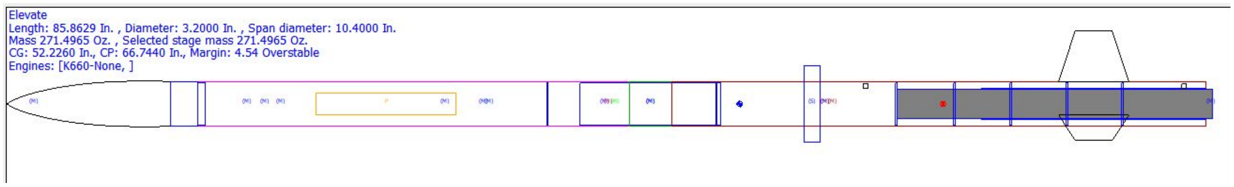
# S.O.A.R.

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# Abstract

The goals of S.O.A.R (Senior Organization for Amature Rocketry) are to launch a rocket to an elevation above 8,000 feet, relative to the ground, and return a payload to designated coordinates. The payload will be delivered using a steerable parachute attached to the nosecone, which will contain the payload. The nosecone will be made of fiberglass, with a bracket to hold the payload. The fin design has changed from the original and will be made of fiberglass. The fins have been designed to balance the center of pressure of the rocket, reduce drag force and for ease of manufacturing. The fins have been changed from an asymmetric to a symmetric design. The fuselage design has remained unchanged, while the mandrel design has undergone a few iterations and is now manufactured. The electronics for the rocket include an altimeter and GPS. A few modifications were made to the electronics bay during manufacturing to address issues that came up during our test flights. A level two certification has been obtained to allow us to launch the rocket. Tests have been carried out with the electronics and steerable parachute system, with success. Manufacturing of the final rocket was underway, with assembly and testing to be completed before the competition on March 28th, 2020. Final testing of the ejection system was to be conducted to ensure proper ejection of the guided parachute and main parachute. Our budget had been reached, with a few expenses left to cover. Travel, lodging and a possible second motor for the competition had not been covered.

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# Introduction

The team goals of S.O.A.R remain unchanged from last semester; build a rocket to launch in the Argonia Cup competition in Argonia, Kansas. In order to win the competition, the rocket must reach a minimum altitude of 8,000 feet and be capable of landing a payload close to designated GPS coordinates. S.O.A.R. plans to achieve this by using a prototype steerable parachute to guide the payload during descent. The Elevate rocket's design consists of three main sections; the nose cone, the fins, and the fuselage.

Minimal design changes were made to the original design for the nosecone. The nosecone will still utilize a Von Karman shape profile that was determined to be the most effective. The main nosecone component will be created from 7781 E-glass fiberglass laid up on a mold made from MDF, with a tip made of aluminum, 3D printed material, or additional fiberglass (whichever will be the most cost and time effective), and an aluminum bracket that will secure the payload to the blast plate throughout flight and descent. Material was removed from the original bracket design and the nose cone tip was altered from a threaded piece to a two-part plug/jack connection. A second design was created for the blast plate assembly to give the team options. This second design is based on a friction fit of the blast plate in the shoulder section of the nosecone achieved by compressing rubber between two fiberglass reinforced wood plates. The design also features a 3D printed payload housing that will attach to the blast plate and carry the payload safely inside the nosecone.

The fins have undergone significant design changes in the last few months. The dimensions of the fins, including the root chord length, tip chord length, sweep length, sweep angle, span length, and thickness, have all been increased. The material of the fins has been altered from fiberglass layups with hardwood cores, to G10 Garolite fiberglass, as machining of the hardwood proved to be ineffectual. The strategy for attaching the fins to the fuselage has been altered as well to Through the Wall mounting, as opposed to exterior mounting. A fin alignment device has been designed to ensure the fins attach to the fuselage as straight as possible.

The fuselage will still be formed from wound carbon fiber to minimize skin drag and weight. The fuselage will be made in three sections: the upper fuselage, the electronics bay, and the lower fuselage. The upper fuselage will contain our main parachute and experimental Steerable parachute, which will be anchored to the nose cone and payload to land separately from the rest of the rocket. The electronics bay will contain the GPS tracker, the Altimeter, and the Accelerometer. These will provide critical analytical data to determine if the goals were met, as well as let us find the rocket after it lands. The lower fuselage will contain the streamer, and most importantly, the rocket's engine. A major consideration for the fuselage was the design of a mandrel on which to wind the carbon fiber. The mandrel must be made in such a way that the finished fuselage component can easily be removed from it. The design consists of 6 sections of aluminum running the length of the mandrel that will be attached together using hexagonal plugs.Three plugs were made for the mandrel. Two of the plugs will have six holes for the mandrel to screw into at each end. The third plug will be placed in the middle of the mandrel to act as support through the winding process. An electronics bay was created and tested as well. The electronics are attached to a thin piece of plywood and include an easy mini altimeter, a GPS tracker, and two batteries for the ejection charges. Calculations were made to determine the amount of black powder necessary to successfully eject the parachutes.

# Nosecone

The nosecone design remains largely unchanged. The payload will still be housed in the shoulder of the nosecone, and the two will descend together while being controlled with a steerable parachute. The previous nosecone design featured a threaded nosecone tip, and a bracket that would secure the payload to the blast plate, with an eye bolt feature that the parachute would attach to.

