# LionTech Rocket Labs

USLI Project Proposal 2016-2017

*The Pennsylvania State University*
*46 Hammond Building State College, PA 16802*
*September 30, 2016*

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# List of Acronyms:

| | |
|---|---|
| A&R | Avionics and Recovery |
| CFD | Computational Fluid Dynamics |
| FAA | Federal Aviation Administration |
| FEA | Finite Element Analysis |
| GPS | Global Positioning System |
| HPCL | High Pressure Combustion Lab |
| LTRL | LionTech Rocket Labs |
| MDRA | Maryland Delaware Rocketry Association |
| MSDS | Material Safety Data Sheet |
| NAR | National Association of Rocketry |
| NASA | National Aeronautics and Space Administration |
| NFPA | National Fire Protection Association |
| PPE | Personal Protective Equipment |
| PSC | Pittsburgh Space Command |
| PSU | The Pennsylvania State University |
| RSO | Range Safety Officer |
| STEM | Science Technology Engineering Math |
| STTR | Small Business Technology Transfer |
| TRA | Tripoli Rocket Association |
| UPAC | University Park Allocation Committee |
| USLI | University Student Launch Initiative |

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# 1: General Information

## 1.1 Important Personnel

### Adult Educator

Michael Micci - micci@psu.edu - (814-863-0043)

### Safety Officer

Laura Reese - ler5201@psu.edu

### Team Leader

Luke Georges - lag5461@psu.edu

### NAR Contact

| | |
|---|---|
| Robert DeHate, President, Animal Motor Works, Inc.<br>LionTech Rocket Labs Mentor, NAR L3 Certification | - rocketflier@gmail.com |

NAR Sections: Pittsburgh Space Command (PSC) #473

## 1.2 Team Roster and Structure

Lion Tech Rocket Labs has approximately 88 active members, ranging from freshman to senior undergraduates and graduate students. However, it is unexpected that all of these students will be able come to the competition due to travel expenses and necessary accommodations. The team is divided into administrative and technical branches for managing resources and completing tasks.

## Administrative

The administrative branch is composed of the President, Vice-President, Treasurer, Secretary, Outreach Chair, Webmaster and Safety Officer. These individuals are responsible for actively providing space for the technical branch to be able to function and managing the team as a whole. The position holder and their respective duties are shown in Table 1.

**Table 1: Administrative Infrastructure**

| Name | Position | Proposed duties |
|---|---|---|
| **Luke** | President | Communicates with project stakeholders, organizes meetings and keeps team on schedule. Guides team in the overall design and construction of the systems. |
| **Evan** | Vice President | Assists President in managerial tasks, meetings with stakeholders and team. Coordinates integration between subsystems. |
| **Justin** | Treasurer | Arranges fundraising events, communicates with sponsors and manages funds for the project |
| **Sam** | Secretary | Records information discussed in meetings and communicates with the general body of the club in the form of reminders and meeting recaps via email |
| **Brian** | Outreach | Organizes events for the club to engage with the community and share experience, knowledge and passion in STEM fields |
| **Tanay** | Webmaster | Manages team website, uploads project deliverables and meeting notes |
| **Laura** | Safety Officer | Ensures team follows safety regulations and implements safety plan |

## Technical

The technical branch is responsible for the design, fabrication, testing, and flight operations of the payloads and flight vehicle. The technical branch is divided in to four main subsystems: Avionics and Recovery, Payload, Propulsion, and Structures. Table 2 displays the officer positions and subsystem duties within the technical branch. Because the team is large, a description of what each subsystem's duties are is given in place of a description of each member's duties. The officers themselves take a leadership role in the subsystems; they guide, teach and work alongside their team to complete their duties. The general members of the club are spread out among each of the four subsystems, under the technical officers.

**Table 2: Technical Infrastructure**

| | Position | Duties |
|---|---|---|
| **Evan**<br>**Gretha** | A&R Leadership | Avionics and Recovery creates the avionics bay for the flight vehicle, tests altimeters, ejection charges and parachutes. On launch days A&R ensures proper parachute packing and successful vehicle recovery. |
| **Torre**<br>**Dan** | Payload Leadership | Payload designs and creates science packages for the project. These tend to involve computing and electrical components within the flight vehicle. Payload ensures these packages are functioning properly when preparing for launch. |
| **Alex P.**<br>**Trevor** | Propulsion Leadership | Propulsion selects motors for the vehicle, performs flight analysis and drag estimates. Propulsion is normally in charge of motor handling and insertion on launch days. |
| **Alex B.**<br>**Kurt**<br>**Anthony**<br>**Kartik** | Structures Leadership | Structures designs and creates the flight vehicle, tests materials and ensures all necessary components of the vehicle are compatible and flight ready. Structures is in charge of final assembly of the rocket for launch. |

# 2: Facilities and Equipment

## 2.1 Facilities:

### LTRL Lab:

The LTRL student lab is located at 046 Hammond Building at the University Park campus of the Pennsylvania State University. The lab houses the equipment and hardware used by the club for the duration of the competition. Access to the lab is available to club leads Sun-Sat from 8:00 am to 11:00 pm. General members can access the lab whenever there is a lead in the lab. Materials and tools in the lab are organized into toolboxes and storage containers for easy access. Most subsystems hold weekly meetings in the lab except in cases that the lab does not offer enough seating. Some of the most commonly used features in the lab include a Dremel for cutting/sanding, a tabletop vice, a handheld drill, and other standard handheld tools. A rough diagram of the lab is shown in Figure 1.

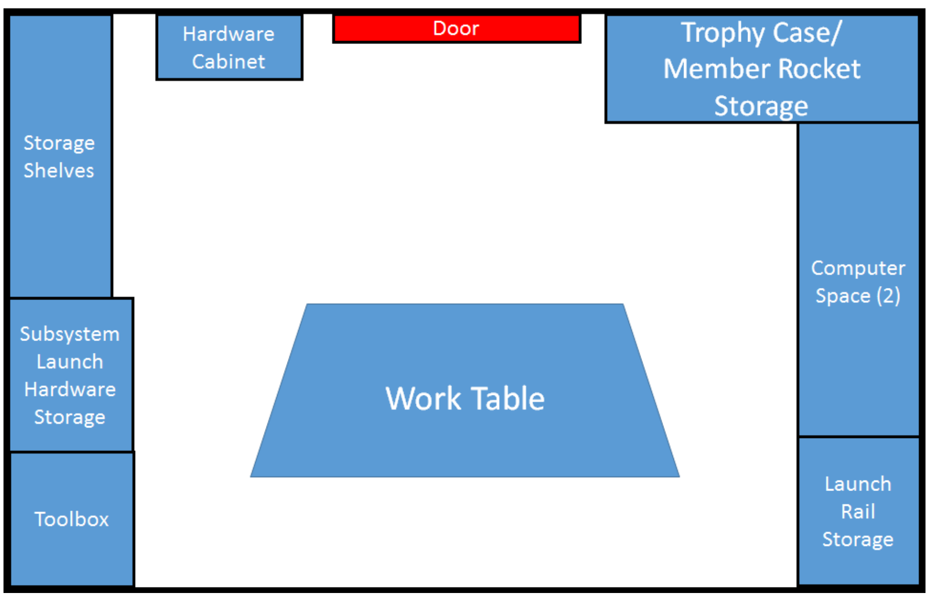



**Figure 1: Layout of LTRL Lab.**

### Penn State Learning Factory:

The Penn State Learning Factory is an on campus machine shop that students can use for their projects. Any student is free to use the shop if they have gone through the Learning Factory certification process. Several club members have a Learning Factory certification. The Learning Factory can be used to access standard machining equipment as well as other tools like high fidelity 3-D printers. Club members often go to the Learning Factory to machine larger or more complex custom components. The Learning Factory is open Mon-Fri 8:00 am to 10:00 pm.

### Aerospace Machine Shop:

The Aerospace Engineering Department and LTRL have recently reached an agreement to allow some LTRL members to use the Aerospace Machine Shop. This machine shop is located a few rooms away from the LTRL lab and is therefore more convenient for club members to use than the Learning Factory. The Aerospace Machine Shop features most basic shop tools. For safety, club member can only use the machine shop in the presence of a trained staff member from the Aerospace Department.

### High Pressure Combustion Lab:

The High Pressure Combustion Lab (HPCL) is a world renowned research facility at Penn State. The HPCL has class 1.1 and 1.3 explosive storage bunkers on their property. LTRL has asked and been granted permission to store rocket motors in the HPCL storage facilities. The HPCL also has reinforced bunkers and specialized test facilities for high pressure combustion systems. The Propulsion subsystem uses these facilities to test their competition motors. A&R also uses the HPCL grounds to test ejection charges for the subscale and full scale rocket.

