Proposal for Entry to NASA Student Launch
Project U.R.S.A.[1]

Space Technologies and Rocketry
University of California, Berkeley
432 Eshleman Hall, MC 4500
Berkeley, CA 94720-4500

September 30, 2016

[1]Upright Recovery and Sight Acquisition

Contents

1 General Team Information

We are the University of California, Berkeley (Cal) Space Technologies And Rocketry team (CalSTAR).

1.1 Key Contacts

Faculty Advisor	Carlos Fernandez-Pello Professor of Mechanical Engineering Dept. of Mechanical Engineering, UC Berkeley ferpello@me.berkeley.edu (510) 642-6554
Team Mentor	David Raimondi President, Livermore Unit of the National Association of Rocketry NAR Section #534 d.raimondi@sbcglobal.net (408) 742-5173
Student Team Leader	Jordan Covert President, Space Technologies and Rocketry College of Engineering, UC Berkeley BS Engineering Physics, Expected 2018 ironbender3@berkeley.edu (916) 549-3397
Safety Officer	Grant Posner College of Letters & Sciences, UC Berkeley BA Computer Science & BA Mathematics, Expected 2019 grant.posner@berkeley.edu (858) 735-3384

1.2 Team Directory

There are approximately 25 active members of STAR[1]. Members are broken into 8 separate sub-teams, with many serving on multiple teams. The sub-teams and sub-team leads are as follows:

Airframe	**Jordan**

[1] A complete list of currently active members can be found Appendix A

Budget	Jia
Electrical	Jacob
Outreach	Aaron
Payload	**Avyay**
Safety	**Grant**
Recovery	**Adam**
Reports	Ryan

Note: Names in boldface are key managers of the U.R.S.A. Project.

1.3 Resources

1.3.1 Facilities

Etcheverry Mechanical Engineering Machine Shop Will be used for majority of our machining, especially that of the airframe and deployable landing legs, and will be the primary storage location of our materials.

- Hours: Mo-Th 8AM-11PM, Fr 8AM-4:30PM, Sa-Su 11AM-5PM
- 3 team members already have access, 3 team members will receive required training this (Fall) semester, and 3 will receive it the following (Spring) semester.
- Relevant Equipment:
  - Band Saw
  - Horizontal Band Saw
  - Mill
  - Lathe
  - Waterjet Cutter
  - CNC Mill

Jacobs Institute for Design Innovation Will be used for manufacturing parts on laser cutters and 3D printers, in addition to electrical work.

- Hours: Mo-Fr 8:30AM-11PM, Sa 12PM-7PM
- Multiple team members have keycard access and training on relevant machines and tools.
- Relevant Equipment:
  - 3D Printers
  - Vacuum Former
  - Laser Cutters

Moffitt MakerSpace Will be used for general construction, assembly, etc. that does not require specialized machines.

- Hours: Mo-Th 8AM-2AM, Fr 8AM-10PM, Sa 9AM-10PM, Su 1PM-2AM
- Open to all students.
- Relevant Equipment:
  - 3D Printers

Berkeley Global Campus at Richmond Bay (BGC) We will use this off-site facility for any testing, manufacturing, or construction that would be imprudent to perform on main campus and is not necessary to perform at a NAR or TRA site.

- Hours: 24/7
- Currently in the process of securing a space at BGC.
- Relevant Equipment:
  - Outdoor testing space

Small-scale Wind Tunnel Will be used for aerodynamics testing.

- Hours: Whenever necessary

1.3.2 Software

Rocket Design and Analysis

- OpenRocket
- SolidWorks (CAD and FEA)
- Ansys (CFD)

Manufacturing

- Adobe Illustrator (Laser Cutter)
- MasterCam X9 (CNC Mill)
- Cura (3D Printing)

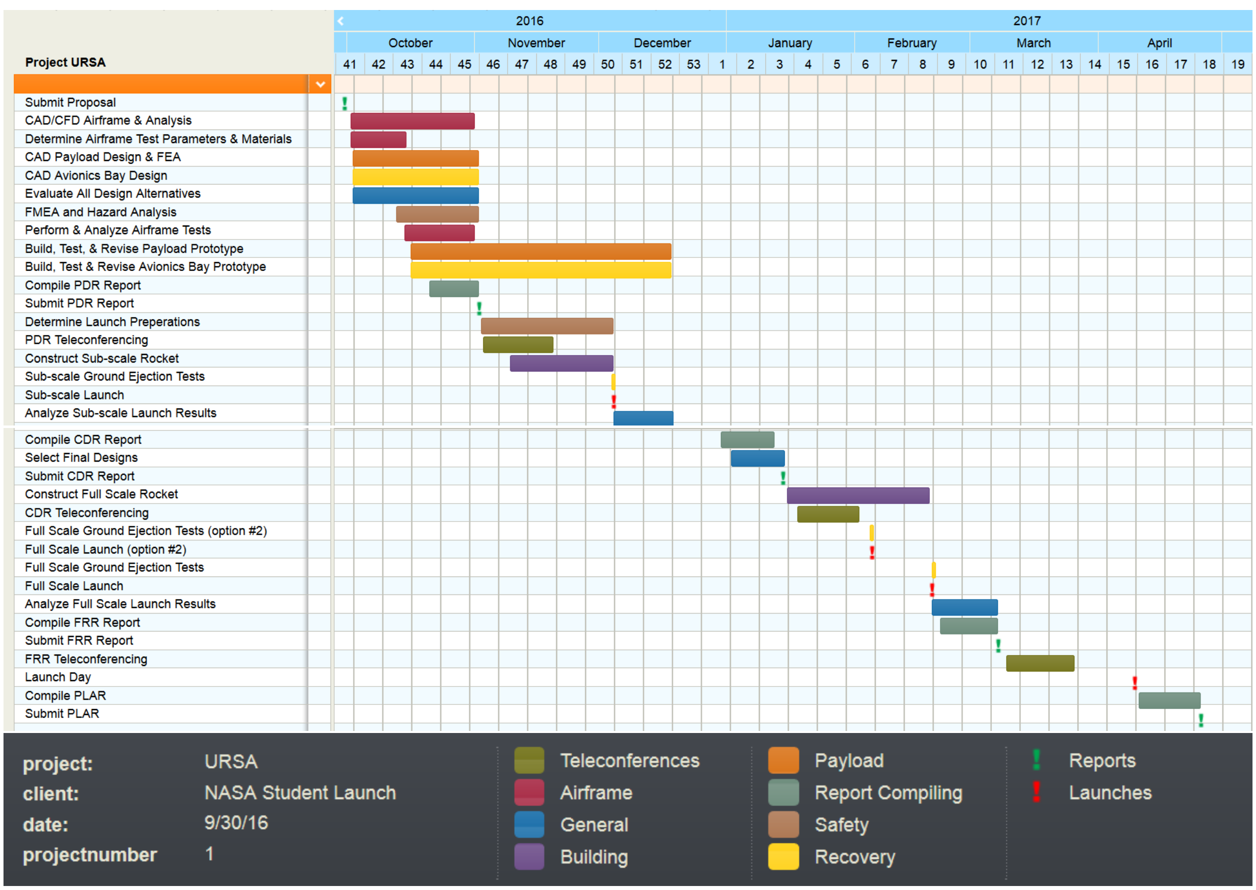
Electrical

- EagleCAD (Electronics design)
- Python, C, Sublime Text (Raspberry Pi programming)

Diagrams

- Adobe Illustrator CS6
- Adobe Photoshop CS6

1.4 Project Timeline



1.5 Funding

At the projected cost $1954.50 for all rocket materials (see full budget in section 8), we currently have more than sufficient funds to complete the project. However, there currently exist enough funds to support only four student team members' travel to, and stay in, Huntsville, Alabama. Our Budget Team has submitted, or is in the process of submitting, applications for funding and sponsorship from multiple sources shown below that would allow all team members who are willing and able to travel to and attend the competition.

Current Budget

Revenues	**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
Expenditures		
None		
Current Balance		4,505.33

Projected Budget

Revenues	Details	Date	Amount
Carryover Budget	See Table Above		4,505.33
Mechanical Engineering Department	Travel Expenses (1 Member)	October 2016	600.00
Engineering Student Council Financial Committee	Travel Expenses (1 Member)	September 2016	600.00
Boeing	Travel Expenses (4 Members)	October 2016	2,400.00
United Airlines	Travel Expenses (5 Members)	October 2016	3,000.00
JetBlue Airlines	Travel Expenses (5 Members)	October 2016	3,000.00
Southwest	Travel Expenses (4 Members)	October 2016	2,400.00
Expenditures			
Components	Airframe	Continuous	808.00
	Recovery	Continuous	556.00
	Electrical	Continuous	270.00
	Payload	Continuous	131.00
	Outreach	Continuous	150.00
	Safety	Continuous	39.50
Transportation	Transporting team and equipment	April 2017	13,617.23
Projected Balance			784.60

1.6 Sustainability

STAR was formed last spring, and this is our first time attempting to compete in the NASA Student Launch or any high-power rocketry competition. Through participation in new student events, attendance at a campus club fair, and increased social media presence this semester alone, STAR has grown to include 13 new team members at the start of the Fall semester. With the high-powered rocket we design and build this year as well as participation in Student Launch, we expect even more success recruiting incoming students and new members to STAR. In addition, we have documented detailed records of all of our work this year in a Google Drive, which we can share to prospective industry partners and members.

1.6.1 Social Media

Our social media campaign has the ultimate goal of sustainability and funding through a large social media base. We're beginning by ramping up the traffic on our Facebook page with the goal of launching a Twitter/Instagram page that will be announced on Facebook to maximize our opening traffic for our other pages. Once we've established a significantly large social media base, we will launch our crowdfunding campaign.

1.6.2 Maintaining Communication

The outreach team plans on sustaining itself through regular communication with our sponsors, partners, and people at outreach events. Regular presence at university events and holding our own publicity efforts will allow us to obtain support to continue the team in coming years.

