**Women in Aerospace**

**University of Illinois at Urbana-Champaign**


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## 1.1 Rocket Design

### *1.1.1 Overall Dimensional Specifications*

The total length of the rocket is 6.42 ft with an outer diameter of 4 in. It consists of a nose cone upper airframe section, coupler section, and booster section. The total weight of the rocket, including the full weight of the motor, is 19.5 lbs. The center of pressure is denoted by a red dot on Figure 1 and is located 5.03 ft from the tip of the nose cone, or 1.39 ft from the base. The center of gravity is denoted by a blue and white dot on Figure 1. It is located 4.20 ft from the tip of the nose cone, or 2.22 ft from the base before the motor has burned out. Once the motor burnout occurs, the center of gravity moves to 3.2 ft from the tip of the nose cone, or 2.5 ft from the base. A diagram showing the location of the center of gravity as the motor burns can be seen in Figure 2.

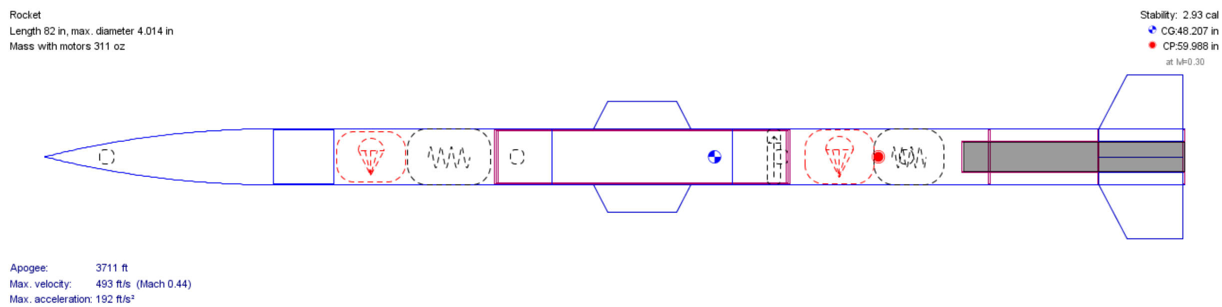


**Figure 1. Diagram of rocket before motor burnout.**

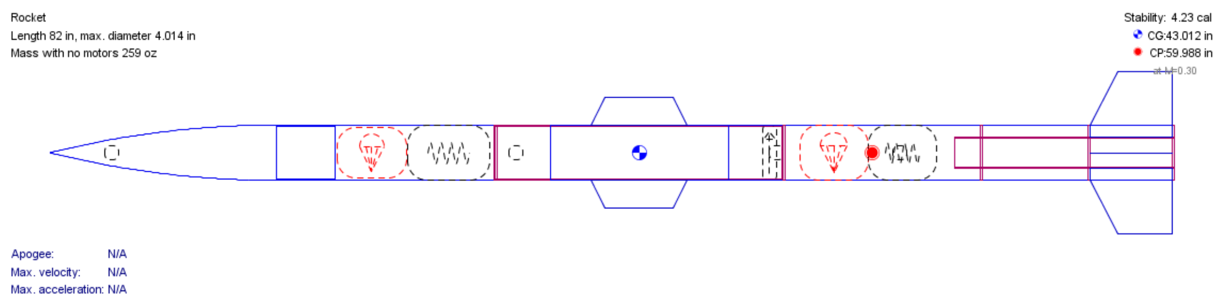


**Figure 2. Diagram of rocket after motor burnout.**

### *1.1.2 Mechanical Design Features*

After careful comparison with other rocket motors of class "K", the motor that was ultimately chosen for competition was the Cesaroni K500 as it provides the best trade between burn time and loading for the rocket. The Cesaroni K500 is a reloadable motor that is 54 mm (2.13 in.) in diameter and 404 mm (15.91 in.) in length. It has a burn time of 3.16 s and a maximum ejection charge delay of 18 s. It has an average thrust of 502 N and a maximum thrust of 595 N occurring at 0.50 s. The thrust curve can be seen below in Figure 3. The total impulse is 1,587 Ns. The launch mass of the motor is 3.25 lbs and the mass after burnout is 1.26 lbs.

