The Pennsylvania State University

LionTech Rocket Labs

2017-2018 USLI Project Nimbus

Proposal

046 Hammond Building, University Park, PA 16802
September 20, 2017

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List of Acronyms

A&R	Avionics and Recovery
CFD	Computational Fluid Dynamics
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
EHS	Environmental Health and Safety
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
SDS	Safety Datasheet
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

Dr. David Spencer - dbs9@psu.edu (814)-865-4537

Team Leader

Justin Hess - jvh5744@psu.edu (267)-718-0062

Safety Officer

Laura Reese - ler5201@psu.edu

NAR Contact

Alex Balcher NAR L2 Certification - #96148SR - alex.balcher@gmail.com

NAR Sections

Pittsburgh Space Command (PSC) #473
Maryland Delaware Rocketry Association (MDRA)

1.2 Team Roster and Structure

Lion Tech Rocket Labs has approximately 50 active members, ranging from freshman to senior undergraduates and graduate students. 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 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
JUSTIN	President	Communicates with project advisers, organizes meetings, and keeps team on schedule. Guides team in the overall design and construction of the systems.
TORRE	Vice President	Assists President in managerial tasks, meetings with advisers and team. Coordinates integration between subsystems.
KRISTI	Treasurer	Arranges fundraising events, communicates with sponsors, and manages funds for the project.
SEBASTIAN	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. Manages team website, uploads project deliverables and meeting notes.
LUZ	Public Relations	Organizes events for the club to engage with the community and share experience, knowledge, and passion in STEM fields.
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 payload and flight vehicle. The technical branch is divided in to four main subsystems: Avionics and Recovery, Payload, Propulsion, and Structures. This year two new positions were created to manage integration between the designed payload and the final flight vehicle. The officer positions and subsystem duties within the technical branch are shown in . Due to the size of each subsystem, a description of the duties of each are is given in place of a description of individual member's duties. The officers take a leadership role in the subsystems while working with the general members in their subsystem to complete their duties.

Table 2. Due to the size of each subsystem, a description of the duties of each are is given in place of a description of individual member's duties. The officers take a leadership role in the subsystems while working with the general members in their subsystem to complete their duties.

Table 2: Technical Infrastructure

NAME	POSITION	PROPOSED DUTIES
JOEY	Chief Payload Systems	Oversee Payload Leadership and guarantees proper integration of the payload with the flight vehicle.
JACKSON	Payload Leadership	Payload designs and creates project specific payloads. These tend to involve computing and electrical components within the flight vehicle. Payload ensures these packages are functioning properly when preparing for launch.
LAWRENCE		
ANTHONY	Chief Flight Systems	Oversee A&R, Structures, and Propulsion subsystems and guarantees proper integration of the flight vehicle with the payload.
CASTLE	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.
GRETHA		
MATT	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.
JOSH	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 oversees final assembly of the rocket for launch.
GREG		

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. A rough diagram of the lab is shown in Figure 1.

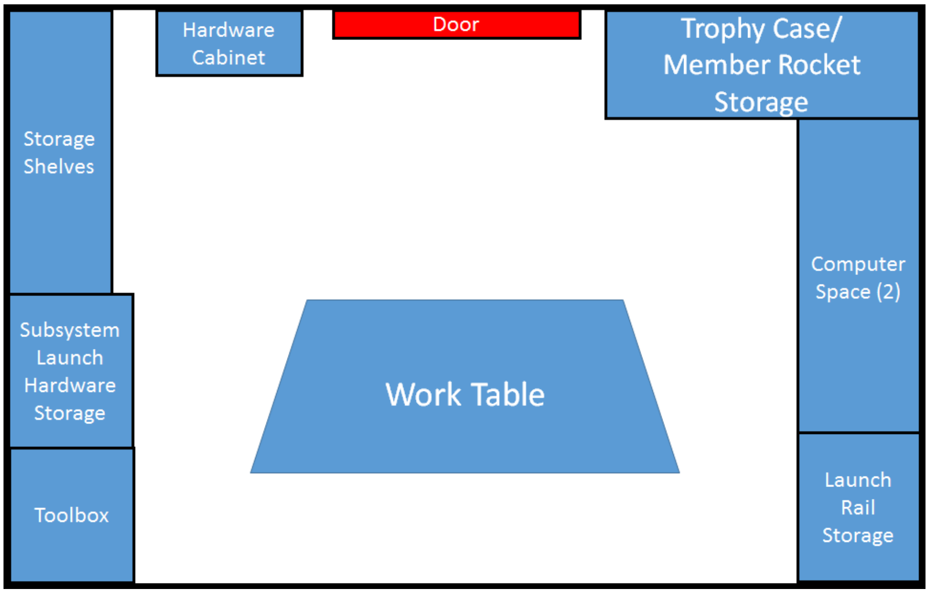


Figure 1: Layout of LTRL Lab

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 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 for competition motor testing. A&R also uses the HPCL grounds to test ejection charges for the subscale and fullscale 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

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. To construct the final flight vehicle, necessary supplies include:

- Fiberglass or blue tube body tubes
- Carbon Fiber Wrapping
- Nosecone
- Body tube couplers
- Fiberglass Fin sheets
- Epoxy Screws
- Steel or Aluminum All Thread Rod
- Centering rings
- Bulkheads
- Custom manufactured parts from:
    - Aluminum stock
    - Steel stock
    - Plastic filament ABS or PLA

Propulsion

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

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

Avionics & 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
- Plywood bulkheads
- U-bolts
- Key switches
- Blast caps
- #2 Nylon shear pins
- Parachutes
- Kevlar blankets
- Shock cord

Payload

The personnel required to design and assemble an autonomous rover include team members with skills in programming, electronics, mechanics, and design. Basic power tools and hand tools will be required to construct the frame of the rover. 3D modeling software knowledge is required for the wheels and the electronics bay. The supplies required to build the rover include:

- Rubber treads
- Wheels
- Aluminum rods
- Arduino Uno microcontroller
- Servos
- Xbees
- Solar Panels
- GPS
- 9V Batteries
- 3d printed electronics unit
- Solar cell
- Soldering iron

The rover also needs an in-flight containment system to protect it from falling out of the rocket after separation and to protect it from black powder. The additional supplies required for this system include:

- Servos
- Wire cables
- A mesh covering
- Aluminum rod

3. Safety

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.

Most of the hazards that are anticipated will occur during launch. However, the construction of the rocket also involves risks, mostly due to the use of power tools and potentially hazardous materials. The primary facility used for construction of the rocket will be the LTRL lab in 046 Hammond. To be granted access to the lab, all LTRL members must take Laboratory Safety training provided by Penn State's Environmental Health and Safety (EHS). In addition, general team members will be supervised at all times by subsystem leads or executive members during the construction of the rocket. Only LTRL executive members and leads have key card access to the lab. General members must be allowed into the lab by an LTRL lead.

Basic construction activities, such as cutting and drilling of materials, will take place in the LTRL lab under the supervision of the appropriate subsystem leads. More complex fabrication techniques will be performed in the Bernard M. Gordon Learning Factory. To use the Learning Factory, students must complete additional safety training under the supervision of the Learning Factory staff.

The primary hazards associated with the selected materials are due to inhalation of small fibers from substances such as fiberglass or carbon fiber. Facemasks are provided to all members working in the LTRL lab whenever such materials are being cut, drilled, or sanded. A full assessment of anticipated risks can be found in Appendix A. The severity of risks is based on the combination of likelihood and impact, which were quantified according to the scale given in below. To reduce these risks, mitigations are proposed which shall reduce either the likelihood or impact of the risk.

3.1 Safety Officer Responsibilities

Laura Reese is the Safety Officer for the 2017-2018 year. The responsibilities of LTRL Safety Officer are as follows:

- Ensure all team members have completed Penn State EHS Laboratory Safety training
- Maintain a list of members that have completed safety training
- Write and maintain a safety manual listing hazards and mitigations of those hazards and containing Safety Datasheets (SDS) for all hazardous substances used during the construction of the rocket
- Brief all members on launch safety and National Association of Rocketry (NAR) regulations before each launch
- Enforce proper safety protocol during construction and launch activities
- Ensure compliance with university regulations, local, state, and federal laws, and NAR regulations
- Maintain launch and safety checklists and ensure that they are taken to each launch
- Monitor team during design phase to ensure that safety considerations are considered during the project design

3.2 NAR Regulations

The LTRL roster includes members who are NAR level 2 certified. Certified members will be the only individuals permitted to purchase motors. LTRL's NAR certified members will handle hazardous materials, including motors and energetic devices, in compliance with the NAR High Power Safety Code. All motors and black powder are stored in the High Pressure Combustion Laboratory (HPCL), which is equipped with a type 4, indoor, portable BTFE explosives magazine. The lab that holds the motors is locked, and the area where the magazine is located is only accessible to members with the proper NAR certification.