### Penn State Computer Labs:

Penn State has multiple computer labs throughout campus with specialized engineering software like SolidWorks and MATLAB. These labs are used for computer aided drafting and design (CAD) as well as computational fluid dynamics (CFD) and finite element analysis (FEA).

## 2.2 Equipment:

### Payload:

The personnel required to fulfill a fragile specimen delivery are club members with knowledge of engineering mechanics and fluid dynamics. Basic power tools and hand tools will be required to construct the materials bag and acceleration bay. The supplies required for the specimen delivery will include:

- Dilatant
- Sealable bag
- Elastic bands
- Epoxy
- Screws
- Sealant
- Spings
- Bulkhead supplies (fiberglass, pine wood, etc.)

The personnel required to complete the Guided Landing System (GLS) project will include club members with programming, electronics, and mechanics experience. Computers with programming capability and program-sharing sites such as BitBucket will be required for the programming segments of the payload. Soldering supplies will be required for the electronics assembly. Basic power tools and hand tools will be required to assemble the parachute cable manipulation hardware. The supplies needed for the GLS will include:

- Battery
- Microcontroller
- Servos
- Parachutes and parachute harnesses
- GPS receiver
- Mounting brackets
- Epoxy
- Screws

### Avionics and Recovery:

The personnel required to construct and handle the avionics and recovery systems include trained club members who have launch-day experience. These members will be trained in the basic shop tools and safety needed for the construction of the Avionics bay. Advanced members will be familiar with proper parachute packing methods as well as deployment charge and drift calculations. Basic power tools and hand tools will be used in the construction of the Avionics bay. The supplies needed for this subsystem include:

- Stratologger SL100/CF altimeters
- 9V batteries
- Steel allthread
- Fiberglass bulkheads
- U-bolts
- Key switches
- Blast caps
- #2 Nylon shear pins
- Parachutes
- Kevlar blankets
- Shock cord

## Structures

The personnel required for the overall construction of the flight vehicle includes club members with knowledge of advanced manufacturing techniques. This includes training in basic power tools and hand tools as well as experience in additive manufacturing, lathe, and mill machines. In order to construct the final flight vehicle necessary supplies include:

- Fiberglass or Blue Tube body tubes
- Nosecone
- Body tube couplers
- Fin sheets
- Epoxy
- Screws
- Steel allthread
- Centering rings
- Bulkheads
- Custom manufactured parts from
- Aluminum stock
- Steel stock
- Plastic filament

## Propulsion

The personnel required for handling solid rocket motors are club members who have previous experience in the preparation and launching of model rockets. These club members are trained specifically in the steps needed in order to prepare, pack, and ignite solid rocket motors. On launch day this job is led by the most experienced member of propulsion in order to provide maximum safety while handling the motors required for launch. The supplies required by propulsion include:

- Final selection rocket motors
- Motor casing (full scale and subscale sizes)
- Motor retainer
- Test firing stand
- E-matches

# 3: Safety Plan

## 3.1 Safety Introduction

LTRL understands the importance of safety in high-power rocketry and the USLI competition. Therefore, LTRL has constructed a safety plan to help identify and mitigate hazards and risks to team members, facilities, and the project. An assessment of anticipated risks can be found in Appendix A. The severity of risks is based on the combination of likelihood and impact. To reduce these risks, mitigation techniques are proposed which shall reduce either the likelihood or impact of the risk.

The Safety Officer is responsible for ensuring that all members are informed of hazards and guidelines for accident avoidance. They oversee the records that ensure every member has completed the required Penn State laboratory hazards training.

A large amount of fabrication work for the project will take place at the on campus Bernard M. Gordon Learning Factory. The facility requires anyone using their machine shop to be certified by facility personnel. A class is offered for basic power tool safety, machining I, machining II, and welding. All members of the Structures subsystem are required to take the basic power tool safety and machining I classes. The Learning Factory personnel will advise LTRL members on manufacturing tasks that are beyond the scope of the team. The safety rules for the LionTech Rocket Labs team are modeled after those of the Learning Factory.

### Handling of Hazardous Materials and Duties of NAR Members

The LTRL roster includes members who are National Association of Rocketry (NAR) level 2 certified. Handling of hazardous materials, including motors and energetic devices are done by a certified NAR Member and in compliance with the NAR High Power Safety Code.

### Safety Briefing

All members are required to take Penn State's initial lab safety training. This training is given via four online modules: Introduction to Safety, Chemical Safety, Hazardous Waste Management and Disposal, and Emergency Preparedness. Successful completion of each module requires passing a quiz at the end. In addition, all members of the Structures subsystem complete shop safety training in order to work at the Learning Factory. All leads complete the initial lab safety training online training, and a subsequent session presented by a Penn State Environmental Health and Safety staff member.

In addition, general members are only allowed to work in the lab under the supervision of the leads. A copy of the lab's Unit Specific Safety Plan, including the Material Safety Data Sheets (MSDS) for all chemicals and hazardous materials used in the lab is also be available to members.

### Caution Statements

When necessary during the course of the project, verbal caution statements are included in plans for specific meetings in which hazards are encountered. Accompanying the caution statements are the relevant precautionary strategies to protect all involved participants. All warnings and procedures are explained to members before starting work and ensuring all involved parties understand and comply with safety requirements. These safety requirements include the required Personal Protective Equipment (PPE) for the specific task or hazard.

### Cognizance of Laws and Safety Agreement

LTRL is cognizant of and will abide by the Federal Aviation Administration (FAA) regulations regarding the use of airspace, the Code of Federal Regulation 27 Part 55 regarding the handling and use of low-explosives, and the National Fire Protection Association (NFPA) 1127 Code for High Power Model Rocketry regarding fire prevention. All flight testing will occur at the launch sites of established high power rocketry clubs and an FAA flight waiver will already be in place.

To be sure that the team members are abiding by the aforementioned laws, motor testing, static fires, and energetic recovery system testing will be performed under the supervision within the facilities of the High Pressure Combustion Laboratory located on campus. All test launches of the competition rocket will be performed during scheduled launch events held by the Maryland Delaware Rocketry Association (MDRA) or another NAR/TRA sanctioned club. MDRA has a strong safety record for many years and has multiple, qualified Range Safety Officers (RSO) that will help ensure that all laws are being followed. Club activities related to launches and propellant occur under the supervision of officers with the proper level of NAR/TRA certification.

### Purchase, Storage, and Use of Rocket Motors

The team roster includes members who are NAR level 2 certified and thus are qualified to purchase, store and use rocket motors. Certified members will be the only individuals permitted to purchase motors.

The motors purchased are then safely stored in a storage bunker at the High Pressure Combustion Laboratory which follows Department of Defense regulations for storage of explosives.

### Range Safety Statement

LTRL will comply with range safety inspection done by the Range Safety officer (RSO). The team understands that the RSO has the final say on rocket safety issues and that the RSO may deny the launch of any rocket for safety reasons. The team also agrees to comply with the safety requirements of the competition and the range safety officer. The team understands the regulations aforementioned and will abide by the stated regulation.

Launch safety checklists will be used to ensure safety and readiness of the rocket for flight.

# 4: Technical Specifications

## 4.1 Structures

### Material Selection and Justification

The two proposed materials for the rocket are fiberglass and Blue Tube. LTRL is currently running tests to finalize the material. Current members of the team only have experience working with fiberglass, so all preliminary designs and simulations were completed with a fiberglass airframe. A selection process was completed as shown in Table 3.

**Table 3: Selection Matrix for body material**

| | | Fiberglass | | Carbon Fiber | | Blue Tube | |
|---|---|---|---|---|---|---|---|
| Attributes | Weights | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Cost | 35% | 2 | 0.7 | 1 | 0.35 | 3 | 1.05 |
| Strength | 20% | 3 | 0.6 | 4 | 0.8 | 2 | 0.4 |
| Mass | 20% | 1 | 0.2 | 2 | 0.4 | 3 | 0.6 |
| Handling | 20% | 2 | 0.4 | 1 | 0.2 | 4 | 0.8 |
| Looks | 5% | 3 | 0.15 | 4 | 0.2 | 2 | 0.1 |
| Total | 100% | | 2.05 | | 1.95 | | 2.95 |

### Vehicle Dimensions

The proposed rocket is expected to be 121 inches long and have a 5 inch diameter. The rocket is estimated to have a dry weight of 40 pounds (fiberglass) or 30 pounds (blue tube). The stability margin off the rail is 2.1 calibers, and increases to a maximum of 4.5 calibers during the launch. Center of gravity and the center of pressure are located 73.5 inches and 93.8 inches respectively, aft of the tip of the nose cone.