1.6.3 Data Inheritance

As mentioned above, all of the team's logistical information is available on a common Google Drive account. All this information will be passed on as the team ages, so that we can build on our successes and failures.

1.7 NAR/TRA Sections

We plan to work with the Livermore Unit of the National Association of Rocketry (LUNAR)[2] to conduct all of our launches and tests. We will also work with LUNAR and our mentor, LUNAR President David Raimondi, to review our design and documentation.

2 Outreach & Educational Engagement

2.1 Goals

The team's plan for outreach is to get involved with as many educational programs (schools, museums, libraries) as possible, and develop strong connections with different groups (aerospace and outreach organizations on campus). Additionally, we want to help establish Aerospace courses at our university.

2.2 Projects

2.2.1 Current/Ongoing

KIPP Bay Area Schools KIPP manages 11 charter schools that provide free education to under-served communities. During Berkeley's Turn the Tables Fair (29 September 2016), we developed a contact with KIPP's Innovation Team. They are in charge of setting up STEM curriculum and activities for the entire school district. We are currently working

[2] We will be testing at the Moffett Federal Airfield: 158 Cody Road — Mountain View, CA 94035

with them to plan outreach events where we and other aerospace teams visit and promote the sciences.

Cal Day 2016 On Cal Day (16 April 2016), UC Berkeley's open-campus day for prospective students, we held a booth and talked to prospective and current UC Berkeley students.

New Engineering Student Orientation 2016 At Engineering NSO, (23 August 2016), UCB College of Engineering's Fall orientation for new freshmen, we held a booth and talked to new and current UC Berkeley Engineers looking for clubs and teams to join.

Calapalooza 2016 At Calapalooza, UC Berkeley's annual student group expo, we held a booth and talked to current UC Berkeley students looking for clubs and teams to join.

2.2.2 Planned

Habitat for Humanity The UC Berkeley chapter of Habitat for Humanity will be bringing local middle school students over for a campus tour. For the science portion of their visit, we are hoping to hold a demonstration and/or lecture about rockets.

Visibility on Campus Although the state of California maintains stringent regulations on model and high-power rocketry, we plan to find ways to increase the visibility of CalSTAR and of aerospace on campus through publicity of our launch events and team projects.

Aerospace Curriculum at Berkeley While UC Berkeley has a great engineering program and is regarded as the number one public university in the world, we do not have an aerospace engineering major, and there are very few aerospace-related classes. We are creating connections with other campus organizations such as the local chapter of AIAA (American Institute of Aeronautics and Astronautics) to work with the school to expand their Aerospace program.

2.3 Evaluation Criteria

2.3.1 Interaction Count

The number of students, teachers, and family members will be estimated at each event, either through a signup sheet or through manually counting.

2.3.2 Interaction Quality

After or during events, we will have a Google Form set up to ask how we are doing and whether or not our outreach has had any strong impact on the individual and/or community. The survey can be found at `https://goo.gl/forms/uxNRAeGVvGRPJFg32`.

2.3.3 Maintained Interaction

Through the signup sheet mentioned in subsubsection 2.3.1 or survey, we will contact students, teachers, and family members afterwards about future events.

3 Vehicle Requirements

1. *The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).*

   Our projected altitude, as calculated using OpenRocket, is around 5400 to 5500 feet AGL. (See subsection 4.4 for more details.) We wanted to initially design at a higher altitude than we need, because we expect the final mass to be greater than what is calculated right now. In addition, it is easier to add mass (with ballast) than to shed mass.

2. *The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.*

   Our main altimeter is the Perfectflite Stratologger CF Altimeter.

3. *The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.*

   The Perfectflite Stratologger CF Altimeter is capable of audibly reporting the rocket's peak altitude.

4. *At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.*

   Both the main and backup altimeter will be held in an enclosed avionics bay. Our avionics bay will have rotary switches on the outside that can arm and disarm all altimeters.

5. *Apogee altitude less than 5,600 feet AGL.*

   See Apogee Altitude above.

6. *All recovery electronics shall be powered by commercially available batteries.*

   All altimeters will be powered by 9V Duracell batteries.

7. *The launch vehicle shall be designed to be recoverable and reusable.*

   A significant factor in the selection of Blue Tube as our airframe material was its durability and resistance to shattering. This, with the addition of recovery electronics, will ensure we are able to recover a rocket that is not significantly damaged.

8. *The launch vehicle shall be limited to a single stage.*

   Our vehicle has one motor and one stage.

9. *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.*

   Completion of all pre-launch actions is expected to take significantly less than the 4 hour limit.

10. *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.*

    No part of the functionality of our design will be affected by the passing of 1 hour.

11. *The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system, without external circuitry or special ground support equipment.*

    The motor we selected is ignitable by standard systems, and nothing in our design requires any additional or unique circuitry or equipment.

12. *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).*

    The Aerotech K1050 motor satisfies these requirements.

13. *The total impulse provided by launch vehicle shall not exceed 5,120 Newton-seconds.*

    The Aerotech K1050 motor has an impulse of 2522 N-s.

14. *The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.*

    Our rocket has a minimum static stability margin during ascent of 2.21, as calculated by OpenRocket.

15. *The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.*

    Our rocket has a velocity at rail exit of 84.6 fps off an 8 foot rail, as calculated by OpenRocket.

16. *All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.*

    We plan to launch the subscale model at LUNAR on December 3rd.

17. *All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.*

    We plan to launch the full-scale rocket at LUNAR on February 4th.

18. *Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.*

    The only structural protuberances (besides rail guides) will be the fins located on the bottom of the rocket, which is aft of the burnout center of gravity.

19. *Vehicle Prohibitions.*

    Our rocket does not utilize any of the materials or features explicitly prohibited in section 1.19 of the NSL Handbook.

20. *The launch vehicle shall not exceed Mach 1 at any point during flight.*

    Our rocket reaches a maximum velocity of Mach 0.66 during flight, as calculated by OpenRocket.

4 Airframe

4.1 Description

The overall length of the proposed vehicle is 8 feet 6 inches. The diameter of the nose cone and front partition is 6 inches, and the diameter of the booster section is 4 inches. The booster is 4 feet in length. It houses an Aerotech K1050 motor, an avionics bay, and the main parachute. The reduced diameter of the booster section serves to reduce the rocket's wake, increasing aerodynamic stability. The booster is connected to the upper section by a 1 foot conical transition that increases the rocket's diameter to 6 inches. The transition houses the drogue parachute. The upper section acts as the rocket's payload. It houses three parachutes, a separate avionics bay, and landing hardware. This section, which includes the nose cone, is 42 inches in length. The ogive nose cone is 18 inches in length, giving it a length-to-diameter ratio that is aerodynamically favorable. Three clipped delta fins are attached to the rear portion of the booster section. The center of gravity of the rocket is located 42.5 inches from the rear of the rocket. The center of pressure is located 28 inches from the rear. The rocket's static stability margin is approximately 2.21.

4.2 Materials

The main body of the rocket will be constructed from Blue Tube. Blue Tube is strong enough to withstand high-impact landings, as well as high G-forces experienced during takeoff. Its heat resistance is high enough to survive the temperatures of the motor's exhaust. Additionally, Blue Tube has a density of approximately 0.871 ounces/inch^3, which is fairly light when compared with other materials such as fiberglass or phenolic. Blue Tube is also much more shatterproof than materials like phenolic, and much easier to work with than materials such as fiberglass. These reasons, coupled with its relatively low price, makes Blue Tube an appealing choice for our main airframe.

The nose cone will be constructed out of transparent polycarbonate. This is to facilitate camera viewing through the nose cone, as required by our payload experiment. The fins will be constructed from fiberglass because of its high strength and flexibility. The motor will be mounted in an inner tube made of phenolic. Centering rings for the inner tubes will be constructed from wood and cut on a laser-cutter.

4.3 Construction

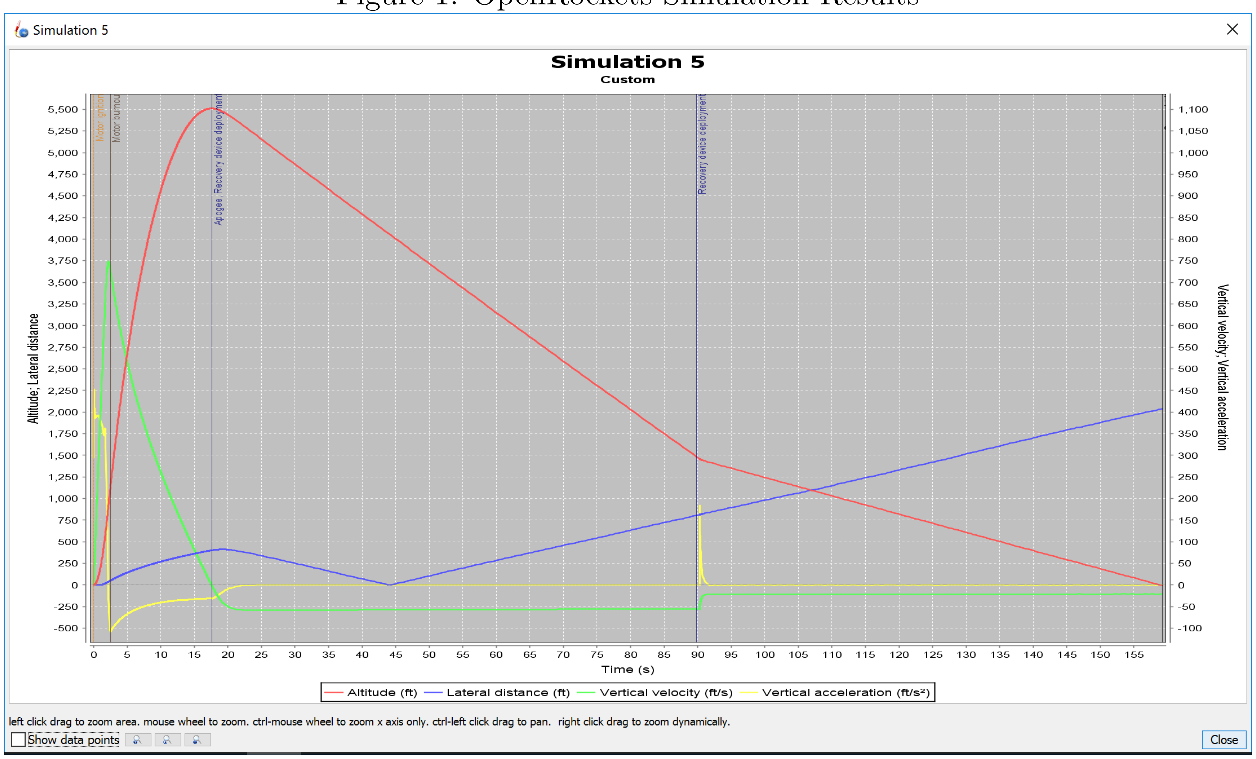
Most of the airframe will be constructed from 48-inch pre-cut lengths of Blue Tube. These sections will be cut into smaller pieces using a horizontal band saw. The nose cone will be made from transparent polycarbonate by vacuum-forming over a 3d-printed mold. The fins, as mentioned before, will be made from fiberglass. The transition section will be made by hand from carbon fiber for strengthening purposes. Slots for the fins will be machined into the booster section using either a CNC mill or a dremel tool. Epoxy will be used as an adhesive for the fins, centering rings, and the separate parts of the rocket.

