# The Pennsylvania State University

# LionTech Rocket Labs

2017-2018 USLI Project Nimbus

## Post Launch Assessment Review

*046 Hammond Building, University Park, PA 16802*
*April 27, 2018*

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# List of Acronyms

| | |
|---|---|
| A&R | Avionics and Recovery |
| CFD | Computational Fluid Dynamics |
| EIT | Electronic and Information Technology |
| 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 and Mathematics |
| STTR | Small Business Technology Transfer |
| TRA | Tripoli Rocket Association |
| UPAC | University Park Allocation Committee |
| USLI | University Student Launch Initiative |

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# 1. Summary of Report

## 1.1 Team Summary

### Team Name and Address

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### NAR Contact/Mentor

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## 1.2 Vehicle Summary

### Vehicle Dimensions

The launch vehicle was designed to incorporate a rover payload while minimizing weight and providing sufficient strength. A diameter of 5.5 inches was chosen to give sufficient space for the payload.  The overall length of the vehicle is 112 in. The dry weight of the launch vehicle is 27.75 lb, while the wet mass, which includes the motor and casing, is 36.3 lb. An OpenRocket rendering of the final flight vehicle is shown in Figure 1. The fully constructed rocket can be seen before its competition flight in
Figure ***2.***

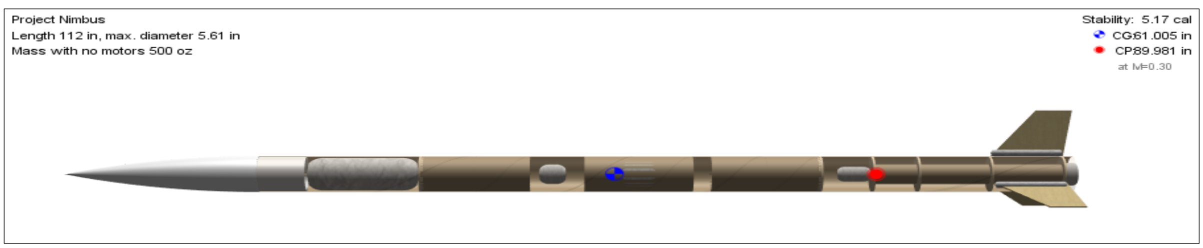


**Figure 1. OpenRocket Rendering of Final Flight Vehicle**


**Figure 2. Constructed Final Flight Vehicle Before Competition Launch**

### Motor Used

An Aerotech L1390 motor was selected for the competition. It is a solid motor with ammonium perchlorate composite as fuel. This gave the launch vehicle an actual apogee of 5008 ft.

### Vehicle Description

The launch vehicle's airframe was constructed of Blue Tube 2.0 wrapped in carbon fiber. The vehicle also included a removable door to the avionics bay to ensure easy access in case of technical difficulties. The vehicle utilized an ogive nose cone made of fiberglass due to its light weight and low cost. The fins were made of fiberglass and held in place by 3D printed fin brackets with nuts and bolts.  The fin brackets were 3D printed so they could be removed in case of structural damage. The 3D printed fin brackets also helped to combat fin flutter and ensure structural integrity. The launch vehicle also included a 3D printed aerodynamic camera cover which aligned the camera to record down-body and protected the camera during flight. The launch vehicle featured three separation points: two for parachute deployment and one for rover deployment. The separation point for drogue parachute is located between the booster and drogue body tube, and the separation point for main parachute will be located between the payload body tube and the main body tube. The rover will deploy through the nose cone after the separation between the nose cone and the nose cone shoulder. The motor was retained using three equidistant centering rings epoxied to the motor tube and to the body of the rocket using JB-Weld.

### Recovery System

The avionics system featured a fully redundant dual deployment recovery system utilizing two independent Stratologger CF altimeters with corresponding independent power sources, switches, and charges. The redundant altimeter was at a one-second delay to prevent potential overpressurization of the body tube. The launch vehicle deployed a 12" Fruity Chutes Classical Elliptical drogue parachute at apogee and a 84" Fruity Chutes Iris Ultra Compact at 700 ft above ground level. Both parachutes were attached to the rocket using a flame resistant 0.5" Kevlar cord able to withstand descent forces. The Kevlar shock cord connecting the booster body tube and drogue body tube featured a Kevlar fireball to reduce stress endured by the drogue-booster coupler from the shock cord during main parachute deployment. These avionic features were designed to ensure airframe integrity, and to guarantee that the rocket would land under the NASA kinetic energy requirement of 75 ft-lbs.