3.3 Safety Briefings

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 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 SDS for all chemicals and hazardous materials used in the lab, is also available to members.

Before each launch, the safety officer will conduct a safety briefing to inform all members of the necessary safety procedures and to inform all members of NAR regulations.

When necessary during 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 PPE for the specific task or hazard.

3.4 Cognizance of Laws and Regulations

LTRL is cognizant of and will abide by the Federation 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, in addition to university regulations governing possession of black powder, motor testing, static fires, and energetic recovery systems, testing will be performed under the supervision of and within the facilities of the HPCL located on campus.

All test launches of the competition rocket will be performed during scheduled launch events of MDRA or another NAR 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 certification. Currently several members of LTRL possess Level 2 certification.

3.5 Purchase and Storage of Motors

Justin Hess, President of LTRL, has Level 2 certification from NAR, and will be responsible for purchasing, transporting, and storing the rocket motors used by LTRL. The LTRL team will be accompanied to the USLI competition in Alabama by the team’s mentor, Alex Balcher, who also possesses Level 2 certification from NAR.

3.6 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.

4. Technical Design

4.1 Flight Vehicle Structure

Vehicle Materials

Blue tube was used last year in construction of the flight vehicle. While blue tube provided good results last year, the club wishes continue pursuing other options to find a lighter and stronger material. Carbon wrapping is one such method in which significant strength can be added to the flight vehicle with a minimal addition of weight. This year's final flight vehicle will either be blue tube or carbon fiber wrapped blue tube. Testing is currently being conducted to finalize the decision on the material. Current members have no experience with carbon fiber wrapping, therefore a baseline of understanding must be achieved before an educated decision can be made. Table 3 contains the Material Selection Matrix (MSM). Although blue tube scored highest in the MSM, carbon fiber wrapped blue tube is still being considered since blue tube experienced zippering failure in the past. Testing is currently being done to determine if wrapping carbon fiber is viable given the limited experience of the team.

Table 3. Material Selection Matrix

		Fiberglass		**Blue tube**		**Carbon Fiber**		**Carbon Fiber Wrapped blue tube**	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Strength	0.25	4	1	2	0.5	5	1.25	5	1.25
Cost	0.15	2	0.3	5	0.75	1	0.15	3.5	0.525
Workability	0.1	2	0.2	3.5	0.35	2	0.2	3	0.3
Weight	0.25	1	0.25	4	1	5	1.25	4	1
Appearance	0.05	5	0.25	3	0.15	5	0.25	5	0.25
Legacy	0.1	5	0.5	5	0.5	1	0.1	1	0.1
Hazardousness	0.1	1	0.1	5	0.5	2	0.2	2	0.2
Total			**2.6**		**3.75**		**3.4**		**3.625**

Vehicle Dimensions

As part of the design process, two possible configurations have been created. The major difference between configurations A and B is that A contains two main parachutes and two dedicated avionics bays while B only includes one main and one dedicated avionics bay. The reason for two configurations is to accommodate different methods of ground deployment for the payload. Both rocket A and rocket B are expected to be 102 inches long and have a 5.5-inch outer diameter. Rocket A is estimated to have a total weight of 35 pounds (carbon fiber wrapped blue tube) or 32 pounds (blue tube). This results in a stability margin off the rail of 2.1 calibers, and an average of 2.9 calibers during the launch. The center of gravity and the center of pressure of rocket A are located 65.6 inches and 81.6 inches respectively, aft of the tip of the nose cone.

Rocket B is estimated to have a total weight of 32.9 pounds (carbon fiber wrapped blue tube) or 31.3 pounds (blue tube). For rocket B, the stability margin off the rail is 2.3 calibers, and an average of 3.01 calibers throughout the flight. Center of gravity and the center of pressure of rocket B are located 68.2 inches and 84.8 inches respectively, aft of the tip of the nose cone. The open rocket diagrams of both rocket A and B can be seen in Figure 2.

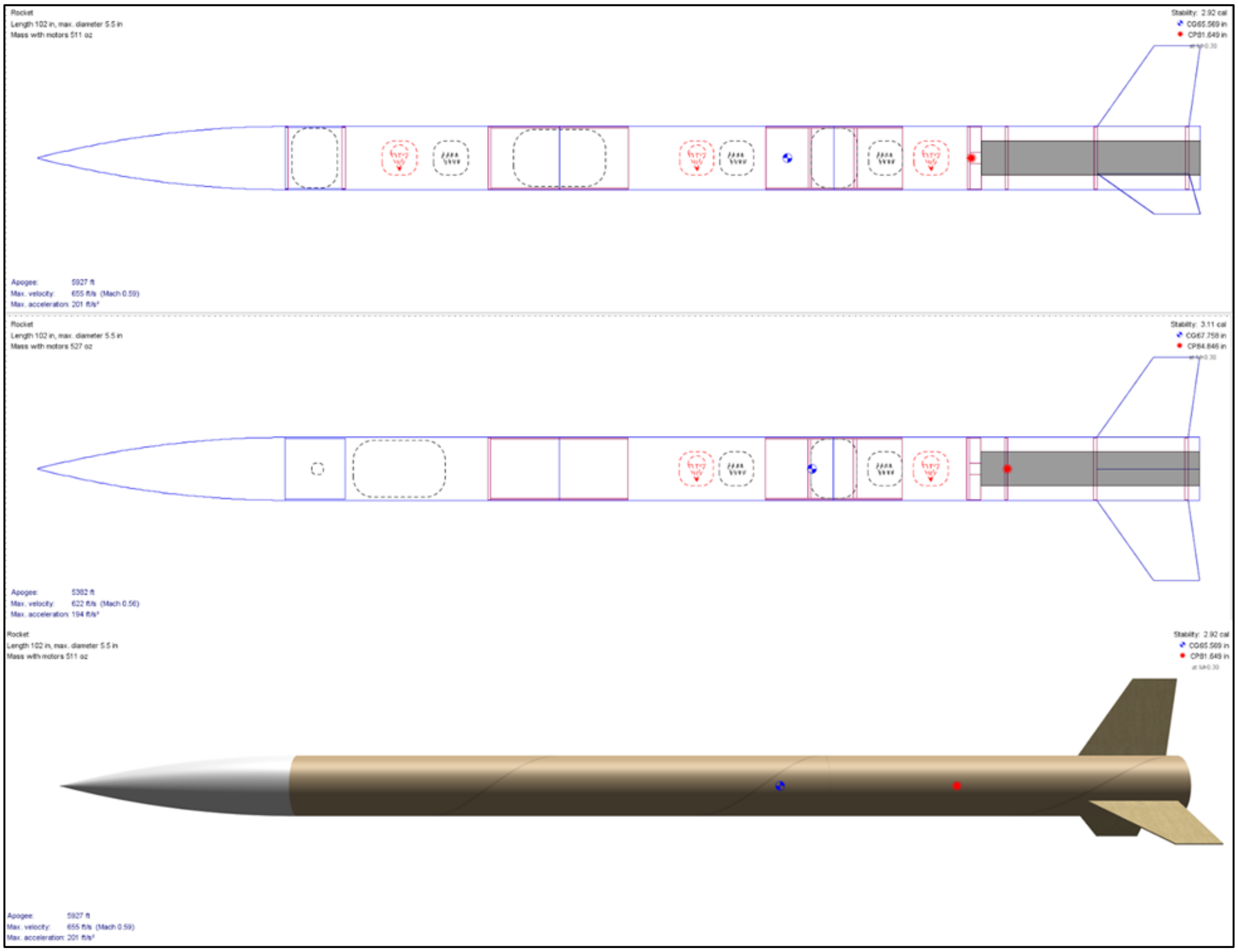


Figure 2. OpenRocket Models

Configuration A (Top), Configuration B (Middle), Exterior of Rocket A (Bottom)

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. In addition to traditional manufacturing methods, LTRL will be employing laser cutting technology to cut custom centering rings and bulkheads. To improve upon last year's fin mounting, the team is modifying the previous 3D printed brackets such that they can be mounted with only screws and bolts as opposed to the steel resin epoxy used last year. The design features a slotted rear centering ring to allow the fin brackets to slide into place, then screwed down tight. The current design is shown in Figure 3.

