# Pioneer Rocketry
# University of Wisconsin-Platteville
# Flight Readiness Report
# NASA's Space Grant
# Midwest High-Power Rocket Competition
# 2014 – 2015

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# Introduction

Pioneer Rocketry is an incredible student organization who has dedicated their time to advancing high powered rocketry through many challenging and incredible launches. After three unsuccessful test launches, the team was hoping in a successful competition launch at the WSGC State Competition. However due to a failure with the electronics on the dart, the parachute was ejected late, ripping the shock cord in two. This in turn made the front half of the dart unrecoverable.

The club did not receive news for their admittance into the Regional Launch until the day before final exams. Sacrificing precious study time, the team redesigned and reconstructed the dart to remedy the issues seen in the State Launch and displayed a high level of resourcefulness as they analyzed the data that was recovered from the launch to determine the required post launch analysis.

This club has shown an incredible resilience in the past launches, and this year has been no exception. Taking what some would consider to be a failed launch, this team has learned from its mistakes and has used this to push themselves forward into the future. With the issues now solved, the team looks forward testing their design against the best teams from across the region.

This team looks forward to be able to add another chapter to this year’s competition, and is thrilled to have been selected by Wisconsin Space Grant Consortium to move forward to the Regional Competition.

Ad Astra!

Jacob Napp
Vice President, Pioneer Rocketry

## General Design

The competition parameters for this year called for the development of an unpowered "kinetic dart", lifted by a separable booster stage. The objective will be to reach the highest altitude possible with the dart, which has no capability of producing thrust. The two stage configuration inspired the name "Thunder & Lightning" for the competition rocket where Thunder is the booster, and Lighting is the dart. The dart carries a suite of electronics gathering data on both its orientation and altitude. Video is captured from the dart as well from an aft-mounted camera. The following section will break down the main design features of both the booster and dart sections of the rocket.