4.4 Flight Metrics

Simulations with standard conditions (STP, zero wind) project an apogee of approximately 5418 feet AGL. With the simulated atmospheric conditions of Huntsville, Alabama in spring (80° F, 12 mph average wind speed), the apogee is approximately 5513 feet. Although the final rocket should project an altitude of exactly one mile, designing a rocket capable of reaching a higher altitude provides enough margin of error in case the final design is over the projected weight. Based on OpenRocket simulations, an allowable excess of up to 28 ounces of added weight would bring the apogee to exactly one mile. Our static stability margin is calculated at 2.21 calibers.

The projected velocity off the rod is approximately 85 feet/second. The maximum acceleration is projected to be approximately 14 G's, and the maximum velocity is 750 miles per hour. (See Figure 1 for details.)

Figure 1: OpenRockets Simulation Results



4.5 Challenges

Challenge	Solution
Insulating Avionics: After much deliberation we chose Blue Tube as the material for our airframe due to its strength and moderate heat resistance. However, the avionics bay is relatively close to the motor, so it is exposed to high heat.	The avionics bay will be insulated by a lightweight material that is capable of absorbing heat very well. Some possibilities include polystyrene or aluminum.
Strength of the Transition Piece: The transition piece will be subject to high stress from the weight of the booster and the weight of the payload.	The transition piece will be constructed out of a tough material such as carbon fiber that can withstand high stress.
Motor Insulation: The main objective is to disperse heat away from the internal walls of the rocket and prevent the heat from damaging the rocket's structure.	Insulate the rocket using a heat-dispersing material. Choosing an adequate insulator will depend on the combustion temperature of the motor. Polystyrene and aluminum are good choices because of their cost effectiveness.
Fin Strength and Placement: The fins will be subject to high aerodynamic forces due to the rocket's high speed and acceleration during flight. It is necessary to reinforce the fins so they will not break during flight or on landing.	The fins will be constructed from fiberglass and epoxy for high strength and flexibility. In addition, placement of the fins a few inches above the base of the rocket is crucial in acquiring a strong hold for the fin slots within the body of the rocket.
Nose Cone Material: In order to detect the ground targets for the payload experiment, it is necessary to mount the housing for the camera in a transparent portion of the rocket. Since the nose cone is the payload, the nose cone will be transparent.	The nose cone will be constructed out of transparent polycarbonate using a 3d printed mold and various vacuum-forming techniques. A major challenge will be ensuring that the vacuum-formed nose cone is uniform. Also, in order to vacuum-form the piece, the 3-D printed mold must be a male mold.

4.6 Other Images

Figure 2: Side View of Rocket

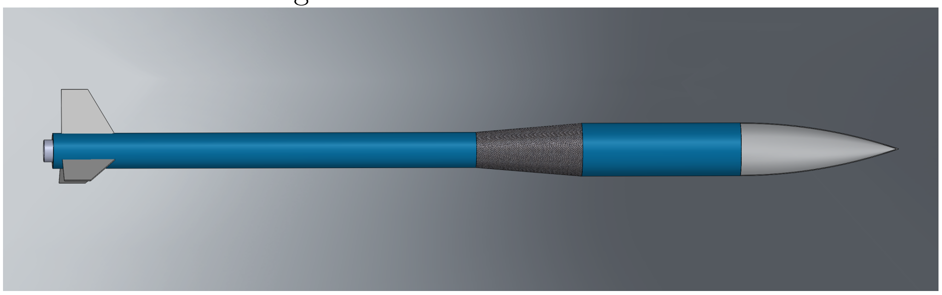
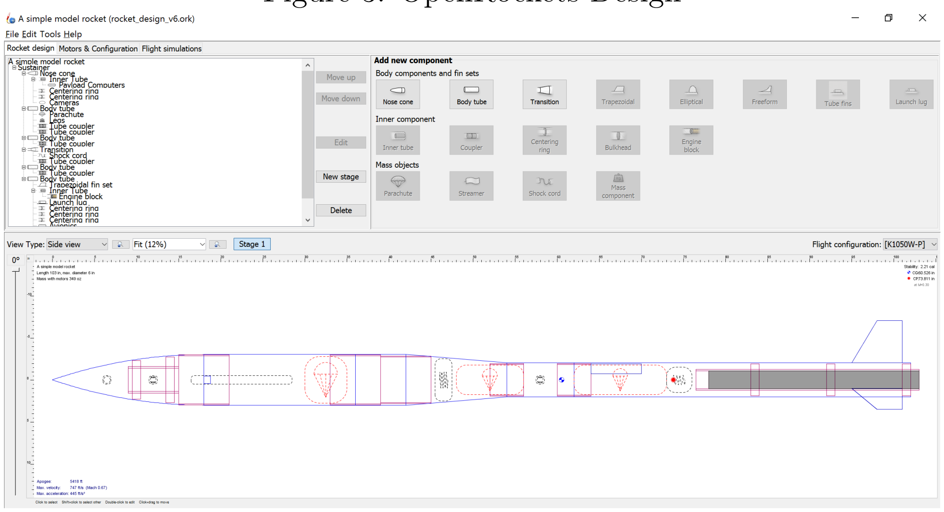


Figure 3: OpenRockets Design



5 Payload

5.1 Motivation

The objective of our payload experiment is target detection with a controlled landing. This experiment is designed to verify that a fully reusable payload section can land in upright orientation with no damage. To this end, SAGITTA-VL (Sight-Aided Ground IdenTification And Vertical Landing) uses a nose-facing camera inside a clear nose-cone to achieve detection of ground targets post main chute deployment (prior to ejection of the payload section). This allows for a significant amount of time to detect and identify the targets, prior to deploying landing devices. The nose-facing camera interfaces with an on-board avionics suite used exclusively to process the feed from the camera. This allows maximum processing power to be allocated to image processing, as well as providing range tracking ability for both sections of the rocket following payload ejection.

The primary mechanism for an upright landing are legs flush with the body during boost and after apogee but before payload ejection. After payload ejection, the activation of the payload recovery system will also activate the legs so they swing outwards into a position that will facilitate vertical landing of the rocket. Rail-guided secondary sliding supports provide a second point of attachment from the leg to the airframe structure, providing additional stability and strength during the impact event.

The goal of the payload recovery system is three-fold: to reduce the overall energy of the system on impact; to slow the payload system sufficiently to where active stabilization of the payload module is not required (before or after impact); and to reduce landing impact damage to the payload section, allowing reuse on future flights.

5.2 Mechanical Design Summary

5.2.1 Payload Description

The payload section of the vehicle consists of the top 18" of the rocket tube, in addition to the nose cone. The bottom of the section will consist of an avionics bay, which will contain independent electronics to control payload operations. These electronics are described in subsection 5.3: Electrical Design Summary. The bottom of the payload section will be attached to the avionics bay for the drogue parachute, and will be eventually separated as an independent section during descent.

The nose cone will be composed of clear polycarbonate, with a nose-facing camera mounted inside. The tubing section will have three cut-out sections spaced at 120° around the circumference of the body. These will serve as the outer surfaces of the "landing legs" used to land the vehicle upright. Each landing leg will have a rectangular plastic support member (manufactured via 3D printing) along the interior surface. Each leg will be mounted into its positions in the airframe at the bottom of the aluminum frame, via a hinge fixed to the uncut airframe on either side of the leg. In addition, the hinges will be fitted with torsion springs that hold the leg at no more than 110° from vertical. This position will be the landing configuration. For the launch configuration, i.e. when the vehicle is on the launch pad, the legs will be folded so as to be flush with the airframe outer surface, and the top of the interior frames will be secured in place by pins. These pins will be electronically moved using a motor, so that they can be retracted at a specific time in order to release the legs to the landing configuration. The outer surface of each leg will consist of a 12" long section of tubing parallel to the longitudinal axis of the airframe. The upper 3" of this section will be 5" in width, with the rest at 3" in width. The space in the airframe tube around the leg cutout will be minimized, and sealed with rubber gasket on the interior of the airframe to reduce drag.

Each landing leg will be additionally attached to a vertical rail that runs throughout the length of the payload section, toward the center of the tube. Each leg is attached via a hinged joint and an aluminum "sliding support" to a rolling joint which slides along the rail. Preliminary geometric analysis shows that a sliding support roughly 60% of the length of the landing leg allows for the maximum range of motion (110°) for the landing legs. A fixed stopper along the rail will define the upper limit of the range of motion and prevent the sliding legs from over-extension.