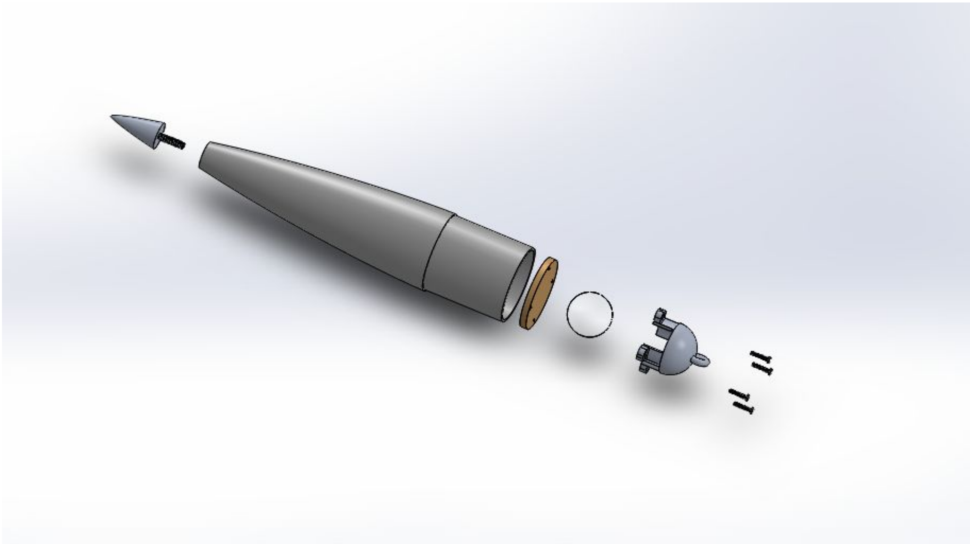


***Figure 1:*** *Exploded view of the previous nosecone design assembly*

The new design features changes to the nosecone tip, and alterations to the payload bracket.

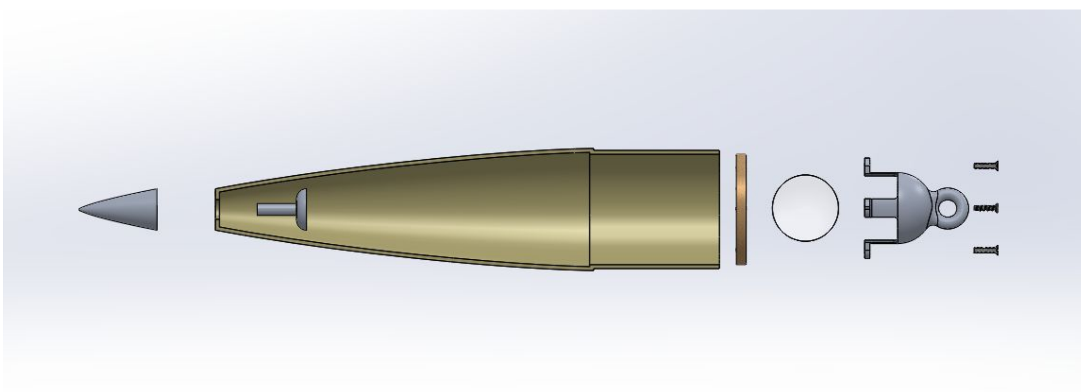


***Figure 2:*** *Exploded view of the nosecone design assembly*

The new nosecone tip will consist of an exterior tip with a 0.3 inch diameter hole drilled out of the flat section on the bottom of the tip. A separate interior component will be used to attach the exterior tip to the fiberglass. The interior component consists of a 0.3

inch diameter rod protruding from a flange. Epoxy will be used to adhere the rod into the hole of the exterior tip, and the flange to the inside of the nosecone. The rod provides extra surface area with which to make a strong adhesion. The flange will hold the tip secure to the fiberglass.

The general design of the payload bracket remains unchanged. It consists of a housing in which the payload will sit, legs with protrusions on the bottom that will be screwed to the blast plate, and an eye bolt attachment feature to connect to the parachute. This bracket will carry the full load produced by the nosecone and its components throughout descent. The previous design was a substantial piece of aluminum that yielded a safety factor pushing 400,000. Material was removed in the new design until a reasonable safety factor was found, while still maintaining enough substance to prevent potential complications during the casting process. The new part was created in Solidworks and stress analysis was performed based on previous calculations regarding the expected forces.

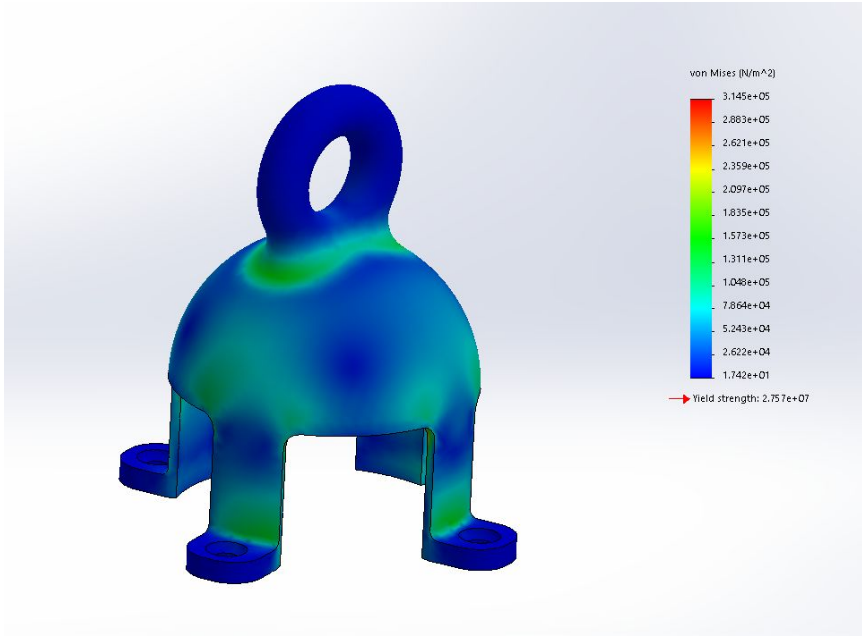



***Figure 3:*** *Stress analysis of the new payload bracket design*

Analysis yielded a safety factor of 87.66. The benefits of material removal was a reduction of weight and lower material costs of aluminum and the PLA for the mold. Two brackets will be made in order to perform testing. The molds for the cast were 3D printed out of PLA filament.