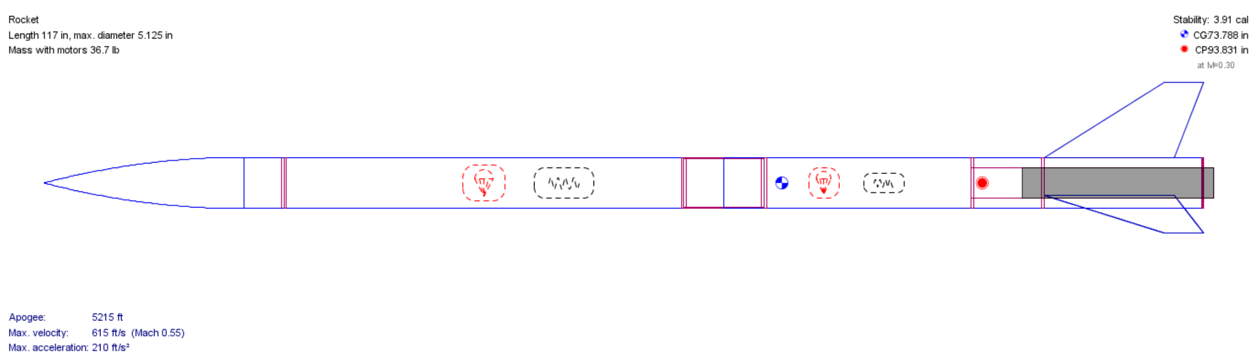



**Figure 2: Preliminary OpenRocket diagram of the rocket**

The rocket’s two separation points are aft of the nose cone and between the avionics bay and booster section. These separation points are to be fastened with shear pins during launch. 1/8” screws will be used to fasten non-separating sections of the rocket.

## Construction Methods

The rocket will be constructed using traditional methods used in high power rocketry. Airframe tubing and fins will be cut to size on vertical and horizontal band saws. Steel infused epoxy will be applied throughout the rocket as a bonding agent. Construction will be completed in a well ventilated lab by members certified by Penn State to use applicable tools and machinery. During the construction process, all members in the lab will be required to wear safety glasses and respirator masks. Those who are handling material will also be wearing hand protection.

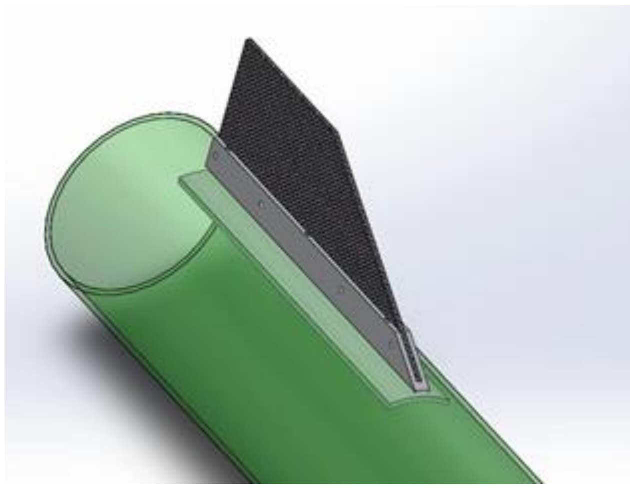


**Figure 3: SolidWorks Model of fin mounting system.**

The fins will be attached using a system of external brackets as shown in Figure 3. LTRL is planning to conduct tests with 3D printed external brackets. LTRL will test various 3D printed filaments such as PLA and ABS, and also look into various metal-infused filaments. If the tests have unfavorable outcomes, LTRL will likely use aluminum, hand machined brackets.

## Major Technical Challenges

The major challenges of the vehicle are storage constraints and balancing cost with material strength and performance. Materials testing will play a vital role in determining a suitable frame that satisfies our cost and strength requirements. With our choice of payloads, the size of the rocket must be minimized for cost, but still allow sufficient clearance and allow easy access to those payloads.

## 4.2 Avionics & Recovery

### Recovery System Concept

For the USLI competition, the rocket will use a dual deployment recovery system in fulfillment of the competition recovery requirements. At apogee, the rocket will deploy the drogue by separating the rocket with a black powder charge at the first separation point. Then, at 700 feet above the ground, the main parachute will deploy with a similar event at the second deployment point. The main parachute will be large enough to slow the rocket to a landing velocity that equates to a kinetic energy of less than 75 ft-lbs for the most massive section.

The avionics bay will be placed in the middle coupler of the rocket linking the two main body tubes. The avionics bay will be attached to the body tubes with steel screws so that it does not detach at these points. The actual separation points will be where the main body tubes intersect the nose cone and the booster section respectively. Placing the separation points at these locations will ensure that the black powder charges push the parachutes out of the body tubes instead of deeper into the tubes. The body tubes will be fastened to couplers with shear pins at the interface for ensured deployment. The recovery events are shown in Figure 4.

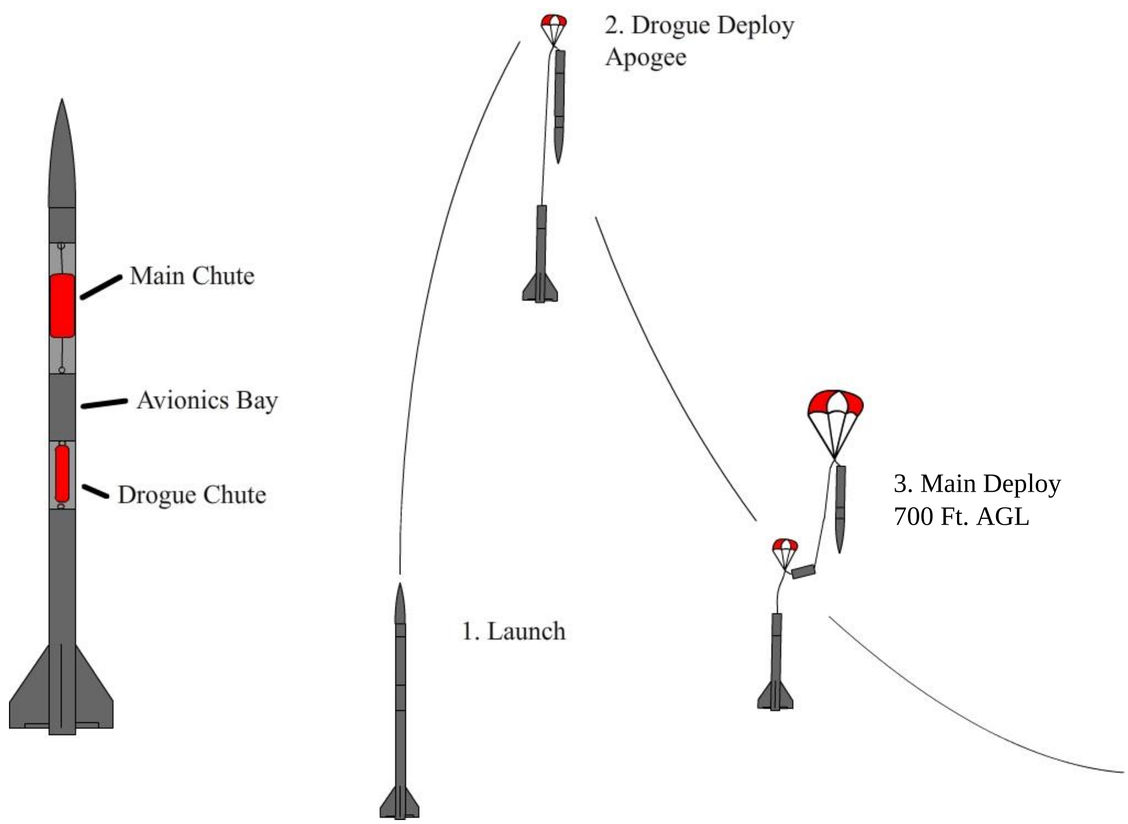



**Figure 4: Recovery cartoon**

## Avionics Bay Design

The avionics bay walls will be constructed from the same material as the rest of the rocket body. However, the bulkheads will be made from fiberglass to ensure maximum load bearing strength during high-g deployments. Each fiberglass bulkhead will feature two blast caps and a ¼" closed U-bolt with the appropriate U-bolt washer to appropriately distribute the forces of deployment. The bulkheads will be connected with two ⅜" allthreads made from aluminum or steel. The material for the allthreads will be decided at a later date based on deployment force calculations. The board that the avionics equipment will be mounted on will tentatively be 3D printed. However, should an additively manufactured avionics board fail to meet strength needs, the board will be replaced with fiberglass.