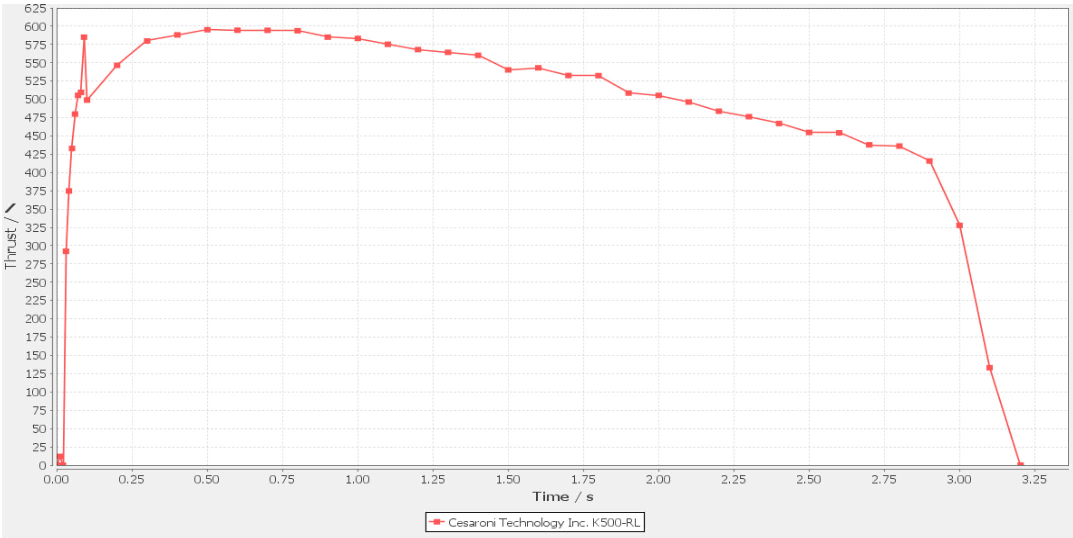


**Figure 3. Cesaroni K500 thrust curve.**

The Cesaroni K500 provides the rocket with a rail velocity of 46.2 ft/s at 6 ft which is greater than the 45 ft/s requirement. The K500 is projected to produce an altitude of 3,711 ft, which is above the minimum required altitude of 3,000 ft. In addition, the short burn time of 3.16 s will allow the active drag system an estimated 12.75 s window of operation.

The upper airframe is composed of the nose cone, a Blue Tube section, the main parachute, shock cords, quick links, and parachute protectors. The nose cone is an ogive profile made of polypropylene plastic with a shoulder length of 3.25 in., an outer diameter of 4 in. and length of 16.5 in. with a weight of 0.657 lbs (298.1 g).  In addition to this, a larger ballast mass of 2.97 lbs (1,347 g) is added to the nose to raise the center of gravity to slightly above the active drag fins after motor burnout. This change in ballast mass and location of center of gravity is due to the 5 in. length added to the coupler and switchband sections of the rocket. The inclusion of the active drag in the design pushed the center of pressure significantly farther forward than a traditional rocket design with fins only at the base of the booster. The Blue Tube attached to the nose cone is 1.67 ft long and 0.66 lbs. In the Blue Tube is the main parachute, shock cord, and their accessories with an eye bolt at the base of the upper airframe to attach the shock cord and parachute.

Outside of the rocket, the camera and camera shroud made of balsa wood are placed on the upper airframe. The shroud is epoxied onto the Blue Tube with the camera held securely in the shroud by a screw with duct tape added as a safety measure so that it is easily removed later to turn it on, turn it off, charge the camera, and obtain data from the SD card.