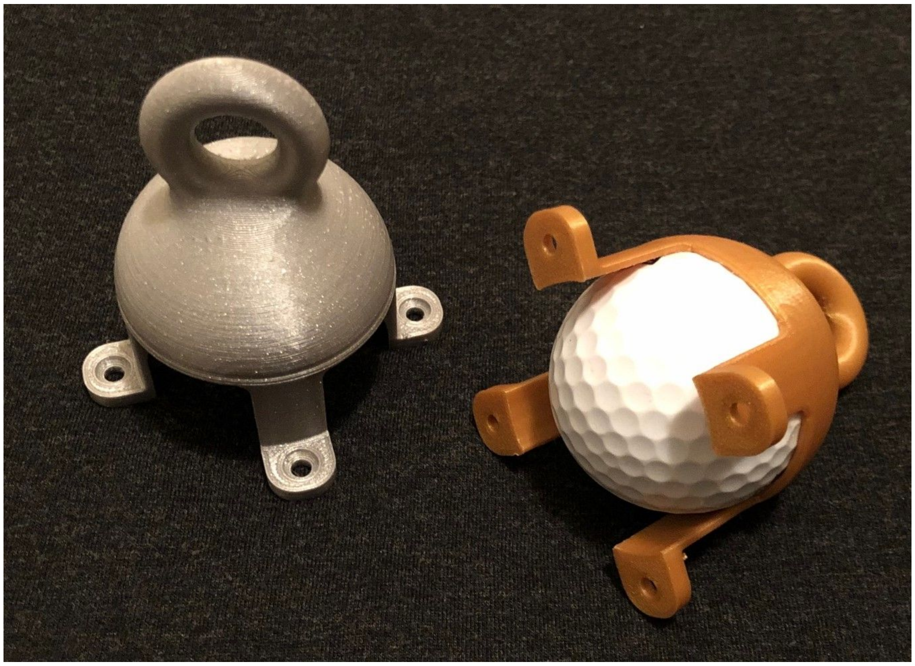


***Figure 4:*** *3D printed payload bracket molds*

Another completely separate design was created for the interior components of the nosecone based on a blast plate utilizing a compression fit.

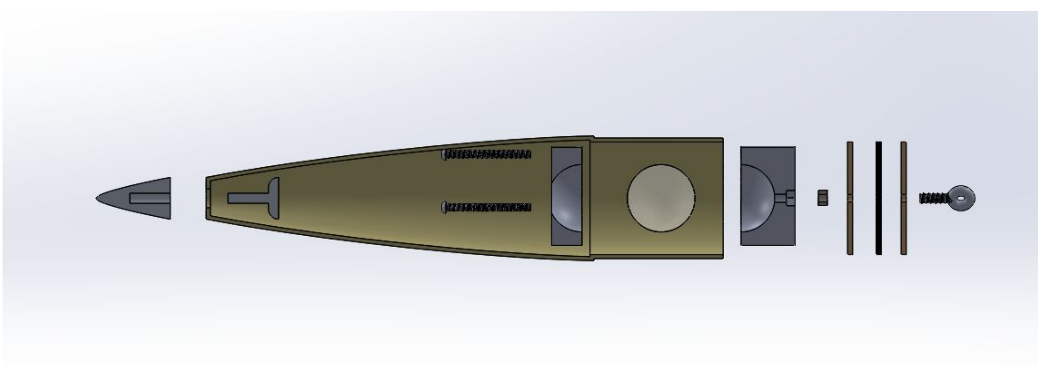


***Figure 5:*** *Exploded view of the second nosecone design assembly*

This design will also be created and a team decision will be made regarding which one to use in the launch. This design features a 3D printed payload holder that will attach to the back of the blast plate and thus house the payload inside the nosecone to protect it from the black powder charge. The payload holder is two parts that will be held together by screws fed through holes running down the length of the holder. When the screws are tightened into the blast plate, the holder will be pressed together, tightly securing the payload to prevent movement and vibration of the payload throughout flight and descent. The section of the payload holder against the blast plate features a hole and an extruded feature to fit the nut for the eyebolt. The payload will be kept off the blast plate to make room for the eyebolt. When the payload holder is attached to the blast plate, the nut will sit tight in the bottom of the holder to prevent spinning while tightening the eyebolt. A benefit of this design is that no load will be acting on the payload or payload holder. This makes it possible to 3D print the part using cheaper PLA filament with little worry of failure.

***Figure 6:*** *Inside view of the two payload holder components*

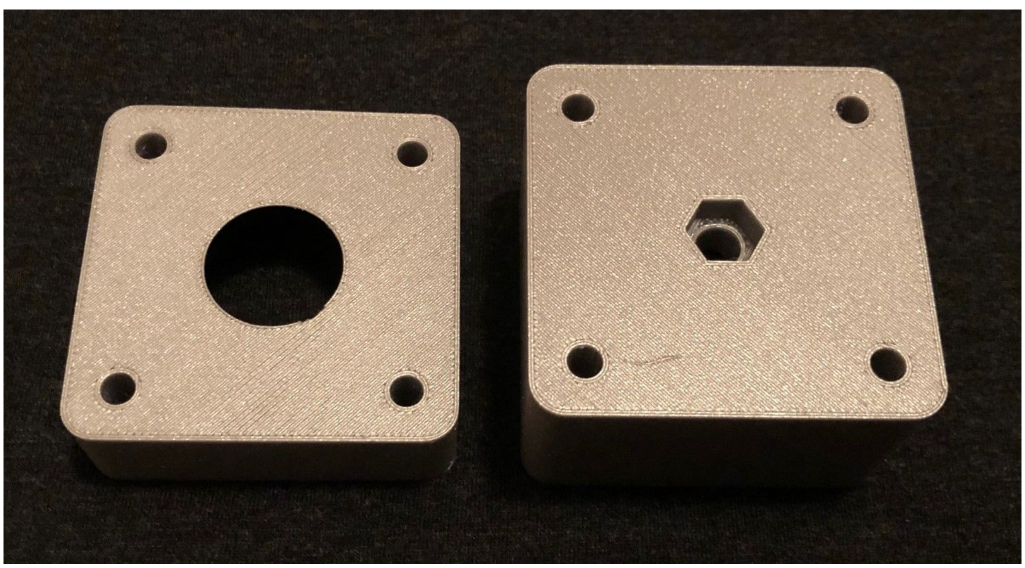


***Figure 7:*** *Top and bottom view of the two payload holder components*

The eyebolt in this design will run through two pieces of thin, fiberglass-reinforced balsa wood, and into the nut secured in the bottom of the holder. Sandwiched between the two plates will be a piece of yet undetermined rubber material. When the eyebolt is tightened into the payload holder, the two plates will compress the rubber and produce a tight friction fit to the inside of the nosecone. The parachute will attach to the eyebolt in the same manner as the other design.