In the upper region of the tubing section of the payload, three small bundled parachutes will be mounted in open containers fixed to the nosecone bulkhead. These containers will be oriented such that the parachutes can be released toward the outside of the vehicle — the position of each parachute corresponds to the upper, wider section of a landing leg. The parachutes will be secured to eyebolts in the nosecone bulkhead. Additionally, each landing leg frame will have a string that is partially wrapped around its corresponding parachute, so that when the landing leg is deployed, it pulls the parachute out of the airframe. Thus, the electrically actuated landing leg deployment doubles as the mechanism for parachute deployment.

5.2.2 Target Detection

Our payload is designed to complete two independent tasks: visual identification of ground targets, and upright landing of the payload section of the vehicle. Target identification is achieved by means of a video camera mounted in the nose of the rocket, which can view the ground through the transparent polycarbonate nose cone. After deployment of the drogue chute, the nosecone and payload section of the vehicle will face the ground, suspended by the shock cord and the drogue parachute. After the main parachute deploys at an altitude of approximately 1000 feet, the falling vehicle will be slowed sufficiently so that the camera can accurately view the ground and provide live image data which can be used to identify and differentiate the targets. Our software package, as described below in subsection 5.3: Electrical Design Summary, will provide a signal to indicate when the identification has been completed.

5.2.3 Upright Landing

After target detection is complete, the entire payload section will be separated from the drogue parachute avionics bay by means of a black powder ejection charge. This deployment will activate the electronic actuation of the holding pins for the landing legs, causing them to retract and allow the landing legs to fall to the landing configuration. This action will cause the deployment of the payload section parachutes. The chute deployment will cause a sharp increase in drag at the upper region of the payload, while the deployment of the legs will shift the center of gravity of the section downward. This combined action will cause the payload section to rotate into the upright position, which it will maintain as it floats to the ground. When it reaches the ground, it will make contact on the landing legs, allowing it to stay upright. The torsion springs and the central rail mechanism will provide suspension to prevent the legs from folding back up as the section hits the ground.

5.3 Electrical Design Summary

To facilitate the target detection and upright landing, a custom image processing software system will be used. It will be run using a Raspberry Pi system. Target detection will begin after the main parachute deploys. Attempting detection at higher altitudes mean a higher risk of the targets being blocked from view by clouds, though the software will consider this and similar possibilities regardless.

Once target detection is complete, the software will:

1. Provide proof that the target has been detected (Req. 3.2.3), either by saving an annotated image to the computer's storage, or by sending a signal with similar proof to the ground station;
2. Trigger the charges to eject the payload section from the rest of the airframe;
3. Trigger the actuator to remove the pins holding the landing legs in place;
4. Confirm that the descent of the payload section is proceeding correctly.

The major factors we considered in determining which specific sensor models to use were cost and utility. In order to keep the electronic systems under budget, in several cases we had to choose relatively inexpensive options over options that were many times more expensive. However, even these cheaper options seem as reliable or as useful, and in some cases, even more useful, then the more expensive alternatives. The sensors are going to be connected to the Raspberry Pi controller system through both digital and analog connections, and the software package will have to perform different operations with each sensor. The sensor package includes:

- Eggfinder GPS system (range: 8,000 ft)
- Sparkfun Triple-Axis Digital-Output Gyro ITG-3200 Breakout
- Sparkfun Triple-Axis Accelerometer Breakout - LIS331 (range: $\pm$24g)
- 8 MP Raspberry Pi Camera Module (1080p video at 60 fps)
- Missile Works RRC3 Altimeter (range: up to 40,000 ft MSL)

5.4 Payload Procedure

5.4.1 Prelaunch and Ascent

Prior to launch, the payload section will be upright and coupled to the rest of the vehicle, with the landing legs locked in the launch configuration. This configuration is maintained throughout ascent.

5.4.2 Drogue Chute Deployment

During the deployment of the drogue chute, the payload will remain coupled to the drogue chute avionics bay, which is tethered to the rest of the vehicle. This will result in the nose cone facing downward, suspended under the drogue chute.

5.4.3 Main Chute Deployment

The main chute will be deployed from the booster section of the vehicle, with no change occurring in the payload configuration. At this time, the camera used for target identification will activate, and attempt to locate, identify, and differentiate the targets during slow descent.

5.4.4 Payload Deployment

When the camera has successfully identified and differentiated the targets, the software package will provide a signal to eject the payload section. This will also prompt the deployment of the landing legs and parachutes, which will cause the vehicle to turn upright. It will remain in the upright orientation, with legs in the landing configuration and all three parachutes deployed, until it lands on the ground.

5.5 Challenges

There are many challenges associated with high-power rocketry, many of which are unknown. The table below, while not all-inclusive, is a list of anticipated challenges associated with this project's payload and their proposed solutions.

Challenge	Solution
Target Detection (Req. 3.2.1)	By building a nose-facing camera, there is more time to successfully identify and differentiate between the targets before mechanisms for upright landing are activated.
Achieving upright orientation for landing (Req. 3.2.2)	After target detection and payload ejection, there will be two mechanisms that will cause the rocket to angle itself upright. First, the force from the legs folding outwards will shift the center of gravity downward, causing the payload to rotate away from its nose-down orientation. Second, once the parachutes deploy and open, they will induce drag at the top of the payload section, causing the payload to completely flip into its upright orientation.
Prevent connection between leg and inner rocket body breaking upon impact with ground	Limit angle between leg and body to no more than 110° at full extension. Let the torsion springs initially used to deploy legs double as a suspension system during impact. Add a support beam that is connected to the leg and body which will provide more support during impact. By adding this other point of contact, the beam will also act as a secondary connection in case the main hinge fails.
Prevent legs from folding back during landing	The three parachutes will decrease the speed of the payload so the force from impact with the ground is lessened. Also, the springs will force the legs downward during landing to keep them in the correct position.
Avoid parachute deployment failure due to snagging	A wider opening for the individual parachutes will be used and the parachutes will be packaged into small bundles to ensure a smooth deployment.

6 Recovery

6.1 Construction Methods

Our avionics bay design will require us to use several different methods in order to construct a functional system. The bulkheads in the rocket will be made using a laser cutter. Using a laser cutter will allow us to make bulkheads that fit snugly into the body of the rocket and cut precise holes for wires, screws, and U-bolts. The single axle in the avionics bay will be constructed by welding a metal, circular plate to each side of the axle. The platform that holds the altimeters and batteries will be 3-D printed in order to customize mounting of the altimeters, while remaining light and structurally sound. The door of the avionics bay will either be cut on a mill from an existing piece of airframe or made of polycarbonate. In the case of a polycarbonate door, we will 3-D print a mold and pour the resin ourselves.

6.2 Requirements

Our recovery design fully meets the requirements as specified in the Student Launch Handbook:

1. *The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.*

   See flight plan in subsection 6.4.

2. *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.*

   Ground tests will be performed on launch days before launch. See the project timeline in subsection 1.4.

3. *At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.*

   See kinetic energy and drag equations in subsubsection 6.4.1.

4. *The recovery system electrical circuits shall be completely independent of any payload electrical circuits.*

   Both the main and backup altimeter will be held in an enclosed avionics bay.

5. *The recovery system shall contain redundant, commercially available altimeters.*

   Our main altimeter is the Perfectflite Stratologger CF Altimeter. Our backup altimeter is the Missile Works RRC3 Altimeter.

6. *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.*

   Our avionics bay will have rotary switches on the outside that can arm and disarm all altimeters.

7. *Each altimeter shall have a dedicated power supply.*

   All altimeters will be powered by their own 9V Duracell battery.

8. *Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.*

   Removable nylon shear pins will be purchased online and used in the main parachute compartment, the drogue parachute compartment, and the payload section.

9. *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.*

   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.

10. *The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight.*

    Both the main and backup altimeter will be held in an enclosed avionics bay that will not be affected by another on-board electronic devices.

6.3 Avionics Bay Design

The design of our avionics bay is rooted on two key characteristics: accessibility and safety. In order to optimize the accessibility of our avionics bay, we have decided to take a rather unconventional approach to the design and build process. Rather than incorporating a movable sled and having to unscrew the bulkhead in order to access the altimeters inside the avionics bay, we have designed a door on the side, allowing us to access the inside of the avionics bay with more ease. This door will be completely detachable, with lips on the edges secured tightly to the rest of the avionics bay with gaskets and at least four primary screws. Furthermore, rather than incorporating the double-axle sled, we will build our platform around a single axle. This single axle will run through the center of the platform, allowing the platform to rotate around that axle, even when the door is open. This will tremendously improve the accessibility of both sides of the platform, becoming a multipurpose access point for the altimeters, batteries, wires, and more. The single axle will be welded into a metal plate on each end, which in turn will be screwed into the 1/4” plywood bulkheads. This is done in order to distribute the stress from the single axle onto the bulkheads. The bulkheads will be secured completely with an adhesive into the sides of the avionics bay once the door is designed. A U-bolt will be secured onto the outer faces of the bulkheads on each side, and each U-bolt will be linked to a parachute on each side with tubular Kevlar shock cords. The drogue chute will be linked to the fore-facing bulkhead, while the main chute will be linked to the aft-facing bulkhead. The bulkheads will have small holes to allow the wires from the altimeter to pass through to ignite the black powder charges. Thus, this design incorporates the consistency of the sled design while vastly improving its accessibility.

In regards to safety, we plan on preventing any aberration to the best of our capabilities. This would include using gaskets to keep the avionics bay as airtight as possible, reducing the probability of fluctuations in the altimeter readings. Furthermore, we plan on covering wires in order to reduce the risk of fire. Finally, our design is designed to make the arrangement of wires in the avionics bay more orderly. This will make minor adjustments in the avionics bay easier and reduce the risk of deployment failure due to incorrect wiring.