Below the upper airframe is the coupler section that consists of one 21 in. section of Blue Tube. This changed from the initial design which consisted of two 8 in. sections epoxied together. The coupler was lengthened to allow more room for the active drag system and the avionics bay and one piece was used instead of two in order to simplify the construction process and increase the strength of the final product. In the previous design, there was not sufficient space to comfortably fit all avionics and wiring needed when the active drag actuator was fully extended. The coupler section now has enough space to contain the active drag system as well as the avionics. There is a Blue Tube switchband centered on the outside of the coupler measuring 13 in. in length with an outer diameter of 4 in. and a thickness of 0.007 in, to create space between the upper airframe and booster section and adding extra strength around the active drag system. This leaves a shoulder with a length of 4 in. on either end to keep the coupler securely attached to the upper airframe and booster. The length of the switchband was also increased from the initial design by 5 in. to match the increase in coupler length.

At the base of the rocket is the booster airframe that consists of a Blue Tube section with a 4 in. diameter measuring 2.70 ft in length. Inside the airframe is the drogue parachute and its accessories. At the top of the booster section, on the outer side of the coupler bulkhead, is an eye bolt to attach the drogue, and the drogue ejection charge is placed to separate stages. In addition, the booster airframe houses the motor, fixed with the motor mount and motor retainer, which are held in place by three centering rings made of plywood as well as an aft enclosure. On the outside of the booster airframe are four fins made out of 0.125 in. thick fiberglass. They are spaced equally around the rocket at 90° intervals, each with a span of 3.85 in. measuring 4.0 in. at the tip and 6.0 in. at the root. The fins are epoxied to the body tube as well as the motor mount tube inside of the body tube for additional support. Along the outside of the airframe are two 1515 rail buttons made out of Delrin-plastic with a length of 0.68 in. and an outer diameter of 0.63 in. Rail buttons will ensure that the rocket leaves the launch rail in the desired direction.

The recovery system of the vehicle consists of an 18 in. drogue parachute stored in the booster section and a 60 in. main parachute housed in the upper airframe. Other components included in the recovery system consist of tubular nylon shock cords, parachute protectors, quick links, eye bolts, shear pins, and an ejection charge. The 18 in. drogue parachute is made out of ripstop nylon, weighs 0.041 lbs, and has a drag coefficient of 0.80. The drogue is attached to 15 ft of tubular nylon shock cord. The 60 in. main parachute is made out of ripstop nylon, weighs 0.83 lbs, and has a drag coefficient of 2.2. The main parachute is attached to a 20 ft tubular nylon shock cord, which weighs 0.57 lbs. The shock cord is then attached to a quicklink, which is hooked onto an eye bolt. The eye bolt is screwed into the coupler and secured by washers and a nut. The ejection charges are located on the sides of the bulkheads facing out of the coupler. The ejection charge for the drogue uses 1.75 g of black powder, while the ejection charge for the main parachute uses 1.8 g of black powder.

*1.1.3 Electronic and Payload Design Features*

The avionics bay, a plywood sheet to hold all avionics, is in the bottom half of the coupler section, is 6 in. in length, and spans the width of the coupler tube. It will be separated from the bottom booster section and upper active drag component with bulkheads. The avionics bay is attached to the coupler section by four clips through which two threaded rods are inserted and go through the entire coupler section. This ensures that the avionics will stay in place and allows the sled to easily slide in and out of the coupler section.

On the avionics bay, one Stratologger altimeter and one 9V battery holder are screwed down and are used to fire the charges on the main and drogue parachutes. Wires connect the Stratologger to the charges, battery, and a clearly labeled switch to arm and disarm it that is passed through a hole in the body tube of the coupler section and screwed in with a nut. Wires from the ports of the Stratologger run through the outside bulkhead of the coupler and connect to the terminal block which is connected to the black powder charges on the other end.

Additionally, the Arduino Mega, 12V Lipo battery, and motor controller, all used to control the linear actuator, along with an accelerometer and SD card shield to record and store acceleration data are located in the avionics bay. The Arduino is attached to the payload sled with the accelerometer and SD card shield directly on top. The X, Y, and Z pins of the accelerometer are attached to analog A8, A9, and A10 pins of the Arduino. Two control and one ground wire run from the Arduino to the motor controller to control both the direction and speed of the actuator. The actuator is then directly wired up to the motor controller. Power runs from the Li-Po battery to a switch located on the switchband and then to both the Arduino and the motor controller. The Stratologger is powered by its own 9V battery with its own switch attached to the switchband. The layout and attachment of the all components on both sides of the sled are shown in Figure 4.