Two Stratologger 100 altimeters will be used for the altimeters. These altimeters were chosen based on their legacy use and durability. Each altimeter will be wired to its own 9V battery power source and its own mechanical key switch. A faraday cage will protect the avionics bay from electromagnetic interference from outside the bay. No equipment other than recovery equipment will be located inside the avionics bay. There will be two deployment charges on each bulkhead for redundancy. Each altimeter will be wired to one of the two redundant charges on each bulkhead. The charges will be timed to go off in a staggered fashion to avoid an overpressure event in the body tube. This system layout ensures a redundant deployment system at each step. A GPS transmitter will be located in the nose cone, at a distance from the avionics bay, to assist in recovery. A tentative layout of the avionics bay is shown in Figure 5. A wiring diagram of the avionics system is provided in Figure 6.

**Figure 5: Avionics bay preliminary layout with fiberglass board**

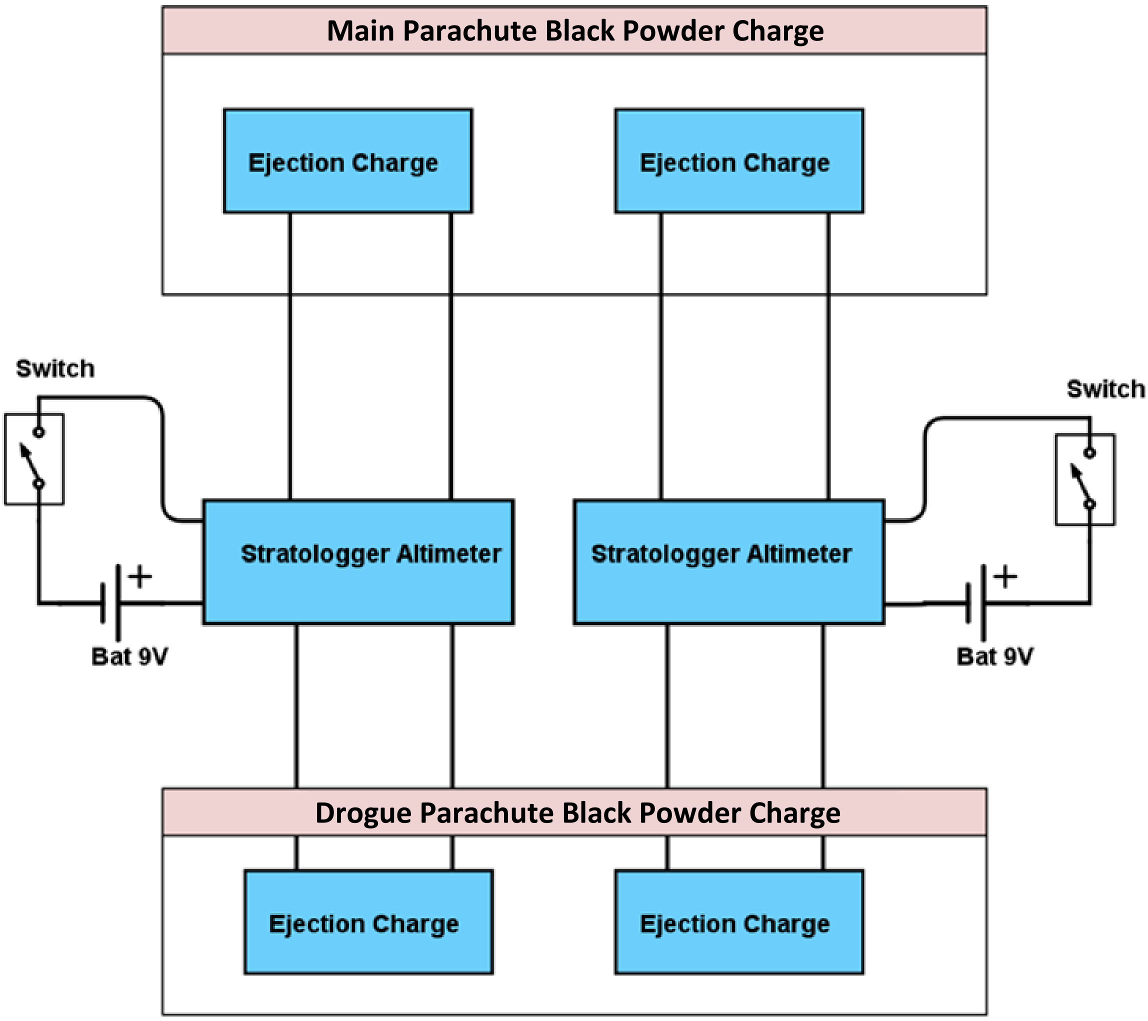



**Figure 6: Avionics wiring diagram.**

## Recovery System Testing

The sizes of the black powder charges will be calculated with a proper factor of safety. Deployment tests will be carried out before launches at the HPCL to verify the black powder calculations and recovery system design. This deployment design will also be tested on the ground before each subscale and full-scale launch in compliance with NASA recovery requirements. Subscale deployment tests and flights will be used to verify deployment techniques and make appropriate changes.

## Major Technical Challenges

Several major design challenges exist for avionics and recovery. The most obvious challenge is ensuring that both of the parachutes deploy fully. Ground testing will be used to ensure that the deployment system overcomes this challenge. In addition to ground testing, A&R has taken the necessary steps to create a system to easily test important hardware. Last year, the A&R team built a vacuum chamber capable of simulating altitudes up to 10,000 ft. The subsystem will use this chamber to test hardware both early in the build process as well as at the end of construction to ensure the hardware remains undamaged. The other main issue is ensuring that the drift on the parachute is not excessive. A&R will address this issue through the use of computer modeling and comparison of these models with launch results. LTRL plans on improving these computer models throughout the year. Through these methods, the subsystem will try to minimize drift distance without overshooting the maximum kinetic energy requirements.

The guided landing payload introduces an additional challenge to the A&R team. A&R will be heavily involved in the design and testing of the guided landing system to ensure that safety requirements for recovery are met and to maximize the effectiveness of the landing system.

## 4.3 Propulsion

### Motor Selection and Designation

The preliminary model for the rocket in OpenRocket was used to estimate the class of the motor and determine baseline designations. As per competition regulation 1.19, the model is based on a single stage motor and shall not be a hybrid, clustered motor, include forward firing motors, or motor that expels titanium sponges. The current estimation for the class of motor is an L motor in the mid impulse class. With potential mass decrease the motor may be decreased to a K class motor. This is in accordance with requirement 1.13 of maintaining an impulse of L-Class or lower.

All motors selected will be from the manufacturer Cesaroni and utilize ammonium perchlorate composite propellant, in accordance with regulation 1.11, and are able to be launched utilizing as 12 volt firing system as mandated by regulation 1.9.

Based on the preliminary rocket model, the primary motor designation will be the L1050 or L800 which will achieve an estimated apogee of 5117 - 5207 ft. The estimated rail exit velocity is 64.4 - 67.3 ft/s, complying with regulation 1.15. A thrust to weight ratio of 5.88 and 7.23, respectively, is achieved with the above motors. Motor selection will be repeated and refined as needed based on changes to the rocket mass and dimensions.

### Technical Challenges

The technical challenges for the propulsion subsystem this year will be to develop an accurate drag estimation program that will be based on subscale wind tunnel testing and full-scale test flights.

The propulsion subsystem is working on a research project and potential future payload that is a hybrid rocket motor utilizing paraffin fuel and Nitrous oxide oxidizer. An initial test bench version will be designed, built, and tested. With an impulse goal similar to a mid-class L motor; with an approximate thrust range 250-300 lbs. After the specifications of the test bench version have been verified work will begin on redesigning it to fit within the dimensions of the full scale rocket.