Figure 4: Avionics Bay: Internal Structure

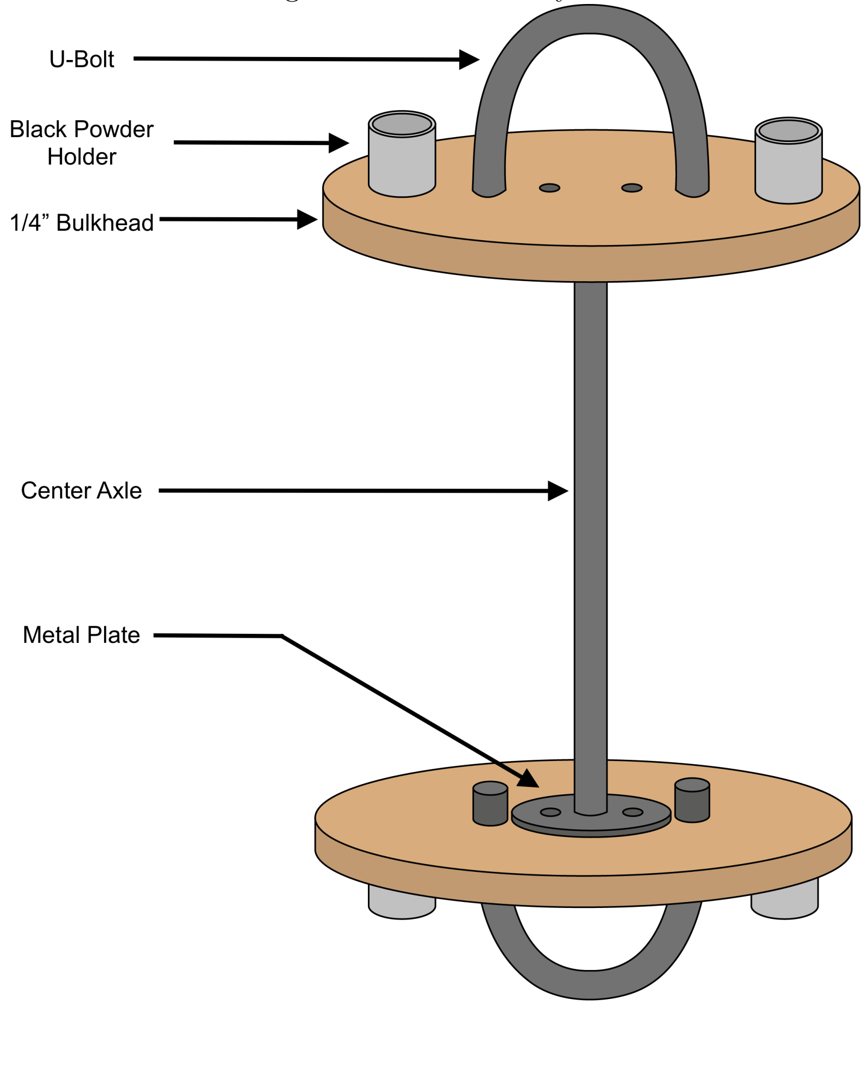


Figure 5: Avionics Bay: Altimeters on Sled

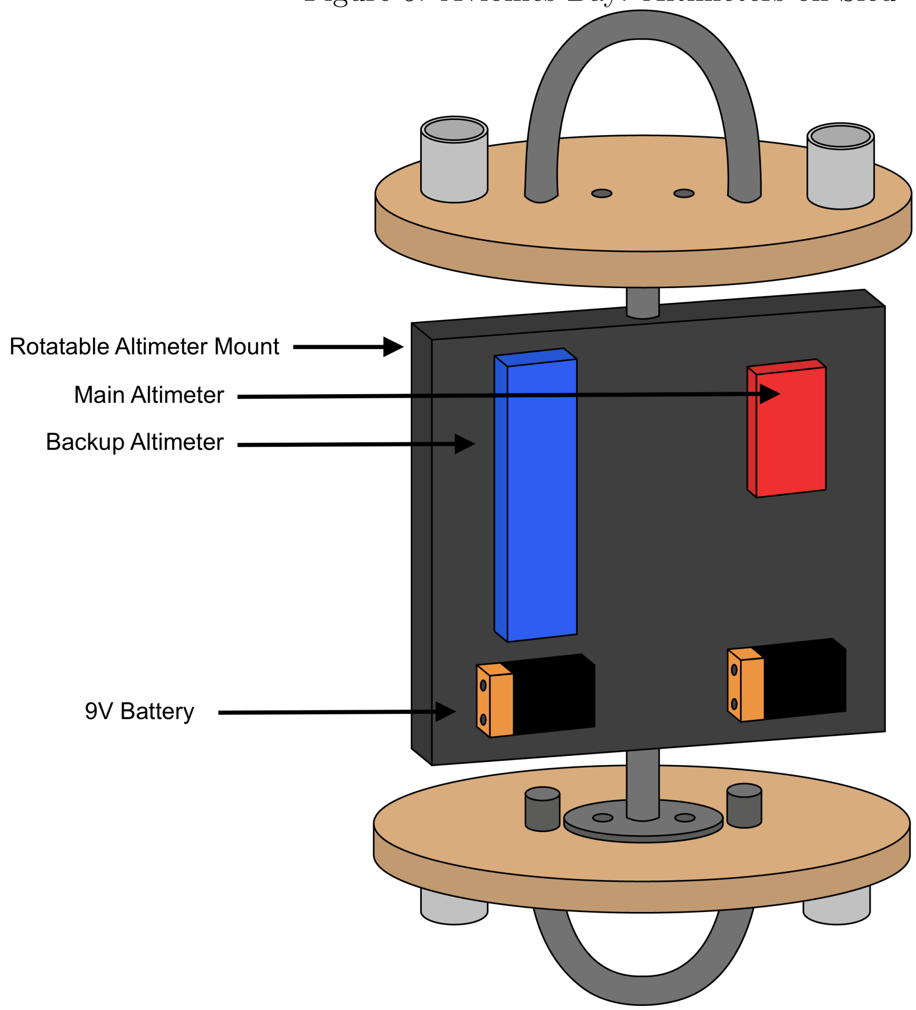


Figure 6: Avionics Bay: Without Door

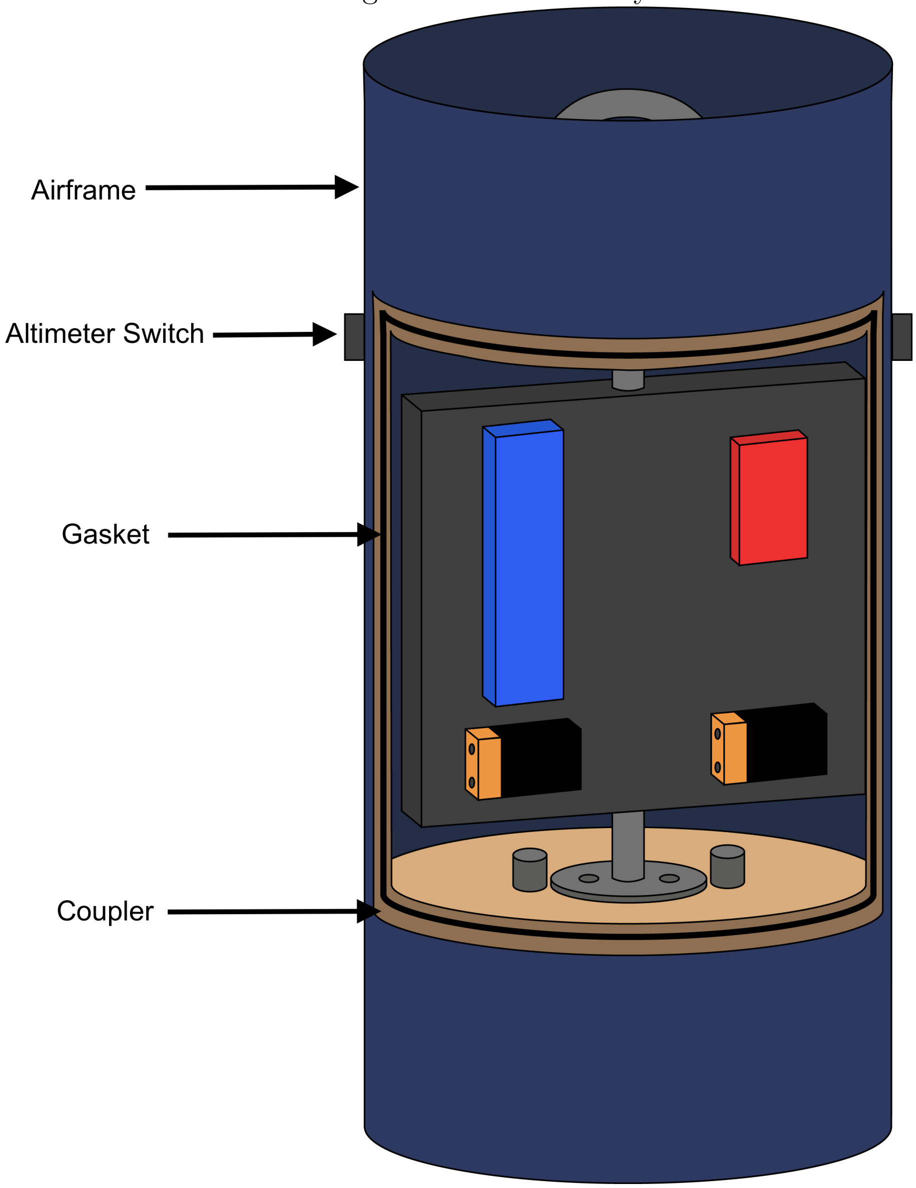
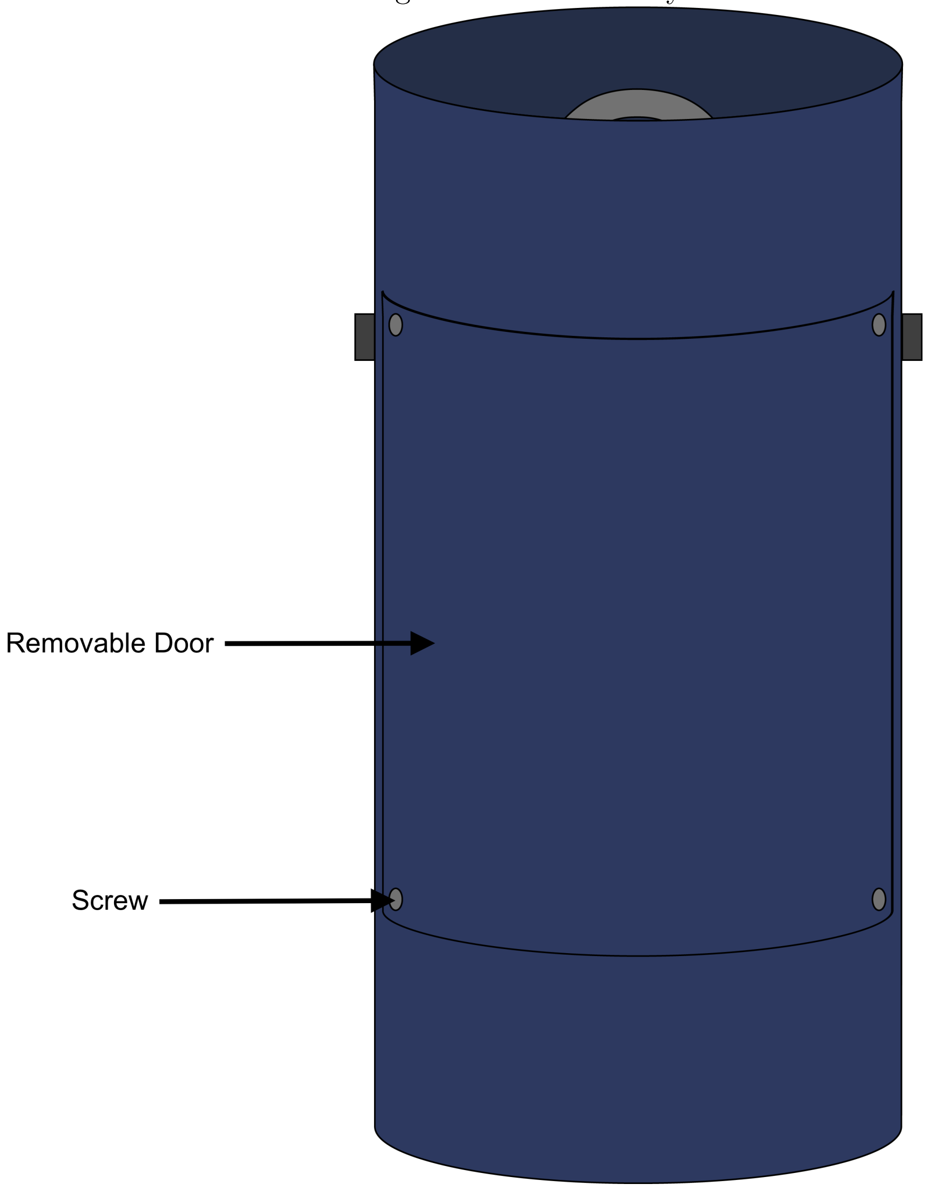