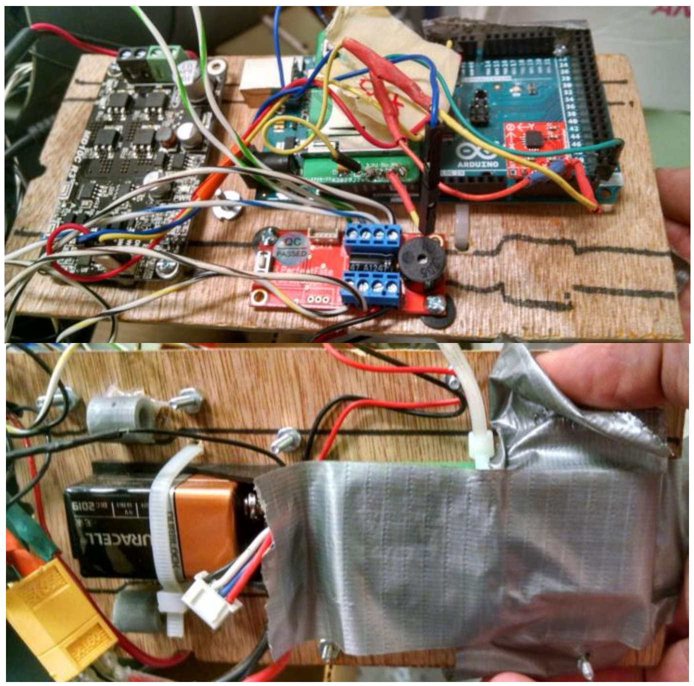

**Figure 4. Avionics bay layout.**

The active drag system consists of two rotating fins located at a distance of 44 in. from the base of the rocket. The fins have a trapezoidal shape with a root chord of 7 in. and a tip chord of 5 in. They have a 2 in. span and are constructed out of fiberglass that is 0.125 in. thick, which is the same material used for the main fins. The rotation point of the fins is located near the center of gravity of the rocket after the motor has burned out to maintain stability. An image of the active drag system before being placed within the body tube can be seen in Figure 5.