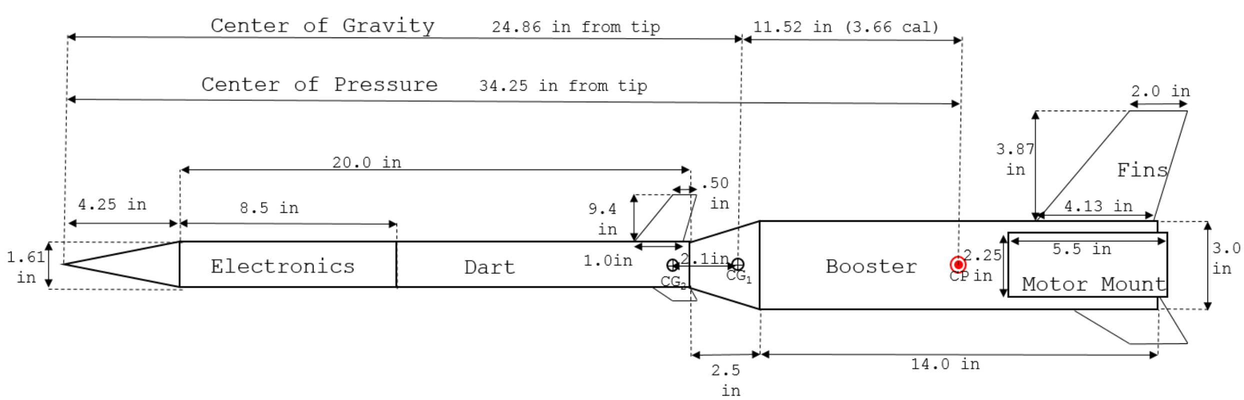


**Figure 1: Dimensioned drawing of rocket before separation**

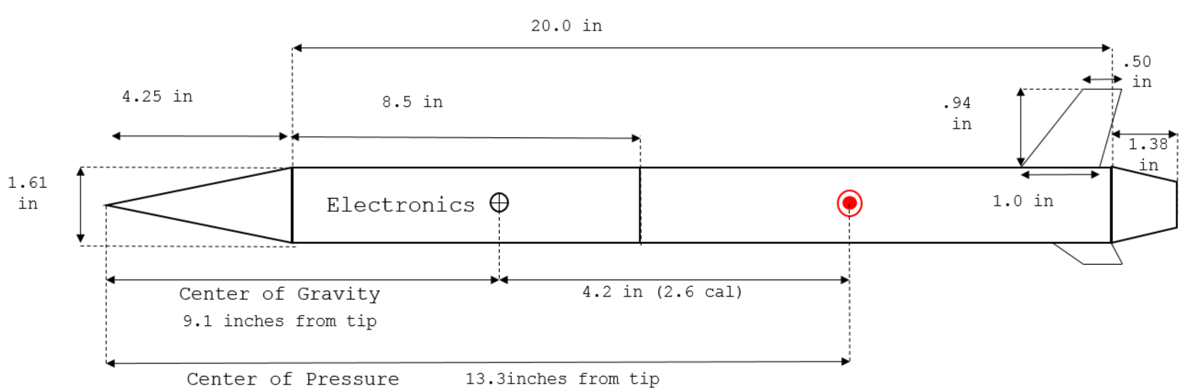


**Figure 2: Dimensioned drawing of dart after separation**

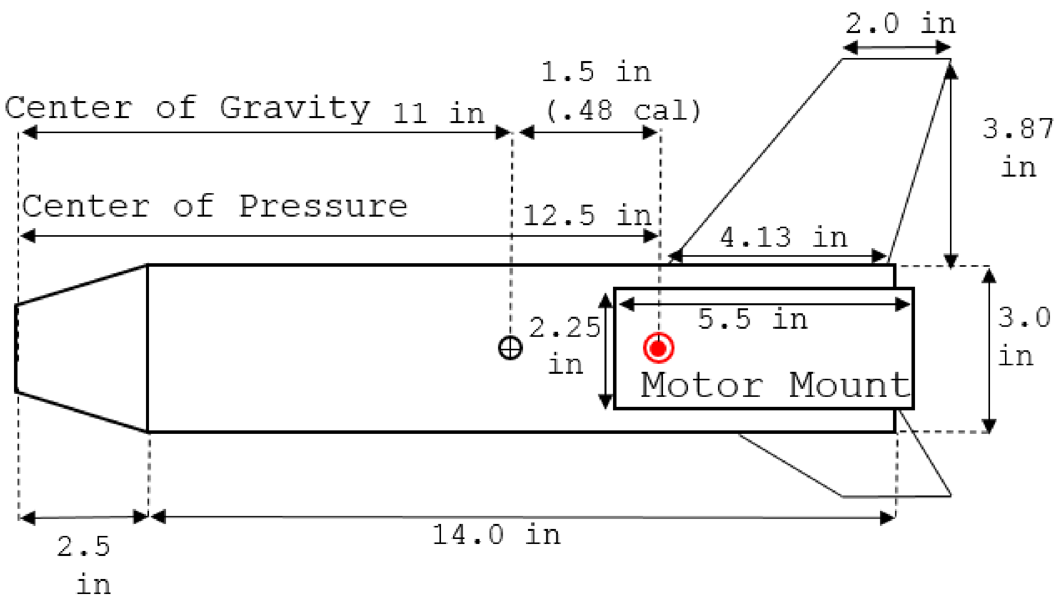


**Figure 3: Dimensioned drawing of booster after separation**

## Dart

### Nosecone

The nosecone selected for the dart is a PLA 3D printed Nosecone. The shape used in for this nosecone is a specialty shape that was created to reduce drag. This shape was evolved using a genetic algorithm written in MathWorks MATLAB and simulated in Star CCM+, a powerful computational fluid dynamics program. This optimization process resulted in a shape that produces ten percent less drag verses traditional shapes in the flight conditions experienced by the dart. This nosecone's fineness ratio of 4.65 (length/diameter) was also selected after extensive simulations to find the optimal ratio between length and diameter. It was determined that increasing the nosecone length will cause the viscous forces of the air to start increasing due to increased surface area. If the nosecone length decreased then the pressure forces will increase due to the increased bluntness of the nosecone.

### Airframe

The body tube selected for the dart is 1.6in blue tube. The original rocket was constructed out of carbon fiber, but due to the short time that was available to construct this rocket, blue tube was the only available alternative. To minimize the drag on the dart the length of the body tube was minimized. The final length of 20in was selected as a compromise between internal volume, for things such as avionics and parachutes, and length reduction for things such as drag.