## 4.4 Payload

### Unknown Object Protection

The main experiment of this year's project will be a fragile payload protection system. A cylindrical case will contain the fragile specimen(s) and be housed within larger acceleration dampening system. Specimens received will be held in the "materials bag", which will be secured in place in the center of the cylindrical case by elastic bands. The elastic bands will connect the materials bag to the payload bay bulkheads. In accordance with section 3.4.1.1 in the Experiment Requirements, LTRL is prepared for the event that there are multiple specimens that need to be protected during flight. Provided that there is more than one specimen, each specimen will be held inside its own materials bag to ensure that the specimens will not cause damage to each other. The materials bag will be made of a soft plastic and all air will be removed from it before it is loaded into the bay. The use of the materials bag allows the protection system to adapt to an object of any size or shape.

The cylindrical case housing the bags will be filled with a non-Newtonian fluid to provide protection from acceleration. The fluid will become rigid during acceleration while conforming to the materials inside the container, which will reduce stress on the materials bag to ensure the specimen remains intact. The materials bag will keep the specimen(s) clean while they are immersed in the fluid. Two springs will surround the cylindrical case holding the fragile materials. These springs will simply act as additional dampening for the protection system. The Unknown Object Protection (UOP) system is shown in Figure 7.

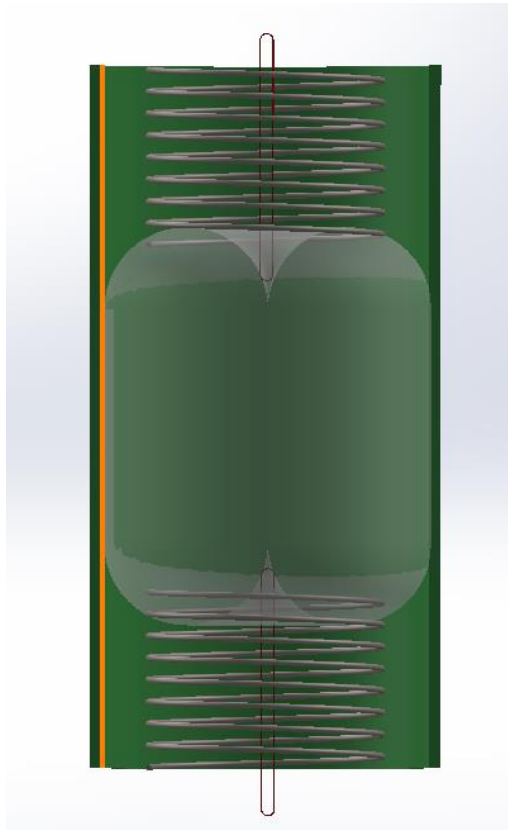


**Figure 7: Tentative design of UOP (Unknown Object Protection)**

The translucent cylinder in the figure is the cylindrical case which will hold the materials bag(s). As shown, the case will be protected from collision with the top and bottom of the payload bay by springs. The materials bag is not shown in the figure.

### Guided Landing System

A guided landing system will also be included on the rocket. A GPS receiver will determine a position of the launching pad before launch. After reaching apogee, the drogue parachute will deploy, and the guided landing system will activate. Control cables, along with traditional parachute strings, will connect the drogue parachute and the rocket body during descent. At the rocket body, the cables will be mounted on reels with counter-force springs. One mounting point will be fixed to the rocket fuselage for security, and two will be mounted on reels to control the attitude of the parachute. As the GPS receiver detects the position of the rocket, the reels will angle the parachute to create a lateral force so that the falling rocket can move towards its target landing position 100 feet from the launch pad. The counter-force springs inside will provide an opposing force on the cables so the reels will be able to change the parachute position a sufficient amount to control the rocket.

### Technical Challenges

There are a few technical challenges that need to be considered when designing the container to protect the fragile object: unknown size of the object, the possibility of multiple objects, and prevention of collisions between the objects, and between the objects and the sides of the vehicle. To address the problem arising from the unknown size and shape of the object, a flexible plastic bag that can hold up to the maximum object size will be use to contain the object. Many material bags and material mounts will be ready for use in the case of multiple objects. To prevent the collision of objects both with each other and the vehicle in the case of rapid acceleration and deceleration, the chamber in which the material bags are held will be filled with a non-Newtonian fluid. Additionally, the cylindrical case holding the fluid and the objects will be surrounded by springs to help cushion the case during changes in acceleration.

The main major technical challenge of the guided landing system is that the parachute strings twist together while the rocket is descending. To ensure this does not happen, the strings will be attached to a rotational bearing system that will allow the reels, cord, and parachute to rotate freely from the body of the rocket. Additionally, the strings will be lubricated so that in the event of entanglement, the reels will still be able to operate the parachute.

# 5: Educational Engagement

## 5.1 Team Involvement

The team will participate in a variety of STEM-themed events in the vicinity of Penn State that are designed to inspire a passion for science and technology in people of all ages. Most of these events will involve setting up exhibits at elementary, middle, and high schools that showcase USLI's past rockets, and describe how they work and what their purposes were. Additionally, the team will show students how the rockets separate to deploy parachutes and describe the various electronic components inside. The team will also host balloon races to demonstrate the concept of propulsion.

Club members will be required to attend at least three of these events throughout the year in order to go to the USLI competition in April. The outreach chair will record who has attended which events, arrange transportation for members to the events, and coordinate club involvement with the organizers of the events. The outreach chair will also make packing lists for what to bring to each event. The team will not bring black powder or rocket motors unless a demonstration launch is planned. In this case, all NAR and FAA requirements will be met and the outreach chair will ensure that such items are authorized at the location.

In addition to community outreach events, club members will have the opportunity to be involved in a mini-rocket competition and a tentative research contract with the High Pressure Combustion Laboratory (HPCL) at Penn State.

The mini-rocket competition is a low-cost activity in which club members will design, build, and launch very small rockets. This will provide members with experience in creative thinking and decision making, which will foster skills for higher level development projects. See Appendix C for the competition outline.

LTRL is pursuing a tentative contract for the NASA Small Business Technology Transfer (STTR) Phase II, through the HPCL to design, build, and demonstrate a hybrid-powered rocket engine. This would serve as a prototype for the upper stage of a sounding rocket that could achieve orbit with a small payload. If the contract is awarded to the HPCL, LTRL members will be involved with the project, which is expected to take approximately two years and could qualify as a senior design project for participating students.