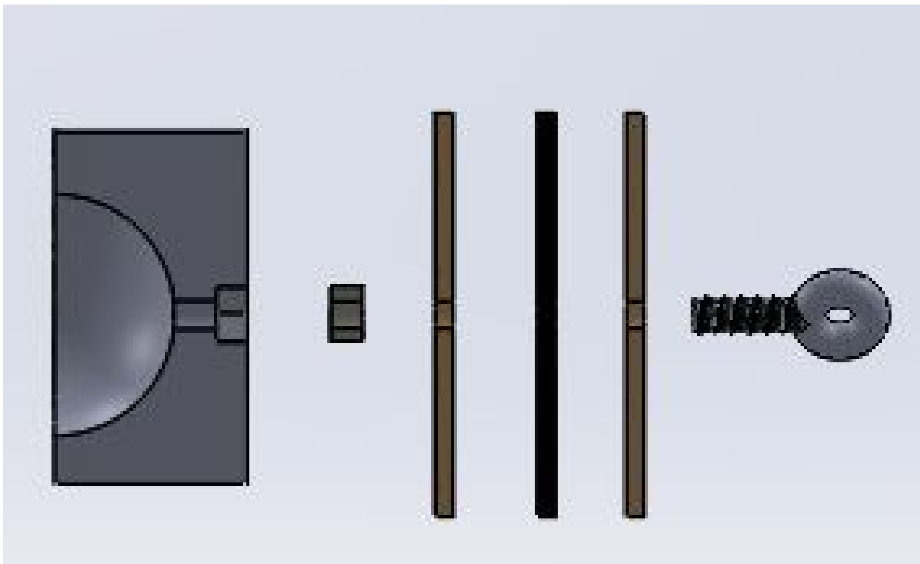


***Figure 8:*** *Close-up view of the blast plate attachment assembly*

The fit will be tested using simple exercise equipment attached to the eyebolt. Once the main fiberglass nose cone is created, the assembly will be fitted to the shoulder. A pulley exercise machine will be attached to the eyebolt with a carabiner. It was already calculated that the largest force the blast plate will experience is a 6.04 lbf. created by the ejection charge. By using a pulley machine, the weight can be adjusted to test the friction fit and blast plate assembly at different forces.

Another important aspect of the nosecone is the parachute. The steerable parachute will attach to the nosecone and the entire nose cone assembly will accompany the payload throughout descent. The parachute was tested during a launch to determine its effectiveness for competition. The parachute was deployed at an altitude of 1,250 feet and was able to land the nosecone 50 yards from the GPS coordinates. The test proved to be an overwhelming success.

The main fiberglass nosecone component will still be made using 7781 E-glass fiberglass, and utilize the Von Karman profile. The mold for the nosecone was crafted from 3 separate 0.75 inch MDF boards that were glued together. The shape was carved out of the MDF using a CNC router. A 0.5 inch flat end mill was used to clear a majority of the material in an adaptive clearing process. A 0.5 inch ball end mill was used to finish the part using parallel passes. Ideally, a smaller step size would have been chosen for the parallel passes to finish the part. Once the mold was routed, a series of sanding took place. 80-grit sand paper was used to clear the material left from the finishing passes, 200-grit was used until smooth, followed by a coat of sanding sealer. A few more cycles of 200-grit sanding and sealing took place. The part will be sanded once more while increasing the grits from 200 to 1,000. The fiberglass will then be laid in the mold and the nosecone assembled.

# Fins

The previous fin design was an asymmetrical design made with a quarter inch thick hardwood core with fiberglass laid up on top for increased strength. Machining the maple hardwood into the desired shape was found to be ineffectual. This circumstance caused a change in material to something easier to work, namely G10 Garolite Fiberglass. The new fin design is symmetrical with a 3.6 inch span, 5 inch root chord, 2.652 inch tip chord, and an 18.3 degree sweep angle. The taper on the airfoil edges has changed from 7 degrees to 8 degrees. The fin will also have a 0.6 inch root that will attach to the motor tube and can be cut down for an ideal attachment length. The G10 fiberglass sheets provided by Apogee Components are 0.125 inch  thick. The change in material allowed us to maintain strength while lowering the thickness, creating a more stable profile for the rocket.