Figure 7: Avionics Bay: With Door



6.4 Parachute Deployment

Because the payload requires enough time to collect the necessary information from the nose of the rocket, our rocket will have the drogue parachute between the avionics bay and the payload and the main parachute between the avionics bay and the booster. We plan on deploying the drogue chute at apogee (Figure 8 — Phase 4). The main parachute will be deployed around 1,000 ft. AGL (Figure 8 — Phase 5) in order to give the payload enough time to confirm all three targets and detach and deploy its own parachute (Figure 8 — Phases 7-8). As shown in Figure 8 — Phase 6, having the drogue parachute closer to the payload will provide less drag force on the payload and allow the downward-pointing camera to hang below the rest of the rocket sections and collect the necessary data.

To deploy the parachutes we will be using two altimeters. Our main altimeter is the Perfectflite Stratologger CF Altimeter. We will be using the Missile Works 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 parachutes. 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

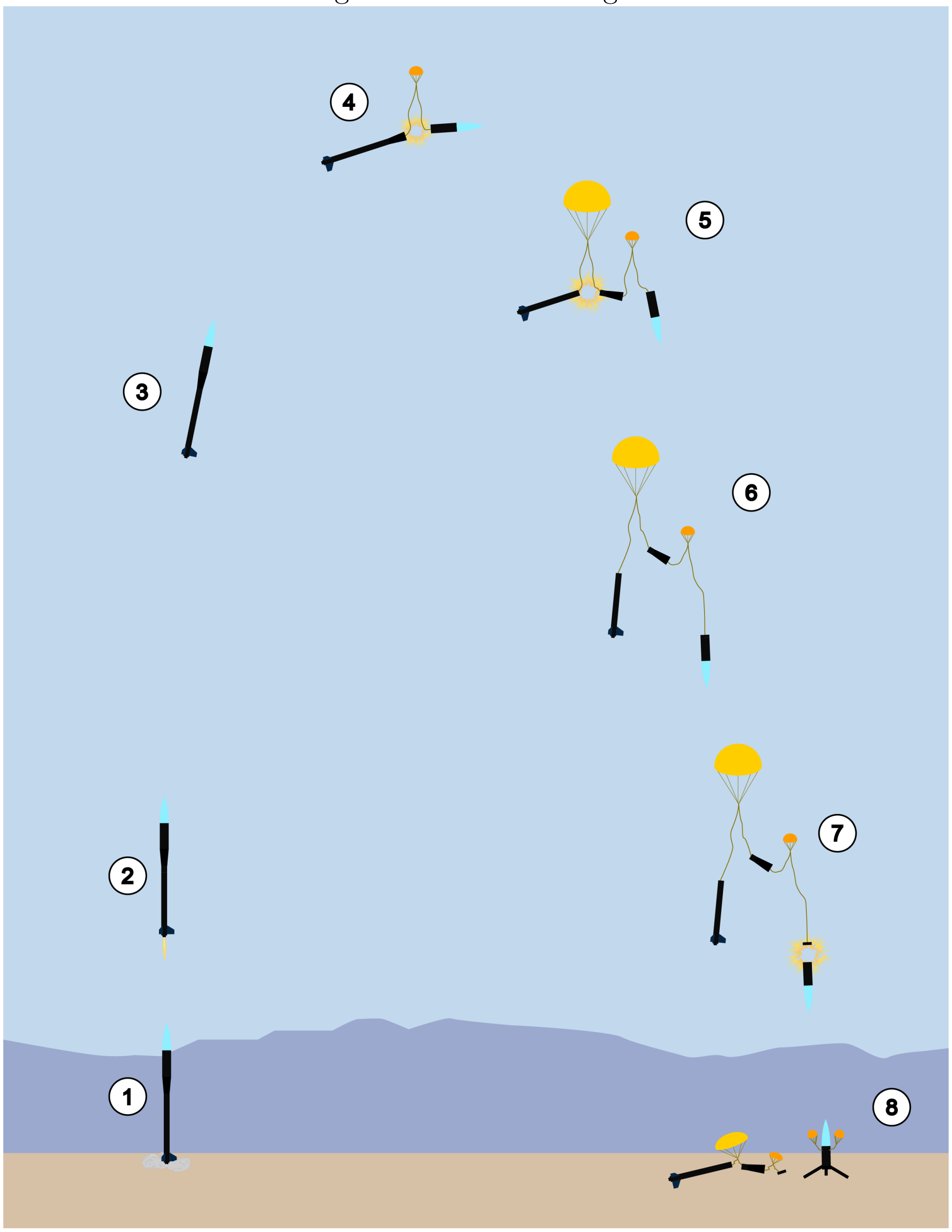
$$N = \frac{PV}{RT},$$

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.

Figure 8: Phases of Flight



Phase	Event
1	Ignition.
2	Powered flight.
3	Coasting.
4	Drogue parachute deployed at an apogee of 5418 ft. AGL
5	Main parachute deployed at an altitude of 1000 ft. AGL

Phase	Event
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.

6.4.1 Kinetic Energy and Drag Equations

See Figure 9 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:

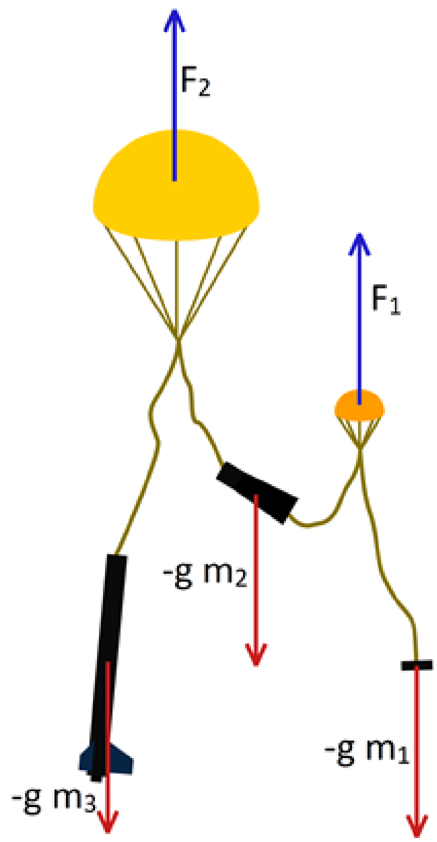
$$KE = \frac{1}{2}mv^2$$

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

Since there are both the drogue and main parachutes, these are the two drag forces:

$$F_1 = \frac{1}{2}\rho C_1 A_1 v^2 \text{ and } F_2 = \frac{1}{2}\rho C_2 A_2 v^2.$$

Figure 9: Applied Forces



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_3) must be considered, because the other sections are lighter and will have less kinetic energy:

$$v_{max} = \sqrt{\frac{2 \cdot 75 \text{ ft} \cdot \text{lbf}}{m_3}} \cdot \sqrt{\frac{32.174049 \text{ lbm} \cdot \text{ft}}{1 \text{ lbf} \cdot \text{s}^2}}$$

