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

December 29, 2016

[1]Upright Recovery and Sight Acquisition

Contents

1 Summary

1.1 Team Summary

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1.2 Launch Vehicle Summary

Our launch vehicle has a total length of 97", with a total weight of 29.25 lbs pre-motor burnout and 25.06 lbs post-burnout. The selected motor is an Aerotech L1150, which has a burn time of 3.1 seconds, total impulse of 791 lbf-s, and a diameter of 2.95". The recovery system utilizes a total of five parachutes: one drogue, one main, and three payload parachutes. Respectively, we will be using a 24" Elliptical Parachute, an Iris Ultra 72" Compact Paracute, and 3 42" Elliptical Parachutes, from Fruity Chutes. The altitude for deployment is measured by two altimeters (Missileworks RRC3 and Perfectflite Stratologger CF). The parachutes will be deployed using 4F black powder, placed in plastic vials.
Further information can be found in the Milestone Review Flysheet on our team website.

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 Acquisition** and **Upright Landing**. The payload section of the vehicle consists of the upper 18" of the airframe, as well as the partially transparent nose cone. A Raspberry Pi camera, mounted in the nose cone, views the ground during descent to identify and differentiate colored ground targets. After Target Acquisition has been completed, the payload section will be ejected from the vehicle, and three landing legs built into the airframe will be deployed to form an upright tripod. The landing legs will be fixed to the airframe via spring-loaded hinges and sliding aluminum rails. The deployment of the legs will cause the deployment of three parachutes mounted underneath the nose cone. This deployment procedure will bring the payload section down under an independent recovery system to land on the landing legs, achieving Upright Landing.

2 Summary of Changes made since Proposal

2.1 Project Plan

Our project plan has undergone few changes since the proposal. They include: setting a deadline of December 3rd, 2016 for the launch of our subscale rocket at the LUNAR launch site at Snow Ranch, and pushing back our schedule for systems testing to take place in November.

2.2 Launch Vehicle

The following features have been modified since the Proposal:
The vehicle no longer contains a transition from a 4" diameter to 6"; rather, the entire vehicle has a diameter of 6". This reduces the difficulty of construction, while better distributing the forces on the airframe. The nose cone has also been modified in order to simplify construction: rather than being fully transparent, it will consist mostly of fiberglass, with a clear polycarbonate tip for the camera. Fiberglass will be used for the fins, as their structural benefits outweight the associated construction difficulties.

The booster section of the vehicle has also been modified. The space in between the motor mount and the airframe walls will be filled with styrofoam in order to prevent the casing from rotating. The manner in which the fins are connected to the booster section has been revised: the fins will extend through the airframe walls down to the motor mount, where they will be glued/epoxied to the mount. The centering rings on the motor mount will be placed such that they contact the edges of the fins, adding two more points of contact for bonding. Additionally, fillets made from carbon fiber strips and epoxy will be used to create a joint between the fins and the airframe walls. Epoxied carbon fiber cloth will extend from the top of the fins down to the motor casing to further increase strength.

2.3 Payload

The payload experiment is largely similar to that presented in our Proposal. The payload consists of a Raspberry Pi camera mounted in the nose cone, which has a transparent tip through which the camera can view the ground. Three landing legs, each consisting of a 3D printed frame attached to cut-out sections of the airframe wall, attached to the base of the payload section via rotating hinges, are loaded using torsion springs.

The following features have been modified since the Proposal: The legs will be held in place until deployment using 1/2" rods pulled by 12V solenoids. The actuation of the solenoids will be staggered, so that the legs deploy sequentially rather than simultaneously. As in the Proposal, the parachutes will be deployed via being pulled out by the legs - however, the parachute compartments will additionally contain spring-loaded blocks to assist in pushing the parachutes out of the vehicle. The hinges and bulkhead at the base of the legs will be mounted 2" from the bottom of the payload section tube, rather than 6" from the bottom (above the payload-to-avionics bay coupler). This will be achieved by cutting slots into the coupler to provide space for the hinges, and consequently reinforcing the coupler with an additional inner tube (doubling the thickness).

2.4 Recovery

There are two primary changes to the recovery system: 1) the switch to a same-sided parachute deployment and 2) the adoption of a two rod non-rotating sled in the avionics bay.

Rather than having the drogue chute and main parachute separated by the avionics bay, and splitting the rocket into three independent sections before the deployment of the payload (nose cone/payload, avionics bay, and boosters), both chutes will be housed on the aft side of the avionics bay, splitting the rocket into two sections (boosters and the rest of the rocket). The main justification is to separate the rocket into fewer components, providing more flexibility in the design of the payload deployment. This requires that the drogue chute will be pulled out first with the first black powder charge, unsheathing the covered main chute, which will be tethered to the U-bolt on the back of the avionics bay. The main chute will then be deployed separately at roughly 1000 ft. above ground level.

After much deliberation, we have decided to implement a dual rod sled design to house the altimeters in the avionics bay rather than having the rotating altimeter platform described in the Proposal. The primary justification is that implementing the door design of the avionics bay – which is still included – would sacrifice some of the structural integrity of the airframe. Removing a rod for a single rod rotating altimeter platform concentrates all the stress on the centering rod, further reducing the structural integrity of the rocket. Thus, in order to compensate for the loss created by the door, we are re-implementing the dual rod sled.

Finally, the kinetic energy, velocity, and black powder charge calculations have been refined to more accurately reflect the current specifications of the rocket design.

3 Vehicle Criteria

3.1 Selection, Design, and Rationale of Launch Vehicle

3.1.1 Nose Cone

The nose cone subsystem consists of the payload section and camera electronics. Our original design called for a nose cone constructed out of transparent polycarbonate, in order to be able to see out of the nose using a camera. It is necessary to have vision out of the nose in order to complete our target identification experiment. After much discussion, we concluded that a fully polcarbonate nose cone would be too difficult to manufacture accurately. Instead, the nose cone will be made using a pre-made fiberglass nose cone with a base diameter 6”. The tip of this pre-made nose cone will be cut off, and a vacuum-formed polycarbonate piece with an approximately ogive profile will be inserted in its place. This simplifies the construction issues and still provides the functionality that is required.

We considered many other alternatives as well, including changing the shape of the nose cone to conical. This would make it significantly easier to construct; however, it would reduce our apogee by 225 ft. (from 5697 ft. to 5471 ft.). This was not an acceptable outcome and therefore was eliminated from contention.

Also, we considered using a fiberglass nose cone and cutting a window out from the side. This would be simpler for construction and would preserve our predicted apogee. However, this would limit the range of the camera. By looking out of the side of the nose cone, there would be a limited view and there would be no guarantee that the ground targets could be identified.

Another alternative that was considered was having a hinged tip in the nose cone. This model would have a full fiberglass nose cone, except that the tip would be removed and then reconnected using a hinge with a servo motor. This would allow us to preserve apogee, ease of construction, as well as visibility. The major issue with this alternative was the unreliability of the servo motor. If the motor fails, then the entire mission fails. Furthermore, a removable tip could also be considered an independent section and would need its own recovery system. This is an unnecessary risk and therefore was also removed from contention.

3.1.2 Body Tube

The body tube subsystem consists of the three sections of tubing, connected by couplers, that house the avionics bay. To connect our different body tube sections, we will use BlueTube couplers that are 6" in length and 0.1" in thickness. For the body tube material, we considered a number of different alternatives, ranging from carbon fiber and fiberglass to quantum tubing and polycarbonate. While carbon fiber offers excellent tensile strength, its extreme brittleness meant that any failure would be catastrophic, and its high cost left very little room for manufacturing failure with our budget. In addition, carbon fiber can interfere with radio signals. Fiberglass was the next best alternative with high tensile strength and heat resistance. However, manufacturing posed the biggest challenge as it required a method of applying sufficient and even pressure along a cylindrical surface. The construction process also required careful application of epoxy to prevent air bubbles that could compromise structural integrity. After factoring in cost, we decided to search for cheaper and easier alternatives. Offering a favorable combination of strength, low cost, and manufacturability, quantum tubing became the next best option, and it would have been our material of choice if not for its low heat resistance. In the end, we selected BlueTube as our body tube material, as it offered nearly the same strength and ease of manufacture but at a lower cost, and with greater heat resistance.

Initially, our design included a transition from a 6" diameter to a 4" diameter section in order to reduce both the weight of the rocket and the wake produced by airflow around the airframe. However, after reconsideration, we redesigned our rocket without the transition piece. Since one of our limiting constraints is a 6" diameter payload, a 4" diameter rocket was not possible, so instead, we set the diameter at 6" throughout the entire airframe. This new design offers many advantages. For one, adding a transition piece adds another point of stress on the airframe, and presents a new set of challenges involving material, strength, cost, and manufacturing. By eliminating the transition piece from the design entirely, we can avoid potential problems with installing a launch lug on the 4 inch diameter section as well as difficulties manufacturing the transition piece. The removal of the transition piece also makes assembly easier, while at the same time creating more space within the airframe for other components of the rocket.

3.1.3 Booster

The booster subsystem of the airframe consists of the body tube, motor mount, engine block, centering rings, and fins. Three centering rings, constructed from plywood, will be placed at 9" intervals, with the first ring placed flush with the bottom of the body tube. Partly due to its reputation as a common material, we chose kraft phenolic for the motor mount since it offers high heat resistance, which is an essential property of the motor mount to protect the surrounding airframe from warping and melting due to the heat of the engine as it burns. The base of the motor mount will extend to 1" below the base of the body tube. We came to a consensus on this feature because it reduced the exposed surface area of the bottom of the rocket, reducing the wake produced by airflow over the airframe while also opening up extra space in the airframe for other components of the rocket.

The fins will be constructed from fiberglass and will be attached through-the-wall to the motor mount, so that it fits inside pre-cut fin slots in the airframe and attaches to the motor mount itself as well as the centering rings for increased structural integrity. To increase the strength of fin attachment to the airframe, kevlar strips will be glued down the sides of the fin and along the motor mount. This will increase the surface area that the epoxy has access for adhesion, resulting in a stronger bond and decreasing the risk of breaking fins both during the rocket's flight and upon landing. Carbon fiber fillets will also be added where the fins are inserted through the body tube to double the fins adhesion to the rocket. Although fin shape is not a critical factor in determining the rockets stability, selecting the proper planform does offer aerodynamic advantages. We considered using an elliptical planform, which offers the most aerodynamic efficiency compared to our other alternative, the clipped delta. However, the clipped delta offered a much easier manufacturing process along with a very small difference in aerodynamic performance. For these reasons, we decided to use the clipped delta shape as our fin planform. To finish, styrofoam will be inserted and fixed inside the space between the body tube and the motor mount mainly to prevent torsion of the motor mount, but it also serves to act as an insulator to absorb the heat of the motor during flight. Figure 1 and Figure 2 show the exterior and interior views of the booster section.

Figure 1: External View of Booster Section

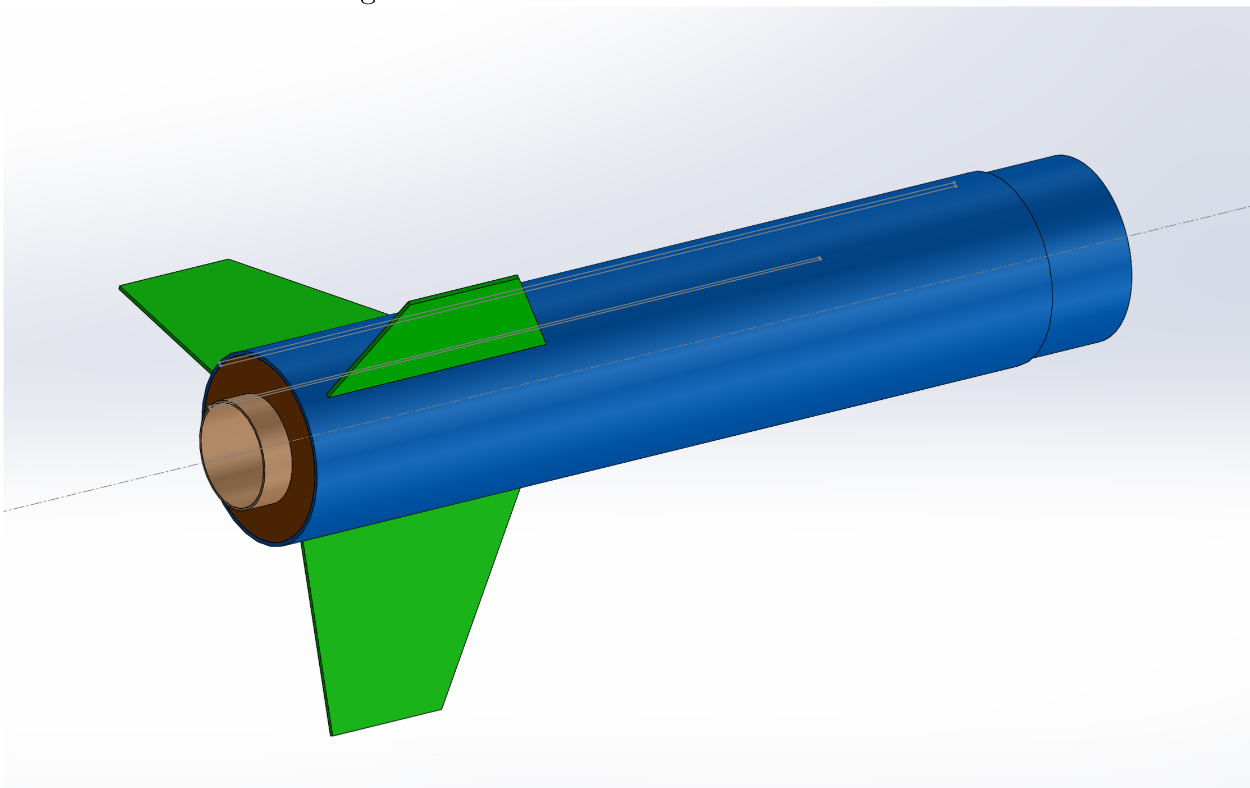
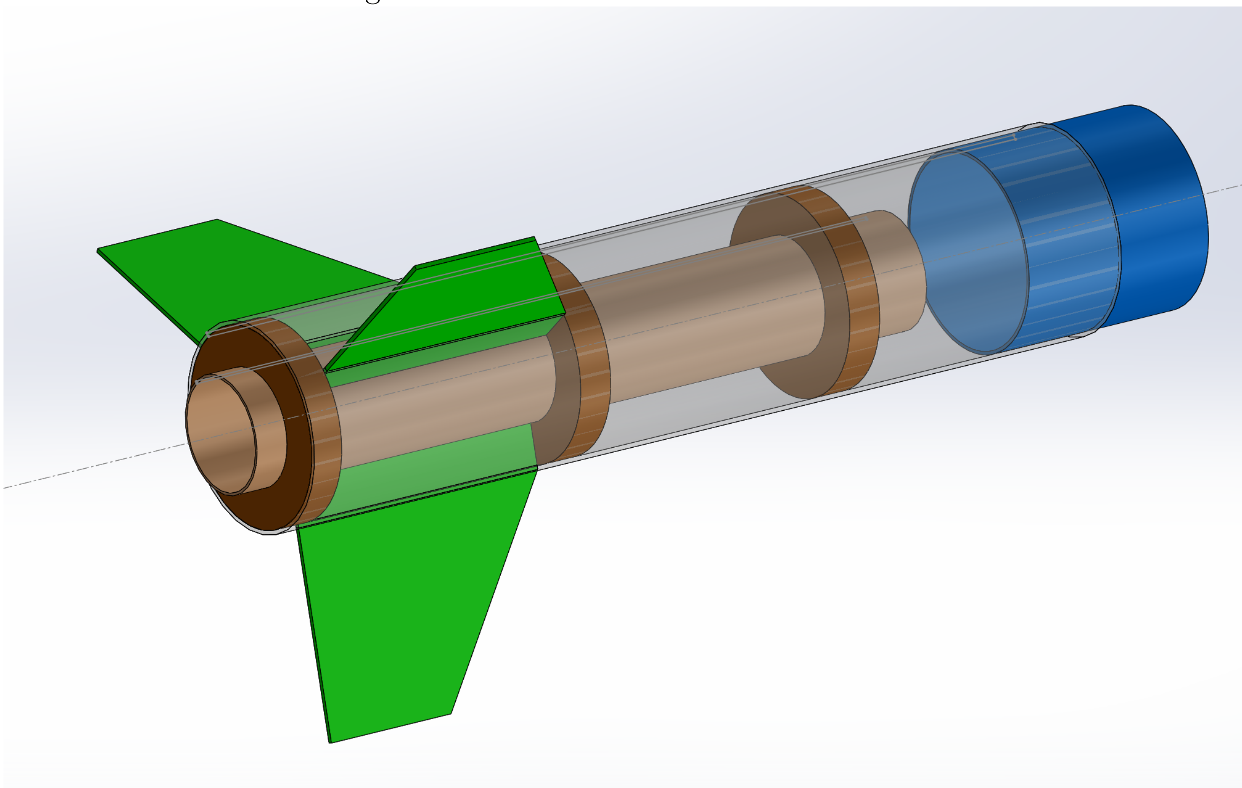


Figure 2: Internal View of Booster Section



3.1.4 Final Design and Schematic

The main airframe will be constructed from 6" diameter blue tube, with a thickness of 0.106". The nose cone will be constructed from fiberglass, and the tip of the nose cone will be shaped from clear polycarbonate. The fins will be made from fiberglass and will be attached to the airframe using fillets made of a carbon fiber/epoxy mixture. The fins will be approximately 0.125" thick. Hollow blue tube couplers connect each individual section. The couplers are 6" in length and connect the nose to the payload, the payload to the avionics bay, the avionics bay to the recovery section, and the recovery section to the booster. The couplers are also made from blue tube, and are 0.146" thick. The empty spaces in between the motor casing and airframe walls will be filled with styrofoam to prevent the motor casing from rotating.