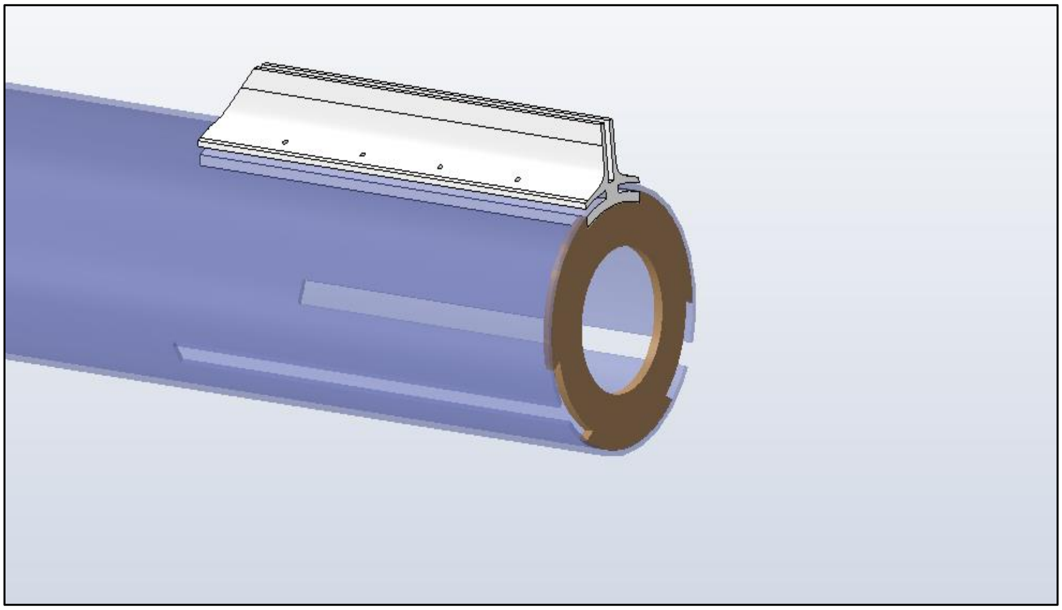


Figure 3. Rendering of Proposed Fin Bracket Design

Major Technical Challenges

The major technical challenges include the wrapping of the blue tube in carbon fiber with no previous experience, and accounting for mass concerns that the carbon fiber might present. The structures team will investigate and practice the wrapping of the carbon fiber over the blue tube to confirm that it is a viable option for material choice. There will also be testing of materials to make sure that carbon wrapped blue tube can satisfy strength requirements. An updated mass document will be kept preventing unexpected mass problems, and the team will have to further investigate potential mass issue that could occur from carbon fiber wrapping. Another concern is the 3D printed fin brackets that will be designed to slide into the body of the rocket. Different designs will be tested to ensure that the fin brackets function properly and do not break during flight.

4.2 Propulsion

Motor Selection and Designation

Motor calculations were made using a preliminary OpenRocket model to estimate the class of the motor and determine baseline designations. As per competition regulation 2.21.2, 3, 4, 5, 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 motor is an L800 motor from Cesaroni, with an impulse around 3750 N•s. This is in accordance with requirement 2.15 of maintaining an impulse of L-Class or lower.

The motor selected will be from the manufacturer Cesaroni and will utilize ammonium perchlorate composite propellant, in accordance with regulation 2.13, and is able to be launched utilizing a 12-volt firing system as mandated by regulation 2.11.

Based on the preliminary rocket model, the primary motor designation will be the Cesaroni L800 which will achieve an estimated apogee of 5633 ft. The estimated rail exit velocity is 63.1 ft/s, complying with regulation 2.17, and the estimated stability off the rail is 2.82 calipers, complying with regulation 2.16.

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

4.3 Avionics & Recovery

Technical Design

LTRL currently has two rocket designs for the USLI competition. The first one, Rocket A, has three separations during descent and the second, Rocket B, has two separations during descent and one on the ground. The main avionics bay, which is incorporated in both designs, will have two independent Stratologger CF altimeters with independent power supplies. It will also have independent charges for both the drogue and main parachute, as shown below in Figure 4. Rocket A will also contain a second avionics bay used to deploy the main second main parachute. Its wiring diagram is shown in Figure 5.

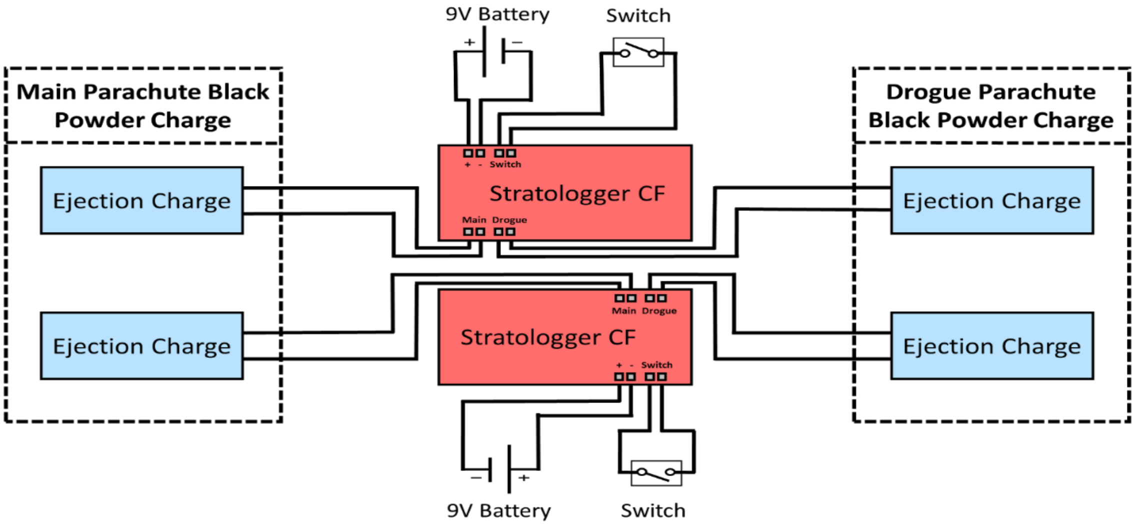


Figure 4. Avionics Bay 1 Wiring Diagram

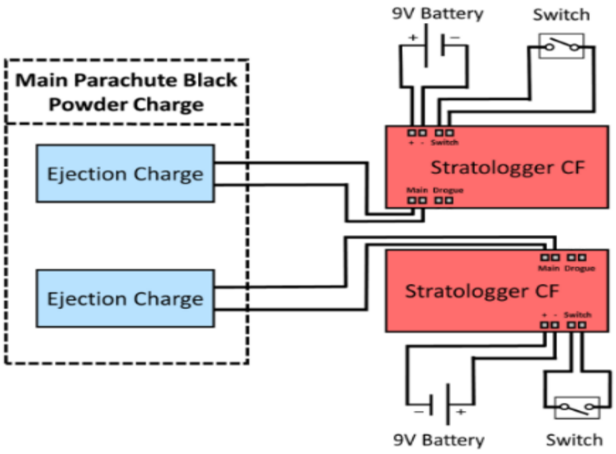


Figure 5. Avionics Bay 2 Wiring Diagram

The avionics bay coupler will hold an aluminum faraday cage. The surrounding bulkheads will also be lined with aluminum. The parachutes will be connected to U-bolts on wooden bulkheads with 3/8" quick links and 1/2" shock cord. The shock cord will be of appropriate lengths such that the rocket sections do not hit into themselves during descent and that the parachutes do not tangle. The initial avionics bay design, shown in Figure 6, is a 3D printed bay that is similar to the one that was successfully used in the 2017 USLI competition. This avionics bay is very compact, but the assembly of the avionics bay can be made simpler. The team is currently working on using quick snap wire connectors to simplify the assembly.