## 1.3 Data Analysis & Results of the Vehicle

### Launch Vehicle

Upon retrieval of the launch vehicle, all structural components were analyzed to determine if significant damage had occurred. The carbon fiber wrapped blue tube successfully withstood all launch, flight, and impact forces without any visual deformation. The fin brackets failed due to unexpected impact forces as a result of a failed main parachute deployment. However, the fin brackets were designed to break from large impact forces to protect the fins. The fin brackets sheared along the inner rib and successfully protected the fin brackets as a result. The impact with the ground also broke the launch vehicle's nozzle, which was not reusable even before it broke. The camera only had footage of the rocket before launch and failed to record any video of the flight.  However, the camera was protected by the 3D printed covering and no structural damage could be seen. In the future, using a new, more reliable camera may be needed to ensure that this will not happen again.

## Flight Results

Figure 3 represents the data of altitude versus time from competition flight. The launch vehicle achieved a max velocity of 5008 ft during competition launch.

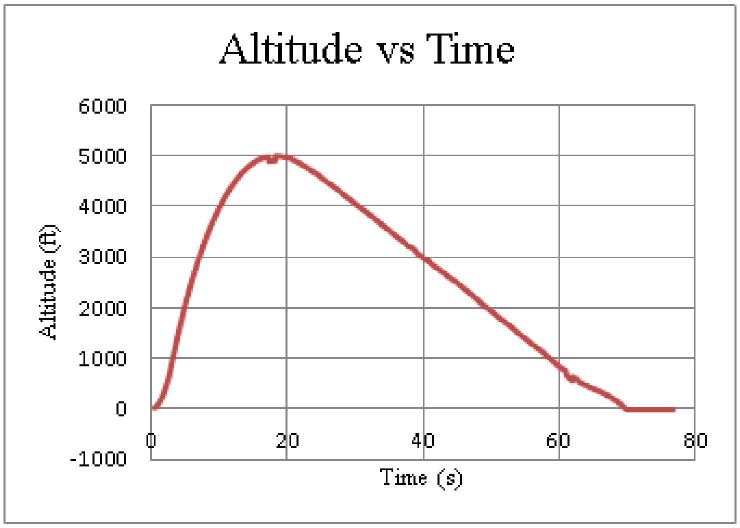


**Figure 3. Altitude vs. Time Plot for Competition Launch**

Figure **4** represents the data of velocity versus time from competition flight. The launch vehicle achieved a max velocity of 721 m/s during competition launch.

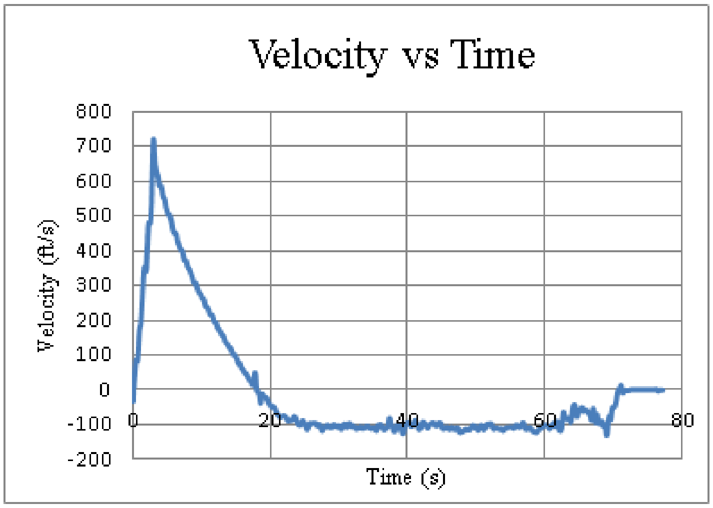


**Figure 4. Velocity vs. Time Plot for Competition Launch**

Figure 5 is the simulation result from OpenRocket. The red line represents altitude versus, time and the blue line represents velocity versus time. From the graphs shown above, the actual flight data agreed with the simulation predictions.