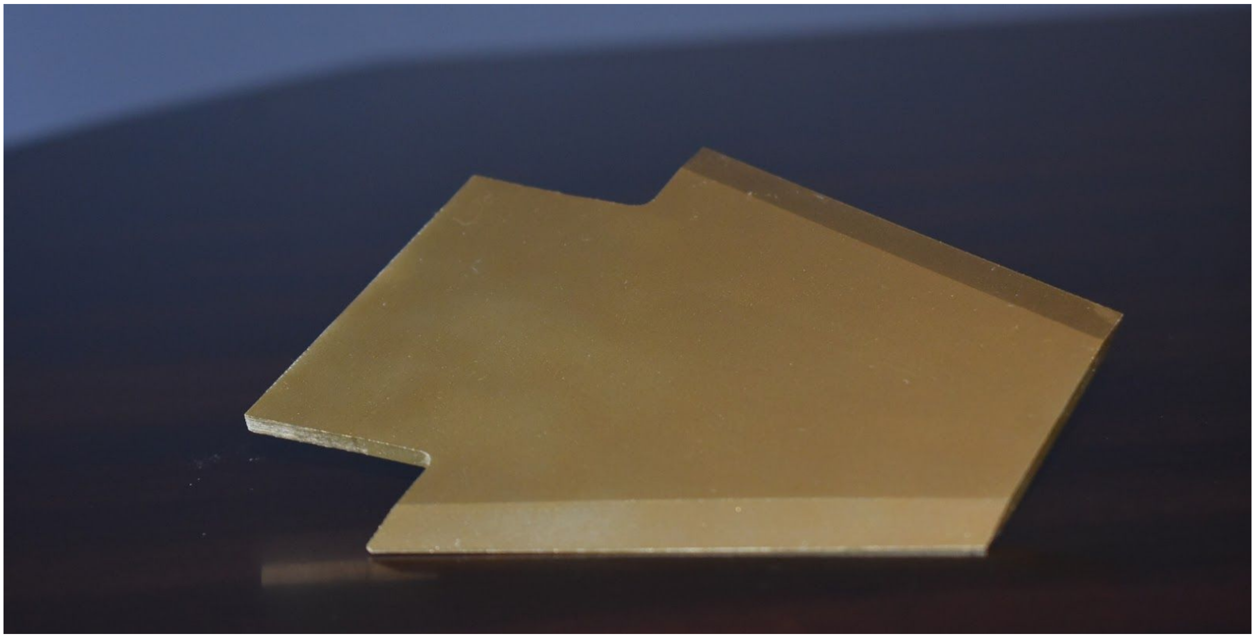


***Figure 9:*** *Completed Fin*

Due to the rocket no longer being minimum diameter, a different method will be used to attach the fins to the body of the rocket called Through The Wall mounting. Two 0.125 inch holes will be drilled into the body of the rocket on each side of the fin for access to the connection between the motor mount tube and the fin. The fin will be slid into the slits in the body and will make contact with the motor mount tube. Epoxy will be injected into each of the holes to create a fillet between the fin and the motor mount. This process will be performed on each side of each of the fins and set to dry. Once the fillets are finished on the inside of the rocket, outer fillets of epoxy will be applied between the fin and the outer body of the rocket and left to dry.

When the fins are first placed into the rocket after the roots have been cut down to size, an aligner will be placed over the top of the rocket body. This aligner will ensure that none of the fins become secured to the motor tube at an angle that would compromise the stability of the flight. This aligner will be machined with the TM2. It will be made of aluminum that is an eighth inch thick. Two identical pieces will be made and bolted together with spacers to hold each side in place.

To machine the fiberglass using the Haas TM-2, an adaptive clearing operation was first used to cut the general shape into the fiberglass with a quarter inch flat end mill, later being refined with a parallel operation on both airfoil surfaces with an eighth inch ball end mill. After these three operations are completed, the part would be flipped in the machine to create a matching profile on the other side. Once all operations are complete, a contour cut will cut out the shape with a quarter inch flat end mill. The first attempt to create the fins resulted in the adaptive clearing cut pushing too deep into the material, causing the first pass on the other side of the part to carve through the fiberglass and ruin the part. Upon inspection, all pieces showed the same defect from the adaptive clearing, meaning they were ruined as well.

For the next attempt, the adaptive clearing cut was removed. This left us with the two parallel cuts and the single contour cut. The fins were flipped after both parallel operations were done to ensure symmetry. The fins were then cut from the blank with a bandsaw, sanded along the edges with 80-grit sandpaper, and painted gold.

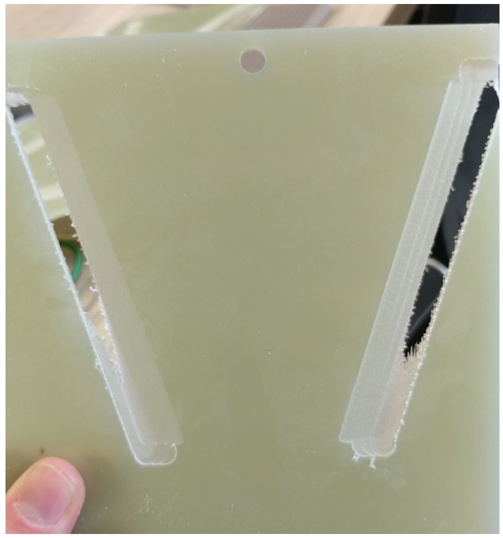


***Figure 10:*** *First Attempt at Fin Manufacturing*

***Figure 11:*** *Second Attempt: Before Removal From Blank*

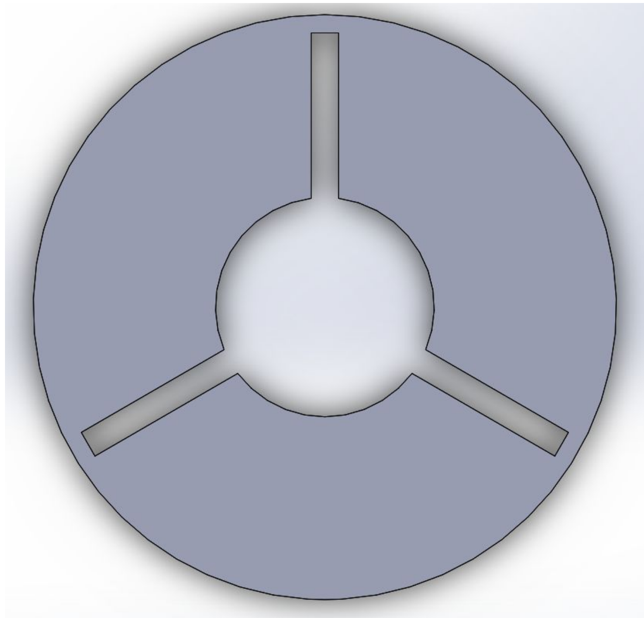


***Figure 12:*** *Draft of Fin Alignment Apparatus*

# Fuselage

The design of the fuselage has stayed consistent and has begun the manufacturing process. The first step in manufacturing was to design the mandrel in Solidworks. The mandrel was initially designed to be three separate body pieces that came together with two plugs that the body pieces screwed into. Due to the ease of manufacturing, this was changed to have six separate body pieces having four identical side pieces and a top and bottom piece that has a different edge angle from the side pieces. This is because when unscrewing, the top and bottom pieces can collapse from the side pieces due to the angle, which will allow for the side pieces to collapse and be able to be removed from the carbon fiber body. The mandrel was machined using the TM2 mill. Each piece had to be machined separately. There are three plugs to the mandrel that were also machined in the same manor. Two of the plugs will have six holes for the mandrel to screw into at each end. The third plug is used for a support in the middle to bear the forces of the X-Winder machine.