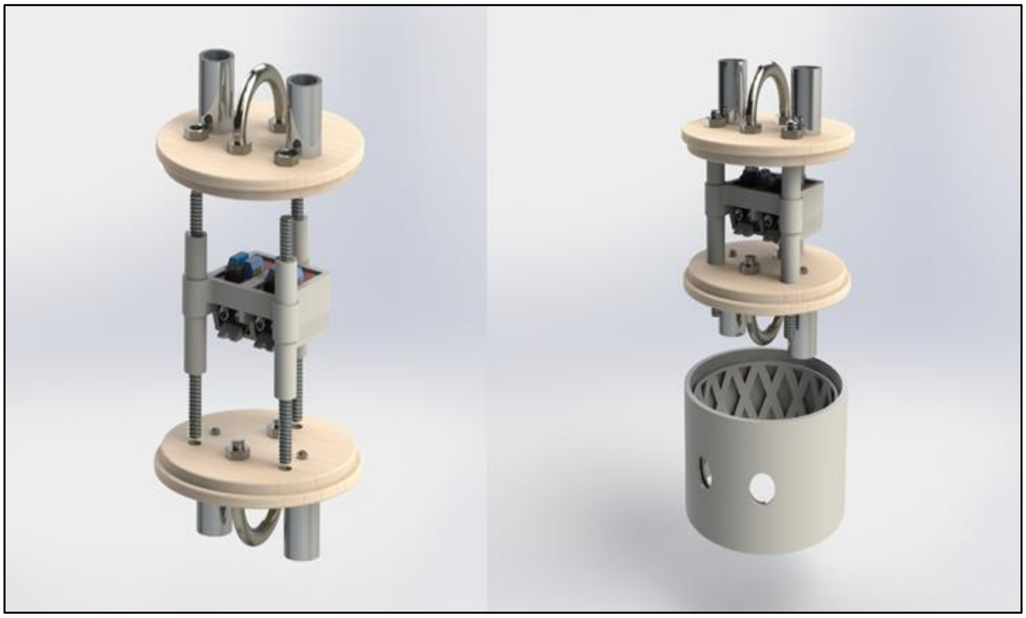


Figure 6. 2017 SLI Avionics Bay

Exploded view (Left), Assembled avionics bay without coupler (Right)

Rocket A

Rocket A will have three in-air separation points as depicted in Figure 7. This will require a second avionics bay with two Stratologger CF altimeters and two independent charges for the third separation. The drogue will deploy at apogee with an estimated 14” diameter parachute. The second separation point will be at 800 ft where an estimated 84” main will be deployed and the rocket will separate into two independent sections, with the aft section falling under the 84” main. At 500 ft, the forward section will deploy an estimated 36” parachute. The second separation point can utilize a black powder charge or a CO_2 charge. While the black powder is more reliable, a CO_2 charge is cleaner and would generate less heat. This is significant because the second separation point is in the same compartment as the rover. As required, each separated section will have an independent GPS unit. Separating the rocket will allow the rover to exit the rocket easily once the rocket has landed.

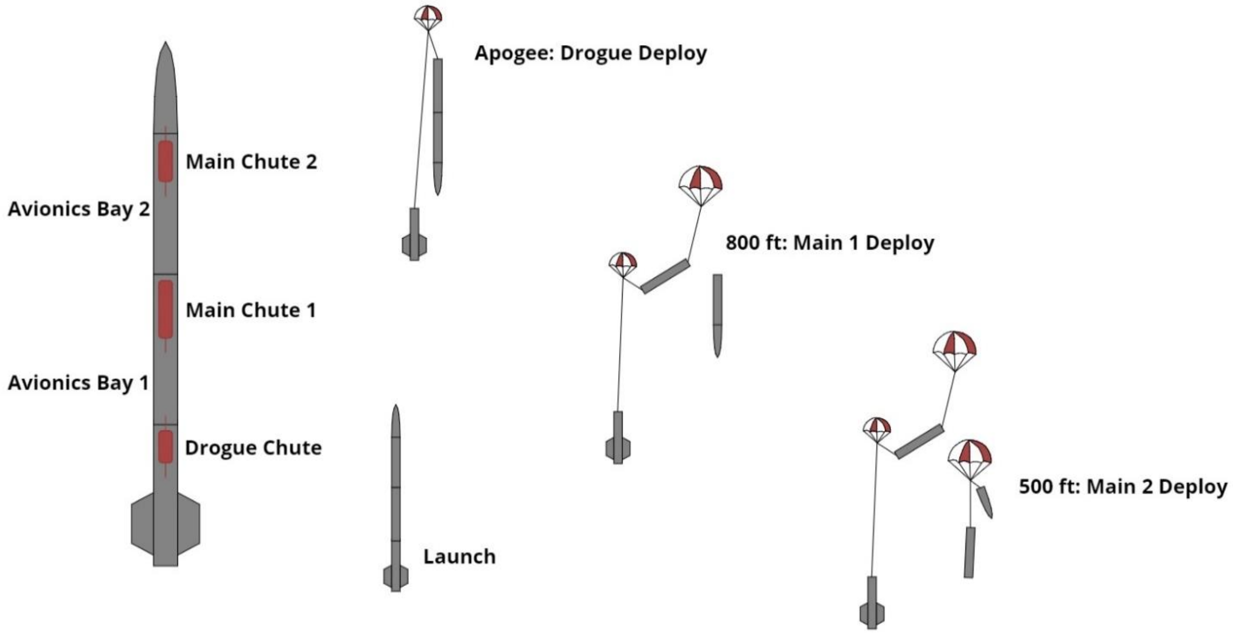


Figure 7. Rocket A Recovery Plan

Rocket B

Rocket B will have two in-air separation points and one separation after landing. As usual, the drogue will deploy at apogee and it is estimated to be 14” in diameter. The second separation will be at 700 ft for the main parachute to eject from the rocket. The parachute deployments are shown in Figure 8. Both ejections will use black powder to break the shear pins. Once the rocket has landed, there will be one more separation for the rover to leave the rocket. This will be a CO_2 charge to break shear pins between the forward section and the nose cone. The charge will be triggered by the team on the ground who will determine if the separation is safe. This will allow the rover to exit the rocket. For this last separation, CO_2 will be used so that there is not a large black powder charge on the ground that could potentially cause a fire or create additional risks.

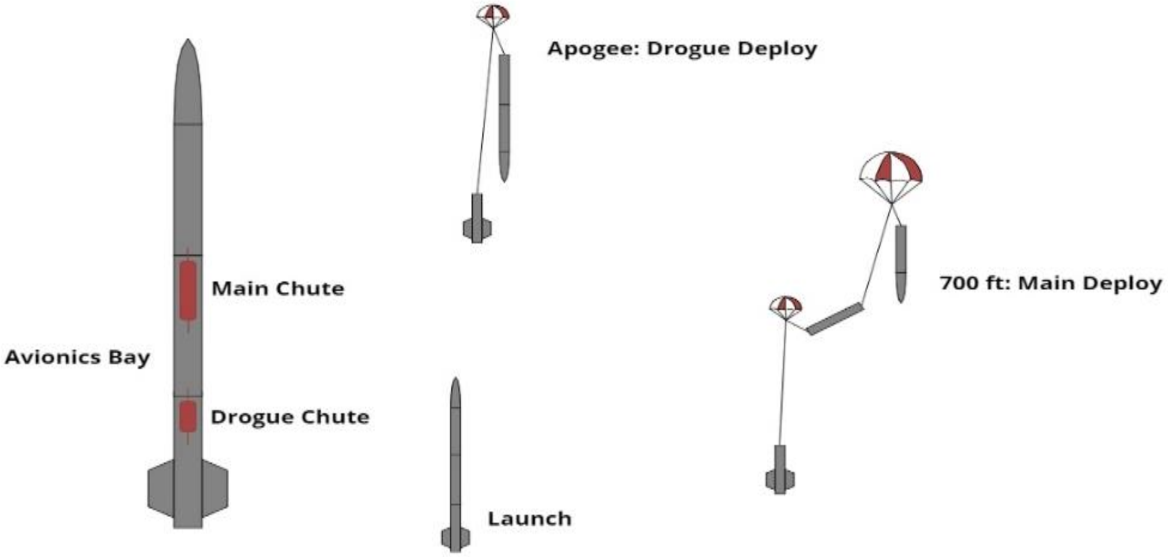


Figure 8. Rocket B Recovery Plan

Design Challenges

The biggest challenge with the rocket this year is allowing the rover to exit. There are two plans for the rocket, because there must be further testing to determine which design would work best. While the CO_2 would not leave soot on the rover, it is not as reliable as black powder. This determination is based on the club's lack of recent experience with CO2 charges. With further testing, CO_2 may become more reliable. Additionally, the black powder generates a lot of heat when it detonates which could damage some of the electronics in the rocket. The rover will be launched several times and there may be some damage that happens each time due to the black powder charge.