The payload section has a total length of 36" (including the 18" nose cone), and weighs approximately 9.5 pounds. This measurement includes the exterior tubing of the payload as well as the interior components. The fins have a root chord length of 8", a tip chord of 4", and a height of 6". The remainder of the mass is in the rest of the airframe and the recovery parachutes. The booster section is 27" in length and weighs approximately 14 pounds including the motor. The motor itself is approximately 8 pounds. The recovery section is 18" in length and weighs approximately 1 pound. The avionics section is 15" in length and weighs approximately 3 pounds. Figure 3 shows the fully dimensioned schematic of the rocket.

The payload section contains a flight computer, a camera, a set of landing legs, and three recovery parachutes. The avionics bay contains the altimeter, GPS, and other sensors. The recovery section includes both the drogue parachute and the main parachute. The booster section contains the motor. The three fins are attached to the booster section one inch from the aft side.

3.1.5 Motor Alternatives

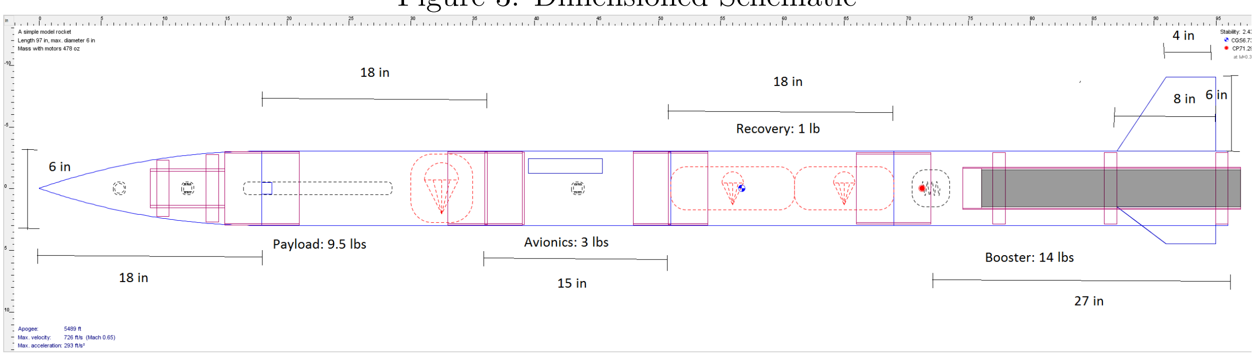
Currently, the motor we plan to use is an Aerotech L1150. This motor provides 790 lbf-s of impulse and an average thrust of 259 lbf.

The justification for choosing this motor mainly involves the estimated apogee. With this motor, simulations show that the rocket will reach an apogee of approximately 5600 feet. Although this measure is extremely close to the maximum allowed height, we predict that the final weights of various components in the rocket, especially in the payload section, will be greater than predicted due to various factors in manufacturing. As a result, our true apogee will be closer to the target of 5280 ft. Because of this, the Aerotech L1150 motor is highly desirable. Aerotech motors are also easily available online and Aerotech is one of the most popular motor manufacturers.

Previously, we had decided on using an Aerotech K1050 motor. However, our estimates of the rocket's weight have increased since the proposal, and as a result, the K1050 was no longer sufficient.

Overall, the Aerotech L1150 provides enough impulse to reach our desired apogee with enough breathing room to add additional weight to our rocket.

Figure 3: Dimensioned Schematic



4 Recovery Subsystem

4.1 Recovery Components

4.1.1 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.

Figure 4: Parachutes Comparison

Designs	**Benefits**	**Costs**
Current: Detachable Door • ⅓ of the circumference	• Accessible	• Can't access back of platform, unless using a rotating altimeter platform (RAP)
Removable Frame	• Easy access to any component, regardless of the internal layout of the avionics bay	• Have to take apart rocket to access • Huge loss of structural integrity
No Door, completely sealed	• More structural integrity	• Could compromise mission if quick access to avionics bay is needed at launch site

Decision: Based on the costs and benefits of each option, we believe toroidal is the best option. A smaller parachute of this type can yield 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 pamera in payload can collect its data. We have thus decided on using a 24" drogue chute and a 72" main chute. Both the drogue chute and main chute will be located in a tube connecting the avionics bay and the booster component. The main chute will be 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 will be 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 will be 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 would removed the bag from the main chute.

4.1.2 Shock Cords

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

Figure 5: Shock Cord Comparison

Designs	**Benefits**	**Costs**
Current: Tubular Kevlar	• Very durable • Can hold high amounts of strain • Lighter than strap nylon	• More expensive per yard ($4.34/yard)
Strap Nylon	• Cheaper per yard ($1.87/yard)	• Not as durable • More massive

Decision: For our shock cords, we chose to use the tubular kevlar cord because it has more durability and can handle higher amounts of strain compared to the strap nylon. Despite the higher price, we agreed that the higher cost would be worth the increase in safety.

4.1.3 Avionics Bay: Internal

Description: For the internal components of our avionics bay, this chart compares the two options, a traditional sled design and an alternative using a rotating platform.

Figure 6: Internal Components Comparison

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

Decision: We initially thought of trying to create an alternative platform for the avionics bay, RAP (see alternatives). However, after thorough analyses and debate, we have decided to not adopt the RAP design over the sled. Though we favored using the RAP, we deemed that it sacrificed too much of the structural integrity at minimal benefit (when the wires are connected, the platform would only be able to rotate as much as the wires would give). Furthermore, since we have already decided on incorporating a door, which would already compromise the structural integrity of the airframe, it would be excessive – and far too risky – to reduce the internal rods from two to one.

4.1.4 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.

Figure 7: External Components Comparison

Designs	**Benefits**	**Costs**
Current: Detachable Door • ⅓ of the circumference	• Accessible	• Can't access back of platform, unless using a rotating altimeter platform (RAP)
Removable Frame	• Easy access to any component, regardless of the internal layout of the avionics bay	• Have to take apart rocket to access • Huge loss of structural integrity
No Door, completely sealed	• More structural integrity	• Could compromise mission if quick access to avionics bay is needed at launch site

Decision: After careful consideration, we have decided to use a door on our avionics bay in order to allow ease of access to electronic devices on and off the launch field. We planning on having our door span 1/3 of the tube circumference in order to allow access to electronics without losing too much structural integrity. Although not having a door maximizes the structural integrity of the airframe, we believe that having access to electronics outweighs this cost. We will maintain the integrity of the airframe by using stronger bulkheads and distributing forces onto the threaded rods that hold the altimeter platform in place. We have decided against the removable frame, as the loss of structural integrity will be too great, as well as the possibility of air flowing into the avionics bay in unwanted areas that could cause the altimeters to malfunction.

4.1.5 Deployment Device

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

Figure 8: Deployment Device Comparison

Designs	**Benefits**	**Costs**
Current: Black Powder System • 4F in plastic vials	• High energy can break strong shear pins • Extremely lightweight • Cost effective	• Messy, blurs camera lens • Potential for damage to rocket from heat
CO_2	• Team is able to purchase, store, and handle CO_2 devices without mentor supervision • No residue from charges • No need for heat blankets on parachutes	• Potential for rupture of CO_2 canisters • Higher weight • More expensive

Decision: Analyzing the cost and benefits of each option, we will be using 4F black powder housed in plastic vials to deploy our parachutes. In efforts to minimize cost, we decided that the black powder will suffice over the CO2 canisters, though this requires our certified team mentor to help process the purchase. Logistically, black powder is lighter and will help with the maximum kinetic energy limitation. One risk in using black powder is that for alternative camera placements close to an charge location, the residue may blur the visual perceptions of the camera; however, this danger is less than the risk that the CO2 ruptures and fails to deploy the parachute or deploys the parachute too early.

4.1.6 Bulkheads

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

Figure 9: Bulkhead Comparison

Designs	**Benefits**	**Costs**
Current: Fiberglass reinforced plywood • ¼ inch	• Lightweight • A hybrid, incorporating the ease of manufacturing plywood and the durability of fiberglass	• Would need to create the hybrid ourselves
Plywood	• Lightweight • Ease of manufacturing using laser cutters	• Possibility of ply separation
Aluminum	• Extremely strong	• High weight
3D Printed	• Ability to manufacture multiple bulkheads on short notice • Very lightweight	• Brittle
Fiberglass	• Very strong	• Expensive • Difficult to manufacture

Decision: In order to protect the avionics bay from the sheer impact of parachute deployment and the abrasive force of black powder explosions, we have decided to adopt a fiberglass reinforced plywood bulkhead. To be more specific, we will use one 1/4" thickness bulkhead fitted for the coupler diameter. We chose these materials rather than the others because fiberglass reinforced plywood is not only light, but extremely durable. Other materials such as aluminum, which is far too heavy, and 3D printed resin, which is too brittle, would not be able to deliver this combination of strength and durability.

4.1.7 Bolts

Description: To provide the maximize strength and stress distribution, we have decided on adopting U-Bolts on each bulkhead.

Figure 10: Bolt Comparison

Designs	**Benefits**	**Costs**
Current: U-Bolts on each bulkhead	• Stronger • Greater stress distribution as a result of the two connections to the bulkhead	• Requires two holes, which if not sealed properly, might increase risk of air pressure fluctuations mid-flight
Eye-Bolts	• Lighter • Only need one hole per bulkhead	• Not as strong as the U-Bolt • Most likely thinner than U-bolt

Decision: In order to optimize structural integrity, we will adopt the dual-rod design.

4.1.8 Center Rods

Description: We plan on adopting the dual-rod design in order ensure the avionics bay portion of the airframe is as structurally stable as possible. Each rod will most likely be made out of aluminum, or some aluminum-based material, because of the durable properties of aluminum. Each rod will be around in diameter and threaded all the way through. Furthermore, the rods will be driven through the platform itself, in order to ensure that it doesnt move during flight.

Figure 11: Center Rod Comparison

Designs	**Benefits**	**Costs**
Current: Dual Rod • ¼'' diameter	• Double the structural integrity • Distribution of stress • Better sled support	• Two times as heavy
Single Rod	• Less weight	• Would probably need a thicker diameter rod • Not as structurally build

Decision: In order to distribute the stress and force of thrust during launch, we have decided to use the U-Bolt instead of the Eye-Bolt. Attaching a U-Bolt to each bulkhead, most likely positioned between the two protrusions from the two center rods, would provide for a much more sturdy avionics bay.

4.1.9 Comprehensive Avionics Bay Analysis

The avionics bay is a critical component of the recovery subsystem. The avionics bay will be 6" in diameter and 16" in length, excluding the length of the shoulders extending out from both ends. The external frame will be made out of blue tube, with three holes of 0.2535" diameters to expose the altimeters to air pressure. Furthermore, there will be 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 will be composed of 1/4" thick fiberglass coated plywood. Each bulkhead will have a U-bolt screwed with nuts and washers to tether the shock cords. The bulkheads will also be 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 will run through the platform from bulkhead to bulkhead. This will provide 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 will be running 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 Figures 12-15.

Figure 12: Avionics Bay

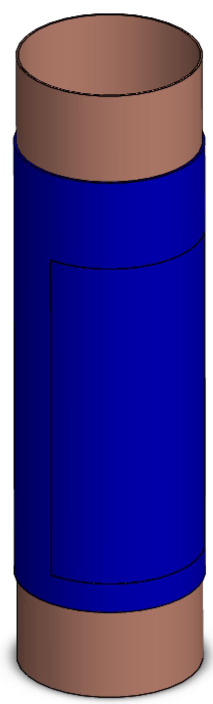


Figure 13: Avionics Bay Without Door

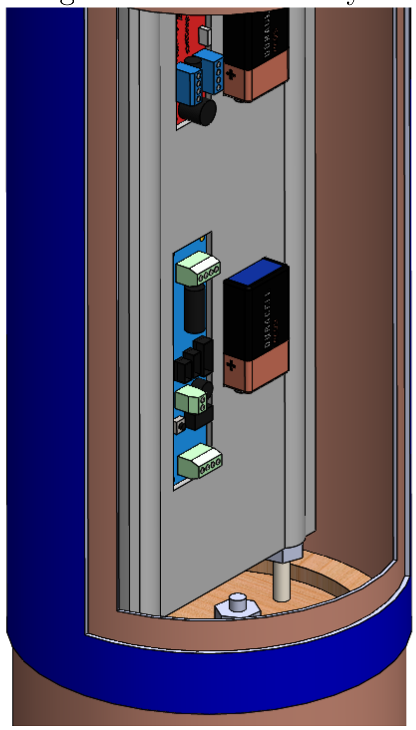


Figure 14: Avionics Bay Internal View

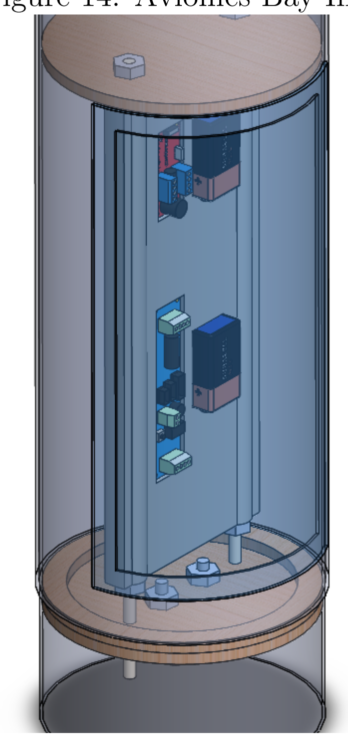
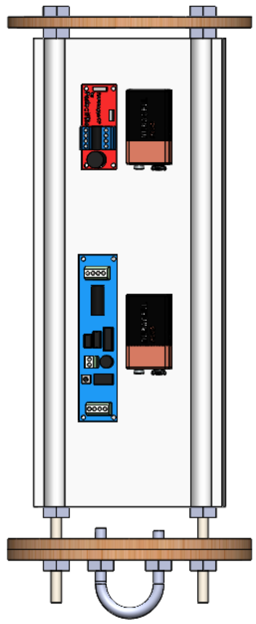