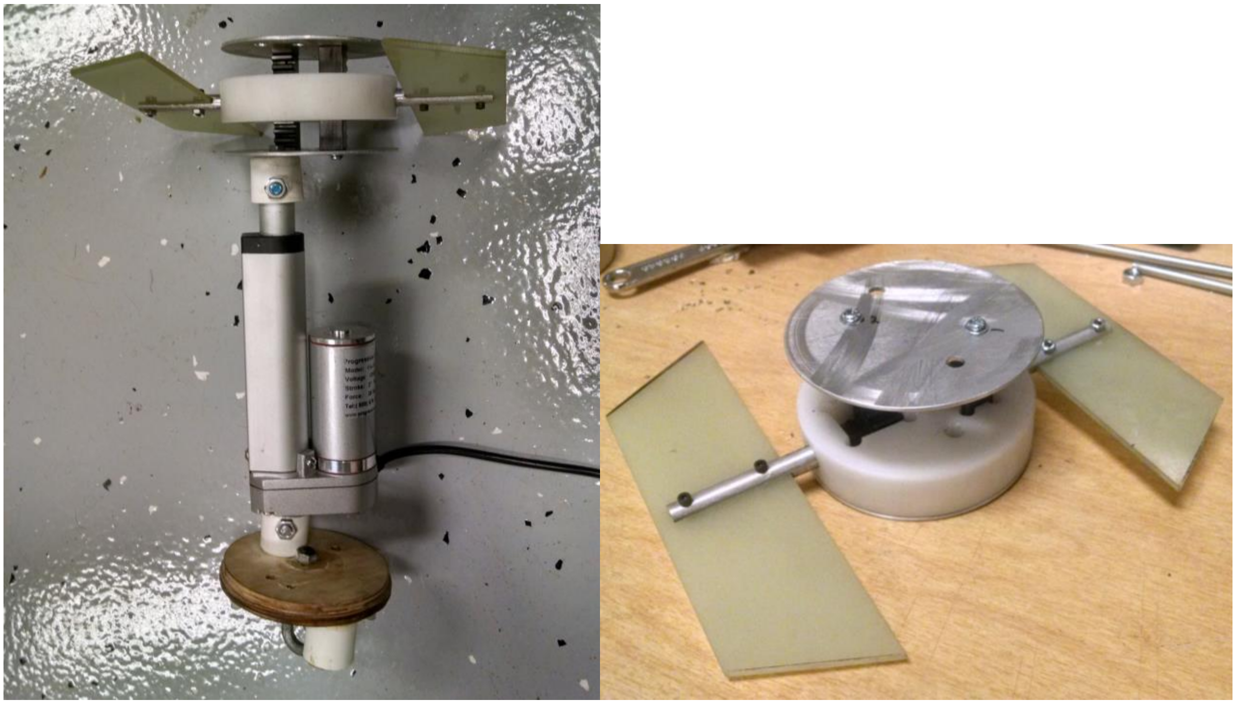

**Figure 5. Active drag system.**

When deactivated, the fins are stowed such that they run parallel to the rocket body to minimize drag. The drag system is activated after motor burnout and returned to initial configuration before apogee. Upon activation, the fins pivot 90° on their center axis, becoming aligned perpendicular to the body tube and thus increasing the surface area and drag on the rocket.

One end of each of the active drag rods are slotted allowing the fins to slide into the rods and be firmly attached by a nut and bolt. Each rod is attached to a spur gear that runs along a gear rack. The gear racks are on opposite sides for each gear so that the gears and fins turn in opposing directions to prevent the rocket from drifting laterally or tumbling about the lateral axis as the fins rotate. The two gear racks are attached to mounting plates on both the top and bottom of the racks. The gears and the rods are attached to the rocket and positioned via a custom Delrin plastic mounting piece. This piece also supports the fins, allowing the drag force to be distributed uniformly across the circumference of the Blue Tube. The top mounting plate is fixed to the end of a 3 in. stroke linear actuator. The actuator pushes the gear racks vertically which turns the gears and in turn rotates the fins. The actuator is powered by the 12V battery located in the avionics bay. Movement is triggered by the Arduino that is programmed to send speed and direction information to the motor controller, both of which are also in the avionics bay as stated previously. The motor controller provides the necessary power to the screw drive of the actuator to raise or lower the shaft as desired. To determine when to deploy the fins, an accelerometer is used to detect when the rocket ignites, and a timer is implemented to deploy the fins for a predetermined amount of time. For the competition, the team plans to read data directly from an altimeter to determine when and how long to activate the active drag. This will give the team more control over system performance. The fins will thus be deployed slightly after motor burnout and will be retracted before apogee based on the computer's prediction.

## 1.2 Construction Techniques

### *1.2.1 Upper Airframe Construction*

Construction of the upper airframe began with the attachment of the shock cord to the nose cone. To attach the shock cord to the nose cone, two holes approximately the size of the shock cord were made in the base of the nose cone using a dremel. The shock cord was then threaded through these holes, tied securely, and the knot epoxied to ensure the shock cord does not come loose. The nose cone with the shock cord fully attached can be seen in Figure 6.

**Figure 6. The shock cord attached to the nose cone.**

Two extra quick links are attached to the nose cone for additional weight, as well as the ballast in the nose cone, to ensure the center of gravity is above the active drag system. The nose cone is attached to the body tube with four 4-40 nylon shear pins. Four pieces of brass are epoxied onto the nose cone to ensure the shear pins break when the ejection charge goes off and that the holes in the nose cone do not become oblong. The brass pieces as well as the nose cone were sanded to allow epoxy to better adhere. The brass pieces were bent to the curve of the nose cone and subsequently epoxied in place. The shear pin holes were then drilled on the upper airframe in line with the brass pieces. After the epoxy on the brass pieces had dried, the nose cone was inserted into the upper airframe and the shear pin holes were drilled in the nose cone through the previously drilled holes in the upper airframe to ensure alignment.