Another technical challenge will be to keep the third separation point intact when the main parachute deploys at 700 or 800 ft. There is a risk that the jerk induced by the main parachute causes the shear pins at the third separation point to break. This risk will be mitigated by ensuring that there is a proper amount of shear pins that will not break when main deploys. In the rocket A configuration, this is further mitigated by the fact that if the shear pins break, there is a parachute inside the forward section that will deploy. It will land safely but it may drift more than anticipated. However, in the rocket B configuration there is no additional parachute so if the shear pins holding the nose cone break during main deployment, this will cause a serious safety concern. These risks are to be tested and further evaluated to ensure that our final rocket design results in the highest success and safety possible.

4.4 Payload

Autonomous Rover Design

This year, the team will build a remotely activated autonomous rover that deploys solar panels as their payload. The design concepts the team is considering are shown in

Table 4 below.

Table 4. Concept Selection Matrix

	Rounded Hubcaps	Rubber Treads	Reversible	Plow	Arduino Control Board	Reach and pull	Spurred Wheels	Flowering Propping Mech
Landing Orientation	1	0	1	0	1	-1	0	-1
Terrain Maneuverability	1	1	1	1	1	-1	1	0
Obstacle Avoidance	1	1	0	1	1	-1	1	0
Powerful	0	1	0	-1	-1	-1	1	0
Rocket Deployable	1	1	1	1	0	-1	-1	1
Remotely Activated	0	0	0	0	1	0	0	1
Deploys Solar Panels	-1	0	0	-1	0	1	0	0
Relays Status	0	0	0	0	1	0	0	0
Visual Input	0	0	0	0	1	0	0	0
Constant Communication	0	0	0	0	1	0	0	0
Impact Resistant	0	1	1	1	-1	-1	-1	-1
Durable	1	1	1	1	-1	-1	-1	0
Dirt Proof	0	0	0	1	-1	1	1	0
Compact	0	1	1	-1	-1	-1	-1	-1
Light Weight	0	-1	0	-1	1	-1	1	-1
Total	**4**	**6**	**6**	**2**	**3**	**-7**	**1**	**-2**
	+	+	+	+	+	x	x	x

The design concepts considered by the team are listed in the first row of Table 4. These concepts were judged based on the criteria listed in the leftmost column. The number at the junction between a concept and a criterion represents how that concept will affect the rover's performance in that criteria: a 1 indicates that the concept will strengthen the rover's performance in that area, a 0 indicates that the concept will have no effect on that criteria, and a -1 means the concept will be detrimental to the criteria listed. The last row shows whether the concept will be beneficial or detrimental to the overall rover design based on the sum of all the numbers in its column. If the sum of a concept is greater than 1, it is considered beneficial. A green plus denotes a beneficial

concept whereas a red x denotes a concept whose advantages do not outweigh its disadvantages. Concepts that received a red x will not be further pursued as potential design concepts.
After the rocket has landed safely, a remote-controlled ground system will open the rover containment mechanism via XBee radio communications. The rover will be turned on and drive out of the rocket. The payload bay will be built so that the orientation of the rocket at landing does not affect the ability of the rover to exit the payload bay. This design includes 2 shelves above and below the rover with a small amount of additional space. Protruding, rotating hubcaps will enable the rover to exit the payload bay regardless of orientation.

The rover itself will drive with rubber treads to ensure that it can overcome various obstacles. The inside of the treads will have wheels connected to axles that will be powered by 9-volt batteries and servos. The wheels also contain protruding, rotating hubcaps that prevent the rover from flipping into the incorrect orientation. Another design choice made to ensure the correct orientation is the symmetry between the top and bottom cross sections of the rover. A solar cell will be used to determine which side of the rover is facing up, and based on that information, the movement algorithm will turn the wheels in the appropriate direction.

The rover will travel at least 5 feet from its initial position after exiting the flight vehicle and then deploy the solar panels. The rover will use a GPS sensor to determine if it has moved five feet. Servos will deploy the solar panels out of the front and back of the rover.

Technical Challenges

The main technical challenge of the payload will be designing a rover that can exit the rocket regardless of its landing orientation. Since adjusting the versatility of the rover is easier than predicting and correcting the orientation of the rocket at landing, the rover will be designed to drive on any surface in any orientation. This design will include a method for determining which side of the rover is facing up, wheels that spin in both directions, protruding and rotating hubcaps to keep the rover on course, and solar panels that deploy out of the front and back instead of top or bottom.

Other technical challenges include designing a rover that will fit within the diameter of the rocket and still have the ability to navigate the terrain. The team will also ensure that the black powder soot from the adjacent avionics bay will not compromise the functionality of the sensors on the rover. The team will also ensure that no harm comes to the rover due to the exposure of the end of the payload bay after separation. The rover will be equipped with treads to overcome various terrains, designed to fit within the constraints of the rocket body, and have a sealed electronics compartment.

The overall risk to observers from this payload is minimal. Because the deployment of the rover is triggered manually upon visual confirmation of the rocket landing, there is little to no chance of the rover accidentally deploying mid-air and free-falling to the ground. The mechanism used to keep the rover secured to the inside of the rocket fuselage will be constructed on aluminum, a high-strength metal. Because of aluminum’s strength, there is almost no chance for the retaining mechanism to fail. In the event that the retaining mechanism does fail, there will also be a mesh cover on the opening of the body tube which will catch the rover in the unlikely event that the retaining mechanism does fail.

Payload Integration

There are several integration challenges that arise as the result of this payload. To properly install the mechanism that will secure the rover to the inside of the rocket fuselage until deployment, the payload and structures subsystems will collaborate to ensure that the installation process does not compromise the structural integrity of the body tube. The payload subsystem will also coordinate with the avionics and recovery subsystem; because the rover deploys out of the opening of a body tube segment, the two subsystems need to coordinate to ensure that an unobstructed opening is available for the rover to exit the vehicle.