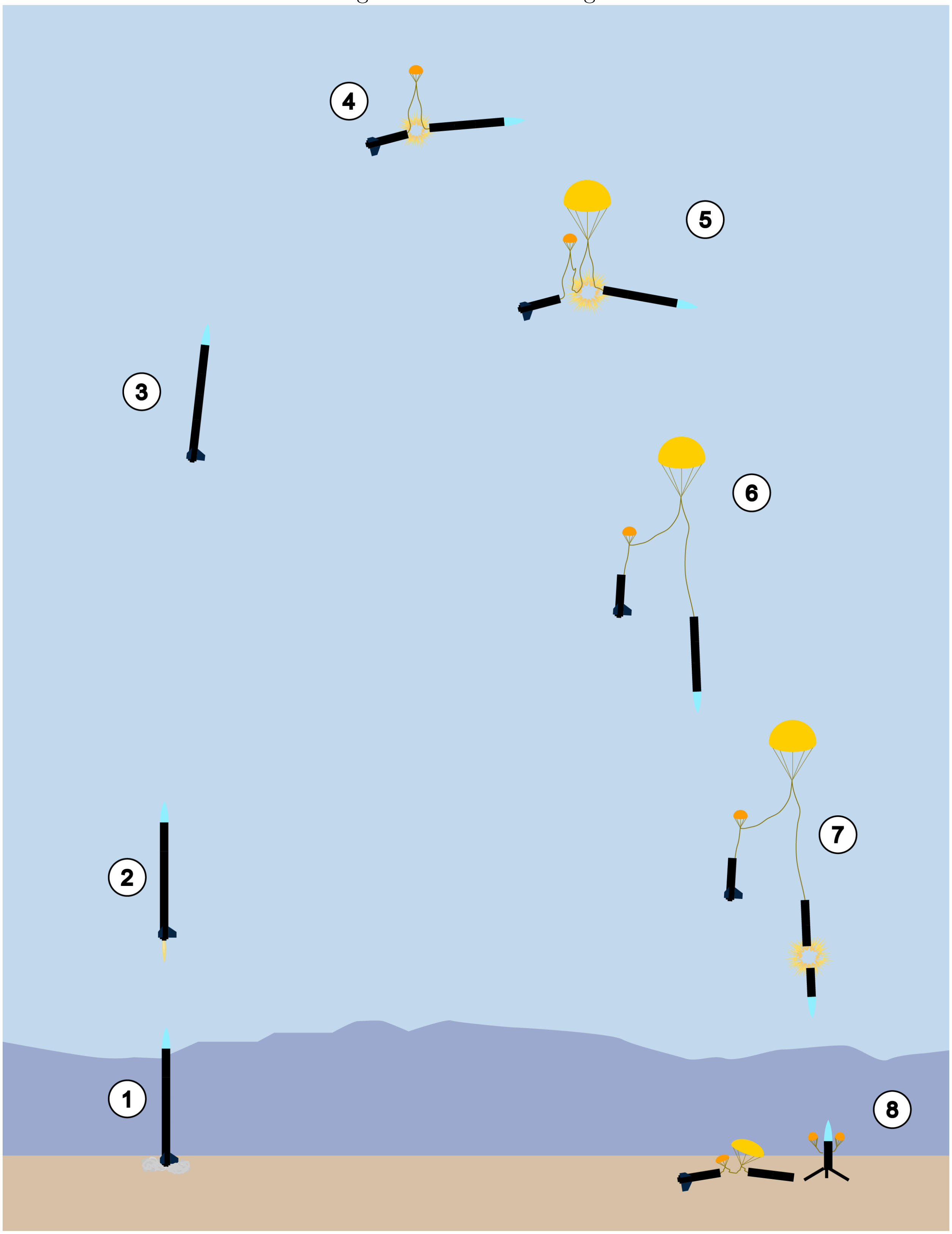
Figure 15: Altimeter Sled and Bulkheads



4.2 Flight Plan

Our flight plan is laid out in Figure 16:

Figure 16: Phases of Flight



Phase	Event
1	Ignition.
2	Powered flight.
3	Coasting.
4	Drogue parachute deployed at an apogee of 5567 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.

4.3 Avionics Bay Static Pressure Port Calculations

In order to equalize pressure within the avionics bay so that the altimeters can read the altitude, we will need a inch diameter hole cut out the airframe for every 100 cubic inches of volume. We can use the equation:

$$A = V\frac{A_ref}{V_ref}$$

Where A is the area that we need to cut out of the airframe, V is the internal volume of the avionics bay, A_ref is the area of a inch diameter hole, and V_ref is 100 cubic inches[3].

$$A = \pi r^2 L \cdot 0.00049087in^-1$$

The internal length of our avionics bay is 12", and the internal diameter is 5.72".

$$A = 0.514in^2$$

We will be using three holes so that none of them are too close to the launch rail on liftoff. We can now calculate the area and diameter of each hole.

$$d_{hole} = 0.2535in$$

Thus, we will need three holes of 0.2535" in diameter for proper pressure equalization.

4.4 Black Powder Calculations

To deploy the parachutes we will be using two altimeters. Our main altimeter is the Perfectflite Stratologger CF Altimeter. We will be using the MissileWorks RRC3 Altimeter for 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. Once we know the force necessary to break the shear pins, we can use the following equations:

$$P = \frac{F}{A}$$

The internal volume of the rocket is

$$V = \pi r^2 L,$$

where r is the radius of the rocket and L is the internal length between bulkheads. From the ideal gas law $PV = NRT$ we get

$$N = \frac{PV}{RT},$$

where $R = 266$ in lbf/lbm and $T = 3307°$ R. Thus

$$\begin{aligned} N &= \frac{F}{\pi r^2} \cdot \frac{\pi r^2 L}{(266 \text{ in lbf/lbm})(3307° \text{ R})} \cdot (454 \text{ g/lbf}) \\ &= 5.161 \cdot 10^{-4} \text{ FL} \end{aligned}$$

The above equation will give us the necessary black powder in grams.

We will use four, 4-40 nylon screws as shear pins. Each pin takes roughly 40lbf to be sheared.

$$F = 160lbf$$

The internal length of the tube that holds the parachute is 24".

$$L = 24in$$

Thus,

$$N = 1.98g$$

To be certain that the shear pins will be broken, we will increase the amount of black powder by a factor of 1.5. This gives us

$$N = 2.97g$$

4.5 Kinetic Energy and Drag Equations

See subsubsection 4.5.1 for a drawing of the forces described in this section. The following equations are used to calculate the sizes of parachutes necessary to land each part with a kinetic energy less than 75 ft-lbf:

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

$$F_D = \frac{1}{2}\rho C_d A v^2$$

Two drag forces are produced since the rocket is slowed by both the drogue and main parachutes:

$$F_{drogue-chute} = \frac{1}{2}\rho C_1 A_1 v^2 \text{ and } F_{main-chute} = \frac{1}{2}\rho C_2 A_2 v^2.$$

All pieces are connected, so their velocities will be the same; thus to determine the maximum velocity, only the kinetic energy of the heaviest section (m_2) must be considered, because the other sections are lighter and will have less kinetic energy:

$$v_{max} = \sqrt{\frac{2 \cdot 75 \text{ ft} \cdot \text{lbf}}{m_2}} \cdot \sqrt{\frac{32.174049 \text{ lbm} \cdot \text{ft}}{1 \text{ lbf} \cdot \text{s}^2}}$$

Since the payload will detach and then land on its own, with its own parachute, the total mass the parachutes must handle is significantly reduced:

$$m_1 + m_2 = m_{total(w/o\ payload)}$$

Terminal velocity will be the maximum velocity, attained when the gravitational and drag forces are equal:

$$m_{total(w/o\ payload)}g = \frac{1}{2}\rho v_{max}^2 C_1 A_1 + \frac{1}{2}\rho v_{max}^2 C_2 A_2,$$

$$v_{max}^2 \leq \frac{k \cdot \frac{1}{2} KE_{max} \text{ lbm} \cdot \text{ft}^2}{m_2 \cdot \text{s}^2},$$

Where k is the conversion factor from lbf to lbm.

$$k \approx 32.174049$$

So then we have the following restriction on parachute areas:

$$C_1 A_1 + C_2 A_2 = \frac{m_{total(w/o\ payload)}g}{\frac{1}{2}v_{max}^2 \rho}$$

The restriction is an upper limit, therefore kinetic energy can be lower, and by extrapolation, velocity ca
 - and we can substitute the value of v_{max}^2:

$$C_1 A_1 + C_2 A_2 \geq \frac{m_{total(w/o\ payload)}g m_2}{75 \text{ ft}^2 \cdot \text{lbm/s}^2 \cdot \rho k}$$

In order to land with a KE less than 75 ft-lbf the two parachutes' coefficients of drag and area must fit the inequality above.

Size Calculations:

- Payload: 9.489 lbm
- Avionics: 4.083 lbm
- Booster: 11.483 lbm
- Total Weight - Payload: $m_{total(w/o\ payload)} = 15.566$ lbm

- Heaviest component = Booster = m_2 = 11.483 lbm

Drogue Chute Size:

Optimally the main parachute deploys at a speed less than 50 mph or 73 ft/s. The drogue parachute will be slowing the descent of the payload as well so the weight we use for the equations is m_{total} = 25.055 lbm. Terminal velocity will be

$$v_t = \sqrt{\frac{2m_{total}g}{\rho C_1 A_1}},$$

which gives us the inequality

$$73\ \frac{1}{3}\text{ft/s} \geq \sqrt{\frac{2m_{total}g}{\rho C_1 A_1}}$$

Given the values g = 32.174 ft/s^2, m_{total} = 25.055 lbm, ρ = 0.0765 lbm/ft^3, and $C_1 = 1.5$, we then solve to get

$$C_1 A_1 \geq 3.919 \text{ ft}^2$$

$$A_1 \geq 2.613 \text{ ft}^2$$

$$\pi r_1^2 \geq 2.613 \text{ ft}^2$$

$$r_1 \geq 0.912 \text{ ft}$$

$$d_1 \geq 1.824 \text{ ft} = 18.038 \text{ in}$$

A drogue parachute of 24" with $C_1 = 1.5$ and $A_1 = 3.14$ ft^2 has $A_1C_1 = 4.71$ ft^2 and will allow for a descent rate slower than 73.33 ft/s. We will be using the 24" Elliptical Parachute from Fruity Chutes.

Main Chute Size (based on 24" drogue chute):

With the previous equations and the coefficient of drag and area for the drogue chute, we can calculate the necessary size of the main chute with the following equation, where $m_{total(w/o\ payload)}$ is used because the payload detaches.

$$C_1A_1 + C_2A_2 \geq \frac{m_{total(w/o\ payload)}gm_2}{75\text{ ft}^2\text{ lbm/s}^2 \cdot k\rho}.$$

With our heaviest component being 11.483 lbm, our maximum velocity required to have every component land with less than 75 ft-lbf is 20.501 fps. We have decided, however, to increase our safety margin by reducing our landing velocity to 15 fps.

$$C_1A_1 + C_2A_2 = \frac{m_{total(w/o\ payload)}g}{\frac{1}{2}v_{max}^2\rho}$$

Given the values g = 32.174 ft/s^2, $m_{total(w/o\ payload)}$ = 15.566 lbm, ρ = 0.0765 lbm/ft^3, C_1A_1 = 4.71 ft, $C_2 = 2.2$, and v_{max}^2 = 15 ft/s, along with the inequality $C_2A_2 \geq 53.4826$ ft^2, we get

$$\pi r_2^2 \geq 24.3103 \text{ ft}^2$$

$$r_2^2 \geq 7.7382 \text{ ft}^2$$

$$r_2 \geq 2.782 \text{ ft}$$

$$d_2 \geq 5.564 \text{ ft} = 66.76 \text{ inches}$$

Thus, we need a parachute with a diameter of at least 66.76" for every part of the rocket to land with a velocity of 15 fps (a velocity lower than 20.501 fps allows each component to land with KE less than 75 ft-lbf). In order to roughly land at 15 fps we will be using an Iris Ultra 72" Compact Parachute from Fruity Chutes.

Final Kinetic Energy:

The rocket, given the 24" drogue parachute and the 72" main parachute, will land with velocity given by the following equation:

$$v_{max}^2 = \frac{m_{total(w/o\ payload)}g}{\frac{1}{2}(C_1A_1 + C_2A_2)\rho}.$$

Given $C_1A_1 = (1.5)(3.14 \text{ ft}^2) = 4.71 \text{ ft}^2$ and $C_2A_2 = (2.2)(28.27 \text{ ft}^2) = 62.203 \text{ ft}^2$, we end up with

$$v_{max} = 13.988 \text{ ft/s}.$$

The kinetic energy of each component at landing is

$$KE = \frac{0.5mv^2}{32.174049}.$$

Thus we end up with the following kinetic energies at landing:

- Avionics and Transition: 4.083 lbm, KE = 12.416 ft-lbf
- Booster: 11.483 lbm, KE = 34.918 ft-lbf

Payload Parachute:

After the payload detaches, it also needs to deploy its own parachutes and land with less than 75 ft-lbf.

$$v_{max} = \sqrt{\frac{2 \cdot 75 \text{ ft lbf}}{m}} \cdot \sqrt{\frac{32.174049 \text{ lbm ft}}{1 \text{ lbf s}^2}}$$

$$v_{max} = \sqrt{\frac{2 \cdot 75 \text{ ft lbf}}{9.489 \text{ lbm}}} \cdot \sqrt{\frac{32.174049 \text{ lbm ft}}{1 \text{ lbf s}^2}}$$

$$v_{max} = 22.552 \text{ ft/s}$$

In order to help stabilize the payload, we will have 3 parachutes for the payload and try to land with a slower velocity of 15 fps.

$$3C_3A_3 \geq \frac{m_{payload}g}{0.5v_{max}^2\rho}.$$

With $m_{payload} = 9.489$ lbm, $g = 32.174$ ft/s^2, $\rho = 0.0765$ lbm/ft^3, $C_3 = 1.5$, it follows that

$$3C_3A_3 \geq 35.474ft^2$$

$$\pi r_3^2 \geq 7.883 ft^2$$

$$r_3 \geq 1.584 ft$$

$$d_3 \geq 3.168 ft = 38.0177 in$$

In order for the payload to land with a velocity of 15 ft/s with 3 identical parachutes, it will need 3 parachutes of 38.0177". We will be using 3 42" Elliptical Parachutes from Fruity Chutes.

$$v_{max}^2 = \frac{m_{payload} g}{\frac{1}{2}(3C_3A_3)\rho}$$

$$v_{max} = 13.578 \text{ ft/s}$$

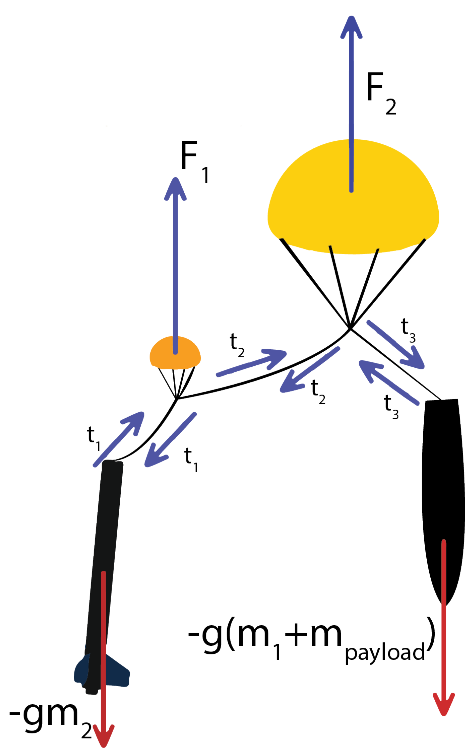
$$KE = \frac{0.5mv^2}{32.174049}$$

$$KE = 27.1856 \text{ ft lbf}$$

4.5.1 Maximum Static Force on Shock Cords

Since the drogue parachute is released at apogee, there wont be a sudden exertion of drag force. The greatest force on each component will be when the rocket reaches terminal velocity with the drogue parachute out and the main parachute is deployed.

With the main parachute providing most of the force, the shock cords should exert forces roughly straight up and straight down with the main parachute at the very top and the two masses at the very bottom.



