelerometer Breakout - LIS331	2	$ 10.00	$ 20.00		
	Microprocessor - Raspberry Pi	1	$ 35.00	$ 35.00		
	Camera - 8MP Raspberry Pi Camera Module	2	$ 30.00	$ 60.00		
	Altimeter - Missile Works RRC3	1	$ 70.00	$ 70.00		
	PCB Printing	2	$ 30.00	$ 60.00		
					$ 495.00	
Payload system						
	48' T-Track Rail	1	$ 30.98	$ 30.98		
	Landing Leg Frames (3D Printed)	3	$ 12.00	$ 36.00		
	Torsion Springs	6	$ 2.50	$ 15.00		
	Shear Pins (Separation of Payload)	4	$ 5.00	$ 20.00		
	Hex Bolts/Misc. Hardware	1	$ 30.00	$ 30.00		
	Aluminum (Support Legs)	1	$ 25.00	$ 25.00		
	L Bracket Mounts	6	$ 3.00	$ 18.00		
	Dowel Pins (Pkg qty 5)	1	$ 8.03	$ 8.03		
	Conical Compression Springs	3	$ 5.21	$ 15.63		
	Rubber Sheet	1	$ 6.72	$ 6.72		
	Misc Subscale Testing Materials (Wood, Gas Springs, etc.)	1	$ 40.00	$ 40.00		
					$ 245.36	
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	
						$ 3,680.94
Transportation to launch site						
	Equipments shipping	1	$ 417.23	$ 417.23		

	Travel budget	18	$ 600.00	$ 10,800.00		
						$ 11,217.23
Misc.				$ 500.00		
GRAND TOTAL						**$ 14,898.17**

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	\$1,000.00
Student Opportunity Fund	\$3,000.00
Total	**\$8,505.33**
Materials Budget	\$3,680.94
Balance	\$4,824.39

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

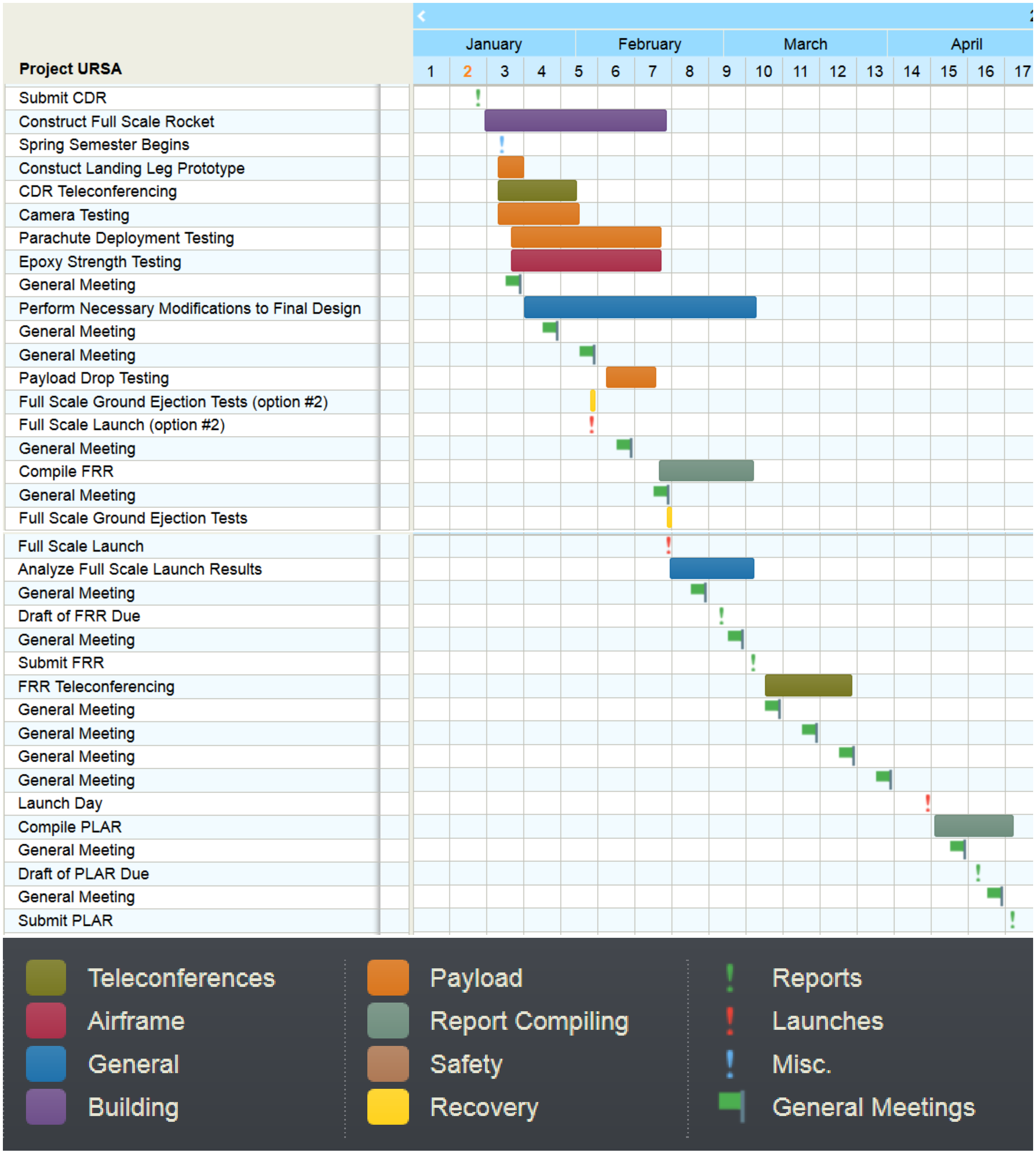
Private Corporations:

1. We will apply for funding from SpaceX and Northrop Grumman in late January.

University Sponsorships: We plan to apply for sponsorships from various UC Berkeley organizations in the Spring Semester:

1. UC Berkeley Mechanical Engineering Department
2. Engineering Student Council
3. AAVP Grant

7.3.4 Timeline



Appendix A Member List

Name	Primary Duties
Aaron	Outreach, Payload, Safety
Adam	Recovery, Co-Vice President
Allen	Recovery
Avyay	Payload, Co-Vice President
Brunston	Payload, Electronics
Carly	Payload, Outreach
Danny	Recovery
Darren	Recovery
Dinesh	Electronics
Grant	Safety Officer
Ilyas	Airframe
Jacob	Electronics
Jamie	Safety, Payload
Jia	Budget, Funding
Jordan	Airframe, President
Juan	Airframe
Kevin	Airframe, Webmaster, Club Historian
Nate	Payload, Electronics
Ryan	Reports Compilation
Sean	Airframe
Tushar	Airframe

Appendix B Members Attending Competition

The following team members will attend launch week in April.

Name	Primary Duties
Adam	Recovery, Co-Vice President
Allen	Recovery
Avyay	Payload, Co-Vice President
Brunston	Payload, Electronics
Carly	Payload, Outreach
Danny	Recovery
Dinesh	Electronics
Grant	Safety Officer
Ilyas	Airframe
Jacob	Electronics
Jamie	Safety, Payload
Jordan	Airframe, President
Juan	Airframe
Kevin	Airframe, Webmaster, Club Historian
Nate	Payload, Electronics
Ryan	Reports Compilation
Sean	Airframe
Tushar	Airframe

Appendix C Recovery Computer Programs

C.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 to land with a given
    Kinetic Energy'''
    return math.sqrt((2*(KEmax)*ftlbf_to_lbmft2persec2)/mass)
    #returns ft/s

def payload(pl):
    '''this gives the ft^2 (area) needed for the parachute'''
    return para_area_v_cd(pl,
                          KEmax_to_vmax(float(input('KE(ft-lbf):')), pl),
                          float(input('coefficient of drag:')))

def drogue_main():
    pl = float(input('payload weight (lbm) -->'))
    av = float(input('avionics bay weight (lbm) -->'))
    btr = float(input('booster weight (lbm) -->'))
    #pl = 9.489
    #av = 4.083
    #btr = 11.483

    #heaviest weight is:
    hv = float(eval(input('HEAVIEST SECTION put "btr", "av", "pl" \
                          (no quotes) or a number -->')))
    total = pl + av + btr

    ##################################################################
    #drogue parachute################################################
```

```
Cd1 = 1.5 #coefficient of drag for Drogue
drogue_vmax = 73 + (1 / 3)#input('max velocity for drogue (ft/s)->')

drogue_area = para_area_v_cd(total, drogue_vmax, Cd1)
drogue_radius = math.sqrt(drogue_area/math.pi) #given in ft

print("drogue is diameter " \
      + 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
safety_factor = float(input('safety factor of \
                (should be between 0 and 1) -->'))
KEmax = safety_factor * KEmax



vmax = math.sqrt((2*(KEmax)*ftlbf_to_lbmft2persec2)/hv)

print("vmax: " + str(vmax))


#calculating the main parachute size ######################################
Cd2 = 2.2

#----------------------------------------------------------------
#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
        break
    elif yn == "n":
        m = total
        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 is diameter " + str(main_diameter_in) + " inches")
print("decided on drogue of " + str(final_drogue_diameter_in) +
            " inches")
```

C.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);
```

C.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.
```

Appendix D Safety Agreement

It is a particular interest and duty of the safety team to ensure that requirements of safety codes and regulations are met when constructing, assembling, and launching a rocket. To abide by these regulations, and in order to maintain overall safety, each team member must follow these rules:

1. Before any launch, pay attention to the pre-launch and safety briefings.
2. At any launch of our main rocket (not sub-scale), stay at least 200 feet away from the launch site when the rocket is ready to launch, and focus on safety.
3. When constructing the rocket, always wear appropriate clothing (no loose clothing near machinery and power tools) and proper personal protective equipment (PPE), and make sure to read relevant MSDS data sheets.
4. If there is any confusion over how to use a tool or machine, ask a more experienced person for help.
5. Always follow instructions of launch officers at a launch site, including the Range Safety Officer.
6. If our rocket does not pass a safety inspection or does not meet all relevant safety requirements, then we must comply with the determination of the inspection and not launch the rocket.
7. Before a launch the team's Safety Officer and team mentor, along with the Range Safety Officer, have the right to deny the launch of our rocket for safety reasons.

Furthermore, each member must agree to abide by all of the following codes and regulations, at the direction of the safety team:

1. NAR High Power Safety Code
2. FAA regulations, including 14 CFR Subchapter F Part 101 Subpart C
3. NFPA 1127

The team as a whole agrees to abide by the following regulations from the Student Launch Handbook:

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Any team member who does not agree to any of the rules above may be refused access to rocket construction or assembly, may not be allowed to attend launches, or may even be removed from the team if necessary.

Appendix E NAR High Power Rocket Safety Code

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the off position when released. The function of on-board energetics and firing circuits will be inhibited except when my rocket is in the launching position.

5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming on-board energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket[8]) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000