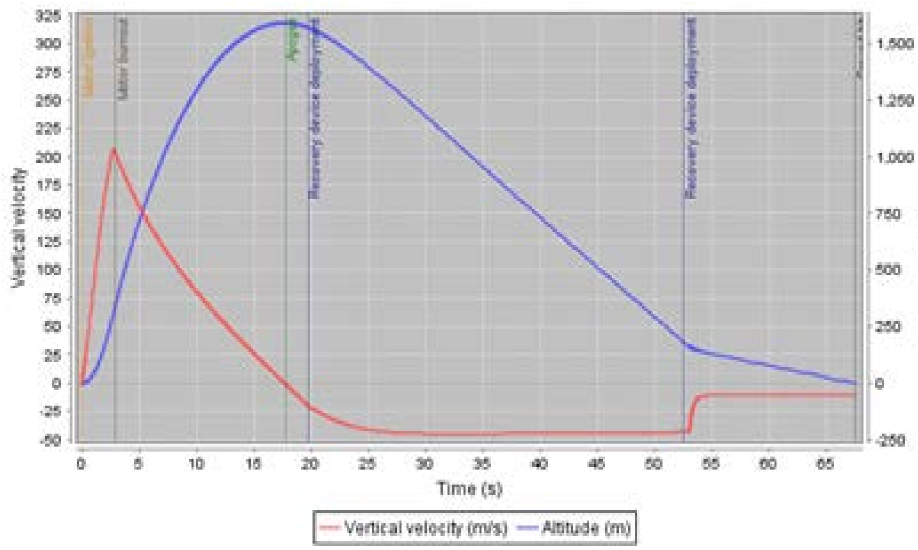


**Figure 5. OpenRocket Altitude and Velocity Simulations for Competition Launch**

Due to high speed winds averaging 15 mph, the vehicle was launched into the high crosswinds to ensure the rocket drifted onto the designated land. The simulation result in 15 mph winds predicts a 4942 ft apogee and 685 m/s max velocity. The actual apogee from the flight was 5008 ft with a max velocity of 721 m/s. There is a 66 ft difference between apogee predictions and results, and a 36 m/s difference between predicted max velocity and actual max velocity. This is due to the variable winds on launch day which may not have been exactly 15 mph during the rockets 15 second ascent time along with the two degree launch angle the rocket was launched at.

## Recovery System

The launch vehicle descended from 5008 ft in 70 seconds with a drift distance of 1000 ft. The altitude versus time plot of the launch vehicle during descent is shown in Figure 6.