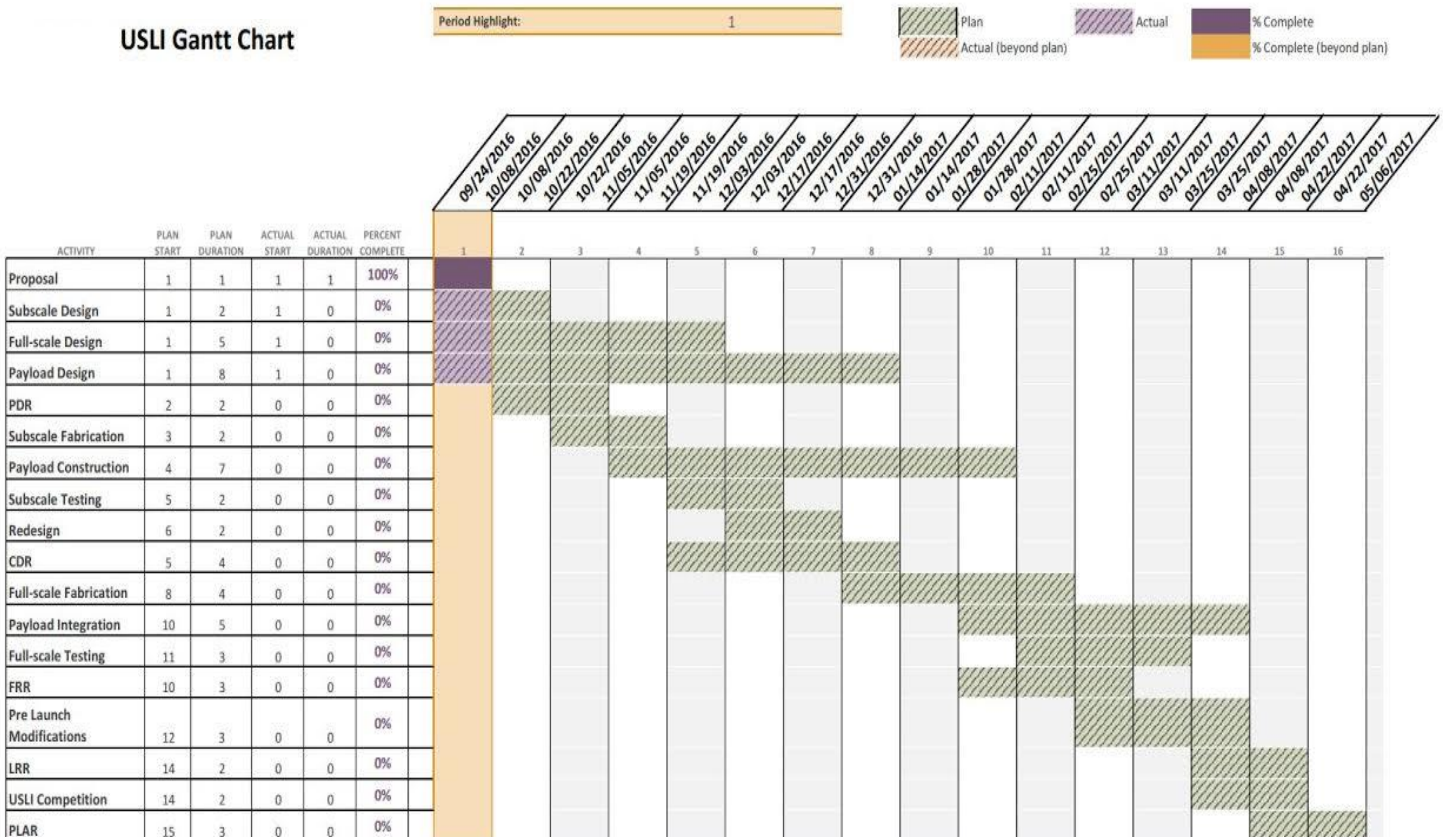
## 5.2 Goals of Outreach Activity

For the purpose of providing a successful and fulfilling outreach experience, four primary objectives have been outlined. These objectives will serve to guide our decisions on how to carry out outreach activities.

1. Get students involved and engaged in activities that foster a sense of wonder for the natural world and its inner workings.
2. To improve scientific literacy and to promote a scientific style of thinking about problem solving.
3. To promote awareness and stimulate interest in STEM fields and advocate student participation in STEM disciplines.
4. To provide team members with opportunities to enhance their teaching and public speaking skills.

# 6: Project Plan

## 6.1 Schedule




| ACTIVITY | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|
| Proposal | 1 | 1 | 1 | 1 | 100% |
| Subscale Design | 1 | 2 | 1 | 0 | 0% |
| Full-scale Design | 1 | 5 | 1 | 0 | 0% |
| Payload Design | 1 | 8 | 1 | 0 | 0% |
| PDR | 2 | 2 | 0 | 0 | 0% |
| Subscale Fabrication | 3 | 2 | 0 | 0 | 0% |
| Payload Construction | 4 | 7 | 0 | 0 | 0% |
| Subscale Testing | 5 | 2 | 0 | 0 | 0% |
| Redesign | 6 | 2 | 0 | 0 | 0% |
| CDR | 5 | 4 | 0 | 0 | 0% |
| Full-scale Fabrication | 8 | 4 | 0 | 0 | 0% |
| Payload Integration | 10 | 5 | 0 | 0 | 0% |
| Full-scale Testing | 11 | 3 | 0 | 0 | 0% |
| FRR | 10 | 3 | 0 | 0 | 0% |
| Pre Launch Modifications | 12 | 3 | 0 | 0 | 0% |
| LRR | 14 | 2 | 0 | 0 | 0% |
| USLI Competition | 14 | 2 | 0 | 0 | 0% |
| PLAR | 15 | 3 | 0 | 0 | 0% |

**Figure 8: Team Gantt Chart/schedule**

## 6.2 Budget

### Funding Plan:

**Table 4: Budget estimates for 2016-2017 competition**

| Expected Costs 2016-2017 | | |
|---|---|---|
| | Fiberglass | Blue Tube |
| **Full Scale** | $1,500.00 | $1,000.00 |
| **Subscale** | $900.00 | $600.00 |
| **Propulsion** | $1,800.00 | |
| **Travel** | $5,000.00 | |
| **Outreach** | $300.00 | |
| **Miscellaneous Equipment** | $1,000.00 | |
| **Total** | **$10,500.00** | **$9,700.00** |

The projected expenditures for the 2016-2017 school year are included in Table 4. This table lists all expected costs for the club. As a final material has not yet been decided this table includes prices for both fiberglass and Blue Tube.

- The full scale and subscale sections include the cost of building materials for the rocket plus additional supplies for material testing.
- Propulsion encompasses all motors needed for subscale and full scale flights as well as additional motors of multiple sizes for motor testing.
- Travel costs are mainly attributed to the Alabama trip during spring semester, however additional funding is required to cover fuel costs for other test launches throughout the school year.
- Outreach costs must also be taken into account and can include travel to outreach locations as well as any supplies needed for the event.
- Miscellaneous equipment includes all tools, equipment, and supplies needed for construction of the rocket.

**Table 5: Expected income**

| Expected Income 2016-2017 | |
|---|---|
| **Aerospace Engineering Department** | $5,000.00 |
| **Mechanical Engineering Department** | $500.00 |
| **UPAC** | $5,000.00 |
| **Club Fundraising** | $1,000.00 |
| **Total** | **$11,500.00** |

Funding for the USLI competition will be mainly provided through various academic sponsors. Table 5 describes the expected funding from these various sources.

- The Aerospace Department of Penn State has been the main sponsor of LTRL and they hopefully will continue to support our club this year.
- The Mechanical Engineering Department at Penn State is also usually willing to provide the club with some funding.
- University Park Allocation Committee (UPAC) is another organization that is dedicated to supporting Penn State clubs. They offer funding for club-associated travel and are the main source of income for travel and housing costs for the USLI competition.
- Yearly dues and fundraising opportunities gathered throughout the school year will also provide funding.

In order to ensure completion of the rocket and the club goals, additional funding may be sought. The Pennsylvania Space Grant is a possible source of funding to which LTRL plans to submit a proposal. This grant is meant to provide support for commonwealth institutions in continuing, expanding, and developing programs. Other sponsors who have expressed interest in the past include the Boeing Corporation and the Engineering Graduate Council at Penn State. These are all resources that will be contacted in search of additional funding.

Depending on the amount of success in acquiring additional sponsors, the club may expand its goals in order to maximize the use of additional funding. Examples include more club launches like the Battle of the Rockets competition, which will allow for increased student participation, learning, and development. Increased research opportunities within rocketry is another area that with more funding could greatly expand the reach and influence of the club.

## 6.3 Community Support

As a returning team, LTRL has established a plan for sustaining and continuing to expand the club for upcoming years. The club continually tries to establish new sponsorships and partnerships by providing companies and departments with a pamphlet that explains the team's sponsorship program at recruitment events. Interested companies are also directed to the team's website where there is information about the process to become a sponsor and examples of how the money from sponsorship helps the team.

In return for sponsorship, the companies' logos will be posted on the team's website. Depending on the level of sponsorship, a company logo may be placed on the rocket. In addition to a logo on the website or rocket, any company that funds one of the team's major outreach events (ie: a launch or event of similar size) will have their logo advertised in multiple places at the event, and the event name will include that company's name.

## 6.4 Sustainability

In order to ensure that the club continues to grow, the team has several methods by which it recruits new members. At the beginning of Fall semester, the team posted flyers, sent out announcements about the club in the various engineering E-newsletters, and gave short presentations about the club to classes of freshmen students. LTRL also utilizes a booth at Penn State's Involvement Fairs to recruit incoming students before fall and spring semesters. As the team graduated a significant number of its members last year and will be graduating a significant amount of its members this upcoming year, recruitment is crucial for sustainability.