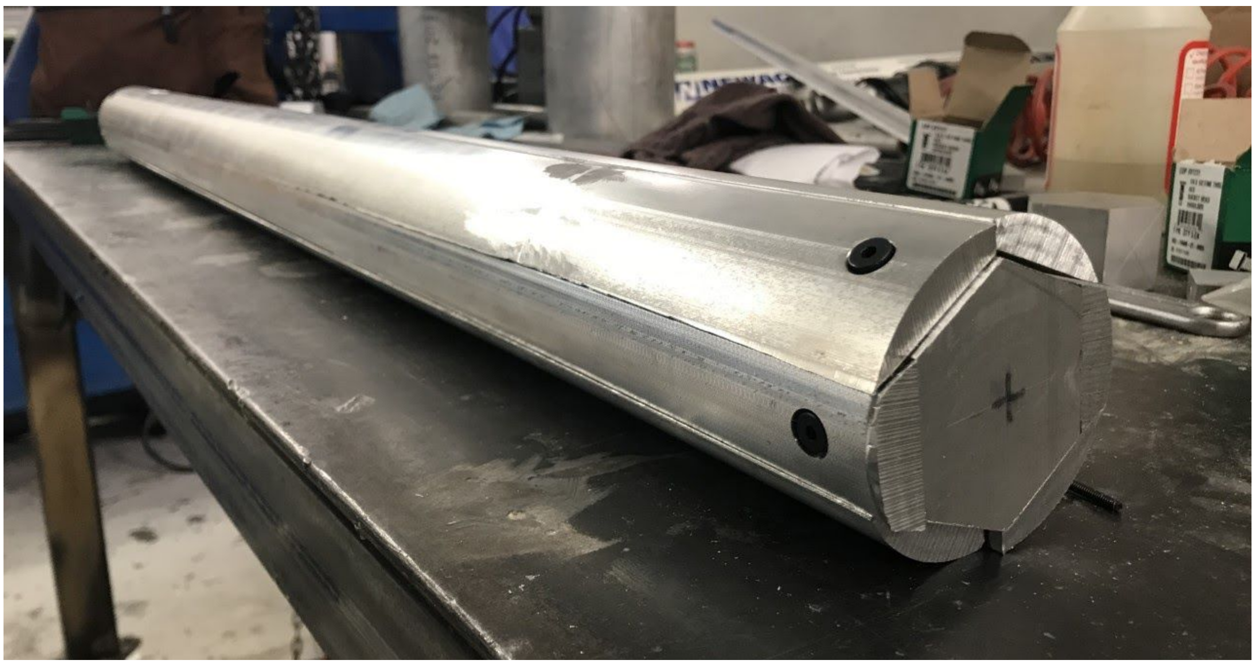


***Figure 13:*** *Assembled Mandrel*

The X-Winder will be used to create a filament wound tube for the fuselage. Carbon fiber will be wound at a 45 degree angle to create the aft and forward sections. The 45 degree angle will be used, as low angles have created problems with manufacturing in the past. Two to three layers of carbon fiber will be applied to give us the wall thickness we desire of 0.05 inches. A small section will be made as a test to find the number of layers required to achieve this thickness. Some sanding may be done to the nose cone or fuselage to create a smooth transition between the two pieces. This will give us an outer diameter of approximately 3.1 inches, with an inner diameter of 3.0 inches. The wound fuselage will be wrapped with a heat-shrink tape, which will then be heated with a heat gun to compress the layers while the resin cures. The aft section will be created first to allow assembly of the fins and motor housing while the forward section is made.

The coupler will still be made out of fiberglass, to allow the radio signals to penetrate. The electronics bay was manufactured out of plywood. The electronics sit on one side of the plywood. This includes, an easy mini altimeter, a GPS tracker, and two batteries for the ejection charges. The design of the bay was made to slide in and out using end bulkheads and long all thread pieces to stay in place inside of the coupler. A similar design was used in our L1 and L2 certification rocket, which had acceptable results.

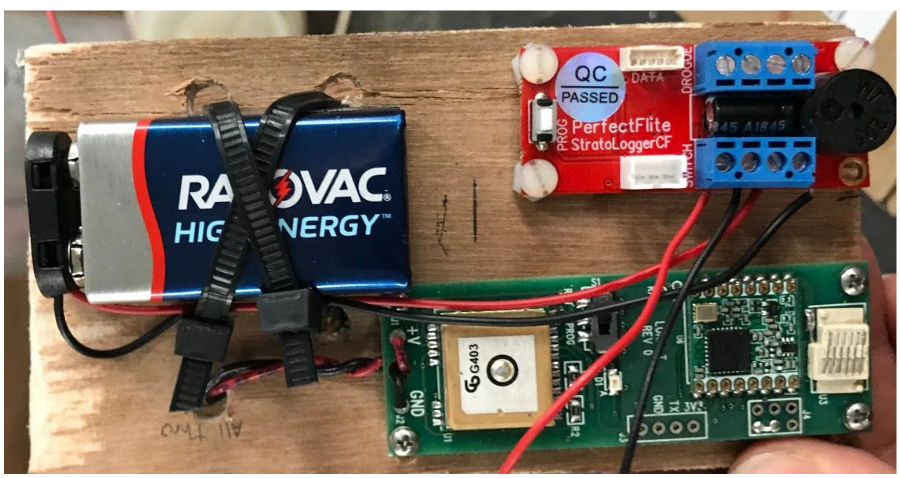



***Figure 14:*** *Electronics Bay Configuration*

There will be two ejection charges. One in the lower airframe and one in the upper airframe. A black powder charge is the most common and reliable method for ejecting a parachute from a rocket. The ejection charge will ignite and generate hot gasses that pressurize the rocket's airframe and exert a net force on the bulkhead of the nose cone. This net force will eject the nose cone, the steerable parachute, shock cord, and main parachute out of the rocket airframe. And the drogue chute out of the lower airframe. This will all happen because the rocket is obeying the Ideal Gas Law. The Ideal Gas Law is the equation for a hypothetical ideal gas. The state of the amount of gas is determined by its pressure, volume, and temperature.

$$Pressure: P = \frac{F}{A} \quad [psi] \qquad\qquad Volume: V = \frac{\pi}{4} D^2 L \quad [in^3]$$

$$Black\ Powder: N = \frac{P * V}{266 \frac{lbf}{lbm} * 3307°R} \left( \frac{454\ grams}{1\ lbf} \right) \quad [grams]$$

***Figure 15:*** *Equations Used to Calculate Black Powder Ejection Charges*

The modern form of this equation is where P is the absolute pressure of the gas, V is the volume occupied by the gas, N is the amount of substance ( in this case the amount of black powder), R is the gas constant, and T is the absolute temperature. The equation can be reordered to solve for N directly shown above (Cavender). The above equation was used to determine the amount of black powder that was needed in both the upper and lower airframe ejection charges. The results are shown below.