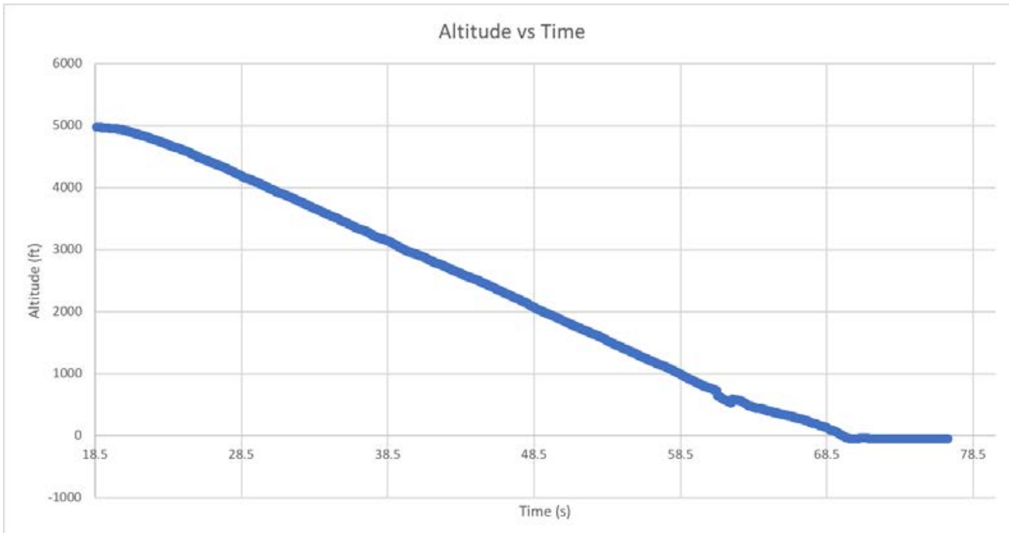


**Figure 6. Altitude vs. Time Plot of Competition Launch Descent**

Drogue descent occurred as predicted with slight variations in descent velocity calculations. Over a period of a few seconds the descent velocity varied 30 ft/s which is characteristic of tumbling during descent. After main charges detonated, the velocity decreased to an average of 70 ft/s but with significantly more variation in velocity, which continued until contact with the ground. The velocity versus time plot of the launch vehicle during descent is shown in *Figure 7*.

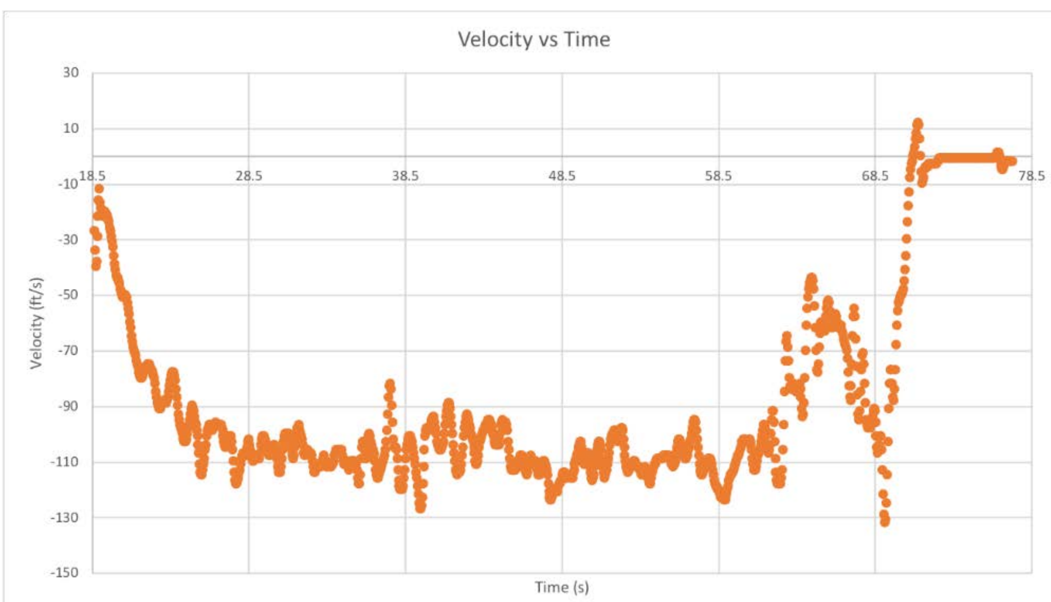


**Figure 7. Velocity vs. Time Plot of Competition Launch Descent**

Despite launch day wind speeds averaging 15 mph, the launch vehicle only drifted 1000 ft, which is well within the acceptable range of 2500 ft. A drift distance of 1000 ft was less than the predicted 1700 ft drift distance due to a failure of main parachute deployment. The launch vehicle impacted the ground at a significantly greater speed than expected due to a main parachute deployment failure, and so the pre-flight calculation of a 61 ft-lb impact kinetic energy is significantly less than the actual kinetic energy experienced during impact. During the failed main parachute deployment, the nose cone deployment system also failed, and the nose cone separated from the rocket and freely fell as a result. This section most likely hit the ground above 150 ft/s resulting in excess of 1000 ft-lb on impact. The sections that stayed attached by shock cord also exceeded the safety requirement from their landing at near drogue descent speed. The vehicle was in good condition after impact despite main deployment failure, and there were no visible signs of damage to any avionics components.