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:

$$m_1 + m_2 + m_3 = m_{total} \text{ (payload already detached from } m_1\text{)}$$

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

$$m_{total} g = \frac{1}{2}\rho v_{max}^2 C_1 A_1 + \frac{1}{2}\rho v_{max}^2 C_2 A_2,$$

$$v_{max}^2 \leq \frac{150 \cdot 32.174049 \text{ lbm} \cdot \text{ft}^2}{m_3 \cdot \text{s}^2},$$

So then we have the following restriction on parachute areas:

$$C_1 A_1 + C_2 A_2 = \frac{m_{total} g}{(0.5) v_{max}^2 \rho}$$

Velocity can be lower (thus $\geq$) and we can substitute the value of v_{max}^2:

$$C_1A_1 + C_2A_2 \geq \frac{m_{total}gm_3}{75\ \text{ft}^2 \cdot \text{lbm/s}^2 \cdot (32.174049)\rho}$$

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: 5.68 lbm
- Avionics and Transition: 3.94 lbm
- Booster: 6.69 lbm
- Payload Connector: 0.71 lbm
- Total Weight - Payload = 11.34 lbm
- Heaviest component = Booster = m_3 = 6.69 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 $m_{total} = 13.067$ lbm. Terminal velocity will be

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

which gives us the inequality

$$73.333\ \text{ft/s} \geq \sqrt{\frac{2m_{total}g}{\rho C_1 A_1}}$$

Given the values $g = 32.174$ ft/s^2, $m_{total} = 17.02$ lbm, $\rho = 0.0765$ lbm/ft^3, and $C_1 = 1.5$, we then have

$$C_1A_1 \geq 2.662\ \text{ft}^2$$

$$A_1 \geq 1.775\ \text{ft}^2$$

$$\pi r_1^2 \geq 1.775\ \text{ft}^2$$

$$r_1 \geq 0.75161\ \text{ft}$$

$$d_1 \geq 1.503\ \text{ft} = 18.038\ \text{in}$$

A drogue parachute of 24 in. 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-inch Elliptical Parachute from Fruity Chutes.

Main Chute Size (based on 24in. 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} does not have the mass of the payload because that part detaches.

$$C_1A_1 + C_2A_2 \geq \frac{m_{total}gm_3}{75 \text{ ft}^2 \text{ lbm/s}^2 \cdot (32.174049)\rho}.$$

With our heaviest component being 6.69 lbm, our maximum velocity required to have every component land with less than 75 ft-lbf is 26.85 fps. We have decided, however, to increase our safety margin by reducing our landing velocity to 15 fps.

$$C_1A_1 + C_2A_2 = \frac{m_{total}g}{(0.5)v_{max}^2\rho}$$

Given the values $g = 32.174$ ft/s^2, $m_{total} = 11.34$ lbm, $m_3 = 6.69$ lbm, $\rho = 0.0765$ lbm/ft^3, $C_1A_1 = 4.71$ ft, and $C_2 = 2.2$, along with the inequality $C_2A_2 \geq 37.68$ ft^2, we get

$$\begin{aligned} \pi r_2^2 &\geq 17.13 \text{ ft}^2 \\ r_2^2 &\geq 5.45 \text{ ft}^2 \\ r_2 &\geq 2.34 \text{ ft} \\ d_2 &\geq 4.67 \text{ ft} = 56.04 \text{ in} \end{aligned}$$

Thus, we need a parachute with a diameter of at least 56.04 inches for every part of the rocket to land with a velocity of 15 fps (a velocity lower than 26.35 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 60-inch Compact Parachute from Fruity Chutes.

Final Kinetic Energy:

The rocket, given the 24-inch drogue parachute and the 60-inch main parachute, will land with velocity given by the following equation:

$$v_{max}^2 = \frac{m_{total}g}{(0.5)(C_1A_1 + C_2A_2)\rho}.$$

Given $C_1A_1 = (1.5)(3.14 \text{ ft}^2) = 4.71 \text{ ft}^2$ and $C_2A_2 = (2.2)(19.27 \text{ ft}^2) = 42.394 \text{ ft}^2$, we end up with

$$v_{max} = 14.2303 \text{ ft/s}.$$

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: 3.94 lbm, KE = 12.40 ft-lbf
- Booster: 6.69 lbm, KE = 21.05 ft-lbf
- Payload Connector: 0.71 lbm, KE = 21.05 ft-lbf

Payload Parachute:

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

$$
\begin{aligned}
v_{max} &= \sqrt{\frac{2 \cdot 75 \text{ ft lbf}}{m}} \cdot \sqrt{\frac{32.174049 \text{ lbm ft}}{1 \text{ lbf s}^2}} \\
&= \sqrt{\frac{2 \cdot 75 \text{ ft lbf}}{5.68 \text{ lbm}}} \cdot \sqrt{\frac{32.174049 \text{ lbm ft}}{1 \text{ lbf s}^2}} \\
&= 29.149 \text{ ft/s}.
\end{aligned}
$$

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 $m_{payload} = 5.68$ lbm, $g = 32.174$ ft/s^2, $\rho = 0.0765$ lbm/ft^3, $C_3 = 1.5$, it follows that

$$3C_3A_3 \geq 21.234ft^2$$

$$\pi r_3^2 \geq 4.718ft^2$$

$$r_3 \geq 1.225ft$$

$$d_3 \geq 2.451ft = 29.431in$$

In order for the payload to land with a velocity of $12ft/s$ with 3 identical parachutes, it will need 3 parachutes of $29.413in$. We will be using 3 $30in$ Compact Elliptical Parachutes from Fruity Chutes.

$$v_{max}^2 = \frac{m_{payload}g}{(0.5)(3C_3A_3)\rho}$$

$$v_{max} = 14.7068 \text{ ft/s}$$

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

$$KE = 19.092 \text{ ft lbf}$$

6.5 Challenges

The table below, while not all-inclusive, is a list of the anticipated challenges associated with this project's recovery system and their proposed solutions.

Challenge	Solution
Accessibility of altimeters	Rather than removing one of the bulkheads below the avionics bay in order to access and fix the altimeters and batteries, we implemented a removable door system so that we can access the altimeters with greater ease on the field. The mount for the altimeters revolves around a center axle, allowing us to access both sides.

Challenge	Solution
Time to execute deployment of payload and parachutes	In order to maximize the time after the main chute deploys for the the payload to capture data, disconnect from the rocket, and deploy its landing mechanisms, we have decided to deploy the main parachute at an altitude of 1000 ft. AGL.
Successful recovery of all components of the rocket	In order to successfully recover all components of the rocket, we will include a GPS in the payload and the tethered components of the rocket so that we can find all components in case of drift. We will choose suitable parachute sizes based on calculation and simulation so that all components land safely. We will use two commercially available altimeters to be certain both parachutes are deployed. We will also perform ground tests of all recovery mechanism to be certain that black powder charges are correctly sized.
Payload must hang below rest of rocket during descent to capture camera data	We will use a longer shock cord for the drogue chute than the shock cord for the main chute so that the payload section hangs below all components of the rocket and the camera's view remains unobstructed.
Preventing false readings on altimeters from air flow over avionics bay door	In order to prevent false readings on the altimeters, as well as failed deployment of parachutes, we will use a gasket on the door of the avionics bay to make the door air-tight. Screws will tightly hold the door in place.
Loss of structural support when removing section of airframe and replacing it with door	To be certain that structural support of the avionics bay isn't compromised with the removal of part of the airframe, we will use a center axle welded to two plates as a point of rotation for the altimeter mounts. This axle will be screwed into the bulkheads.

Recovery Challenges and Solutions

7 Safety

The utmost concern of the team is safety during all aspects of rocket construction, assembly, and launch. The team's Safety Officer, Grant Posner, will ensure that team operations and procedures are carried out safely according to codes and regulations.

7.1 Risk Assessment

The safety team considers the following items to be some of the most likely or worrisome risks to the completion of the project:

Risk	Effect	Severity & Likelihood	Mitigation
Improper use of power tools	Injury to team members	2C	Require team members to read all relevant safety documents of Jacobs Hall/Etcheverry machine shop before use of equipment; furthermore, experienced team members will supervise less-experienced members to make sure that construction is carried out safely.
Improper handling of hazardous materials/chemicals	Explosion or fire, personal injury (burns, loss of eyesight, cuts, etc.)	2C	Experienced team members/team mentor should supervise all handling of hazardous materials, or the team mentor should handle materials him/herself. 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.
Transportation: forgetting equipment/parts	Rocket may lack a part that is required for safe flight	2D	The team will maintain a list of all rocket components and required equipment, and each item will have a specified team member who shall ensure that the item is accounted for before transportation.
Launch safety: not covering all items on a checklist	Rocket may be improperly or unsafely set up, launching mechanism could fail, team could fail to abide by regulations (such as the NAR HPRSC)	3B	Call-and-response system for completing a checklist: one team member calls out each checklist item, and a separate member completes the item and verifies it is complete out loud. If there is any confusion, the checklist item should be clarified by the member calling out the items.

Risk	Effect	Severity & Likelihood	Mitigation
Flight testing	Rocket failure or damage; injury to team members and/or spectators	2D	All flight tests will abide by NAR/TRA safety codes, along with applicable federal, state, and local regulations. Checklists will be used (as described above), and all present team members will be briefed on hazard and accident avoidance. Ground tests will be used to ensure stability of the rocket before flight.

Project Risks & Mitigations

7.2 Facilities

The team plans to use Jacobs Hall, the Etcheverry machine shop, the Richmond Field Station, the MakerSpace in Moffitt Library, and occasionally team members' residences for design and construction. All the university-owned buildings have safety information and codes, and use of several of these spaces require university training. Team members will read, know, and abide by the facilities' rules, and shall also consider safety briefings by the Safety Officer, in order to maximize safety when working on the rocket at any of the listed locations. The planned use of the facilities is described in the Facilities section of this Proposal.