### Weights

The Dart has the capacity for housing up to 500g of counter weight. This modularity will allow the proper selection of weight to maximize altitude. To determine the difference between insufficient momentum to overcome drag and too much mass a Simulink model was created. This model takes into account the booster mass and drag as well as the darts mass and drag. The Simulink model indicates we should have a mass around 765g. An optimization was also run in open rocket to find an optimal mass of 753g.

### Avionics Bay

The avionics bay consists of a sled between two bulkheads. Two 6-32 threaded rods span the length of the AV bay and tie the nosecone, counterweights, AV sled, and parachute mounting point together. The rods will carry the load of parachute ejection and descent.

This year's competition requirements were to measure and record the pitch, roll, and yaw, of the dart, namely the rotation around the dart's three major axes, during the duration of the dart's flight. Additionally, downward facing video captured from the dart during the airborne period following the launch. To achieve the latter goal, a striped down action camera which mounts inside the secondary electronics bay located in the tail cone of the dart was selected. This configuration allows us to get downward facing video without adding obstructions to airflow to the dart that would increase the air resistance. It also allows the camera to passively reorient to continue taking downward facing video after deployment of the parachute.

The primary challenge was to develop a system that records the rotation of the boosted dart during its flight for later comparison with our flight video. To do this a sensor kit attached to an Arduino Micro was built. This system utilizes a 9 degree of freedom sensor capable of recording the angular velocity, axial acceleration, along with as the magnetic field found at the rocket. The angular velocity can be integrated to find the rocket's rotation. The earth's magnetic field will have a very nearly constant strength and direction, and this will be utilized to determine the rockets orientation.

For easing the recovery of the rocket there is a GPS unit called The Big Red Bee installed onboard the rocket. The Big Red Bee sends the rockets GPS coordinates over a 900Mhz radio signal to a handheld radio device that is stationed at the launch site. It was used successfully in previous competitions to quickly locate and recover the rocket.

### Recovery

The dart will fly on a 18in hemispherical parachute made of ripstop nylon features a spill hole. The hemispherical shape and spill hole increase the stability of the parachute during descent. Attaching the parachutes to the rocket is Kevlar shock cord. The Kevlar was selected due to its incredible strength as well as heat resistance, both of these characteristics are valuable in rocketry. Unlike traditional rockets, the parachute is deployed from the bottom of the rocket so there is a reduced chance of breaking fins on impact.

### Camera Pod

Like the nosecone on the dart the tailcone is also 3D printed with PLA plastic. 3D printing the tailcone allowed for a simple construction of an otherwise complex geometry which was needed to house the camera. The camera pod is roughly elliptical shape and is shaped around fitting the camera. The camera is sealed inside by a bulkhead attaching to the shock cord. Due to the camera being mounted to the bottom of the rocket and having the camera pod separate, the camera will always be pointed downward and have a view of the ground.

### Fins

The fins on the dart are composed of .06in thick G10 fiberglass. G10 fiberglass was selected instead of the carbon fiber that we used on previous darts because we were able to laser cut the material, making our fins much precisely sized. Their shape is trapezoidal, with dimensions that were selected to maximize stability and reduce drag. The fins are swept back at the mid chord 30 degrees to move the center of pressure backwards. The fins also have a higher than normal aspect ratio (span/average chord) with a span of .94in. The root chord of the fins is 1.0in tapering down to a tip chord of .5in

## Booster

### Transition

The transition between the dart and booster is another 3D printed part on this rocket. The Transition serves two purposes on the rocket. The first is to smoothly increase the rocket diameter from the 1.5in tube of the dart to the 3in tube of the booster. The second purpose of the transition is to hold the base of the dart during the boost portion of flight. The entire tailcone of the dart as well as 0.25 in of body tube are contained in the transition. Inside the transition there are two plates of wood with the exact profile of the tailcone cut into them allowing for secure retention against rotation and lateral movements but no restriction axially.

A variant of this transition was designed to accommodate a set of mirrors to redirect the image from the tail of the dart down the side of the booster. This addition would allow the video to be taken throughout the entire flight not only after separation.

### Airframe

The booster tube is carbon fiber and is 3in in diameter. To maximize momentum imparted to the dart the booster needs to be as light as possible. To achieve this, the booster was made to be as short as possible. The final length of 14in was determined to produce an ideal combination between stability and weight.