# 7: Appendices

| Risk | Description | Likelihood 1(Least)-5(Most) | Impact 1(Least)-5(Most) | Mitigation |
|---|---|---|---|---|
| **Overall Project** | | | | |
| Project falls behind schedule | Major milestones are not met in time | 4 | 3 | Weekly status meetings project plan |
| Project is over budget | Testing/travel/fabrication costs exceed expectations | 3 | 4 | Compare prices from different vendors, avoid excess shipping costs |
| Parts are unavailable | Testing or fabrication parts | 2 | 3 | Use non-exotic materials and check for availability. Order parts far in advance |
| Labor leaves/graduates | Seniors graduate or students stop attending meetings | 5 | 3 | Recruitment at beginning of each semester. Team building activities. |
| Injury of Team Personnel | Team member become hurt while working on project | 1 | 5 | Identify potential safety hazards. Inform and enforce team safety |
| Integration Failure | Parts don't fit together properly | 2 | 4 | Shared online documents |
| Club loses funding | One or more sources can no longer provide funding | 2 | 5 | Dedicated member to track expenses |

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| | | | | and make possible funding contacts. |
| Club loses facilities | Room 46 Hammond no longer available | 1 | 5 | Maintain clean environment and proper storage of materials |
| Theft of Equipment | Parts or testing equipment get stolen | 1 | 3 | Only subsystem leaders and officers will have card access to the USLI lab |
| Failure to acquire transportatio n | Transportation to Alabama cannot be acquired | 2 | 5 | Have plan to carpool if necessary |
| Weather does not cooperate on flight test day | Winds in excess of 20mph or excessive rain | 3 | 3 | Schedule backup launch day |
| Damage during testing | Failure of recovery devices, hard landings, etc | 3 | 3 | Ground testing, parts |
| **LAUNCH** | | | | |
| **Propulsion** | | | | |
| Motor CATOs | Catastrophic motor failure during launch | 1 | 5 | Inspect motor grains prior to installation. Have a certified member assemble the |

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| | | | | motor with another observing. |
| Igniter does not light motor | Motor either chuffs or does not light | 2 | 1 | Use a properly sized igniter and cap the nozzle |
| Motor does not stay retained | Ejection charges push motor out rear of rocket | 1 | 5 | Use of active motor retention |
| **Vehicle** | | | | |
| Airframe or couple buckles | Airframe or coupler buckles during ascent or landing | 1 | 4 | Use only materials tested for HPR flights |
| Airframe zippers | During ejection, shock cord cuts into body tube | 2 | 3 | Deploy parachute precisely at apogee with altimeters |
| Fin flutter | Fins break off of rocket | 1 | 5 | Scale model testing, use robust fin geometry, testing of fin brackets |
| Premature airframe separation | Drag separation or internal pressure causes separation | 1 | 3 | Pressure relief holes and use of nylon shear pins |
| **Recovery** | | | | |
| Drogue chute fails to deploy | Drogue chute either does not leave the tube or doesn't unravel | 2 | 3 | Ground test recovery system for optimal |

| | | | | |
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| | | | | ejection strength |
| Main chute fails to deploy | Main chute either does not leave tube or doesn't unravel | 2 | 4 | Maintain sufficient airflow to deploy main chute from deployment bag |
| Main chute deploys first | Main chute deploys at apogee | 3 | 3 | Proper labeling of wires, ground test, use correct number of shear pins |
| Main and drogue get tangled | Main chute gets deployed below drogue and tangles | 2 | 4 | Use adequate lengths of recovery harness |
| Ejection charges do not ignite | No parachute deployment, ballistic descent | 2 | 5 | Use fresh batteries for each launch, check altimeter continuity |
| Ejection charges ignite early/late | Ejection occurs before/after apogee | 2 | 3 | Properly sized vent holes |
| Parachute gets burned | Ejection charges damage parachute | 1 | 3 | Use Nomex/Kevlar chute protector |
| Recovery harness burns | Ejection partially or fully burns through harness | 1 | 4 | Use heat resistant recovery harness material |
| Recovery harness | Bulkhead, U-bolt or harness breaks | 2 | 3 | Adequately size recovery |

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| attachment breaks | | | | harness, flight test |
| High kinetic energy at landing | Rocket lands at an excessive velocity | 2 | 4 | Accurate estimate, OpenRocket |
| **Avionics** | | | | |
| Altimeter doesn't detect pressure change | No data is recorded and ejection charges are not fired | 1 | 5 | Properly sized vent holes away from airflow obstructions |
| Loss of power | Battery dies or wires become unattached | 2 | 4 | Use fresh batteries that can withstand rocket accelerations, redundant altimeters |
| **Payloads** | | | | |
| Parachute controls tangle parachute | Attempted control of drogue parachute tangles lines | 2 | 4 | Test parachute ejection mechanism, ensure that all control surfaces do not interfere with parachute strings |
| Guided landing system causes danger to spectators | Rocket is guided towards spectators | 2 | 4 | Test guided landing system in multiple test flights |

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|---|---|---|---|---|
| Fluid leaks from payload protection bay | Loss of rocket stability, loss of protected payload | 1 | 2 | Ensure protection bay is liquid tight, include barrier space between protection bay and rest of rocket |

## Appendix B: Table of Requirements

Vehicle Requirements

| Requirement Number | Satisfaction |
|---|---|
| **1.1** | The onboard payload will be delivered to an apogee of 5,280 feet above ground level. |
| **1.2** | The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude. |
| **1.2.1** | The official altitude shall be reported via a series of beeps from the official scoring altimeter. |
| **1.2.2** | The vehicle will have a second altimeter to provide dual redundancy for all deployment charges. |
| **1.2.3** | At the LRR, a NASA official will mark the altimeter that will be used for the official scoring. |
| **1.2.4** | At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter. |
| **1.2.5** | All audible electronics, other than the official scoring altimeter shall be capable of turning off. |
| **1.2.6.1-4** | All competition scoring rules are understood and shall be followed. |
| **1.3** | All recovery electronics shall be powered by commercially available 9V batteries. |
| **1.4** | Materials and construction methods used allow for the repeated use of the vehicle. |
| **1.5** | Flight vehicle’s design consist of three sections to contain the parts for payload, avionics and recovery, and propulsion respectively. |
| **1.6** | The vehicle contains only one stage of thrust. |
| **1.7** | Vehicle is easily assembled and disassembled by using screws and couplers to fit each section together. |
| **1.8** | The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component. |
| **1.9** | The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. |

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| **1.10** | The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch |
| **1.11** | The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR). |
| **1.11.1** | Final motor choices shall be made by the Critical Design Review |
| **1.11.2** | In the event the motor needs to be changed after CDR it shall be approved by the NASA Range Safety Officer (RSO) |
| **1.12.1** | The minimum factor of safety shall be 4:1 with supporting design documentation included in all milestone reviews. |
| **1.12.2** | The low-cycle fatigue life shall be a minimum of 4:1. |
| **1.12.3** | Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank. |
| **1.12.4** | Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when. |
| **1.13** | LTRL is a University team |
| **1.14** | Our stability margin at point of static exit currently sits at 2.1 calibers, exceeding the 2.0 required stability margin. |
| **1.15** | The vehicle will have a minimum velocity of 64.4 ft/s at rail exit. |
| **1.16** | A subscale launch for the vehicle is currently scheduled for November 13th, 2016. |
| **1.16.1** | Subscale design will resemble a 3:5 scale of the full size launch vehicle. |
| **1.16.2** | The subscale shall carry an altimeter for apogee altitude reporting. |
| **1.17** | A checklist shall be made to ensure that the sub-requirements of 1.17 shall all be followed |
| **1.18** | No structural protuberance will be located aft of the burnout center of gravity. |
| **1.19.1** | The vehicle will not include forward canards. |
| **1.19.2** | The launch vehicle shall not utilize forward firing motors. |
| **1.19.3** | The launch vehicle shall not utilize motors that expel titanium sponges. |

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| **1.19.4** | The launch vehicle shall not utilize hybrid motors. |
| **1.19.5** | The launch vehicle shall not utilize a cluster of motors. |
| **1.19.6** | The launch vehicle shall not utilize friction fitting for motors. |
| **1.19.7** | Vehicle ballast shall not exceed 10% of the total weight of the rock |
| **1.19.8** | The vehicle ballast will not exceed 10% of vehicle weight. |

Recovery System Requirements

| Requirement Number | Satisfaction |
|---|---|
| **2.1** | A drogue will deploy at apogee and a main will deploy at 700ft. |
| **2.2** | LTRL will ground test ejection charges before any subscale or full scale launch. |
| **2.3** | The parachutes will be correctly sized so that each component of the rocket lands within the kinetic energy constraint of 75ft-lbs. |
| **2.4** | The recovery system wiring will be completely independent of any payload components. |
| **2.5** | There will be two independent altimeters, power supplies, and ejection charges for redundancy. |
| **2.6** | Motor ejection will not be used to separate the rocket. |
| **2.7** | Each altimeter will have a separate key switch that will be accessible from the outside of the rocket. |
| **2.8** | Each altimeter will have an independent battery. |
| **2.9** | Each key switch will be able to stay in the on position while on the launch pad. |
| **2.10** | Removable sheer pins will be used to keep the rocket together until the ejection charges cause separation. |
| **2.11** | There will be a GPS unit installed that will constantly send the position of the rocket. |
| **2.11.1** | All parts will be tethered but if any are not, they will have independent GPS units. |
| **2.11.2** | The GPS unit will be functional on launch day. |
| **2.12** | The recovery system electronics will be in a faraday cage as to not interfere with any component of the rocket or other rockets. |
| **2.12.1** | The recovery system will be in a coupler without any other payloads or electronic components. |
| **2.12.2** | The faraday cage will protect the recovery system from any interference. |
| **2.12.3** | The faraday cage will protect the recovery system from any interference. |

| | |
|---|---|
| **2.12.4** | The faraday cage and being in its own coupler will protect the recovery system from any interference. |