Note: Tension forces point more vertically in real life. Calculations will reflect this.

$$v_{terminal} = \sqrt{\frac{2m_{total}g}{\rho C_1 A_1}}$$

$$F_1 = m_{total}g$$

$$F_1 = 806.1195\frac{lbmft^2}{s^2}$$

$$F_2 = \frac{1}{2}\rho\frac{2m_{total}g}{\rho C_1 A_1}C_2A_2$$

$$F_1 = 10646.084\frac{lbmft^2}{s^2}$$

The total acceleration of the system will be dependent on F_2 because the force of gravity and F_1 will be in equilibrium at terminal velocity.

$$\text{Acceleration of the system} = \frac{F_2}{m_{total}} = 424.908\frac{ft}{s^2}$$

The largest static tensile force (right after the main parachute is released) will be t_1 and t_3 which can be calculated by finding the necessary tensile force that needs to be applied in order to get the correct acceleration.

$$\frac{F_2}{m_{total}} = \frac{t_3 - g(m_1 + m_{payload})}{m_1 + m_{payload}}$$

$$(\frac{F_2}{m_{total}} + g)(m_1 + m_{payload}) = t_3$$

$$\frac{F_2}{m_{total}} = \frac{t_1 - gm_2}{m_2}$$

$$(\frac{F_2}{m_{total}} + g)(m_2) = t_1$$

$$t_3 = 666.833\frac{lbmft^2}{s^2} \qquad t_1 = 564.194\frac{lbmft^2}{s^2}$$

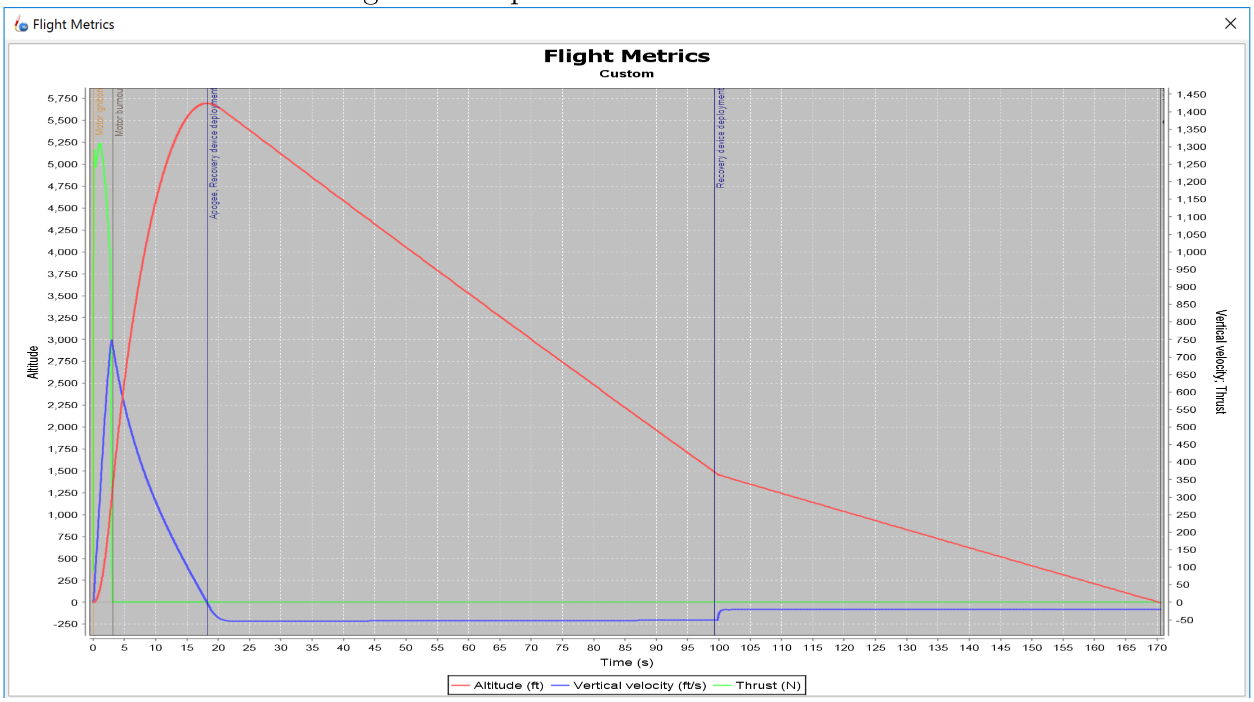
$$t_3 = 20.726ftlbf \qquad t_1 = 17.535ftlbf$$

4.6 Mission Performance Predictions

The projected altitude of the rocket is 5697 ft. Although this projection is currently above the maximum allowed altitude, we predict that some sections of the rocket may ultimately be heavier than our current prediction, particularly the payload. Additionally, ballast can be added to the rocket in order to increase weight and reduce apogee. Also, changes to the construction of the nose cone are likely to significantly increase the drag coefficient of the rocket, further reducing apogee.

The maximum velocity of the rocket during flight is Mach 0.67. The maximum acceleration is 9.3 G's, and the motor provides a maximum thrust of 292 lbf. Our flight simulation results are illustrated in Figure 17.

Figure 17: OpenRocket Simulation Results

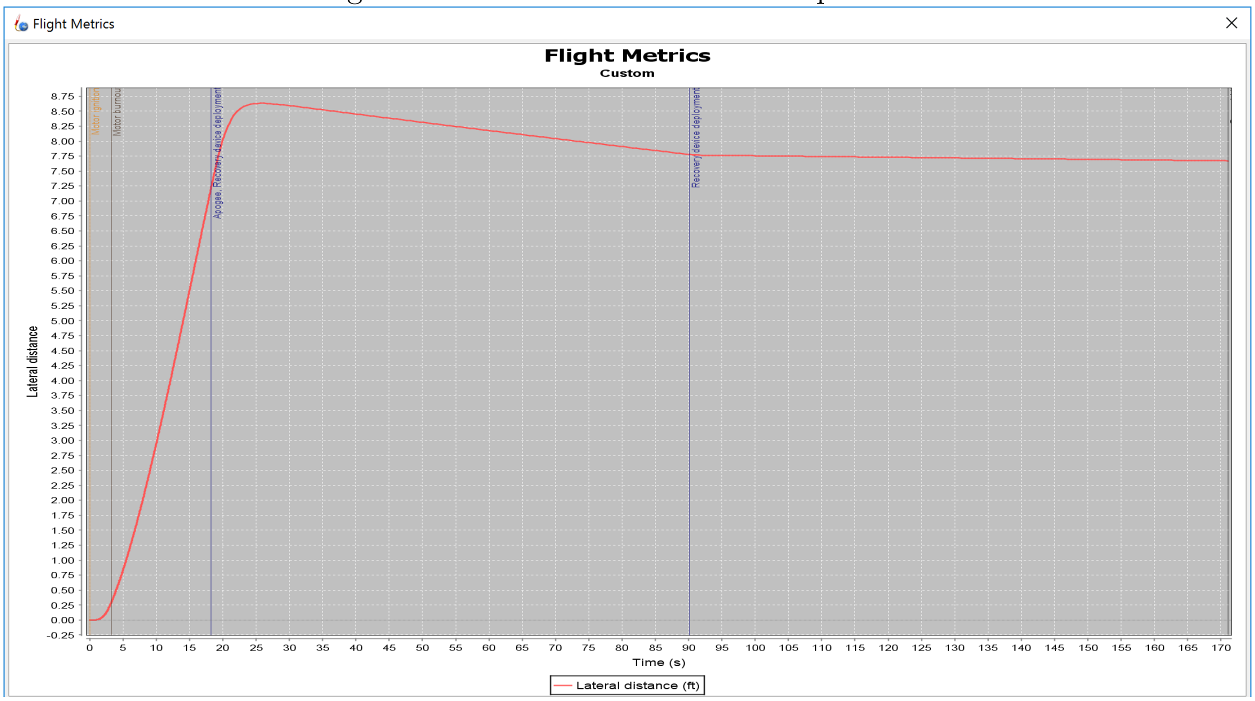


The mass of the payload section is projected to be 9.5 pounds. The mass of the avionics bay is projected to be approximately 2.25 pounds. The remainder of the rocket, including the rest of the airframe, the motor, and the parachutes are projected to weigh approximately 17.5 pounds. The total weight of the rocket is 29.25 pounds.

The static stability margin is calculated to be 2.34 calibers. The center of pressure is located 71.3" from the tip of the nose, and the center of gravity is located 57.2" from the tip of the nose.

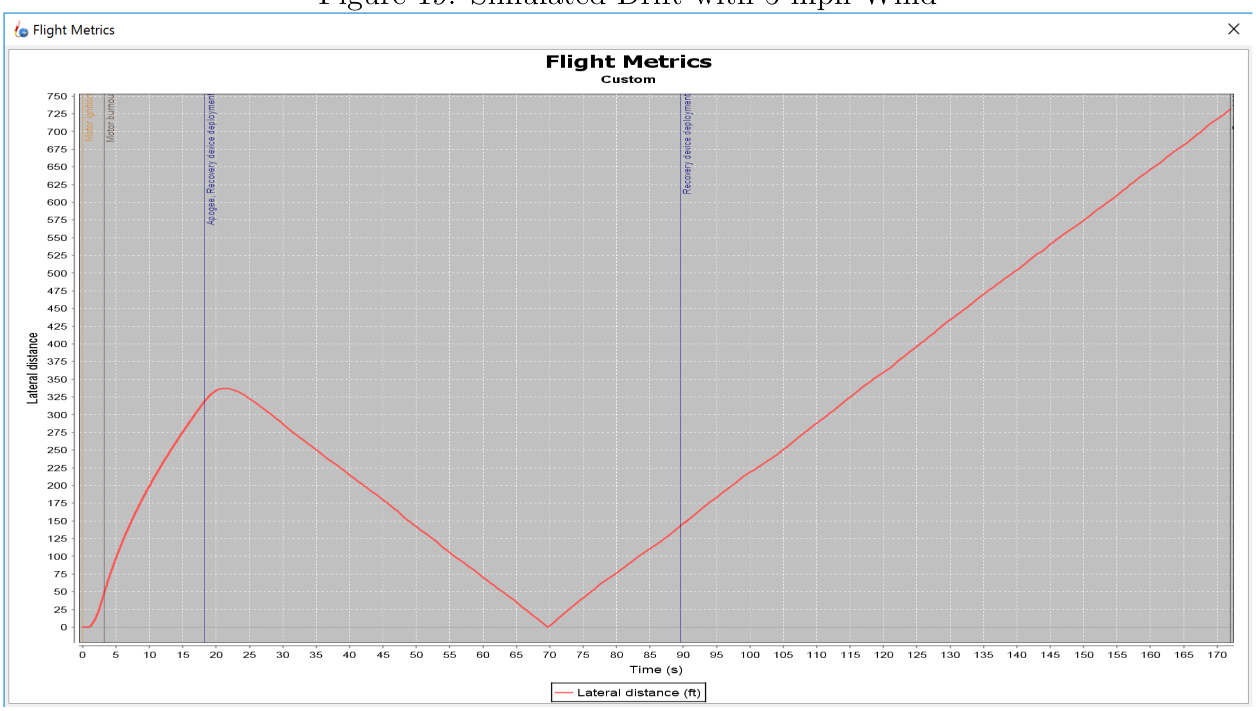
The total drift of the rocket with no wind is approximately 7.75 ft.

Figure 18: Simulated Drift with 0 mph Wind



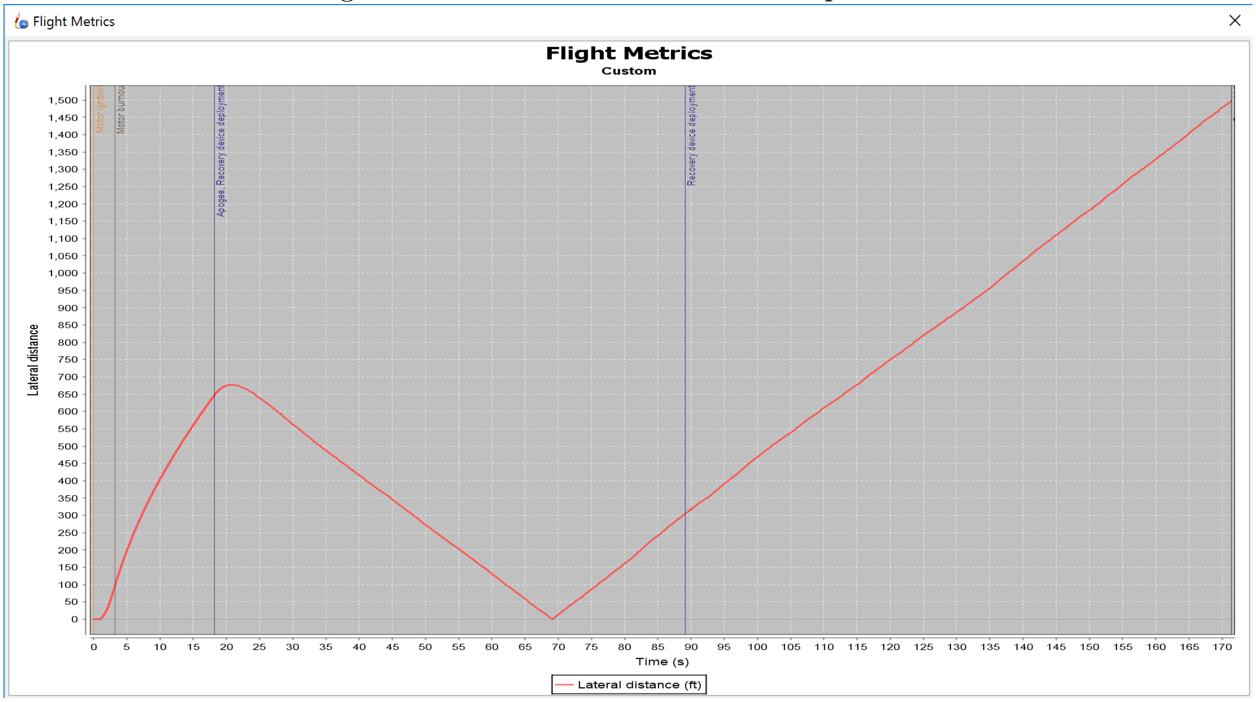
The total drift of the rocket with 5 mph wind is approximately 750 ft. (Fig. 19).

Figure 19: Simulated Drift with 5 mph Wind



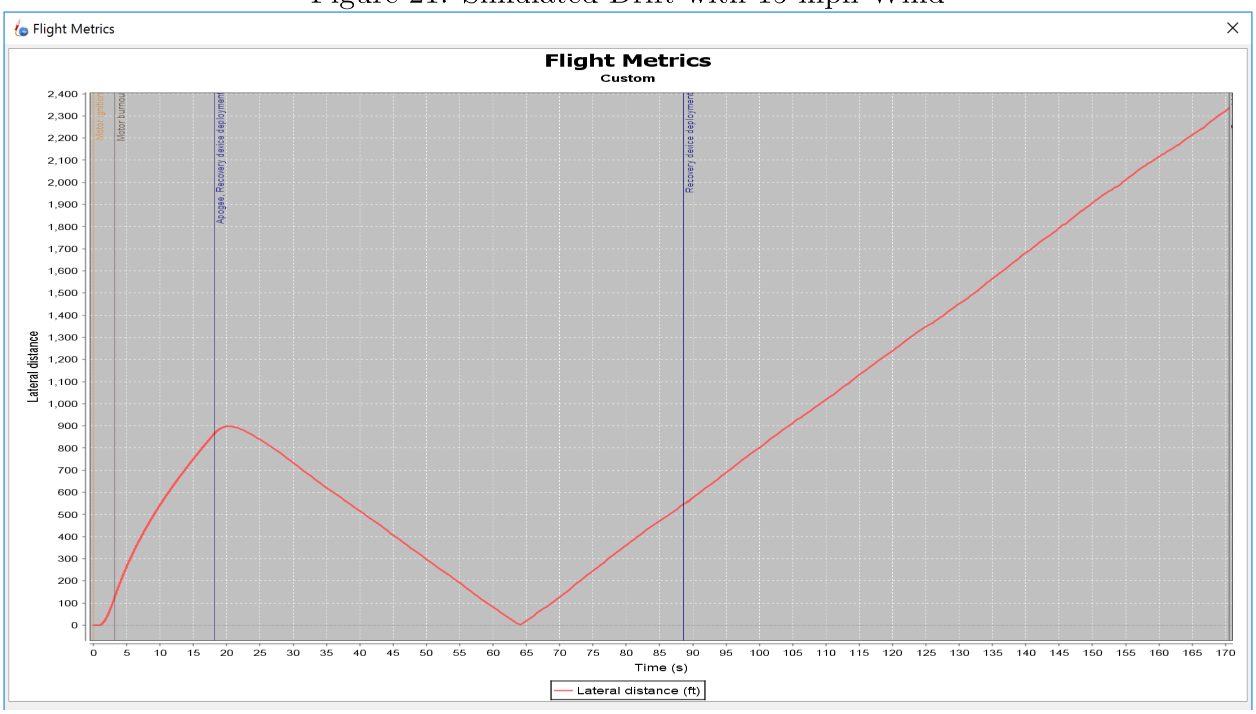
The total drift with 10 mph wind is approximately 1450 ft. (Fig. 20).