### Recovery

From our simulations, we determined that a 24 inch hemispherical parachute would be Ideal for a safe recovery. These simulations have been validated by two test flights, both of which involved perfect recovery of the booster.

### Fins

For the booster the fins are made from .06in carbon fiber. For both aesthetic and aerodynamic purposes they are the same shape as the dart fins but scaled to be much bigger. The root chord is 4.125in tapering to a tip chord of 2.063in with a span of 3.867in.

## Construction Techniques

This year's competition posed many unique challenges to construction due to the unique boosted dart design. This is the first 54mm motor, the smallest diameter, and the shortest rocket that Pioneer Rocketry has ever built.

A new construction technique, which we have we have named "in the wall" fins, In the wall fins are a combination of both surface mounted fins and Through the wall fins where there is a precision milled slot for a fin tab to extend into but does not extend through the tube wall.  The slot in the tube not only gives a guide to align the fin but also gives additional surface area for the epoxy to hold on to. This technique was used because of the unique design of this year's competition rocket and the inability to extend the fins through the darts body tube.

The booster section has through the wall fins with precision milled fin slots. Through the wall fins are where the fin extends through the wall of the bodytube and is epoxied onto the motor tube. The Through the Wall method of attaching fins epoxies the fins on two different surfaces making this a very robust construction method Laser cut fin guides were also used to ensure proper alignment of both sets of fins.

Also, new to the organization are severalmaterials, including carbon fiber airframe, carbon fiber fins, and various 3D printed components. Because of the added strength of the carbon fiber airframe and fins, we chose not to fiberglass over the fins.

When dealing with potentially harmful materials, all proper safety measures were observed. Material safety data sheets were available for all volatile materials and proper safety equipment such as glasses and respirators were utilized.

The laser cutter was extensively used during the construction of the rocket. Components made on the laser cutter include bulkheads, centering rings, electronics sleds, and a cradle to hold the dart in place during boost.

## Stability Analysis

Based on the open rocket model the stability margin for the combined booster and dart with an unburnt motor is 2.99. At the moment before ideal separation, which occurs at motor burnout, the combined rocket's stability margin will grow to 3.66. The center of gravity will move forward 3.2 inches to 22.7 inches from the tip of the rocket. As a combined entity the rocket is incredibly stable. After Separation the dart has a stability margin of 2.6. The separated booster has a stability margin of 0.5. While normally a rocket with a stability margin of 0.5 would raise concerns the fact that the rocket is already moving and stable at the point of separation mitigates these concerns. These claims can be supported through analysis of test flight video taken from the previous prototype dart. In that video you can see the booster trailing behind the dart perfectly stable.

Pioneer Rocketry competes in the annual WSGC competition, and conducts its own launch events at the University of Wisconsin-Platteville. It is because of the launches conducted on university land, that the team has a good understanding of the equipment and procedures necessary to reduce the chance of accidents involving property damage or bodily harm.

All flights at the University of Wisconsin-Platteville occur at Pioneer Farms, which is the university's agriculture-research and animal science center. Because of the location of the Platteville Municipal Airport near the farm and the size and altitude of the rockets being used, special waivers have been obtained from the FAA that allows these launch events to occur.

For various reasons (including both the size of the rockets being launched, flight altitudes, and the close proximity to which Pioneer Farms is located to the Platteville

Municipal Airport) special waivers of approval are required (and have been granted) by the FAA for these launch events to occur.

The team's launch controller was designed with both a key-operated arming switch along with two momentary switches; wired in series to minimize the likelihood of accidental launch events. The team's launchpad was built from steel coated in heat-resistant paint, and was designed as an angle-adjustable tripod (+/- 20 degrees) with a blast deflection plate and a six foot launch rail. In case of dry weather conditions, the option to blanket the launch area with commercially-purchased Nomex fabric is available as well.

Procedural checklist exists for both preflight and post flight operations, which are used for rocket assembly, launch, and recovery. Procedures involving volatile materials such as black powder, motors, and lithium-polymer batteries extend into safe storage through the use of fire-hazard storage lockers and PVC battery-bags. Several members of Pioneer Rocketry are certified in high-powered rocketry by the NAR, and attend all launch events as range safety officers (RSOs).