| Upper Airframe | | | | | |
|---|---|---|---|---|---|
| L = | 30.75 | in | **Calculations** | | |
| D = | 3.1 | in | P = | 39.7473323 | psi |
| A = | 7.54767635 | $in^2$ | V = | 232.091048 | $in^3$ |
| Force on Shear Pin = | 50 | lbf | Black Powder in grams = | | 4.76109006 |
| 3 Shear Pins = | 150 | lbf | | | |
| F = | 300 | lbf | | | |

| Lower Airframe | | | | | |
|---|---|---|---|---|---|
| L = | 38.125 | in | **Calculations** | | |
| D = | 3.1 | in | P = | 39.7473323 | psi |
| A = | 7.54767635 | $in^2$ | V = | 287.755161 | $in^3$ |
| Force on Shear Pin = | 50 | lbf | Black Powder in grams = | | 5.90297751 |
| 3 Shear Pins = | 150 | lbf | | | |
| F = | 300 | lbf | | | |

***Table 1:*** *Calculations for Grams of Black Powder Required for Ejection Charges*

The force calculation is dependent on the force it takes to break the shear pins used to hold together each airframe. The shear pins used in this rocket have a maximum shear force of 50 pounds. We will have three shear pins for each section of the body, which is a total of 150 pounds of force on the shear pins. We doubled that value to ensure breakage of the pins, which is the force used to calculate the amount of black powder amount. The results show that the lower airframe will need about 6 grams of black powder and the upper airframe will need about 4.8 grams of black powder. This will be ground tested multiple times to ensure the results needed, which is for all the components inside the airframes to eject.

A retaining cap will be manufactured to hold the motor casing in place. This cap will prevent the motor casing from moving fore or aft in relation to the motor tube and provide an easy way to secure and remove the motor casing. Using a friction fit on a motor of this size may not keep the motor in place and could make it difficult to remove the motor after recovery. The retaining cap will be made in two pieces from aluminum. The inner piece will be adhered to the motor tube with epoxy and will have threads on the outer surface. The outer cap will have threads on the inside surface and screw on to the inner cap, to hold the motor casing in place. The motor casing is made with a flange at the base, and this flange will be held in place by the retaining cap.

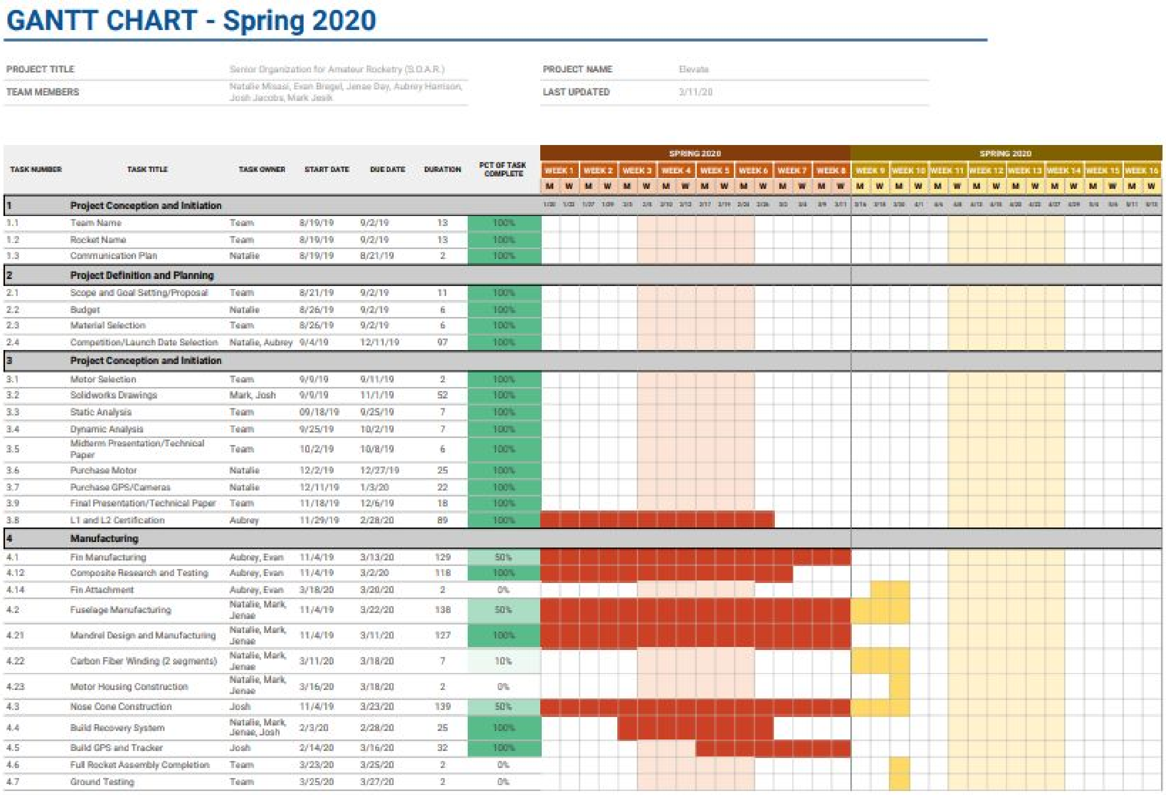
# Conclusion

In order to reach the goal of launching a payload and landing it as close to GPS coordinates as possible, changes had to be made to each component of the rocket. The design of the nosecone remained largely unchanged, however the design for the component that holds the payload was modified and is still to be determined. Test pieces for each holder have been manufactured. A mold for the nosecone is also in the final processes of being manufactured. For the fin portion of the design, many changes were made in order to improve the design. The size was modified slightly in order to maintain stability. The material of the fins was also changed due to there being increased strength of a new and thinner material than the previous design. A first attempt at manufacturing the fins has been made, however there have been issues of cutting through the fiberglass during manufacturing. Changes have been made to the program and the fins have been manufactured correctly. The fuselage of the rocket has maintained its original design. Progress has been made on the manufacturing of the mandrel, and the final steps that need to be taken are simply winding the carbon fiber filament on the Xwinder around the mandrel part.