# 2. Payload Summary

## 2.1 Payload Overview

### Brief Payload Description

This year's payload competition was to design and build an autonomous rover that is secured in the launch vehicle during flight and deployed after landing. Once the rocket has landed, a signal must be sent to tell the rover to leave the rocket and drive a minimum of 5 ft. After it has reached the specified distance, the rover must deploy solar panels.

### Payload Summary

The rover was designed to receive a signal from the communications system, and detonate a black powder charge to disconnect the nose cone from the main body tube. The rover would then freely drive from the payload bay on to the ground. The rover used two ultrasonic sensors to detect and avoid potential obstacles. After driving more than the minimum distance of five feet, which was determined by a GPS, the rover stopped and used servos to extend the solar panels to complete the challenge. The rover was retained during flight by two shelves epoxied to the inside of the body tube.

## 2.2 Data Analysis & Results of the Payload

The rover payload had multiple failures during the descent. At main deployment, the nose cone separated unexpectedly and released the rover. Failure analysis suggests that the jolt from main deployment caused a wire to short inside the rover which caused the nose cone to deploy prematurely. This shortage failure caused the rover and nose cone to fall from the main deployment altitude.

At recovery, the rover was intact but unable to drive due to disconnection from the power source during landing. Structurally, the rover remained intact despite free falling from 700 ft. The rover would currently be able to function if the power sources were reattached.

# 3. Visual Data Observed

During descent, both of the parachute ejection charges fired as expected. The drogue parachute deployed at apogee and there were two puffs of smoke signifying that both ejection charges deployed. This was a good indication that both altimeters were functioning. During drogue descent the shock cord wrapped itself around the around the body tube almost 10 times. At 700 ft above ground altitude, the main parachute ejection charges fired as expected. The main parachute was ejected out of the main body tube into the payload-main coupler. The parachute unexpectedly remained lodged in this coupler and never deployed. The coupler fell towards the ground at an angle such that the shock cord had to flip the section around to pull the main parachute out. This did not occur since all the components fell at a similar velocity and the main parachute remained in, until contact with the ground. Upon recovery of the rocket it was observed to be that the main parachute was folded correctly and was only being held in the coupler by about 3 inches, so it could not have been snagged on any of the filed down screws. Upon inspection, the parachutes showed no signs of damage which is due to the fact that they were fully protected by the Nomex blankets. The avionics bay was unharmed and could be used for other flights. The entire recovery harness also showed no signs of damage due to the fact that it is made of Kevlar and was connected properly.

# 4. Scientific Value

The structures division of LTRL experimented with and implemented many new designs and concepts into the launch vehicle this year. In years past, LTRL utilized 3D printing and due to the success rate, LTRL decided to implement more 3D printing into the rocket. The use of 3D printing made it much easier and less time consuming to create specific parts needed for the launch vehicle. For example, the new fin bracket design that was utilized in the launch vehicle worked perfectly in that it made it easy to interchange fins and protected the fins from damage in case of an impact. Learning more about 3D printing will make it possible to create specific and more advanced parts in the future.

The use of carbon fiber for structural integrity along with blue tube was another experiment that was successful, in that there was no visual damage to the flight vehicle's main structure after multiple flights. Because of this, LTRL plans to move forward with carbon fiber experiments and eventually have a launch vehicle made completely out of carbon fiber.

Last year, the avionics bay was 3-D printed for the first time and due to its success, LTRL decided to 3-D print the avionics bay again with a PLA filament. This 3-D printed avionics bay has many advantages and is significantly more convenient that making a conventional avionics bay on a wooden board. LTRL did change the design of the avionics bay in an attempt to improve the new design, making it much more accessible by cutting a door in the rocket. This made the interior accessible from outside the rocket without disassembling the AV bay. The door made it possible to pull a piece out of the AV bay, without disassembling it in entirety. This allowed for quicker and easier assembly on launch day which was important because there were time sensitive components of the rocket. The avionics bay maintained structural integrity throughout the flight and the 3-D printed coupler that held the faraday cage protected the avionics electronics. While there were wiring issues with this AV bay, it was still a great improvement and due to its ease and success, will most likely be used again in the future with modifications. There was a lot of experimentation with ejecting the nose cone from the body of the rocket with a carbon dioxide canister charge which lead to learning about and experimenting with CO2 which opens up its possible use in the future.