## Changes since Last Design Report

Since our last preliminary design report, we have had 2 separate test flights, both occurring at Richard Bong State Recreation Area, on April 25$^{th}$ and May 2$^{nd}$. Sadly neither of these test flights were entirely successful. On April 25$^{th}$, we used Vaseline to lubricate the separation point, and observed beautiful separation immediately after burnout. Due to the small size of our rocket, and our high altitude, we quickly lost sight of the dart, and were unable to locate it. On May 2$^{nd}$, we flew our identical rocket in the WSGC collegiate rocket competition. Similar to the last launch, we were unable to find the dart after the flight. However, we did manage to recover the tailcone, which holds the camera. Upon analyzing the video, we estimate our apogee to be around six thousand feet. Unfortunately, it is clear from our video that our parachute was ejected from the rocket ten seconds after apogee, resulting in the Kevlar cord snapping, and the rest of our dart continuing ballistically into the ground.

We have since constructed another rocket, trying to address the problems raised by these two test flights. We will be adding a GPS to our rocket, to aid us in locating it after the flight. We will also be using much stronger shock cord with five times the strength of the cord used in the test. Finally, we have reduced the size of the fins, to minimize drag caused by the fins. The dart is still very stable, with a stability margin of 2.6

## Rocket Operation Assessment

The flight profile of the rocket consists of 5 phases including boost, separation, coast, deployment, and recovery. The Vmax CTI I445 motor provides approximately 96 lbf of thrust over a 1.1 second burn duration. The short duration of the boost phase provides a rapid transfer of kinetic energy to the upper stage of the rocket, allowing for a quick transition from the boost phase to the separation phase of the flight. It is ideal for separation to occur immediately after the booster's propellant is expended, as the booster contributes nothing except additional drag after exhaustion.

The two stages of the rocket (booster and dart) are coupled together using a custom transition section built from birchwood and 3D printed PLA plastic. A friction-fit holds the two stages together until motor burnout is complete. Because the drag force applied to the booster section is greater than that applied to the dart, the booster section is "pulled away" and prepares for parachute deployment from a motor-timed ejection charge.

After separation, the dart continues towards apogee for a considerable length a time due to the amount of stored kinetic energy. Once reaching apogee, the Raven 3 altimeter triggers a deployment of the Dart's parachute. For the recovery phase, several ground teams are dispersed from the launch to triangulate an approximate landing position for the dart. This technique is used as a failsafe, in case contact is lost with the dart's BRB900 GPS telemetry system.

In launching the rocket, checklists are a useful tool. We have developed detailed pre and post flight checklists that will be used to ensure a safe launch and recovery. These checklists have served us well at previous launches, and we plan on using them at this launch as well.

## Test Flight Performance

The flight of Thunder and Lightning began as expected however due to a deployment failure all data besides the camera's video was lost. Because of this the data used in analyzing our flight is incomplete and error prone.

At the beginning of the flight, the rocket performed exactly as expected. During boost, the rocket held together rigidly and flew straight and true. Like our prediction, the dart separated from the booster at motor burnout.

After separation, both dart and booster coasted smoothly to apogee. The booster had a perfect motor ejection at 10 seconds and performed exactly as planned. The dart, however, did not perform quite as well. We found that through analyzing the video that the dart deployed its ejection charge 10 seconds after apogee. It is believed that our static ports were obstructed and that the internal pressure lagged behind the external pressure and caused a delayed detection of apogee. The shock of deploying the parachutes at high velocity caused a shock cord failure and resulted in the parachute and camera to separate from the rocket thus resulting in the loss of altimeter and rocket orientation data.

Having only the camera data at our disposal, a method of analyzing the rocket's flight had to be developed. By taking every tenth frame of our video and tracking the location of three landmarks in the video frame height and angle from vertical could be tracked over time. In figure 1 the altitude and angle from vertical are shown and plotted over time.