Figure 20: Simulated Drift with 10 mph Wind



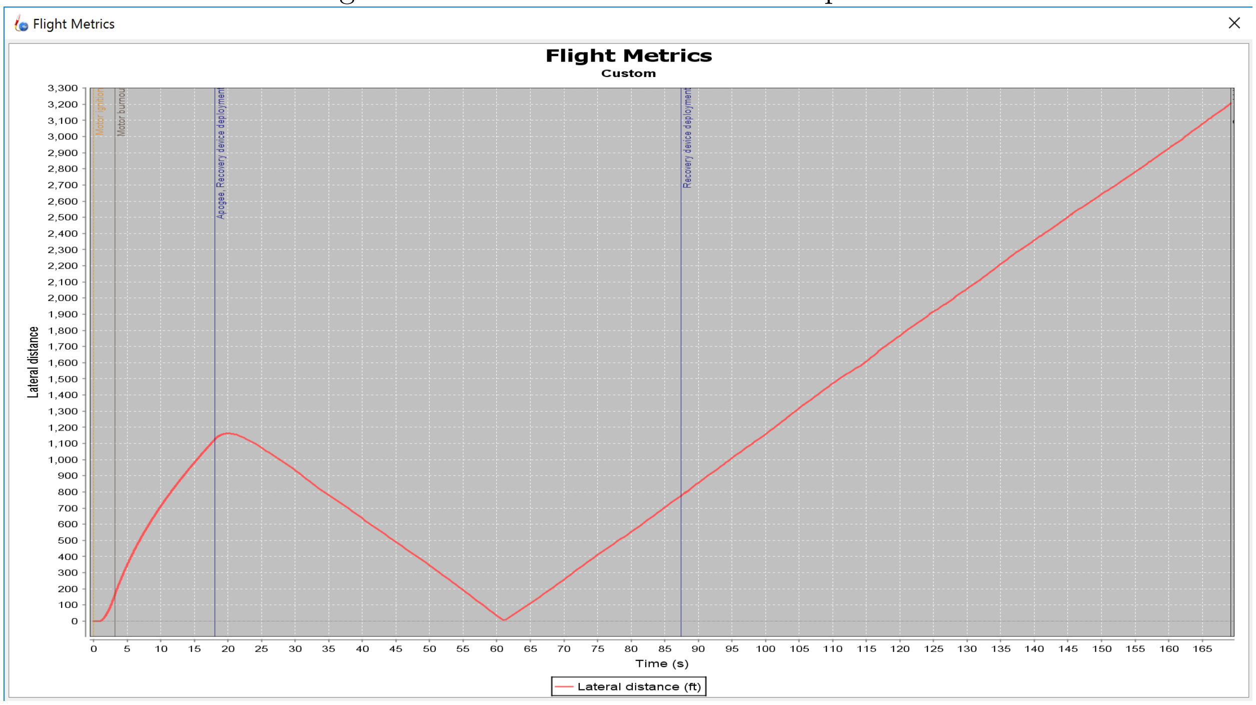
The total drift with 15 mph wind is approximately 2300 ft. (Fig. 21).

Figure 21: Simulated Drift with 15 mph Wind



The total drift with 20 mph wind is approximately 3200 ft. (Fig. 22).

Figure 22: Simulated Drift with 20 mph Wind



5 Safety

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

- Maintaining hazard analyses, team procedures, and safety protocols.

- Conducting pre-launch briefings and hazard recognition and accident avoidance briefings.

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

5.2 Checklists

These checklists are preliminary and details are liable to change before the Critical Design Review. We will likely add more items to the Materials & Components list, and might reorder some items in the Assembly and Launch checklists.

5.2.1 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 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:
   (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:
   (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) Stuff parachutes into the parachute section.
   (k) Connect parachute section to the booster section.
3. Payload:
   (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:
   (a) Connect payload section to avionics and booster sections.
   (b) Verify couplers are sufficiently tight, and can hold the entire weight of the rocket.

5.2.2 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 C.
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.

Launch Checklist

1. Verify the stability of the rocket: is it safe to fly?
2. 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, and 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. "Ensure that no person is at the pad except safety personnel and those required for arming and disarming operations." [NAR HPRSC]
7. Install electrical motor igniters.
8. Test igniter continuity.
9. Ensure no person is closer to the launch pad than the distance specified in field (3): minimum personnel distance.
10. Count down at least 5 seconds, and then launch the rocket.

11. In case of misfire, remove the launchers 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.

5.3 Personnel Hazards Analysis

The CalSTAR safety subteam does not envision any major safety issues with any of the team personnel. Certainly the risks below may occur, but we expect that proper training and safety reviews will mitigate all of the risks and allow for safe construction, assembly, and launch of the sub-scale and full-scale rockets. All construction will be carried out only by experienced and university-trained team members, and our mentor or other certified adults will handle hazardous materials whenever possible. Thus we expect team members to be exposed to a minimal number of possible hazards.

Furthermore, our team has MSDS documents available online at the team website (at https://stars.berkeley.edu/sl.html) for team members to read and use. We have MSDS for many of more hazardous materials we will be working with, and encourage all team members to understand the documents fully. We do not have operating manuals for machinery on our team website, but all team members who UC Berkeley manufacturing facilities (such as the Etcheverry Hall ME Student Machine shop or the Jacobs Hall MakerSpaces) must complete stringent training, which cover topics such as proper operating and handling of machinery and all safety protocols. Jacobs Hall does have operating manuals online, and all team members who use the equipment in Jacobs Hall should be familiar with these manuals.

Risk	Effects	Severity & Likelihood	Mitigations
Inadvertent launch before rocket is at launch pad and site is clear	Possibility of major injury to team members or bystanders from physical contact with the rocket or its exhaust	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.

Risk	Effects	Severity & Likelihood	Mitigations
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.

Risk	Effects	Severity & Likelihood	Mitigations
Exposure to hazardous materials/chemicals (in particular fiberglass, epoxy, spray paints)	Skin, eye, and/or respiratory irritation; coughing or, in severe cases, lung damage and reduced respiratory capability	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.

Personnel Hazards Analysis

5.4 Failure Modes and Effects Analysis

This is not a comprehensive list of failure modes, but we expect that these failure modes are the most likely and problematic, so we have considered how to address these issues in particular.

We have separated the failure modes analyses into multiple sections, each particular to one vehicle subsystem.

Airframe Failures Modes

Risk	Causes	Effects	Severity & Likelihood	Mitigations

Rocket altitude does not reach desired range of 5280 ft	Inaccuracy of OpenRocket model; weather conditions at launch	Significant loss of points	E3	Use OpenRocket to ensure vehicle will reach range at a variety of given wind conditions; verify accuracy of calculations with hand calculations and results of sub-scale and full scale launch
Fins are damaged on landing to the point where vehicle is no longer flight capable	Impact of rocket with ground	Rocket loses launch capability	E3	Use 3/16 fiberglass fins to ensure strength; fillet with West Systems epoxy and chopped up carbon fiber covered with teflon to both motor case and body
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 insure no deformations
Frame becomes compromised	Severe impact or other external forces	Instability during flight; failure to meet ready-to-fly condition after landing	D2	Perform structural analysis on material to ensure that structural integrity is not severely affected during flight; ensure all parts of rockets are intact and free of any imperfections that might occur during shipment

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; use styrofoam to fill space between motor mount and body tube to absorb torsional forces
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

Payload Failures Modes

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Shear on leg hinges during deployment	Excessive force on one leg	Possible upright landing failure	C3	Use hinges that can withstand more force than anticipated from our stress analysis of the system.
No chute ejection	Parachutes stuck inside compartments due to poor packing or cords unwinding without pulling parachute	Destruction of rocket and possible injury to bystanders	E2	Implement redundancy in the system with two mechanisms that will eject parachute and test these mechanisms. In particular, use springs to aid in ejecting parachutes.
Parachute lines tangle	Simultaneous deployment and close proximity of parachutes	Parachutes lose effectiveness, and rocket lands with greater than 75 ft lbf.	D3	By releasing the legs at different times, the parachutes have a smaller chance of tangling after ejection. Apply staggered deployment, and test this.
Legs don't deploy	Failure of pin actuation due to software failure or more friction on the pin than the solenoid can counteract	No chute ejection and possible destruction of rocket	E2	Test electronic pin system and ensure that the solenoids are capable of actuating pins against friction due to spring torque.
Legs or leg hinges break upon landing	Excessive force on one leg	Damage to engine section such that the rocket cannot fly again. Possible upright landing failure.	B2	Use hinges and legs that can withstand more force than anticipated from our stress analysis of the system.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Incomplete uprighting	Uneven terrain or a strong crosswind	Upright landing failure	B4	Sufficiently long legs and a slow enough descent speed will lower the risk of an incomplete upright landing. Test the validity of the system during small-scale testing.
Sliding rails get stuck	Misaligned or dirty leg rail system	Damage to engine section such that the rocket cannot fly again. Possible upright landing failure	B2	Test leg deployment to ensure legs are capable of full and smooth extension (aided by copious application of WD-40).

Recovery Failures Modes

Risk	Causes	Effects	Severity & 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.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
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; Tinder 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 altimeters 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.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Deployment charges are not sized properly	Rocket is either damaged from too large of ejection charge or parachutes are not deployed from too small of ejection charge	Black powder was not accurately allocated for each charge region	E2	Perform several ground tests to be sure that charges will deploy chutes.
Shock cords snap at deployment	Sections of the rocket descend without parachute, damaging the rocket and potentially injuring bystanders	Minor cut to begin with; force of rocket is 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.

Electronics Failures Modes

Risk	Causes	Effects	Severity & 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).

Risk	Causes	Effects	Severity & Likelihood	Mitigations
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.

Risk	Causes	Effects	Severity & Likelihood	Mitigations

Launch Operations Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Altimeters are not set up correctly	Incorrect wiring, incorrect mode set on altimeter, incorrect calibration	Black powder detonation before launch, or failure of payload ejection and parachute deployment	E2	Test altimeter setup before launch and verify correct wiring and altimeter mode.
Motor does not ignite	Improper installation of igniter, slow burn, electrical delay	Failure to launch the rocket, injury to nearby personnel if motor ignites after a delay	B3	Per the NAR High Power Rocket Safety Code, remove the launcher's safety interlock and then wait 60 seconds after a motor misfire before approaching the rocket.
Improper installation of rocket on launch rail	Misalignment of launch rail buttons, launch rail is bent or not smooth	Launch rail negatively affects flight path of rocket	C2	Visually inspect the launch rail and rocket rail buttons and verify that there are no burrs, bumps, bends, etc.
Premature black powder detonation	Altimeter gives false reading due to improper setup	Possible injury to nearby personnel, possible damage to rocket components	D2	Verify several times that all altimeters have correct settings and are correctly wired.
Couplers are loose	Couplers were not machined correctly to specifications	Rocket may come apart on the launch rail or in flight	C3	Verify that couplers are tight enough by lifting the rocket and ensuring that no part falls off the bottom. If couplers are loose, then add tape around the coupler.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Landing legs are not secure and held in place	Landing leg pin actuation failure due to software or mechanical issues	Landing leg may suddenly swing up possibly strike any nearby personnel	C2	Tie a rope around the landing legs and payload section once the landing legs are secured at the section walls, so that in case of pin actuation failure the rope will inhibit any motion of landing legs.
Cord is not properly wrapped around payload parachutes	Insufficient understanding of how to properly wrap cord around parachutes	Parachute may fail to deploy	D3	Design explicit and detailed procedure in the Assembly Checklist for wrapping cord around parachutes.

5.5 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 manufacturers 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.

5.6 Project Risks and Consequences Analysis

This section contains logistical risks (typically money and time, rather than mechanical failure of devices).

Payload Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Payload construction falls behind schedule	Lack of materials; Lack of effort; Lack of clear schematics	Does not affect subscale launch, will use weight substitute	C4	For prototype construction, make sure a strict schedule is laid out and that design is completed
Payload goes over budget	Parts too expensive or too many mistakes and redos required	Does not affect subscale launch, will use weight substitute	C4	Make sure costs are considered while designing the payload

Recovery Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Recovery construction falls behind schedule	Lack of materials; Lack of effort; Lack of clear schematics	Will prevent successful subscale launch as recovery is responsible for separation and landing	D1	Make sure a strict schedule is laid out and that design is complete. Also make sure to buy materials early so that shipping is not an issue.
Recovery goes over budget	Parts too expensive or too many mistakes and redos required	Very critical, recovery has one of the highest costs for parachutes and charges. May prevent teams from buying other necessary components	D1	Make sure costs are considered while designing and either use substitutes or extreme caution while testing.

Airframe Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Airframe construction falls behind schedule	Lack of materials; Lack of effort; Lack of clear schematics	Will prevent successful subscale launch as airframe makes up the rocket.	D1	Make sure a strict schedule is laid out and that design is complete. Also make sure to buy materials early so that shipping is not an issue.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Airframe goes over budget	Parts too expensive or too many mistakes and redos required	Blue tube is decently expensive, and carbon fiber components are difficult to manufacture. May prevent teams from buying other necessary components	D2	Make sure costs are considered while designing and either use substitutes or extreme caution while testing.

6 Payload

6.1 Payload Objectives

SAGITTA-VL is designed to execute a "Target Detection and Upright Landing" experiment: this involves using an onboard camera housed in the upper airframe and nose cone to identify and distinguish between three differently colored 40 ft. square tarps. The upper airframe section is then ejected, and landed under its own recovery system, deploying legs built into the airframe wall in order to land on the ground upright. The purpose of this experiment is to verify the capability to examine and differentiate features of the landing zone in order to verify safe landing sites or potential ground hazards, and perform an upright landing of a reusable payload. The success of this mission will be defined by the following criteria:

1. The onboard camera system gathers continuous visual data to inspect the landing zone (to be verified after landing).
2. The onboard Raspberry Pi software package identifies the position and color of each target (to be verified after landing).
3. The payload section is ejected from the main vehicle via black powder charge.
    - The payload ejection occurs only after A) the camera successfully identifies and differentiates the ground targets or B) the vehicle descends to an altitude of 500 ft.
4. All three landing legs successfully unfold from the airframe to an angle of 110 degrees.
5. All three parachutes open and rise to the top of the descending payload.

6. The payload descends while maintaining upright orientation.
7. After landing, the payload maintains upright orientation on the ground to a maximum angle of deviation of 20 degrees, until recovery.

6.2 Payload Systems

Recovery	Nose cone	Camera	Landing Legs	Deployment	Post-Landing Stability
Parafoil	Ogive nose cone with replaced clear top	Nose facing, mounted high in nose cone with clear top	3 legs hinged near base of payload section using doublewall	Servo latch, torsion spring hinges, sliding plastic support legs*	None additional (lightweight)
1 parachute, ejected from top of payload	Side window	Side facing	3 legs hinged above shoulder	Servo latch, spring steel hinges, sliding additive manufactured support legs	Hemispherical weighted based
3 parachutes, ejected from leg slots	Opaque ogive nose cone, unjettisoned	Rear facing		Aluminum support legs	Active post-landing weighted stability
3 parachutes with varying cord length, ejected from leg slots	Opaque ogive nose cone jettisoned (separate recovery)	Nose facing, mounted on bulkhead below nose cone		Gas spring support legs	Telescoping leg extensions

6.2.1 Target Acquisition System

The target acquisition subsystem includes the camera, camera mounting devices, and visibility devices. Several variations of this system are outlined in Section 6.2. Placement options for the camera were highly dependent on the nose cone trade studies - these were evaluated based on requirement constraints, camera sensing limitations and advantages, and deployment of potential recovery mechanisms.