5. Educational Engagement

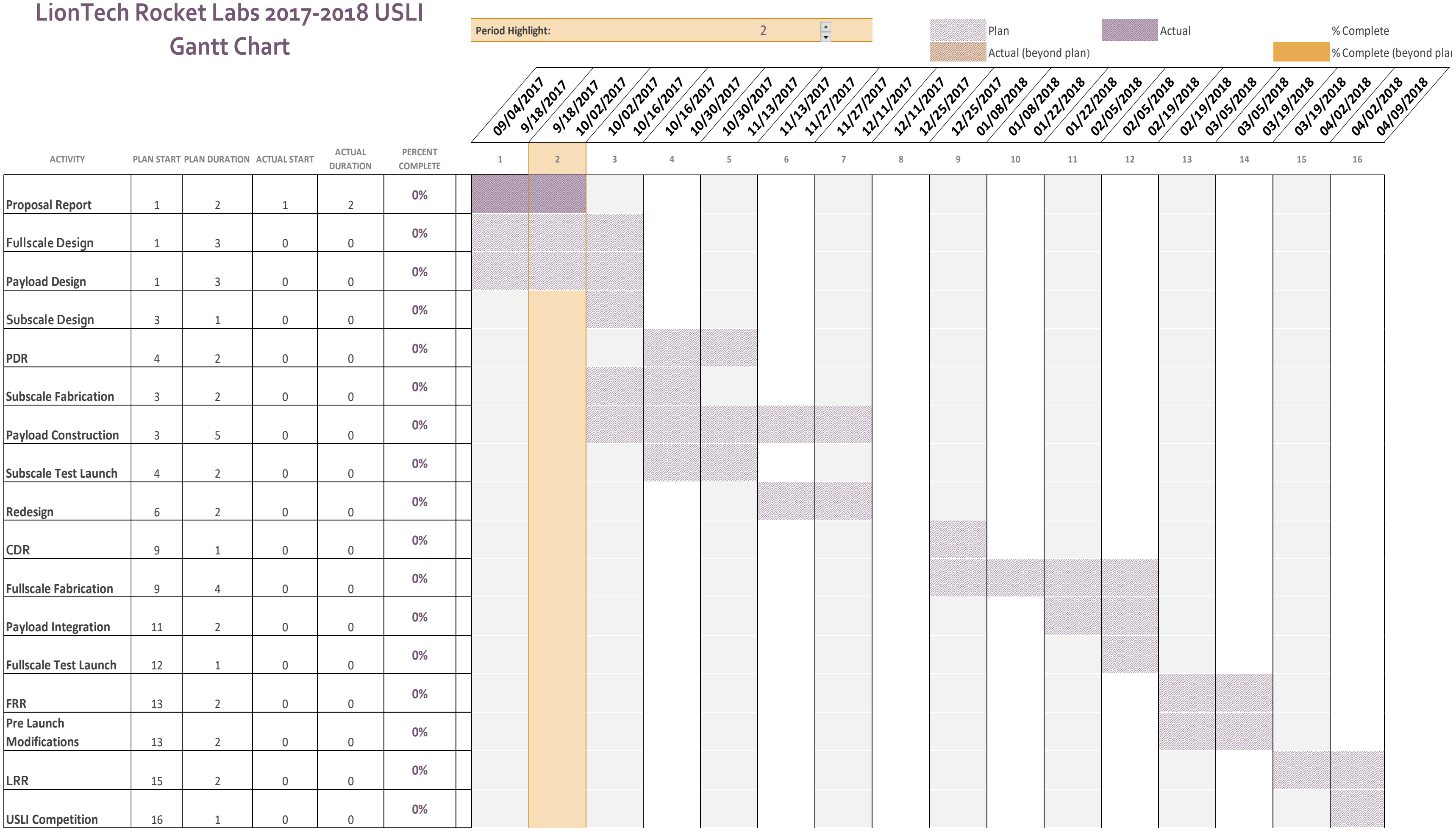
5.1 Team Involvement

The team will participate in a variety of STEM-themed events near Penn State and in team members' hometowns 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 display LTRL's past USLI 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. For younger students, the team will host balloon races to demonstrate the concept of propulsion. For older students, the team will teach the students how to build drinking-straw rockets to demonstrate how fins affect stability.

Club members will be required to attend at least three of these events throughout the year to go to the USLI competition in April. The public relations 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 public relations 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 public relations chair will ensure that such items are authorized at the location.