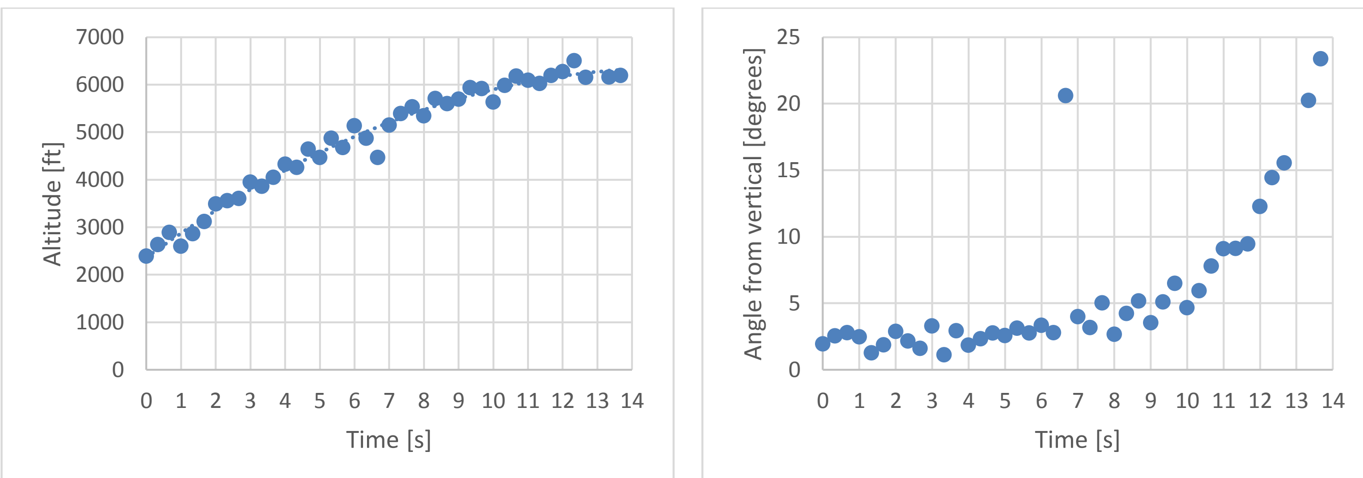


**Figure 4: Left- Altitude vs time. Right - Angle from vertical vs time. This time is from the initial frame analyzed and not motor ignition.**

From this data it can be seen that our rocket flew much higher than predicted reaching an apogee of around 6200ft. This is much different than our expected apogee of 5500ft. The main reason the difference can be attributed to the uncertainties present in the data collected by the camera. Many of the frames in the video had distortions due to the motion of the rocket as well as from the lens of the camera. While this explains some of the variation in the data it would not account for the additional 700ft of altitude over our predicted. It is believed that the models used by OpenRocket are ill suited for the prediction of drag on a rocket with a rounded tail and over estimates the drag on the dart. The prediction of 5500ft already included corrections for lesser drag but it appears as though it is even less than expected.

## Conclusion

Pioneer Rocketry has faced many challenges this year. After 4 failed launches, it would be easy for a team to give up, but Pioneer Rocketry persevered and kept on moving forward. Getting ready for the competition was not an easy feat, but Pioneer Rocketry excels under pressure. After learning from the previous mistakes, the team is confident in a successful launch at the Regional Competition.

This clubs member base is not small, and for this reason Pioneer Rocketry is modeled differently than most contenders in this year's competition. Their intent is to become more than just an isolated group of rocketeers, but rather to become an integral part of their University's selection of student organizations. It is hoped that over the coming years the team will expand its membership, build more rockets, conduct more launches, receive more High Powered Rocketry certifications, and lend credit to the use of aerospace applications as part of an undergraduate college curriculum.

The club is incredibly grateful for all the help offered by the Wisconsin Space Grant Consortium. Without the willingness for the University of Wisconsin-Platteville's Pioneer Farm, there would never have been a chance to get as many test launches before the competition. Finally, the club would also like to thank the Minnesota Space Grant Consortium for hosting this event.

Ad Astra!