An opaque, ogive nose cone was selected for both the rear-facing camera option as well as the nose-facing bulkhead mounted option. This option was designed in tandem with the single parachute recovery option, as a fully opaque nose cone would preclude the necessity of replacing a portion of the nose cone to allow the camera to perform sensing operations. In order to completely jettison the ogive nose cone, the rocket would contain more independent sections than the maximum specified in the requirements (Statement of Work, Vehicle Requirements 1.5). Packaging issues and camera sensing issues prevented the continued exploration of this option despite redesigning the ejection of the nose cone to rely on a shock cord to keep it tethered to the payload section; the nose cone interfering with the sensing portion of the experiment would not be an insignificant issue.

A side-facing window in the nose cone paired with a side-facing camera was a briefly considered option. Deficits in the field of view for the camera and the issue of ensuring an unobstructed view while sensing under the main parachute allowed us to eschew this option to focus on issues in the selected option for our PDR configuration.

The selected configuration is an opaque ogive nose cone with a custom clear polycarbonate tip. The camera will be placed on a bulkhead high in the nose cone, mounted at or above the height of the shoulder. Camera sensing will occur during descent under the main parachute. After the camera detects the target zones or the altimeter indicates 500 ft. AGL, the payload section will detach from the rest of the rocket and deploy its individual recovery system. The placement for the camera was dictated by the design prerogative to reduce the effects of tunnel vision–i.e. a highly limited angular field of view. This allows for maximum sensing time, and flexibility with regard to recovery options and packaging concerns.

6.2.2 Landing Legs

The landing leg subsystem includes all devices associated with the construction and deployment of the legs on which the payload lands upright. The primary variation in landing leg designs was the mechanism to help aid in upright landing on any terrain. The motivation behind telescoping or extending the landing legs was 1. to create a wider landing base that would provide a greater chance for successful upright landing, and 2. to allow the legs to reach below the 6" coupler at the bottom of the landing section without necessitating cutting into the coupler to make room for the landing legs.

Designing functional extending legs has a number of challenges, notably:

- How to cause the telescoping/extension
- How to ensure this will not occur while the leg is still within the airframe
- How to ensure extension will be reliable and not affect parachute deployment
- How to ensure the telescoping joint or hinge is not a structural liability '

For the method of extension, the following ideas were considered: a compressed spring that, when allowed to, extends the leg outwards; extended surgical tubing that, when allowed to, compresses and pulls the leg to swing on an axle; string attached to both the central sled inside the body and extending portion of the leg that, as the leg begins to pivot out of the airframe, becomes taught and pulls the leg to extension; and an electrical actuator (most likely a servo) that rotates the extending part of the leg.

Design	Pros	Cons
Spring	Simple. Provides source of suspension.	Spring will only compress to a certain extent, limiting extra length. Must prevent extension until leg is far enough out of the frame.
Surgical Tubing	Simple and allows for greater length than spring	Must prevent extension until leg is far enough out of the frame.
String	String length can be modified so that leg is extended when desired.	Liability for string to get caught on something
Electric Actuator/Servo	Maximum control of when and how leg extends	Requires more wiring. Must also package actuator within tubing.

The leading method for our Preliminary Design Review is surgical tubing. It was chosen for its relative simplicity and passivity, the fact that it can be self contained, and it allows for close to 100% increase in leg length. The main challenge that this selection raised is how to prevent extension until the desired moment, when the extending portion will not get stuck in the body. Failure in this will lead to certain payload failure.

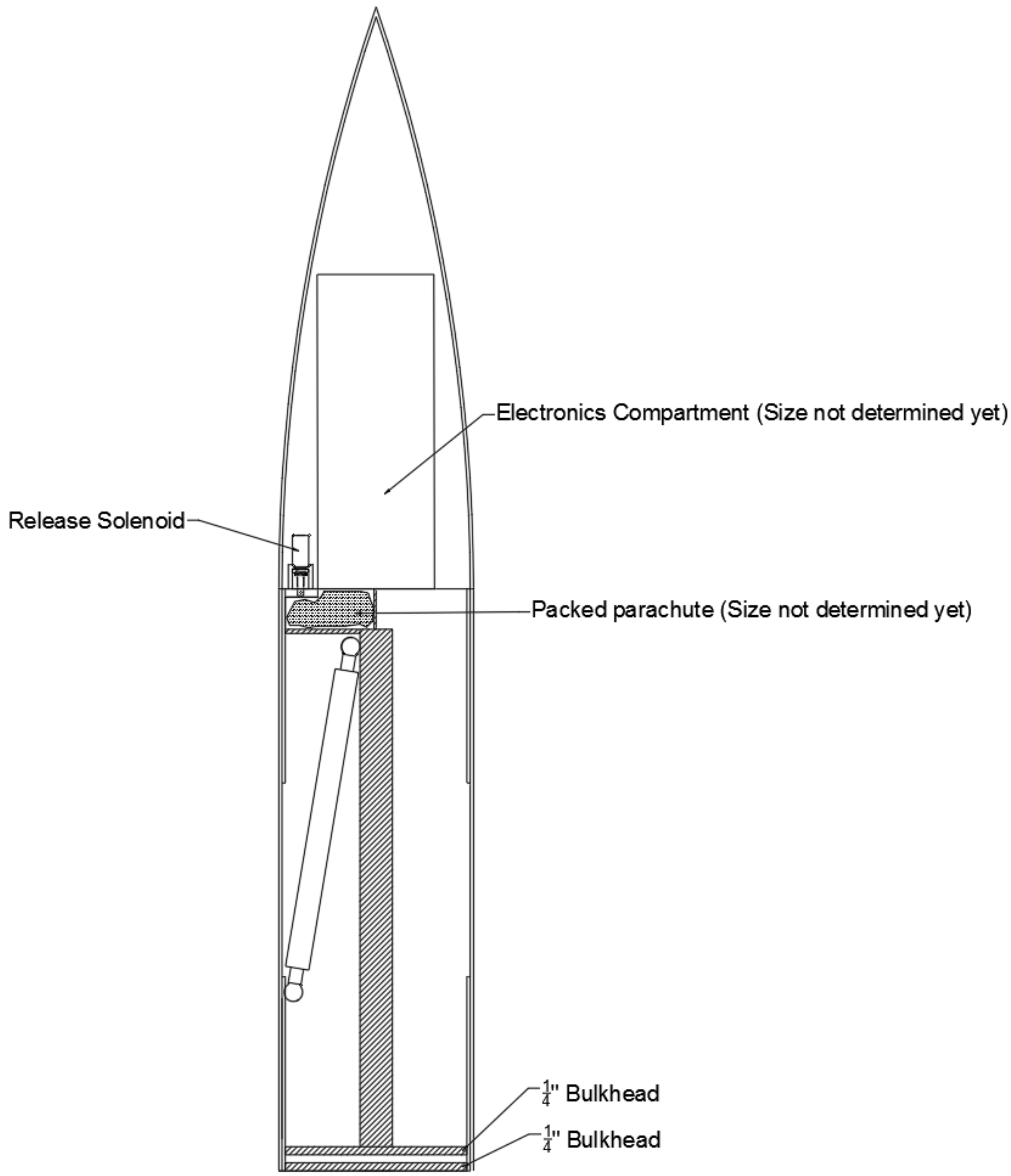
Additionally, another design component of the landing legs is the connection point with the payload. Placement of the landing leg hinge was formerly dependent on the top of the connecting shoulder at the bottom of the payload section. That constraint limited the effective footprint of the legs, as they would have to extend at a severe angle to prevent the bottom of the payload section from impacting the ground first. To work around this constraint, slots will be cut in the shoulder to lower the landing leg hinge near the end of the payload section. To mitigate the loss in structural integrity by cutting the tubes, these couplers will be reinforced by double-walled construction.

6.2.3 Deployment Trades

To achieve vertical landing, our primary design option is to deploy 3 legs 120° apart in a tripod-like configuration. We explored deployment via closed gas springs through fixed point and leg mounted designs.

For fixed point closed gas springs, we attempted to see whether or not we could use a gas spring mounted in a way such that both ends of the spring are fixed to the payload body and leg with pins, so that both ends are free to rotate. For this specific design, we set a few constraints. First, we wanted the maximum spring extension to occur when the leg is fully deployed. If this is satisfied, we would not need a locking mechanism to limit the angle of the leg. Second, as per the design name, we wanted both ends of the gas spring to be fixed. However, rough CAD models (Figure 23) and calculations have demonstrated that the smallest economically viable gas spring[1] will not fit in such a design. The gas spring will need to extend past the centerline of the payload. Given that we need three gas springs set up symmetrically around the centerline, the gas springs will need to intersect and pass through each other. Thus this design is not possible.

Figure 23: Gas Spring System - Closed

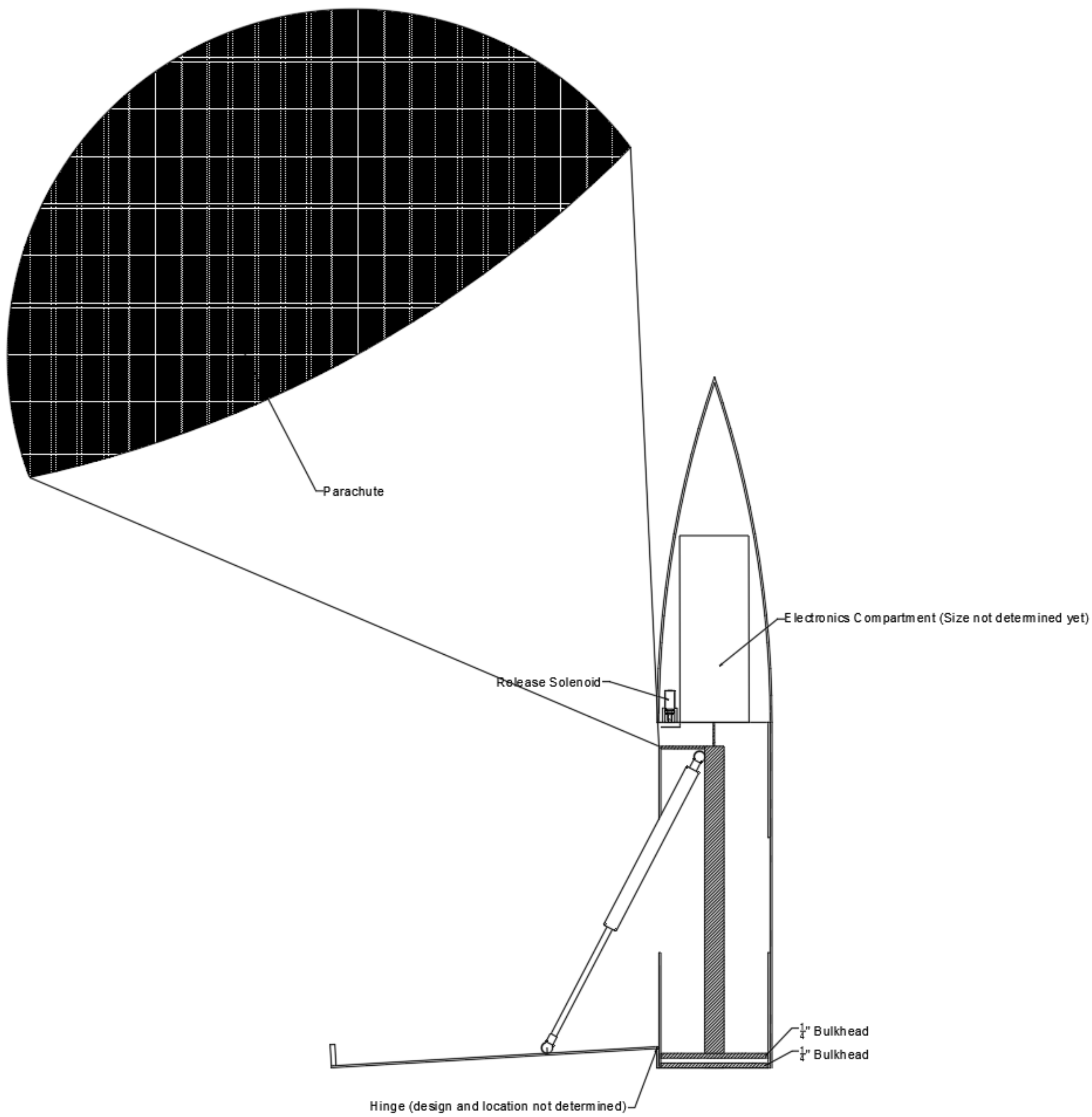


Our calculations were only close approximations. We treated leg thickness as negligible (actually 0.1"), and assumed the hinge is 1" above payload floor, centered on the wall. We

[1]From McMaster-Carr. There are gas springs that can fit, but they are almost triple the cost.

also assumed the leg will be 17" (Payload height of 18" without fixed length of 1" below the hinge).

Figure 24: Gas Spring System - Open



When a leg is fully deployed (Figure 24), it makes an angle with the floor, assumed to be perfectly flat. This angle can be calculated with

$$\theta = \arcsin \frac{\text{Distance from floor to hinge}}{\text{Leg length}}$$

$$\theta = \arcsin \frac{1}{17}$$

$$\theta = 3.37°$$

The leg also creates an angle between the airframe body and itself. This angle is

$$180° - (90° - 3.18°) = 93.37°$$

Now we will calculate the angle the gas spring will make with the leg. Because this is for a fixed point on the leg, the distance from the hinge to the point of connection with the gas spring will be the same with the leg closed or deployed. This creates an isosceles triangle. Therefore the angle is

$$\frac{180° - 93.37°}{2} = 43.31°$$

and the angle the gas spring makes with the floor will be

$$43.31° + 3.37° = 46.68°$$

The gas spring is fixed at both ends, therefore, the compressed and extended angle will be the same. The maximum compressed horizontal length a gas spring can have is the distance from the airframe to the center-line (3"). The maximum compressed overall length, can then be calculated with

$$l_{max} = \frac{l_{horizontal}}{\cos \theta_{floor}}$$

$$l_{max} = \frac{3"}{\cos 46.68°}$$

$$l_{max} = 4.37"$$

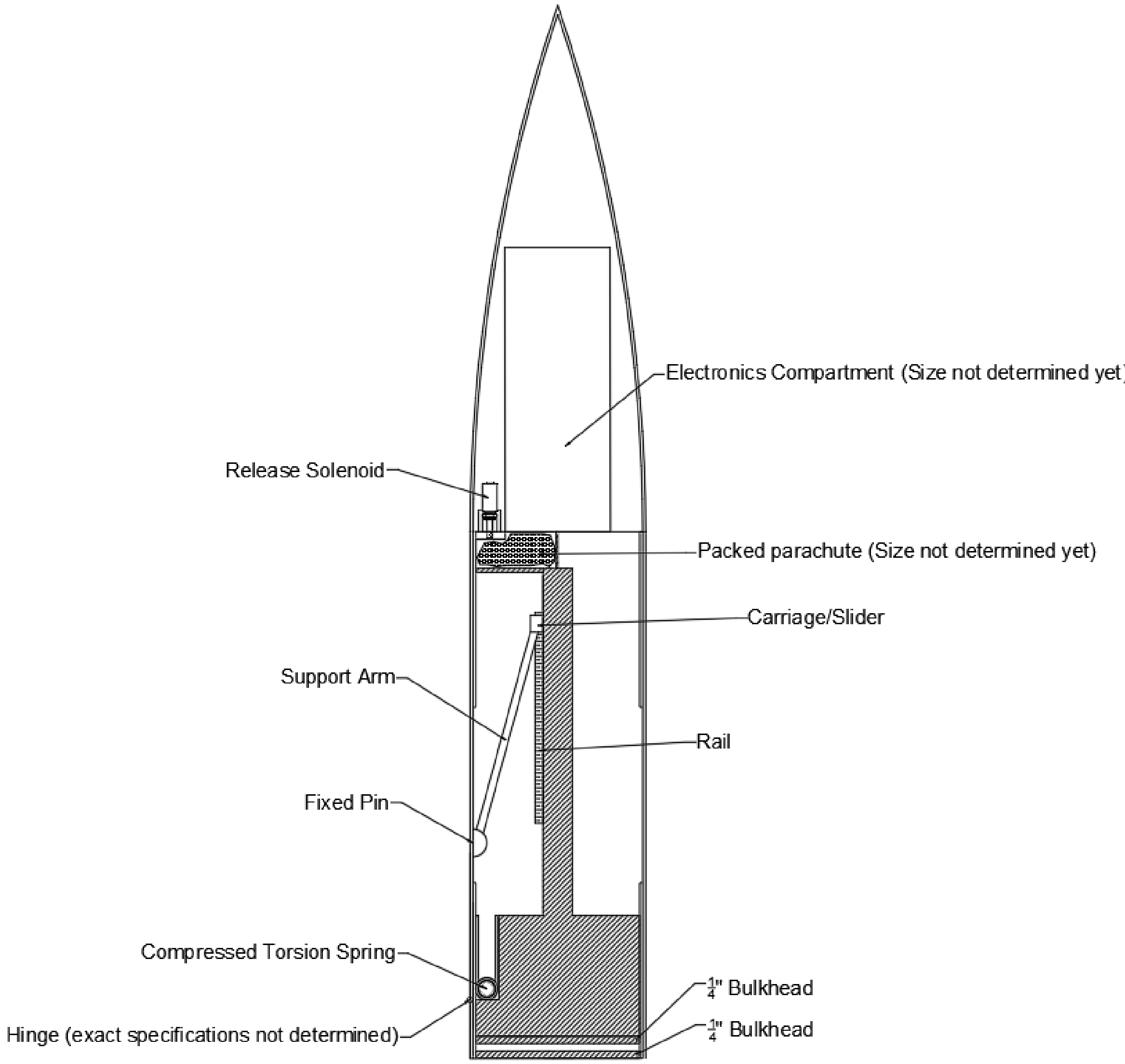
The smallest compressed length available on McMaster-Carr for less than $20.00 is 5.04".