6. Project Plan

6.1 Gantt Charts



LionTech Rocket Labs 2017-2018 USLI Gantt Chart

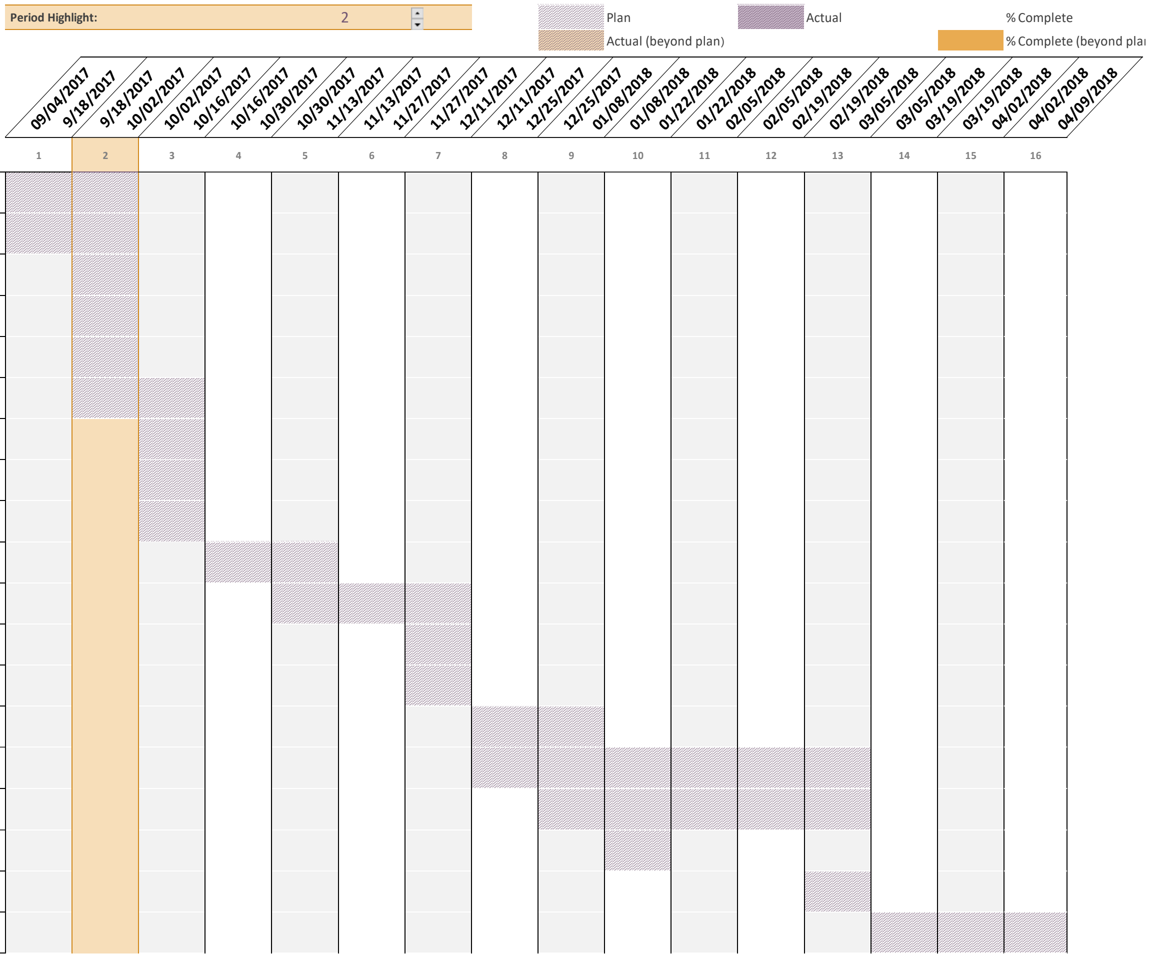
Period Highlight: 2

▨ Plan
▩ Actual
% Complete
▧ Actual (beyond plan)
■ % Complete (beyond pla

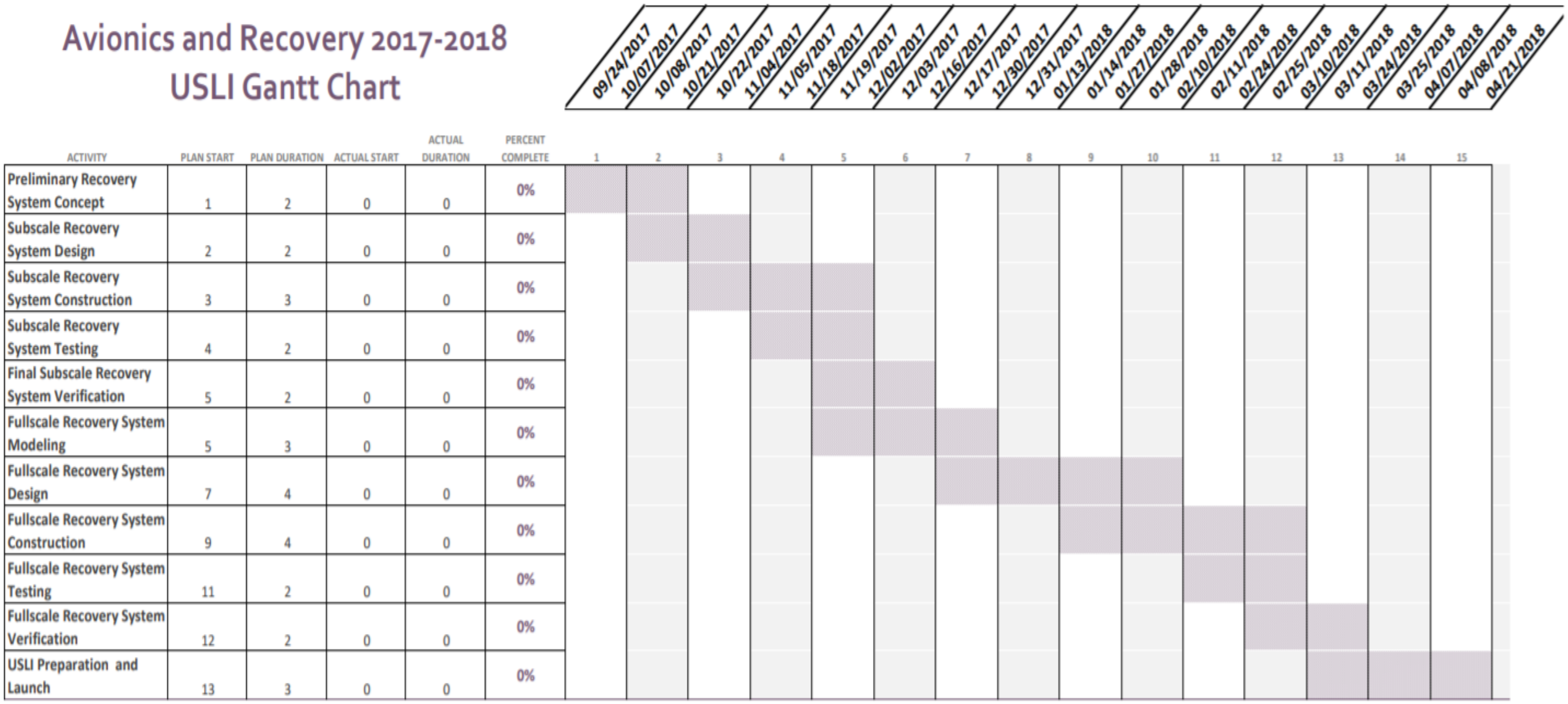
ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	09/04/2017 9/18/2017 1	9/18/2017 10/02/2017 2	10/02/2017 10/16/2017 3	10/16/2017 10/30/2017 4	10/30/2017 11/13/2017 5	11/13/2017 11/27/2017 6	11/27/2017 12/11/2017 7	12/11/2017 12/25/2017 8	12/25/2017 01/08/2018 9	01/08/2018 01/22/2018 10	01/22/2018 02/05/2018 11	02/05/2018 02/19/2018 12	02/19/2018 03/05/2018 13	03/05/2018 03/19/2018 14	03/19/2018 04/02/2018 15	04/02/2018 04/09/2018 16
Proposal Report	1	2	1	2	0%	▩	▩														
Fullscale Design	1	3	0	0	0%	▨	▨	▨													
Payload Design	1	3	0	0	0%	▨	▨	▨													
Subscale Design	3	1	0	0	0%			▨													
PDR	4	2	0	0	0%				▨	▨											
Subscale Fabrication	3	2	0	0	0%			▨	▨												
Payload Construction	3	5	0	0	0%			▨	▨	▨	▨	▨									
Subscale Test Launch	4	2	0	0	0%				▨	▨											
Redesign	6	2	0	0	0%						▨	▨									
CDR	9	1	0	0	0%									▨							
Fullscale Fabrication	9	4	0	0	0%									▨	▨	▨	▨				
Payload Integration	11	2	0	0	0%											▨	▨				
Fullscale Test Launch	12	1	0	0	0%												▨				
FRR	13	2	0	0	0%													▨	▨		
Pre Launch Modifications	13	2	0	0	0%													▨	▨		
LRR	15	2	0	0	0%															▨	▨
USLI Competition	16	1	0	0	0%																▨

Structures and Propulsion 2017-2018
USLI Gantt Chart

Period Highlight: 2



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Design	1	2	0	0	0%
Material Testing	1	2	0	0	0%
Proposal Report	2	1	0	0	0%
Subscale Design	2	1	0	0	0%
Subscale Motor Testing	2	1	0	0	0%
Subscale Modeling & Simulations	2	2	0	0	0%
Subscale Construction	3	1	0	0	0%
Subscale Evaluation	3	1	0	0	0%
Subscale Launch	3	1	0	0	0%
Preliminary Design Review	4	2	0	0	0%
Finalize Fullscale Design	5	3	0	0	0%
FullscaleRocket Modeling & Simulations	7	1	0	0	0%
Fullscale Motor Testing	7	1	0	0	0%
Fullscale Construction	8	2	0	0	0%
Fullscale Evaluation	8	6	0	0	0%
Fullscale Test Launch	9	5	0	0	0%
Critical Design Review	10	1	0	0	0%
Flight Readiness Review	13	1	0	0	0%
USLI Prep and Launch	14	3	0	0	0%



Avionics and Recovery 2017-2018
USLI Gantt Chart

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	1 09/24/2017 10/07/2017	2 10/08/2017 10/21/2017	3 10/22/2017 11/04/2017	4 11/05/2017 11/18/2017	5 11/19/2017 12/02/2017	6 12/03/2017 12/16/2017	7 12/17/2017 12/30/2017	8 12/31/2017 01/13/2018	9 01/14/2018 01/27/2018	10 01/28/2018 02/10/2018	11 02/11/2018 02/24/2018	12 02/25/2018 03/10/2018	13 03/11/2018 03/24/2018	14 03/25/2018 04/07/2018	15 04/08/2018 04/21/2018
Preliminary Recovery System Concept	1	2	0	0	0%	▨	▨													
Subscale Recovery System Design	2	2	0	0	0%		▨	▨												
Subscale Recovery System Construction	3	3	0	0	0%			▨	▨	▨										
Subscale Recovery System Testing	4	2	0	0	0%				▨	▨										
Final Subscale Recovery System Verification	5	2	0	0	0%					▨	▨									
Fullscale Recovery System Modeling	5	3	0	0	0%					▨	▨	▨								
Fullscale Recovery System Design	7	4	0	0	0%							▨	▨	▨	▨					
Fullscale Recovery System Construction	9	4	0	0	0%									▨	▨	▨	▨			
Fullscale Recovery System Testing	11	2	0	0	0%											▨	▨			
Fullscale Recovery System Verification	12	2	0	0	0%												▨	▨		
USLI Preparation and Launch	13	3	0	0	0%													▨	▨	▨

Payload 2017-2018 USLI Gantt Chart

Period Highlight: 1

🟧 Plan | Actual | % Complete
Actual (beyond plan) | % Complete (beyc

09/04/2016 9/18/2016 9/18/2017 10/02/2017 10/02/2017 10/16/2017 10/16/2017 10/30/2017 10/30/2017 11/13/2017 11/13/2017 11/27/2017 11/27/2017 12/11/2017 12/11/2017 12/25/2017 12/25/2017 01/08/2018 01/08/2018 01/22/2018 01/22/2018 02/05/2018 02/05/2018 02/19/2018 02/19/2018 03/05/2018 03/05/2018 03/19/2018 03/19/2018 04/02/2018 04/02/2018 04/09/20

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Preliminary Conceptualization	1	2		0	0%	🟧	🟧														
Material Selection	1	2		0	0%	🟧	🟧														
Electronics Container Design	2	3		0	0%		🟧	🟧													
Motor Selection	3	3		0	0%			🟧													
Drive Train Design	3	5		0	0%			🟧	🟧	🟧											
Frame/Suspension Design	3	5		0	0%			🟧	🟧	🟧											
Tread Design	4	6		0	0%				🟧	🟧	🟧										
Solar Panel Deployment Mechanism Design	5	7		0	0%					🟧	🟧	🟧									
Flowchart/Identify Modules	4	6		0	0%				🟧	🟧	🟧										
Assembly of Rover	5	10		0	0%					🟧	🟧	🟧	🟧	🟧	🟧						
Complete Software Modules	6	9		0	0%						🟧	🟧	🟧	🟧							
Test/Review Modules Independently	8	10		0	0%								🟧	🟧	🟧						
Design/Build Containment Chamber	7	11		0	0%							🟧	🟧	🟧	🟧	🟧					
Consolodate Modules	9	12		0	0%									🟧	🟧	🟧	🟧				
Test Subsystems of Rover	12	13		0	0%												🟧	🟧			
Test Full Assembly of Rover	13	14		0	0%													🟧	🟧		

6.2 Budget

Table 5 displays the expected costs of the 2017-2018 academic year. The table accounts for both blue tube and blue tube wrapped in carbon fiber as the team has not yet decided which material will better suit this year's project.