**Special thanks to of our friends:**
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Todd Kemnitzer
Dedicated Friends and Family alike

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# Appendices

## Appendix I: Budget

Prior to the building of the competition rocket it was anticipated that we would only build one rocket for the season. We however built one non-competition rocket five dart sections, and three booster sections.

| Item Purchased | Company Purchased From | Unit Price | Quantity | Shipping/Tax/ Discount | Total Price | Total Price for Order |
|---|---|---|---|---|---|---|
| Multipurpose Garolite 1/8" Thick, 12" x 12" | McMaster-CARR | $ 19.36 | 1 | $7.44 | $ 26.80 | |
| Multipurpose Garolite 1/16" Thick, 12" x 12" | | $ 9.98 | 1 | $ - | $ 9.98 | $ 36.78 |
| HD Wing Camera 1280x720p 30fps 5MP CMOS | Hobby King | $ 38.84 | 1 | $9.99 | $ 48.83 | $ 48.83 |
| SparkFun microSD Trans flash Breakout | SparkFun | $ 9.95 | 1 | $ 4.01 | $ 13.96 | |
| SparkFun 9 Degrees of Freedom IMU Breakout-LSM9DS0 | | $ 29.95 | 1 | $ - | $ 29.95 | $ 43.91 |
| 3"x48" Carbon Fiber Airframe | Caroline Composites Rocketry | $ 180.00 | 1 | $ - | $ 180.00 | |
| 38mm x 48" Carbon Fiber Airframe | | $ 100.00 | 1 | $ - | $ 100.00 | $ 280.00 |
| Hatchbox 1.75mm Orange PLA 3D Printer Filament - 1kg Spool | Amazon | $ 23.98 | 1 | $ 7.24 | $ 31.22 | $ 31.22 |
| 54mm Blue Tube | Apogee Rockets | $ 23.95 | 1 | $ 12.34 | $ 36.29 | |
| AeroPack 54mm Retainer Body - L | | $ 17.12 | 1 | $ - | $ 17.12 | |
| Aero Pack 54mm Retainer Cap | | $ 17.12 | 1 | $ - | $ 17.12 | |
| Standard Rail Buttons (1" Rail) | | $ 3.07 | 2 | $ - | $ 6.14 | |
| Standard AirFoiled Rail Buttons | | $ 7.00 | 1 | $ - | $ 7.00 | $ 83.67 |
| Wood Filler | Heiser Ace Hardware | $ 5.99 | 1 | $ 0.33 | $ 6.32 | $ 6.32 |
| Raven 3 altimeter | Featherweight Altimeters | $ 155.00 | 1 | $ 10.00 | $ 165.00 | $ 165.00 |
| MicroBeacon | Apogee Components | $ 12.00 | 2 | $ - | $ 24.00 | |
| Pro-38 delay adjustment tool | | $ 15.89 | 1 | $ - | $ 15.89 | |
| 38 mm blue tube | | $ 16.49 | 2 | $ - | $ 32.98 | |
| 75mm blue tube | | $ 29.95 | 1 | $ - | $ 29.95 | |
| Pro-54 delay adjustment tool | | $ 29.37 | 1 | $ 19.66 | $ 49.03 | $ 151.85 |
| Camera, A-Cam | Hobby King | $ 38.00 | 2 | | $ 76.00 | |
| Lipo battery (Item 59370) | | $ 3.30 | 3 | $ 10.93 | $ 20.83 | $ 96.83 |
| 24" spherachute for rocket. | Spherachute | $ 22.50 | 2 | $ 7.00 | $ 52.00 | $ 52.00 |
| I455 Rocket Motor | Wildman Hobbies | $ 52.99 | 2 | $ - | $ 105.98 | $ 105.98 |
| Carbon Fiber Plate (Plate-Twill-Gloss/Matte-12x24x0.06 inch | RockWest Composites | $ 65.99 | 1 | $ - | $ 65.99 | $ 65.99 |
| Threaded Rods | MCS Industrial Supply Co. | $ 1.43 | 3 | $ - | $ 4.29 | $ 4.29 |
| Kevlar Cord 300# | Apogee Rockets | $ 24.50 | 1 | $ - | $ 24.50 | |
| Nylon Shear Pins - 20 Pack | | $ 2.95 | 3 | $ - | $ 8.85 | |
| Standard Airfoiled Rail Buttons | | $ 7.00 | 1 | $ - | $ 7.00 | |
| AeroPack 54mm Retainer Body - L | | $ 17.12 | 2 | $ - | $ 34.24 | |
| AeroPack 54mm Retainer Cap | | $ 17.12 | 2 | $ 8.04 | $ 42.28 | $ 116.87 |
| | | | | | Total Cost | $1,289.54 |