Experimental Requirements

| Requirement Number | Satisfaction |
|---|---|
| **3.1.1** | The fragile specimen protection payload challenge has been selected |
| **3.1.2** | An additional guided landing payload will be flown in the rocket, but will not be submitted for scoring. |
| **3.1.3** | The guided landing payload will be included in reports so that the safety of the project can be reviewed by overseeing engineers. |
| **3.4.1** | A chamber filled with dilatant will house a flexible bag, which will contain and protect the fragile materials. The chamber will be suspended by elastic bands in order to provide gross acceleration dissipation. |
| **3.4.1.1** | All specimens will be placed in separate bags and inserted into the dilatant, which will cushion each specimen individually. |
| **3.4.1.2** | The cushioning provided by the dilatant, combined with the acceleration dissipation of the elastic bands will ensure that any material placed inside the chamber will be able to survive the accelerations and shocks of launch, landing, and recovery. |
| **3.4.1.3** | A sealable materials bag inside the chamber will allow for insertion of specimens, while the dilatant will allow for objects to be of unknown size and shape. |
| **3.4.1.4** | All dilatant for cushioning will be permanently housed inside the rocket during preparation, with enough volume left inside the bay between the elastic regions and materials chamber to permit for displacement due to specimen volume. All specimens will be sealed in watertight bags. |
| **3.4.1.5** | The material chamber will be large enough to house a 3.5” by 6” cylinder. |
| **3.4.1.6** | The mass of the objects will be accounted for in the estimations of flight, as well as the accelerative forces on the materials chamber. |

Safety Requirements

| Requirement Number | Satisfaction |
|---|---|
| **4.1** | The team will use launch and safety checklists. |
| **4.2** | Laura Reese is listed as safety officer |
| **4.3** | The safety officer will perform all responsibilities as listed. |
| **4.3.1** | The safety officer will monitor the team with an emphasis on safety. |
| **4.3.1.1** | The safety officer will monitor the team during design of the vehicle and launcher. |
| **4.3.1.2** | The safety officer will monitor the team during construction of the vehicle and launcher. |
| **4.3.1.3** | The safety officer will monitor the team during assembly of the vehicle and launcher. |
| **4.3.1.4** | The safety officer will monitor the team during ground testing of the vehicle and launcher. |
| **4.3.1.5** | The safety officer will monitor the team with an emphasis on safety during the sub-scale launch tests. |
| **4.3.1.6** | The safety officer will monitor the team with an emphasis on safety during the full-scale launch test. |
| **4.3.1.7** | The safety officer will monitor the team with an emphasis on safety during the launch day. |
| **4.3.1.8** | The safety officer will monitor the team with an emphasis on safety during the recovery activities. |
| **4.3.1.9** | The safety officer will monitor the team with an emphasis on safety during educational activities. |
| **4.3.2** | The safety officer will implement all procedures developed by the team for construction, assembly, launch and recovery activities. |
| **4.3.3** | The safety officer will managed and maintain current versions of the team's hazard analyses, failure modes analyses, procedures and chemical inventory data. |
| **4.3.4** | The safety officer will assist in the writing and development of the team's hazard analyses, failure modes analyses and procedures. |

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|---|---|
| **4.4** | The team's mentor is Robert DeHate. |
| **4.5** | The team will abide by the rules and guidance of the RSO. |
| **4.6** | The team will abide by all rules set forth by the FAA. |

General Requirements

| Requirement Number | Satisfaction |
|---|---|
| **5.1** | Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches. |
| **5.2** | The team provided a project plan including project milestones, budget and community support, checklists, personnel assigned, educational engagement events, risks, and mitigations. The team will follow the project plan. |
| **5.3** | Foreign National Team members will be identified to NASA by Preliminary Design Review. |
| **5.4** | The team members attending the launch will be identified by Critical Design Review. |
| **5.4.1** | Only actively engaged team members will come to launch week activities. |
| **5.4.2** | One mentor will come to launch week activities. |
| **5.4.3** | At most two adult educators will come to launch week activities. |
| **5.5** | The team will engage at least 200 participants in educational, hands-on science and math related activities throughout the year and write reports on these events. The reports will be submitted at most two weeks after the activity. |
| **5.6** | The team has developed a website for the competition. The website will be kept up to date throughout the competition. |
| **5.7** | Teams will post, and make available for download, the required deliverables to the team website by the due dates specified in the project timeline. |
| **5.8** | All reports shall be delivered in pdf format. |
| **5.9** | Every report shall include a table of contents outlining major sections and their respective sub-sections. |

| | |
|---|---|
| **5.10** | Every report shall include page numbers at the bottom of the page. |
| **5.11** | The team shall provide proper video conference equipment needed to perform a video teleconference with the review board. |
| **5.12** | The flight vehicle will be capable of launching using the launch pads provided by the launch service provider. |
| **5.13** | The team will meet the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards. |

## Appendix C: Mini Rocket Competition Outline

# Mini-Rocket Competition

| Teams: | Advisor | | | | |
|---|---|---|---|---|---|
| Team 1 | Kartik | Matt E. | Jonathan B. | Prashant | |
| Team 2 | Anthony | Matt C. | Minjie | Prachi | Josh D. |
| Team 3 | Alex | Aisyah | Brendon O. | Yigitcan | |
| Team 4 | Kurt | Spencer K. | Lindsay E. | Maria | Tharaka |
| Team 5 | Kartik | Ryan S. | Kriston R. | Sebastian N. | Greg |
| Team 6 | Anthony | Tanish M. | Luz S. | Scott G. | Brian L. |
| Team 7 | Alex | Michael C. | Nikhil N. | Prajwal C. | Jay P. |
| Team 8 | Kurt | Dave S. | Bill W. | Mike O. | Nick |

Goals:

Coolest looking rocket – 10 points

Straight flight – 10 points

Successful parachute ejection and re-usability – 10 points

Lowest Mass - 10 points

Winning team receives … TBD

Getting Started:

Phase 1: Design – The first step is design a stable rocket, in OpenRocket, that fits the given specifications. OpenRocket can be downloaded for free at http://openrocket.sourceforge.net/.

There are 3 key components in designing a stable rocket. They are center of mass (CG), center of pressure (CP) and thrust to weight ratio. For a rocket to be stable, its CP must remain behind (aft) of its CG during the entirety of the flight. Stability is measured in units of calipers. A caliper is measured as the outer diameter of the rocket. Windy conditions on launch day can cause an initially stable rocket to become unstable. To prevent this from happening, design your rocket to have a minimum stability of 2 calipers during flight. The rockets stability is at its lowest during takeoff (off the rod). To counteract potential stability issues off the rod, aim for at least an average thrust to weight ratio of 4:1.

Once your team has a stable rocket design in OpenRocket, create SolidWorks Models for:

Rocket Components & Specifications:

1. Body Tube – The body tube will be constructed by wrapping multiple sheets paper around a ¾-inch diameter pvc pipe. After gluing the papers together, slide the paper off the pvc pipe and you have your well-crafted body tube.

2. Nosecone

| | |
|---|---|
| Outer Diameter (OD) | Equal to OD of body tube (measure) |
| Shoulder Length | ½ inch |
| Shoulder Diameter | ¾ inch |

* Be sure to include a 1/8-inch hole on the bottom of the nosecone for attaching the parachute.

3) Booster – The booster section includes the fins and motor retainer.

| | |
|---|---|
| Outer Diameter | ¾ inch |

4) Recovery – Includes the parachute (plastic bag) and shock cord (rubber band).

5) Motor – One motor will be provided to each team (pending approval from club). We will be using Estes C6 18 mm motors.

Hints:

- Add mass estimates for every component of the rocket to ensure an accurate CG.

Phase 2: Print

Once your team has completed the SolidWorks design, save it a .STL file. This puts your design into a file type that a 3D printer can read. We will be printing our rockets at the maker commons in the Library.

Phase 3: Build

More info to come…

Phase 4: Launch Day TBD