To attach the main parachute within the upper airframe, a quick link was attached to the nose cone shock cord and one to the coupler sub system. The shock cord was then attached to the ends to the quick links and a loop was created in the middle of the cord to attach the parachute. The parachute was folded according to proper folding procedures and wrapped in a parachute protector. Once all sections of the parachute were covered by the protector, the parachute was attached to the shock cord and inserted into the vehicle with the least protected side of the parachute facing away from the coupler to minimize the risk of the black powder charge burning the parachute.

Additionally, a camera shroud of balsa wood was constructed with the main purpose of filming the deployment of the active drag fins. A dremel was used to carefully cut a section out of the balsa so the camera could easily slide in and out. Using coarse sandpaper wrapped around the body tube of the rocket, the balsa wood was sanded to fit the rounded shape of the upper airframe tube. The rest of the block was sanded to create the most aerodynamic shape possible. Using a five-minute epoxy, the camera shroud was attached to the body tube just above the active drag fins. In order to secure the camera during flight, a screw and washer were screwed into the balsa wood to tighten the hold on the camera. Additionally, duct tape was wrapped around the shroud and camera, being careful not to cover the eye hole of the camera or disrupt the video.

*1.2.2 Coupler Section Construction*

To allow for easy installation and removal of the parachutes, a combination of eye bolts and quick links were used. Two carbon steel eye bolts were attached to either side of the coupler. Each one was screwed into a bulkhead. For extra precaution, epoxy was added around the eye bolt.

The coupler was held to the upper airframe with four screws and four t-nuts. Holes were drilled evenly around the rocket through both the upper airframe and coupler for the t-nuts and screws. The t-nuts were then epoxied into these holes to secure them in place. When the rocket was assembled, the screws were inserted into the t-nuts to keep the coupler attached to the upper airframe.

The coupler and switchband were attached with epoxy. Two rings of epoxy were made on the switchband: one at the base of the coupler, and one at the center of the coupler. The coupler was then slid onto the switchband, spreading the epoxy rings out over the entire inside of the coupler. It was then set to dry.

The construction of the active drag began with the creation of the active drag fins. The fins were first cut out of fiberglass, using a diamond saw, to the dimensions stated above in Section 1.1.3. The fins were then attached to a 4 in. aluminum rod by a slot in the rod and two screws. Both the slot for the fins and the holes for the screws were machined in a mill. Next, both gear racks were run through the Delrin mounting piece and screwed on to a metal plate on either side. This Delrin piece was turned in a lathe and also machined in a mill to achieve a proper fit. To attach the active drag system to the avionics bay, holes were drilled through the metal plates and the mounting piece for the threaded rod to run through. The plastic mounting piece was then held in place by the rods that ran through the Blue Tube. To assemble in the rocket, the plastic mounting piece was first inserted, followed by the fins being inserted into the mount and spur gear. Then the set screws were tightened on the rod and finally the bottom aluminum plate was screwed onto the gear rack.

In constructing the avionics bay, each component was first measured and its size recorded. A plan was drawn based on the space allotted for the avionics and the size of the components. Once an acceptable plan was drawn, the placement of each component was marked on a piece of ⅛ in. plywood that was 6 in. by just under 4 in. to ensure a tight fit in the rocket. Once the components were marked out on the plywood, holes were drilled for zip-tying the batteries to the board. Once the holes were drilled, the components were placed on the plywood and secured in place. All wires not soldered on were then connected in the layout described in Section 1.1.3.