Through the process of developing a solution to the competition, the payload subsystem determined that an autonomous rover can be used in potential rocket launches to then drive around a given area to survey and obtain information. The deployment of the solar panels, after a predetermined distance, will help provide power to the rover. The inclusion of the ultrasonic sensors will also help ensure that the rover is able to drive around obstacles so that there is no risk of damage. The integration of the ultrasonic sensors and solar panels will help make sure the rover is able to be functional for a long period of time. The autonomous aspect of the rover is vital because if LTRL does not have access to the rover it is able to function on its own.

# 5. Lessons Learned

This year, LTRL decided to experiment with carbon fiber. As this was the first year using the materials, there were a lot of difficulties. LTRL did not have access to an oven, so the epoxy was cured using heat shrink tape heated by a hairdryer and a heat gun. The epoxy cured quicker in some areas compared to others as there was not an equal amount of epoxy on all areas of the carbon fiber wrapped blue tube. The lead to warping of the body tube at the ends where more epoxy was present. This created unsmooth transitions from section to section and resulted in couplers no longer fitting in the body tube. The idea of vacuum bagging the blue tubes was also brought up midway through the process, however, it was decided against as most of the tubes had already been wrapped in carbon fiber prior. Next year, LTRL will try to bake fully carbon fiber tubes, or vacuum bag them if LTRL does not gain access to an oven during the construction phase of the rocket.

During separation the main parachute failed to deploy and from this failure, there is a great deal to learn about packing the parachute and the interior of the rocket where the parachute resides. To ensure that either parachute does not get stuck in the future, the interior of the coupler that the parachute is ejected into needs to be completely smooth, the screws need to be filed, and possibly covered. The inside of the coupler and the packed parachute could be covered in a low friction material such as baby powder. The other solution is to change the lengths of shock cord, the location of the attached parachutes, and the order that they are packed in. This will require further testing next year before a final decision can be made. When assembling and wiring the avionics bay, it was observed that the wires were being wedged and bent awkwardly each time. The continued stress on the wires during setup began to damage the wires and caused some to break once the avionics bay was assembled in the rocket. Learning from this, the design of future avionics bays will be adjusted to ensure that the wires do not have to make acute bends and to have a more secure connection to the altimeters. A&R also learned the importance of always having spare parts. Although the team did not launch in Alabama, there were insufficient initiators, black powder and wadding so that extras had to be purchased at launch. This experience solidified the importance of having spare parts on launch day.

While working with the rover, the team could improve on time management, especially during the design phase of the payload. The team came up with multiple different ideas during the design phase, however, those designs were often too complex or too time consuming to complete during the building phase of the rover. While the design phase was not ideal, the team did well on time management during the building phase of the rover. In the future, the team should take less time to design the rocket in extreme detail, and instead work on building and testing. At the beginning of the semester the team had some questions on the durability and usability of 3-D printed PLA filament. At the launch, the team learned that the PLA filament is very sturdy and can hold up to some high stress. The rover, which was built entirely out of 3-D printed PLA filament, fell from about 700 feet and hit the ground without much, if any, damage to the body. From this experience, the team learned that the filament will hold up from fall damage. However, the PLA will crack when trying to screw through it.

The motor performed well as expected, however due to the damage during recovery it is not reusable.

The importance of proper, accurate, updated procedures and checklists was the biggest lesson for the propulsion team this year. During the fullscale test flight, the motor nozzle did sit tightly in the motor casing. This was due to a missing Cesaroni spacer ring at the top of the motor assembly; its installation was not listed in the launch day procedures that were available. Fortunately there was an experienced mentor at the launch who had seen the problem before and knew how to safely fix the problem.

# 6. Summary of Overall Experience

Participating in NASA's USLI competition was a very valuable experience. All members gained valuable experience working in an integrative team, constructing a design that the members personally made, and overcoming challenging problems that are not encountered in the classroom.