Table 5. Expected Costs 2017-2018

	Carbon Fiber Wrapped Blue tube	Blue tube
Fullscale	$1,400.00	$1,000.00
Subscale	$800.00	$600.00
Testing	$500.00	
Propulsion	$1,500.00	
Travel	$5,000.00	
Outreach	$100.00	
Miscellaneous Equipment	$1,000.00	
Total	$10,300.00	$9,700.00

The fullscale amount is comprised of the costs to build the fullscale rocket. The subscale amount is the expenses of building the subscale rocket. Testing accounts for the costs of running the necessary tests to make design decisions and prove that the design works. Travel costs predominantly covers expenses from traveling to and from and staying in Alabama. Additionally, travel covers the costs of fuel for test launches during the school year. The propulsion cost consists of expenses for all the motors required for both subscale and fullscale. Outreach covers the costs of fuel to drive to events and any supplies needed to stage the event. Miscellaneous accounts for all the tools and equipment used to make the rocket.

6.3 Funding

Error! Reference source not found. shows the expected funding that the club will receive mainly from academic sponsors, but also through fundraising.

Table 6. Expected Income 2017-2018

Penn State Aerospace Engineering Department	$5,000.00
Penn State Mechanical and Nuclear Engineering Department	$1,000.00
University Park Allocations Committee (UPAC)	$5,000.00
Club Fundraising	$1,000.00
Pennsylvania Space Grant	$2,500.00
Total	$14,500.00

Penn State's Aerospace Department has consistently supported LTRL and the team is hopeful that they will continue to do so this year. The Mechanical and Nuclear Engineering Department has been willing to give funding to the club in the past to show support for the mechanical engineering students. University Park Allocations Committee (UPAC) is a Penn State organization that supports various clubs at Penn State. They offer funding to help with travel costs and help cover most of LTRL's travel expenses for the Alabama trip. Annual dues and fundraising during the academic year also provides additional funding.

To account for other expenses that may arise, more funding will be pursued. Funds may come from the Pennsylvania Space Grant, which is a grant intended to support groups that are seeking exploration in aerospace fields. LTRL will have to submit a proposal and be approved to receive this grant. The club will also be getting in contact with the Engineering Graduate Council at Penn State and the Boeing Corporation as they have given LTRL funds in the past and the team is hopeful that these sponsors are willing to consider supporting the club again.

6.4 Sustainability

LTRL always pursues new partnerships within the Penn State community. This year, the team aims to develop a relationship with the Electrical Engineering and Computer Science Department. To maintain partnerships within the university that have already been established, LTRL will continually update the Penn State departments from which funding is received so that the departments see how vital their contributions are to club activities and that the team uses the money well. Keeping the departments up-to-date about how their funding has made a difference will help motivate them to continue providing financial assistance in future years. The team will maintain partnerships with Penn State faculty by reaching out to them for technical guidance and editing advice for milestone reports.

LTRL will recruit new students every semester by participating in extracurricular fairs held by Penn State and holding lab tours for interested students. The team will retain members by ensuring that each student is actively engaged in the design, building, and testing processes of the competition. Additionally, LTRL will provide many opportunities for general members to attend launches throughout the academic year.

LTRL will maintain partnerships with the elementary, middle, and high schools in the area by attending science and STEM events that the schools host and providing an interactive learning experience for the children at these events. LTRL will also participate in events hosted by Penn State for children interested in STEM. In the past, the team has helped with events for groups such as The Girl Scouts of America, and they will continue to seek out these educational engagement opportunities this year.

7. Appendices

Appendix A: Risk Management

Impact Ratings

Serious injury occurs to a club member, serious damage occurs to the LTRL lab or another facility, club is disbanded: **5**

Moderate injury occurs to a club member, moderate damage occurs to tools or facilities, serious structural damage occurs to the rocket requiring a complete rebuild, the LTRL team cannot attend the Alabama competition: **4**

Moderate structural damage occurs to the rocket requiring repairs in the lab for several days or weeks, the LTRL budget becomes strained, the building of important parts of the rocket is severely delayed: **3**

Structural damage occurs to the rocket requiring repairs in the lab, but not requiring several days to repair, time delays occur to various subsystems, the club requires significantly more money than was budgeted (> $500): **2**

Structural damage occurs to the rocket requiring repairs that can be made at the launch site, the rocket is slightly behind schedule, the club goes slightly over budget (<$500): **1**

Likelihood Ratings

Chance of the situation happening is very high, and the situation has occurred several times in the past four years of club operation: **5**

Chance of the situation happening is high, and the situation has occurred at least once in the past four years or nearly occurred several times in the past four years of club operation: **4**

Chance of the situation happening is moderate, and the situation has nearly occurred at least once in the past four years of club operation: **3**

Chance of the situation happening is low, and the situation has not occurred, or nearly occurred during the past four years of club operation: **2**

Chance of the situation happening is very low, and the situation has never occurred or nearly occurred during the past four years of club operation: **1**

Table A1. Risk Management

Risk	Description	Likelihood	Impact	Mitigation
Overall Project				
Project falls behind schedule	Major milestones are not met in time	4	4	Weekly status meetings, follow project plan and Gantt chart
Project is over budget	Project requires more money than allotted	2	4	Properly allot resources over time
Damage during testing	Failure of recovery devices, hard landings, etc	4	3	Ground testing, ensure spare parts are kept
Club loses facilities	Room 46 Hammond no longer available	1	5	Maintain clean environment and proper storage of materials
Weather does not cooperate on flight test day	Winds in excess of 20mph or excessive rain	4	3	Schedule backup launch day
Parts are unavailable	Testing or fabrication parts are not available when needed	3	3	Use non-exotic materials and check for availability. Order parts far in advance
Labor leaves/graduates	Seniors graduate or students stop attending meetings	1	5	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
Club loses funding	One or more sources can no longer provide funding	2	4	Dedicated member to track expenses and make funding contacts.
Integration Failure	Parts don't fit together properly	2	3	Shared online documents, integration meetings
Failure to acquire transportation	Transportation to Alabama cannot be acquired	1	4	Have plan to carpool if necessary

Theft of Equipment	Parts or testing equipment get stolen	1	3	Only subsystem leaders and officers will have card access to the USLI lab
Flight Vehicle				
Airframe or coupler 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	3	3	Pressure relief holes and use of nylon shear pins
Propulsion				
Motor CATOs	Catastrophic motor failure during launch	1	5	Inspect motor grains prior to installation. Have a certified member assemble the 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
Avionics & Recovery				
Ejection charges do not ignite	No parachute deployment, ballistic descent	2	5	Use fresh batteries for each launch, check altimeter continuity
Drogue chute fails to deploy	Drogue chute either does not leave the tube or doesn’t unravel	3	4	Ground test recovery system for optimal ejection strength

Main chute fails to deploy	Main chute either does not leave tube or doesn’t unravel	3	4	Maintain sufficient airflow to deploy main chute from deployment bag
Main chute deploys first	Main chute deploys at apogee	4	3	Proper labeling of wire, ground test, use correct number of shear pins
Recovery harness attachment breaks	Bulkhead, U-bolt or harness breaks	2	5	Adequately size recovery harness, flight test
High kinetic energy at landing	Rocket lands at an excessive velocity	3	4	Accurate estimate, OpenRocket
Main and drogue get tangled	Main chute gets deployed below drogue and tangles	2	4	Use adequate lengths of recovery harness
Recovery harness burns	Ejection partially or fully burns through harness	1	5	Use heat resistant recovery harness material
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
Loss of power	Battery dies or wires become unattached	2	5	Use fresh batteries that can withstand rocket accelerations, redundant altimeters
Altimeter doesn’t detect pressure change	No data is recorded and ejection charges are not fired	2	5	Properly sized vent holes away from airflow obstructions
Payload				
Payload shifts during launch	Center of mass shifts in the rocket, the payload cannot be deployed	3	4	Securely fasten payload into the rocket
Payload falls out of rocket	Payload retention mechanism fails before landing or is activated prematurely	1	5	Construct retention mechanism from durable materials, build in fail-safes to prevent accidental deployment, test extensively

Rover becomes unfastened during flight	Structural failure or premature release of fasteners attaching rover to inside of rocket body	2	1	Securely fasten rover to rocket body with materials rated to withstand high acceleration, conduct extensive testing on control software