As mentioned above, we set a few constraints. We could work without them, but this would involve a lot more complexity. We would need to install a locking mechanism that will limit the angle of the leg and make sure that it is strong enough to withstand the force from the gas spring. This would add weight, time, and money to the construction of the leg.

Another design is leg mounted rail design. In this design, we attempted to increase the maximum length of the gas spring by allowing one end to slide freely.

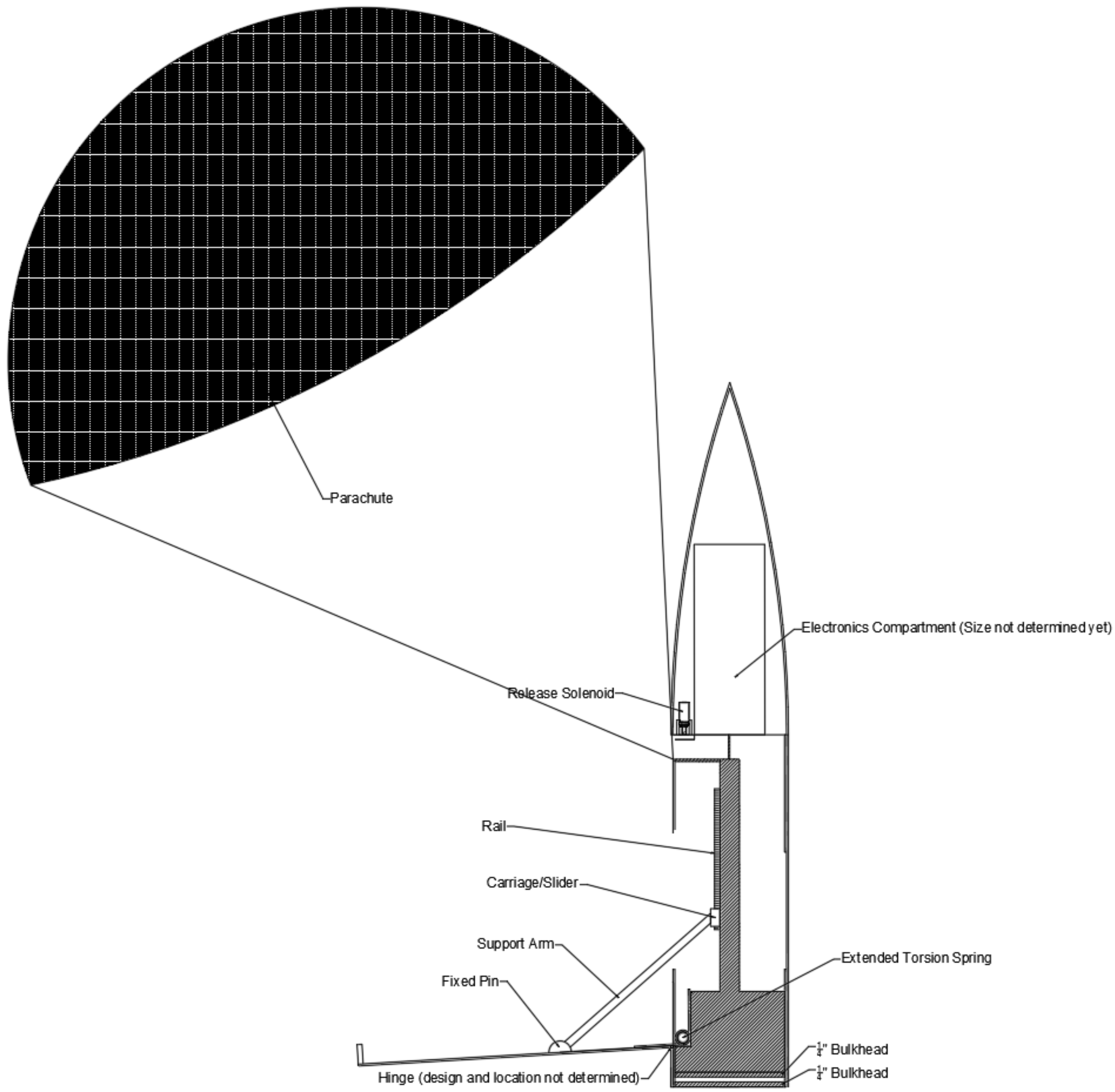
In this configuration, the upper end of the gas spring is fixed to some internal structure. The lower end is fixed to a carriage on a rail on the leg. Both ends are free to rotate, but only the lower end is free to move laterally.

Figure 25: Selected Alternative: Sliding Rail System - Closed



Due to the issues surrounding the gas springs as well as their added cost and weight, we have chosen the 'sliding rail system' as presented in our Proposal: namely, the use of three aluminum rails and a sliding support leg fabricated using additive manufacturing attached via L-bracket hinges. This solution balances weight, cost, and complexity concerns. (Figure 25)

Figure 26: Selected Alternative: Sliding Rail System - Open



Torsion springs were initially selected as the primary hinging mechanism for the landing legs, as they were a mechanically robust solution to deploy the legs (Figure 26). Spring steel has added stiffness and rigidity relative to the torsion springs; as such, they are the chosen hinge/deployment mechanism for our PDR configuration. A solenoid-powered pin will keep the legs in place until deployment. Additive manufacturing processes were selected for the support legs to save weight relative to metal-based alternatives.

6.2.4 Payload Recovery

The payload recovery subsystem consists of the parachutes and deployment devices for the independent payload section. Several alternatives were considered based on camera orientation and active versus passive recovery systems.

Initially, we considered various possibilities for an active recovery system, in which the falling payload is directed toward a ground target. A primary method was to control the descent of our payload like a paraglider, using a parafoil as our parachute. Through small motors that could independently adjust the length of separate parachute cords, we would have the ability to direct the payload to a specific landing location while also controlling the payload orientation to achieve upright landing. This option was was ultimately discarded due to the difficulty of implementing it compatibly with a camera viewing through the nose cone.

The other active recovery system option would entail thrusters that control the orientation and landing location of the payload. Although this option is advantageous given the accuracy in descent and landing it grants, it was abandoned since it was deemed not feasible given the timeline, resources, and experience level of this project.

The passive system option for a rear facing or side facing camera is a single parachute ejected from the top of the payload. This possibility, resembling a traditional recovery system, provides simplicity and reliability by eliminating the chance of parachutes tangling. However, this option was removed after a nose cone facing camera orientation was chosen.

The other passive system option is for a nose cone facing camera orientation. In this scheme, the deployment of each of the three landing legs will result in the ejection of three parachutes. Behind each parachute is a board with a compressed spring that will aid in the ejection of the parachute once the legs deploy. Additionally, attached to each leg will be a thin cord which is looped around each corresponding parachute that, upon deployment of the legs, will pull the parachutes out of their respective chambers. The cord will then unravel from the parachute as it pulls away and the parachute begins to open. This recovery system is advantageous because it allows for a nose cone facing camera and upright payload landing without separation of the nose cone from the payload. Additionally, using the landing legs as the deployment mechanism for the parachutes simplifies the recovery procedure by eliminating the need for additional electronics and black powder charges. However, that same feature can also be considered a drawback since, there is a risk that the parachutes will snag and not deploy. This risk can be minimized through the design of an unobtrusive parachute chamber, and redundancy from having both the cord and spring used for deployment. Another risk associated with three parachutes is the chance for entanglement between the chutes during deployment. One possible solution to this risk is varying the cord length on each parachute so that at full extension, each parachute is at a slight angle. In theory, this would separate the parachutes enough to prevent entanglement, however after discussion, it was inconclusive whether this technique would be successful. Alternatively, staggering the deployment time of each leg would lower the chance of parachute entanglement. While its possible that this process might temporarily misalign the orientation of the rocket, once all three parachutes are fully deployed, the rocket should correct itself in time for an upright landing.

Ultimately, with consideration of the camera orientation and an upright landing, the recovery system option of three parachutes ejected by the landing legs and springs at staggered times was selected.

6.2.5 Post-landing stability

Post-landing stability devices include devices, such as telescoping legs or suspension systems, used to ensure that the vehicle remains upright upon landing. One of the major selection criteria for the post-landing stability options was weight and how the mechanism would affect the center of mass for the payload section. We split the options into active stability options and passive stability options, with preference for passive stability to reduce risk.

Our primary active stability option consisted of shifting weight in the base of the payload to move the center of mass closer to the center of our tripod leg system on an uneven surface, and to prevent tipping after landing. Weight shifting would either be achieved using a rack-and-pinion system or an electromagnetic system shifting loose iron oxide. This was ultimately discarded due to feasibility concerns, the increased weight requirement, and the increased number of failure modes.

The chosen system extends the length of the existing legs, which increases the effective base area of the payload section; this is covered in section 6.2.2.

6.3 Payload Design

The selected configuration was selected to align with the the experimental tasks outlined in our Proposal–namely to identify target zones and land the payload section upright with no damage. Furthermore, certain main payload components such as camera orientation contributed to the selection process of other payload components such as the recovery system. The following options are the primary alternatives chosen after consideration of the costs and benefits.

For the camera and nose cone, the selected option is an opaque ogive nose cone with a custom-built clear polycarbonate tip and a nose facing camera mounted above the shoulder. The final landing leg design consists of telescoping legs mounted in slots cut into the airframe and coupler. For deployment, the final option is deployment by torsion springs attached at the connection point for the base of the legs along with a sliding rail support leg system. For the recovery, three parachutes ejected by the landing legs and springs at staggered times is the selected option.

6.3.1 Payload Electrical System

The main physical components of the payload electronics system consist of an electric match to ignite the deployment charge, three solenoid actuators to release the legs, and the Raspberry Pi camera.

The operation of the payload electronics proceeds in the following schedule:

1. Initialize the camera for the sensing procedure.
2. While the targets have not yet been identified and the section is still above the minimum height of 500 ft. according to the payload altimeter:
   (a) Capture an image using the camera.
   (b) Look through the image captured for three regions of color, one of each target color.

(c) If the image contains all three necessary contiguous regions of color, and all are of a sufficient size in the image, then the targets have been identified. Save the image to the file system, along with a file noting the positions in the image of the three regions of color identified.

3. At this point, the targets have been identified or the section has reached 500 feet. The main sensing procedure is now done. While images may be captured after this point for better record-keeping, none of them should overwrite the image of the targets that was captured and saved above.

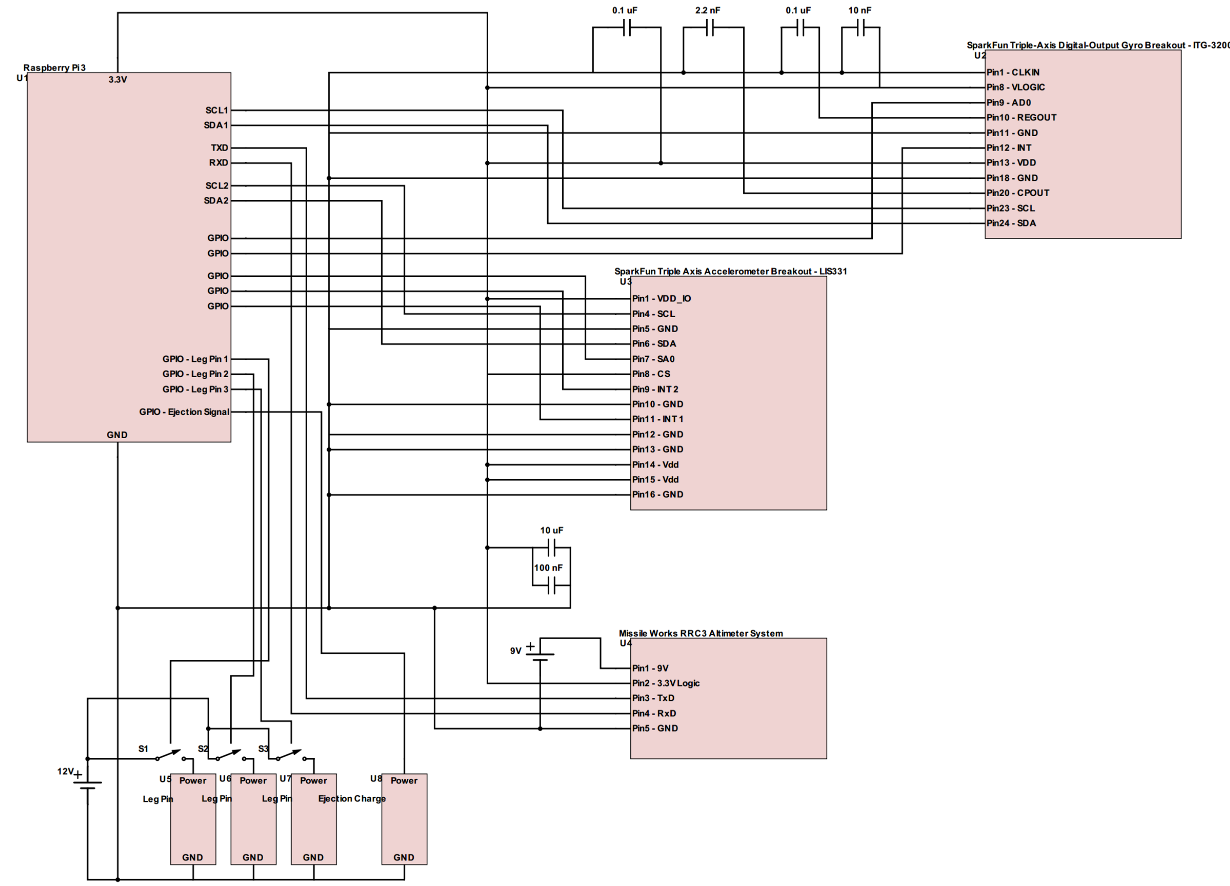
4. Send a signal to the electric match, to fire the charges to eject the payload from the rest of the rocket body.

5. Send signals to actuate the solenoids on the pins holding the three legs, to allow them to spring out of the airframe along with the parachutes.

Some parameters in the software description above are not specified at this time, most notably the 'sufficient size' of the targets in the image. This and other parameters will be determined experimentally with ground testing.

The electrical schematic shown in Figure 27 demonstrates the connections between the Raspberry Pi, the accelerometer, the gyroscope, and the altimeter. The 'ejection charge' component should be regarded as a black box of several components, not just an electric match - we will not be driving the electric match directly from the port on the Raspberry Pi, due to minimum current constraints. The camera connections are not shown because they are implemented with a ribbon cable directly to the camera port of the Pi and do not require individual wiring. The GPS is not shown in the schematic because it is self-contained and does not have specifications available to view online. The GPS requires 3.3V and a 2S 7.4V Lithium-Polymer battery is recommended by the vendor.