LTRL tried something new this year by wrapping carbon fiber around the blue tubes. This was decided upon to increase the structural integrity of the rocket as carbon fiber can take higher loads than blue tube alone. Since this was LTRLs first year using carbon fiber, there were many hiccups as there was not much experience with using the material. For the knowledge and experience that LTRL had with using carbon fiber, the wrapped blue tubes came out as expected. The tubes did not look the greatest, however, the tubes survived all launches without any major structural damage. By experimenting with carbon fiber this year, LTRL members gained valuable experience that will translate to next year, where LTRL will try to create tubes made completely out of carbon fiber. A new avionics bay and coupler was developed which allowed for quicker assembly during launch day. This system with the addition of modifications will be used in the future because it was so successful. In terms of the rover, during the design process the payload subsystem believed that too much time was spent on figuring out the best way to design the rover. Due to this extended period of designing, the payload subsystem was not able to test as many of the options that were being discussed. This led to the overall experience of the team realizing the importance of time management and extending testing for multiple ideas to get the optimal results.

# 7. Budget Summary

Table 1 summarizes LTRL's money inflow for the 2017-2018 competition year. Table 2 summarizes LTRL's money outflow for the 2017-2018 competition year.

**Table 1. Inflow 2017-2018**

| Donor | Requested Amount |
|---|---|
| Penn State College of Engineering | $1,000.00 |
| Penn State Aerospace Engineering Department | $2,000.00 |
| Penn State Mechanical Engineering Department | $1,000.00 |
| University Park Allocations Committee (UPAC) | $6,000.00 |
| Pennsylvania Space Grant | $3,965.62 |
| The Boeing Company | $500.00 |
| Club Fundraising | $1,105.00 |
| Prior Club Funds | $1,502.59 |
| **Total** | **$17,073.21** |

**Table 2. Outflow Overview 2017-2018**

| Budget | Total Cost |
|---|---:|
| Fullscale | $2,662.80 |
| Subscale | $604.37 |
| Travel | $7,612.56 |
| Outreach | $150.00 |
| Miscellaneous Supplies and Equipment | $500.49 |
| **Total** | **$11,530.22** |

This year the club was able to acquire sufficient funding needed to construct the subscale and full scale launch vehicle and travel to Huntsville, Alabama to participate in the NASA sponsored University Student Launch Initiative (USLI). Full scale expenses consist of those needed to build and test the final flight vehicle. Subscale expenses account for the costs needed to construct the subscale rocket and conduct subscale launch testing. Propulsion expenses include the motors from both subscale and full scale as well as some necessary fittings for full scale motor installation. Travel expenses consist of the travel to Alabama and fuel reimbursements for travel to various test launch sites. Primary expenses for the trip to Alabama were the costs of staying in the hotel and the renting of the vans used to drive to Alabama from Penn State. Outreach expenses are the fuel reimbursements for members traveling to the outreach sites in addition to the purchasing of equipment for demonstrations. Miscellaneous supplies and equipment covers the expenses of purchasing any tools or equipment necessary for construction of the launch vehicle and payloads.

Without all of the sponsors for LTRL, a successful year would not have been possible. The primary source of funding for the club was the Penn State University Park Allocation Committee providing $6,000.00 to cover equipment and travel expenses. LTRL received $3,965.62 from the Pennsylvania Space Grant as the club continues to expand opportunities for Pennsylvanians to learn about and participate in NASA's aeronautics and space programs. Penn State Aerospace Engineering Department agreed to donate $2,000.00. The Penn State Mechanical and Nuclear Engineering Department also agreed to donate $1,000.00. The club fundraising collected $1,105.00 from club dues. The Boeing Company donated $500.00 to the club this year. The club was able to save $1,502.59 from last year's funding and include it in this year's effort to construct the launch vehicle.

The sponsors' support was used to fund LTRL to completion of the University Student Launch Initiative. This year $2,662.80 was used to build the full scale rocket. This amount includes expenses of the airframe, payloads, motor, and internal equipment that allowed for successful flight. The cost of travel is also a main expense, coming to be $7,612.56. This accounts for all test flights, transportation to Alabama, and housing in Alabama. The remaining funding will be used next year to once again accomplish LTRL's goal of competing at a high level in NASA's USLI completion.