7.3 NAR Member Procedures

Our NAR team mentor will purchase all rocket motors and any energetic devices that the team requires, and also transport, store, and install these devices, or will delegate these tasks to another NAR/TRA-certified member. Our mentor will perform all hazardous materials handling and hazardous operations, or will delegate to a certified and experienced person to perform hazardous operations. Members of the team will never handle a motor or energetic devices, and will not handle hazardous materials. The team will maintain safety by leaving hazardous operations to experienced, certified people.

At each launch the team's Safety Officer will confirm with the team's mentor that all the requirements of the NAR high power safety code are followed, so that our experienced mentor can supervise operations and ensure that all operations are safe. In particular, the Safety Officer and team mentor will ensure that all safe minimum distances are observed, and that all launch mechanisms (ignition system, motor, launch pad and rod) are safe and abide by codes and regulations.

7.4 Safety and Pre-Launch Briefings

The safety team will present weekly safety briefings to the rest of the team. These safety briefings include any new safety tips or advisories from the previous week, as well as any new hazard analyses or modifications to old hazard analyses, so that the entire team is up-to-date with information about hazardous materials, procedures, or actions. Furthermore, the safety team will give a presentation on hazard recognition and accident avoidance prior to rocket construction, and before any launch, to maintain team awareness of proper safety protocols. This presentation will cover such topics as construction safety, in particular proper use of machine shop equipment and construction accident avoidance; proper use of PPE; launch safety codes; and any other topics that will improve team safety.

Before every launch the Safety Officer will give a pre-launch briefing to the members of the team. This briefing shall include the above briefings on hazard and accident avoidance, and will also include discussion of relevant launch codes and regulations, in particular the NAR high power safety launch code, and will include any pertinent information on local weather conditions, possible failures, rocket recovery plans, and any location-specific hazards.

7.5 Caution Statements and Documentation

Necessary caution statements will be placed in all plans, procedures, and other working documents that pertain to any operation or procedure with risks involved, such as, for example, airframe construction with composite materials. These caution statements will include information on proper use of Personal Protective Equipment, in particular the proper use of safety goggles, closed-toed shoes, and any specialized safety equipment relating to specific tasks such as (for example) the use of respirators while constructing with composite materials and the use of gloves while handling epoxies and glues. Furthermore, these caution statements will reference relevant MSDS data sheets and procedure-specific safety codes and regulations.

Documents for risky (even low-risk) procedures will always be easily accessible to team members observing the procedures. For example, MSDS data sheets will be physically accessible to team members working with chemicals or other materials, and documentation on PPE will be physically accessible close to construction equipment.

7.6 Complying with Applicable Laws

The team will comply with all applicable laws when constructing and launching rockets. Specific plans for federal regulations are as follows:

Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C: Amateur Rockets We comply with §101.23 (General operating limitations). The team shall make calculations and simulations for the rocket of operation to ensure that it is launched in a suborbital trajectory, not launched into foreign territory or launched into any hazardous environments (such as buildings, urban areas, or aquatic landmarks). The rocket will not be launched into any government property, aircraft, or aircraft territory of any sort. Absolutely no live animal or such organisms will be launched in, or attached to, any part of the rocket. The rocket will not ever be launched at a target. The rocket will only be launched vertically, perpendicular to the ground, towards the sky. We further comply with §101.25 (Operating limitations for Class 2-High Power Rockets and Class 3-Advanced High Power Rockets). The team shall be extremely cautious when planning to launch any rocket. If any of the following conditions are met, the rocket shall not be launched: launch into any clouds or vision restriction hazards of more than half of the flight, before sunrise or after sunset, or within 5 miles of any airport or airspace range. All members should be excluded from the appropriate range when launching the rocket, for safety reasons. A member of the safety team shall bring a fire extinguisher to any rocket launch. The team will provide the necessary information to the nearest FAA ATC facility when planning on launching a rocket if the rocketry club does not.

Code of Federal Regulation 27 Part 55: Commerce in Explosives Our NAR mentor will handle all motors and energetic devices legally and safely.

NFPA 1127: Code for High Power Rocket Motors The team's rocket shall be inspected by a Range Safety Officer before launch, and if the rocket does not pass the inspection, then the rocket shall not be launched. Furthermore, the rocket will be designed to be stable in expected operating conditions, and will have a recovery system designed to safely deliver all parts of the rocket to the ground after launch.

NFPA 1127 is largely based on the NAR high power rocket safety code, which the team shall abide by.

7.7 Testing

Testing will be used as much as possible to ensure that the final rocket is stable and safe, and that all the components of the rocket meet design requirements. Sub-scale tests will be used to verify that integration of various components works as planned, and wind tunnels may be used to ensure aerodynamic stability of the rocket.

All tests will be carried out while following all applicable safety codes and regulations, in particular for sub-scale launches.

7.8 Rocket Deployment & Recovery

First and foremost, our safety priority is the team itself, which implies that in the situation of unintentional black powder ignition, shock cord snap, bulkhead deformity, or deployment failure, our main objective is to protect the crew from any injuries by removing every individual from harm's way.

Our second safety concern is the use of black powder and electronic matches. We will have our mentor purchase both the electronic matches and black powder. They will install both the electronic matches and black powder before all ground tests and launches. While the electronic matches and black powder are being handled, all members of the team will wear protective glasses. Our safety officer will make sure that there are no open flames or substantially hot objects nearby. The members of the recovery team will make sure that the altimeters are off and that no wires are live. During any ground tests, the members of both safety and recovery teams will clear the immediate vicinity of testing and check that all other team members are wearing their protective glasses.

Our third, but also extremely important priority, is the rocket itself. A single perturbation that distorts the performance and ability of the shock cords/bulkheads can jeopardize not only the structure of the rocket, but the success of the competition itself. Thus, any and all aberrations in the designing and testing phase for the implementation of the shock cords and bulkheads must be addressed and fixed. More specifically, our most hazardous situations involving a defective shock cord or bulkhead include, but are not limited to, entanglement of the shock cords during parachute deployment, which would inhibit the lift-off and/or landing of the rocket; busted bulkhead from impact of black powder that might damage the performance of the avionics bay's equipment; and others. Thus, CalSTAR is taking the initiative to invest in equipment that would counteract both of those potential issues. For the entanglement dilemma, investing in swivels and possibly a slider parachute would streamline deployment, allowing a greater degree in deployment flexibility while simultaneously improving the consistency of deployment. For the bulkheads, the primary method of counteraction would be investing in a sturdy enough bulkhead, sealed with gaskets and secured firmly with our center rod and U-bolts, in order to minimize possible damage from a high temperature/pressure explosion. With the right equipment and mentality, CalSTAR will ensure that failures in the shock cords and bulkheads will not jeopardize the mission or the life of its members.

Our fourth, and most important, safety concern with recovery is deployment failure. In the case that a parachute deploys prematurely during ascent, we will warn all of those around the site of launch and keep a close watch of the rocket so that team members and spectators can safely clear the area before crash landing. In the case that one or multiple parachutes fail to deploy, we will again warn all of those in the vicinity and keep watch of the rocket in order to clear the area where it may crash. In order to minimize these risks, we will use two altimeters. One altimeter will be the main one, and the other will be in place for redundancy in the case that the first does not work. We will also perform multiple ground test to be sure that we are using the correct amount of black powder to break our shear pins and deploy the parachutes.

7.9 Safety Agreement

The team agrees to abide by the following requirements, along with other safety rules:

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.

See Appendix B: "Safety Agreement" for a list of safety rules and evidence of team member agreement to the rules.

8 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	
	motor mount	1	$25.00	$25.00	
	Sub-scale rocket materials	1	$285.00	$285.00	
	3d printed models	1	$50.00	$50.00	
	motor	1	$188.00	$188.00	
				$ 808.00	
Recovery system					
	Perfect Fligth Stratologger CF Altimeter	1	$60.00	$ 60.00	
	Missile Works RRC3 Altimeter	1	$70.00	$ 70.00	
	Drogue Parachute	1	$60.00	$ 60.00	
	Main Parachute	1	$130.00	$ 130.00	
	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	
				$ 556.00	
Electrical					
	GPS - Eggfinder GPS System	1	$ 100.00	$ 100.00	
	Gyro - Sparkfun Triple-Axis Digital-Output Gyro ITG-3200 Breakout	1	$ 25.00	$ 25.00	
	Accelerometer - SparkFun Triple Axis Accelerometer Breakout - LIS331	1	$ 10.00	$ 10.00	
	Microprocessor - Raspberry Pi	1	$ 35.00	$ 35.00	
	Camera - 8MP Raspberry Pi Camera Module	1	$ 30.00	$ 30.00	
	Altimeter - Missile Works RRC3	1	$ 70.00	$ 70.00	
				$ 270.00	
Payload system					
	Support leg track	1	$ 25.00	$ 25.00	
	Landing legs	3	$ 16.00	$ 48.00	
	Torsion springs	6	$ 2.50	$ 15.00	
	Shear pins (separation of payload (4) and legs (3))	7	$ 5.00	$ 5.00	

	Hex Bolts	1	$ 10.00	$ 10.00		
	Support legs	1	$ 10.00	$ 10.00		
	Alt - L bracket mounts	6	$ 3.00	$ 18.00		
					$ 131.00	
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	
						$ 1,954.50
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						**$ 15,571.73**

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
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.

B.1 Signed Agreement

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
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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.

Print your name and sign below if you agree to follow all the rules above:

Name	Signature
Grant Posner	
Jacob Barkley	
Jamie Stankiewitz	
Ryan O'Gorman	
Darren Huang	
Adam Huth	
Danny Chu	
Mary Liu	
Jarrod Hsu	
Dinesh Parimi	
Tushar Singh	
Ilyas Kamil	
Avyay Panchapakesan	
Juan Fuentes	
Jacob Posner	
Brunston Poon	
Nate Young	Nathaniel Young
Caroline Pritchett	
Jordan Covert	
Allen Ruan	

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[3]) (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