Figure 27: Payload Electrical Schematic



6.3.2 Payload Interfaces

The payload is a self-contained independent section and comprises the upper portion of the launch vehicle, including the nose cone. The upper 8.5” of the nose cone is made from clear polycarbonate, with the remainder made from fiberglass. The nose cone is coupled to the payload tube by a 3” shoulder.

The payload is coupled to the avionics bay section of the main vehicle via a coupler tube glued into the avionics bay with a 6” shoulder. The upper 4” of the shoulder will cut to contain 2.5” wide slots, positioned at 120°apart. This allows the legs to be mounted 2” from the base of the payload tube, with the hinges positioned in the shoulder slots.

6.4 Precision and Repeatability of Payload

The payload experiment is designed for complete repeatability with minimal modifications between executions. The entire payload section is to be assembled independently of the main vehicle, and can be tested on its own. For use on the main vehicle, it can be coupled to the avionics bay via a single interface, as described in Section 5.3.2. The Target Acquisition experiment can be executed repeatedly using the Raspberry Pi camera, providing data that is analyzed after recovery. The Upright Landing experiment causes no modifications to the payload system components except for the actuation of the holding pin, which will be controlled via onboard electronics. In order to reset the payload section to its launch configuration, the legs can be folded into place and locked by re-actuating the holding pins. The payload recovery system is also fully repeatable with minimal procedure needed to reset between executions. The three parachutes will be permanently fixed to the upper bulkhead in the payload section, and simply folded and packed in the chute compartments for the launch configuration. The strings used to pull the chutes by the landing legs will be permanently fixed to the landing legs, and can be wrapped around the chutes for launch configuration.

The precision of the payload experiment depends on the values supplied by the GPS, gyroscope, accelerometer, and altimeter. The sensitivity of the gyroscope is 14.375 LSBs per °/s with a range of ±2000 °/s, the sensitivity of the accelerometer is 12 mg/digit with a range of up to 24g, and the sensitivity of the altimeter is 1.5mbar (40 feet at STP).

7 Project Plan

7.1 Requirements Compliance

7.1.1 Handbook Requirements Verification

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 will be purchased and used to record the official attitude.	Completed. Altimeters have been purchased and attachment has been determined.
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.

Requirement	Verification Plan	Status
The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Verified through inspection of design.	Completed. Our vehicle only has 3 independent sections.
The launch vehicle shall be limited to a single stage.	Verified through inspection of design.	Completed. Our vehicle has one motor and one stage.
The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	Assembly and pre-launch checklists will be made to make sure preparations takes within 4 hours. Will be verified by a test launch.	In Progress. Checklists are being made and will be practiced for preparation.
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, and nothing in our design requires any additional or unique circuitry or equipment.

Requirement	Verification Plan	Status
The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Verified by inspection of design and motor selection.	Completed. The Aerotech L1150 motor satisfies these requirements.
The total impulse provided by a College and/or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	Verified through inspection of design and motor selection. An Aerotech L1150 motor will be used.	Completed. The Aerotech L1150 motor has an impulse of 3589 N-s.
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Will be verified using OpenRocket to determine center of pressure and gravity.	Completed. Our rocket has a minimum static stability margin during ascent of 2.34, as calculated by OpenRocket.
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Will be verified by testing and OpenRocket simulations of rocket.	Completed. 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.	Will be verified by a test launch before the CDR.	In Progress. We plan to launch the subscale model at LUNAR on December 3rd.
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.
Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	Verified through inspection of design.	Completed. No protuberance on the rocket is located aft of the burnout center of gravity in our design.

Requirement	Verification Plan	Status
Vehicle Prohibitions	Verified through inspection of design.	Completed. Our rocket does not utilize any of the materials or features explicitly prohibited in section 1.19 of the NSL Handbook.
The launch vehicle shall not exceed Mach 1 at any point during flight.	Verified through testing and OpenRocket simulations.	Completed. Our rocket reaches a maximum velocity of Mach 0.66 during flight, as calculated by OpenRocket.
Teams shall design an on-board 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.	Not Started. To be verified at launch.
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.
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. Preliminary checklists have been completed and included in this report. Will be updated throughout year 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.

Requirement	Verification Plan	Status
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 clubs RSO.	Demonstration during launches.	Not Started. 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.	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.
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.
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.	In progress. Currently working to identify who, based on availability and funds will be attending launch.

Requirement	Verification Plan	Status
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. In communication with local Charter school group. Plans to collaborate with other student groups for upcoming high school outreach day.
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.	In progress. Once date & time is finalized, we will book an on campus room with proper equipment.
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. Once the rocket is crafted and assembled, we will adjust the weight of the rocket until it reaches 5280 ft. agl.
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.	In Progress. Once the black powder charges have been ordered and the subscale/full scale has been built, the ground ejection test will commence.

Requirement	Verification Plan	Status
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Verified through OpenRocket simulations 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.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Verification through inspection by design. The recovery system electronics will be housed in the avionics bay, which will be between the booster and payload sections of the rocket, while the payload electronics will be housed specifically in the payload section. Upon inspection, the independence should be self-evident.	Completed. The avionics bay and the payload electronics have been designed to be completely independent.
The recovery system shall contain redundant, commercially available altimeters.	Verification through inspection of design. Upon inspection, the two different altimeters (Perfectflite Stratologger CF and Missileworks RRC3) will be clearly visible.	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.	In Progress. Once materials are acquired, the design will be implemented.
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.

Requirement	Verification Plan	Status
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.
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.
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. Once the rocket is crafted and assembled, we will adjust the weight of the rocket until it reaches 5280 ft. agl.

Requirement	Verification Plan	Status
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.	In Progress. Once the black powder charges have been ordered and the subscale/full scale has been built, the ground ejection test will commence.
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Verified through OpenRocket simulations 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.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Verification through inspection by design. The recovery system electronics will be housed in the avionics bay, which will be between the booster and payload sections of the rocket, while the payload electronics will be housed specifically in the payload section. Upon inspection, the independence should be self-evident.	Completed. The avionics bay and the payload electronics have been designed to be completely independent.
The recovery system shall contain redundant, commercially available altimeters.	Verification through inspection of design. Upon inspection, the two different altimeters (Perfectflite Stratologger CF and Missileworks RRC3) will be clearly visible.	Complete. We have designed our avionics bay platform to house both the different altimeters.

Requirement	Verification Plan	Status
Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad, and is capable of being locked in the ON position for launch.	Verification by inspection and demonstration. Our avionics bay will have rotary switches on the outside that can arm and disarm our altimeters.	In Progress. Once materials are acquired, the design will be implemented.
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.
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 electonics.

Requirement	Verification Plan	Status
Teams shall design an on-board 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.	Not Started. To be verified at launch.
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.
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. Preliminary checklists have been completed and included in this report. Will be updated throughout year 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 clubs RSO.	Demonstration during launches.	Not Started. Team safety officer will inform team of rocketry club rules and will ensure all rules are complied with.

Requirement	Verification Plan	Status
Teams shall abide by all rules set forth by the FAA.	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.
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.
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.	In progress. Currently working to identify who, based on availability and funds will be attending launch.
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. In communication with local Charter school group. Plans to collaborate with other student groups for upcoming high school outreach day.

Requirement	Verification Plan	Status
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.	In progress. Once date & time is finalized, we will book an on campus room with proper equipment.

7.1.2 Team Derived Requirements Verification

Requirement	Verification Plan	Status
Keep Apogee under 5400 feet.	OpenRocket simulations and our Perfectflite Stratologger CF Altimeter will verify that the design and an Aerotech L1150 motor meets the altitude requirement.	In progress. Our current projected apogee exceeds this limit. We are, however, currently overshooting intentionally because it will be easier to add weight (losing altitude) in the form of ballast than to lose weight.
Nose cone is transparent and camera can get clear pictures in order to match payload mission criteria.	Test by viewing objects with our camera through the nose cone, observing quality and ability to identify targets from a distance.	Not started.

Requirement	Verification Plan	Status
We are going to define a maximum damage criteria in which the actual damage in all of the categories is less than or equal to will be defined as success. Broken is defined as not reusable. The criteria is the following: Zero fins are broken. Zero pieces of the Nose Cone are broken. Zero sections of the rocket are broken. Camera, Avionics altimeters, and GPS are functioning Parachutes have no tears.	Visual inspection upon landing. Demonstrate electronics are responsive and functional.	Not started, will take place immediately following launches.
Keep weight of the rocket below 40 lbs.	Inspection, weigh all components before assembly, and weigh entire rocket after assembly.	On track, weight is currently 29.25 lbs.
All three landing legs successfully unfold from the airframe to an angle of 110 degrees.	Analysis using SolidWorks to ensure design and geometry will allow for this. Inspection upon landing that legs are near 110 degrees.	In progress, have performed geometric calculations, begun 3D modeling.
All three parachutes open and rise to the top of the descending payload.	Testing by dropping prototype from height in permitted and safe location.	Not Started.
The payload descends while maintaining upright orientation.	Analysis to ensure center of mass of payload section is below point of contact of parachutes.	In Progress, parachute locations intentionally placed high up to ensure this will occur.
After landing, the payload maintains upright orientation on the ground to a maximum angle of deviation of 20 degrees, until recovery.	Visual inspection upon recovery.	Not started.

Requirement	Verification Plan	Status
All sections land with a speed equal to or below 15 ft/s.	Demonstration by readings from accelerometer during descent.	In Progress, have performed drag calculations to ensure we land at a speed below the limit.
For CDR, FRR & PLAR Complete draft of all sections at least 1 week before submission deadline.	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.

7.2 Budgeting and Timeline

7.2.1 Budget

Items	Sub-items	Quantity	Unit price	Anticipated Cost		Subtotal
Fall 2016 NASA SLI Rocket						
Airframe						
	Polymer Nose Cone	1	$80.00	$80.00		
	Airframe Body	1	$180.00	$180.00		
	Glue/Epoxy	2	$30.00	$60.00		
	Motor Mount	1	$25.00	$25.00		
	Sub-scale Rocket Materials	1	$315.00	$345.00		
	3D Printed Prototypes	1	$50.00	$50.00		
	Motor	2	$188.00	$196.00		
	Motor Shipping	2	$80.00	$160.00		
					$ 1,096.00	
Recovery system						
	Perfect Flight Stratologger CF Altimeter	1	$60.00	$ 60.00		
	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	1	$85.00	$ 85.00		
					$ 776.00	
Electrical						
	GPS - Eggfinder GPS System	1	$ 100.00	$ 100.00		
	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	2	$ 70.00	$ 140.00		
	PCB Printing	2	$ 30.00	$ 60.00		
					$ 465.00	
Payload system						
	Support Leg Track	3	$ 15.00	$ 45.00		
	Landing Legs	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	$ 10.00	$ 10.00		
	Aluminum (Support Legs)	1	$ 25.00	$ 25.00		
	L Bracket Mounts	6	$ 3.00	$ 18.00		
	Leg Pins	3	$ 30.00	$ 90.00		
					$ 259.00	
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	
						$ 2,785.50
Transportation to launch site						
	Equipments shipping	1	$ 417.23	$ 417.23		
	Travel budget	22	$ 600.00	$ 13,200.00		
						$ 13,617.23
Misc.				$ 500.00		
GRAND TOTAL						**$ 16,402.73**

7.2.2 Current Funding

Received	Details	Amount
Student Opportunity Fund	Travel expenses	$1,401.01
Engineering Student Council	Equipment	$1,604.32
Northrop Grumman	Equipment and travel expenses	$1,500.00
	Total	**$4,505.33**
	NSL Budget	$16,402.73
	Balance	-$11,897.40

Note: We have sufficient funding for all manufacturing-related purchases.

7.2.3 Applied Funding

1. We have also sent in an application to Student Opportunity Fund for $3000.00 to cover our travel expenses.
2. We have sent out emails requesting sponsorship to JetBlue and United Airlines in order to help with competition travel expenses.

7.2.4 Future Funding Plan

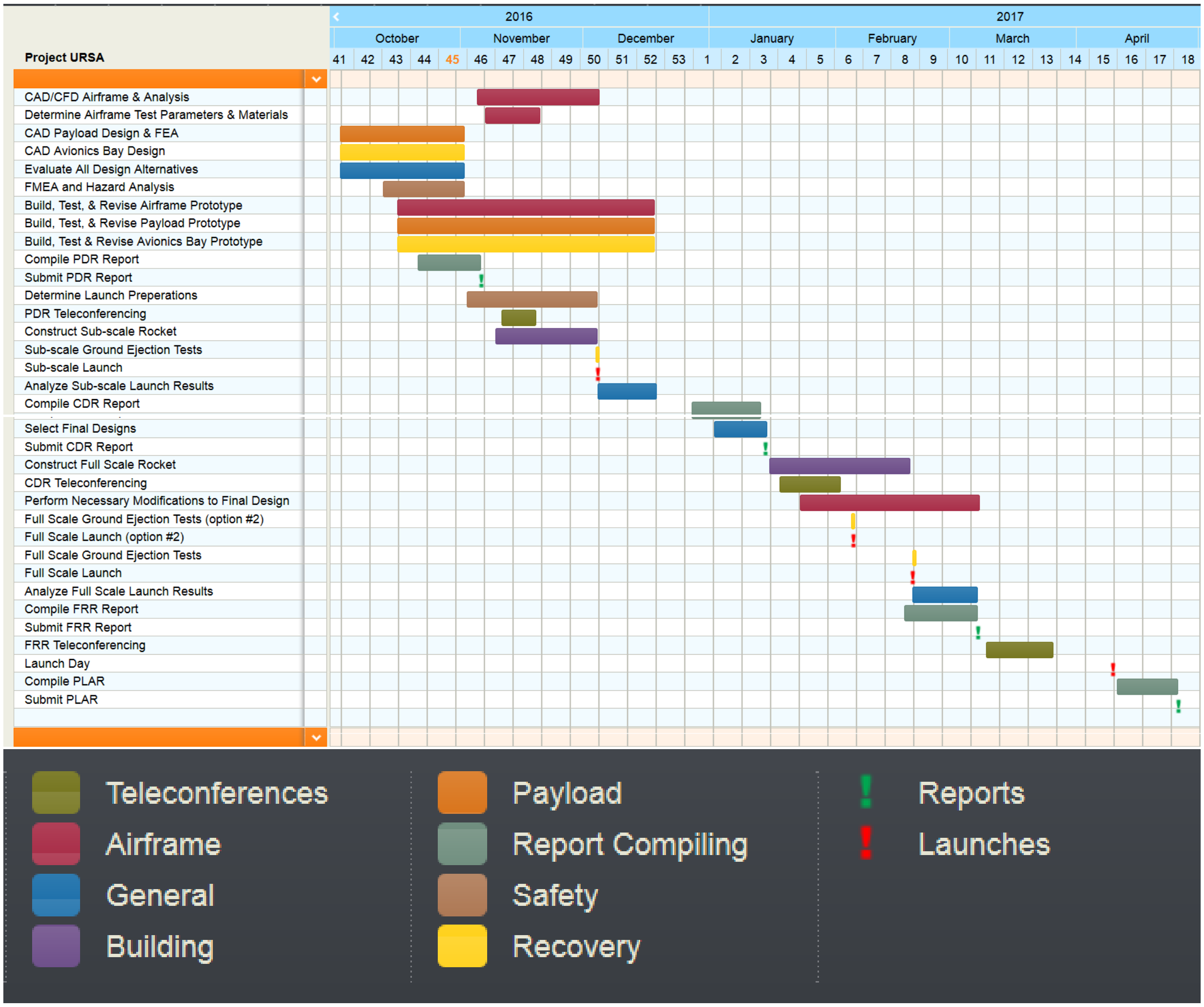
Within UC Berkeley Campus:

1. We will send a funding request to UC Berkeleys Mechanical Engineering Department in early November 2016.
2. We have also signed up for The Big Give, hosted by ASUC Student Union of UC Berkeley. Part of the funds raised here will be used in this project.

Private Corporations:

1. We will request funding from Northrop Grumman in Early November.

7.2.5 Project 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
Jacob	Safety
Jamie	Safety, Payload
Jarrod	Recovery
Jia	Budget, Funding
Jordan	Airframe, President
Juan	Airframe
Kevin	Airframe, Webmaster, Club Historian
Mary	Recovery
Nate	Payload, Electronics
Ryan	Reports Compilation
Tushar	Airframe

Appendix B 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 C 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[2]) (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