# Appendix II: Construction Photographs


Figure 6: Milling the fin slots on the booster

Figure 7: Laser cutting the GRAIL Dart Retention System


Figure 5: Test fit of the fins before epoxying

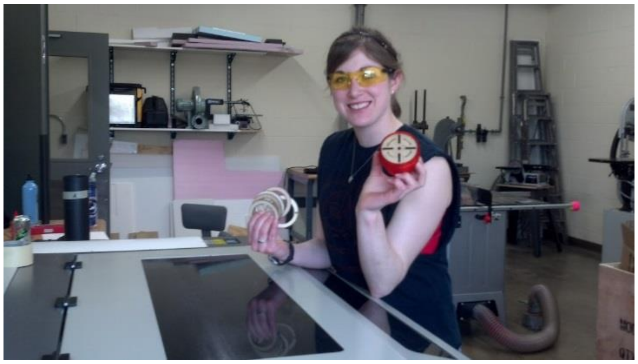

Figure 8: Maria with the completed GRAIL Dart Retention System

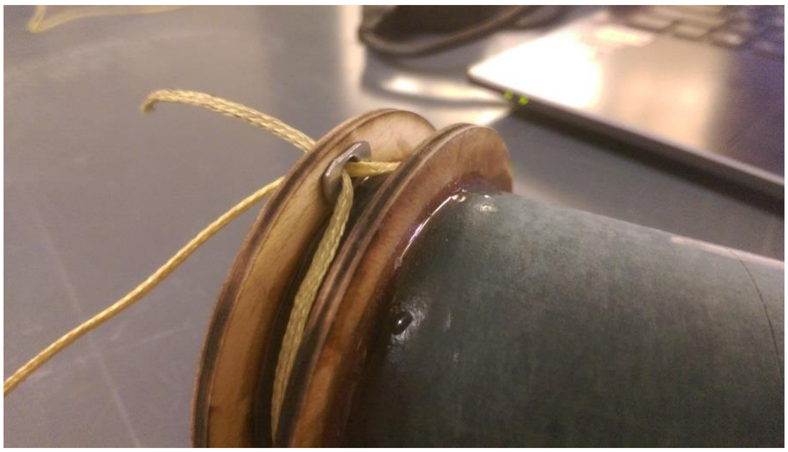

Figure 9: Attaching the shock cord to the booster

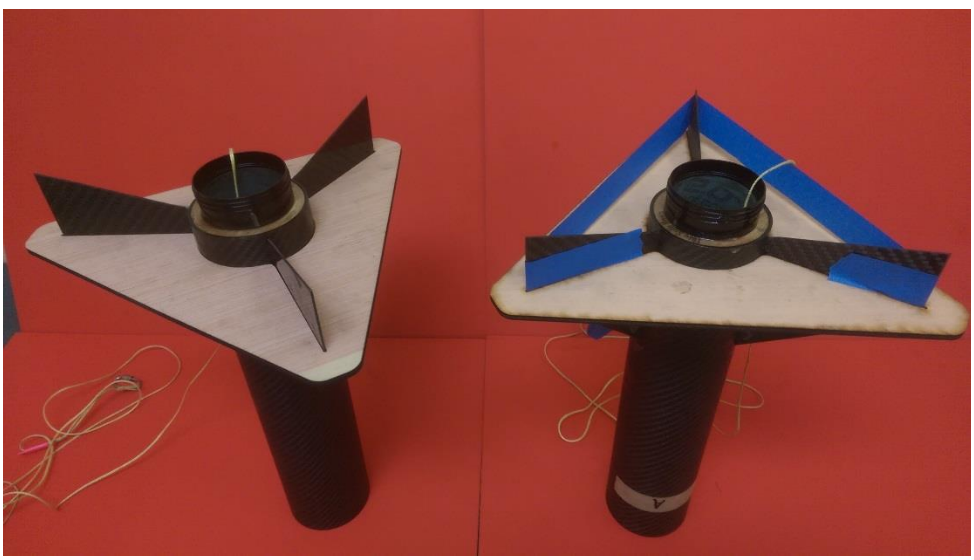

Figure 10: Fins being epoxied into place

**Figure 11: Original dart's fillets**

**Figure 12: Christina, Adrian, and Jake standing next to the completed rocket on the launch pad**

Figure 14: Rocket completed and ready for painting

Figure 13: Rocket completed and ready for painting