# References

Cavender, Daniel. “How To: Size Ejection Charges .” *How To Articles*, HARA Rocketry, 2016, hararocketry.org/hara/wp-content/uploads/2014/05/How_To_Size_Ejection_Charges.pdf.

# Appendices




| TASK NUMBER | TASK TITLE | TASK OWNER | START DATE | DUE DATE | DURATION | PCT OF TASK COMPLETE |
|---|---|---|---|---|---|---|
| **1** | **Project Conception and Initiation** | | | | | |
| 1.1 | Team Name | Team | 8/19/19 | 9/2/19 | 13 | 100% |
| 1.2 | Rocket Name | Team | 8/19/19 | 9/2/19 | 13 | 100% |
| 1.3 | Communication Plan | Natalie | 8/19/19 | 8/21/19 | 2 | 100% |
| **2** | **Project Definition and Planning** | | | | | |
| 2.1 | Scope and Goal Setting/Proposal | Team | 8/21/19 | 9/2/19 | 11 | 100% |
| 2.2 | Budget | Natalie | 8/26/19 | 9/2/19 | 6 | 100% |
| 2.3 | Material Selection | Team | 8/26/19 | 9/2/19 | 6 | 100% |
| 2.4 | Competition/Launch Date Selection | Natalie, Aubrey | 9/4/19 | 12/11/19 | 97 | 100% |
| **3** | **Project Conception and Initiation** | | | | | |
| 3.1 | Motor Selection | Team | 9/9/19 | 9/11/19 | 2 | 100% |
| 3.2 | Solidworks Drawings | Mark, Josh | 9/9/19 | 11/1/19 | 52 | 100% |
| 3.3 | Static Analysis | Team | 09/18/19 | 9/25/19 | 7 | 100% |
| 3.4 | Dynamic Analysis | Team | 9/25/19 | 10/2/19 | 7 | 100% |
| 3.5 | Midterm Presentation/Technical Paper | Team | 10/2/19 | 10/8/19 | 6 | 100% |
| 3.6 | Purchase Motor | Natalie | 12/2/19 | 12/27/19 | 25 | 100% |
| 3.7 | Purchase GPS/Cameras | Natalie | 12/11/19 | 1/3/20 | 22 | 100% |
| 3.9 | Final Presentation/Technical Paper | Team | 11/18/19 | 12/6/19 | 18 | 100% |
| 3.8 | L1 and L2 Certification | Aubrey | 11/29/19 | 2/28/20 | 89 | 100% |
| **4** | **Manufacturing** | | | | | |
| 4.1 | Fin Manufacturing | Aubrey, Evan | 11/4/19 | 3/13/20 | 129 | 50% |
| 4.12 | Composite Research and Testing | Aubrey, Evan | 11/4/19 | 3/2/20 | 118 | 100% |
| 4.14 | Fin Attachment | Aubrey, Evan | 3/18/20 | 3/20/20 | 2 | 0% |
| 4.2 | Fuselage Manufacturing | Natalie, Mark, Jenae | 11/4/19 | 3/22/20 | 138 | 50% |
| 4.21 | Mandrel Design and Manufacturing | Natalie, Mark, Jenae | 11/4/19 | 3/11/20 | 127 | 100% |
| 4.22 | Carbon Fiber Winding (2 segments) | Natalie, Mark, Jenae | 3/11/20 | 3/18/20 | 7 | 10% |
| 4.23 | Motor Housing Construction | Natalie, Mark, Jenae | 3/16/20 | 3/18/20 | 2 | 0% |
| 4.3 | Nose Cone Construction | Josh | 11/4/19 | 3/23/20 | 139 | 50% |
| 4.4 | Build Recovery System | Natalie, Mark, Jenae, Josh | 2/3/20 | 2/28/20 | 25 | 100% |
| 4.5 | Build GPS and Tracker | Josh | 2/14/20 | 3/16/20 | 32 | 100% |
| 4.6 | Full Rocket Assembly Completion | Team | 3/23/20 | 3/25/20 | 2 | 0% |
| 4.7 | Ground Testing | Team | 3/25/20 | 3/27/20 | 2 | 0% |

***Figure 17:*** *Spring 2020 Gantt Chart*

| **Purchased Item** | **Cost** | | **Donated Items** | **From** | | **Future Purchases** | **Rough Cost** |
|---|---|---|---|---|---|---|---|
| Apogee: L1/L2 Rocket Kit | 124.3 | | Motor Casings | MotoJoe | | Parachute | 50 |
| Plasticare: Fiberglass/Epoxy + misc | 122.47 | | 6061 Aluminum | EMJ | | Eyebolts | 10 |
| Home Depot: Wood, Cleaner, etc. | 16.4 | | 6061 Aluminum | Doug | | Swivels | 5 |
| Amazon: Masks | 63.54 | | GPS System | Brian Houghton | | Fiberglass Coupler | 50 |
| Apogee: Engine and Camera Hood | $47.95 | | Motor Casings | John Jamieson | | Motor Retainer | 40 |
| Apogee Rivets + Bulkheads | 20.27 | | | | | Fiberglass Piston | 10 |
| Tripoli Memberships | 35 | | | | | Parachord | 40 |
| MotoJoe Motors | 253.01 | | | | | **Total** | **205** |
| Front Range Lumber | 23.62 | | | | | | |
| Home Depot: MDF, Threaded Rod | 12.73 | | | | | | |
| Home Depot: Ebay Material | 18.74 | | | | | | |
| Home Depot: Threaded Rods | 3.4 | | | | | | |
| Home Depot: Nuts + Bolts | 2.39 | | | | | | |
| Altus Metrum (Altimeter) | 86.78 | | | | | | |
| LOC Replacement Fin | 18.45 | | | | | | |
| LOC - Cert 2 Parachord | 16.72 | | | | | | |
| Amazon: Sandpaper | 14.87 | | | | | | |
| L1 2nd Flight Motor | $20.00 | | | | | | |
| MotoJoe Motor (I Motor + Parachute) | $57.48 | | | | | | |
| **Total:** | **958.12** | | | | | | |

***Table 2:*** *Summary of Purchases and Costs*