Black powder charges were used to eject the parachutes. On each bulkhead, there were two ejection canisters and two terminal blocks. To test the black powder ejection charges, 1.75 g of black powder was added to the canister on the bulkhead facing the booster tube for the drogue and an igniter was safely placed in the black powder. Then, wadding was inserted to fill the rest of the space not occupied by the black powder or the igniter. Finally, the canister was covered by foil tape, as it was safer than regular tape. Once the canister for the drogue was safely filled, the same procedure was done for the main parachute using 1.8 g of black powder. The team tested the black powder charges the week before the test flight and both ejection charges were successful.

Shear pins were added to the bottom of the coupler section to connect to the booster section while still allowing separation when ejecting the drogue parachute. Three evenly spaced 4-40 nylon shear pins were used for this connection making a total of seven pins for the entire rocket. During the team's test flight, all shear pins broke and allowed for the successful deployment of both the main and drogue parachutes.

#### *1.2.3 Booster Section Construction*

The motor mount was assembled as the first step in the construction of the rocket. First, an Aero Pack 54mm Motor Retainer was secured at the extreme aft end of the rocket using a high strength epoxy and constrained using a rear closure. Next, three centering rings made of ¼ in. plywood with 54 mm and 98 mm in inner and outer diameter respectively, were created and epoxied onto the motor mount tube. The locations of the centering rings were marked on the motor mount and body tube: the top ring slightly below the top of the motor mount tube, the middle ring aligned with the top of the fins, and the bottom ring aligning the retainer with the bottom of the rocket. Each centering ring was secured using a high strength epoxy, and each ring was applied one at a time to ensure that the previous one had dried before moving on to the next. Following this, the motor mount tube was inserted into the body tube

The drogue parachute was added to the booster section of the rocket using the same method described in Section 1.2.1 for the main parachute. To attach the shock cord for the drogue, one quick link was attached to the coupler section and the second to the uppermost centering ring attached to the motor mount tube. This chute was similarly folded, covered with a parachute protector, and inserted into the booster section.

#### *1.2.4 Fin Construction*

The fiberglass main fins were first carefully measured and drawn on a sheet of ⅛ in. fiberglass using a ruler, both as a measuring device and a straightedge, and a t-square ruler to ensure 90 degree angles when needed. The fins were cut using a diamond saw. They were cut with some tolerance around the drawn outlines to avoid cutting them too small. Once the fins were cut, they were sanded using a circular sander to make fine adjustments to the size until they had the correct dimensions.

The main fins were attached to the motor mount tube through slots in the body tube. First the places on the fins that would have epoxy were scratched with and exacto knife to allow for better adhesion between the fiberglass and epoxy. Then all parts of the rocket that could not get epoxy on them were covered with tape as a precautionary measure against spills. Then a fin jig to hold the fins in the correct positions while they dried was created by laser cutting ⅛ in plywood based on a CAD model with the dimensions of the rocket. The fin jig was then sanded in the inner corners to make room for the epoxy fillets on the outside of the rocket. The fin jig can be seen nearly complete in Figure 7. Sanding the fin jig can be seen in Figure 8.

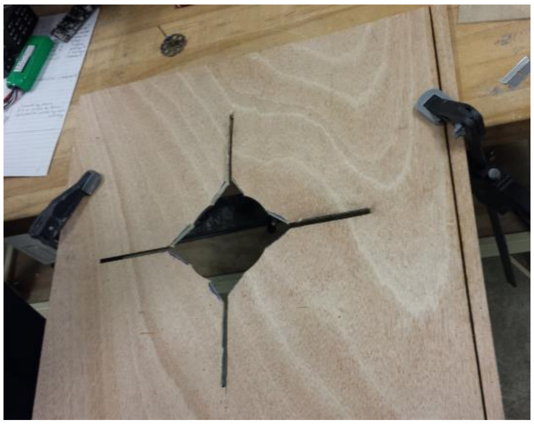

**Figure 7. Fin jig before sanding complete.**

**Figure 8. Sanding the fin jig.**

Once the fin jig was created, the team began to epoxy the fins on. First the outer fillets were done two at a time with each set being done at least 6 hours apart to allow the epoxy to properly dry. The fins shown before and after the first set of outer fillets were added can be seen in Figures 9 - 11.

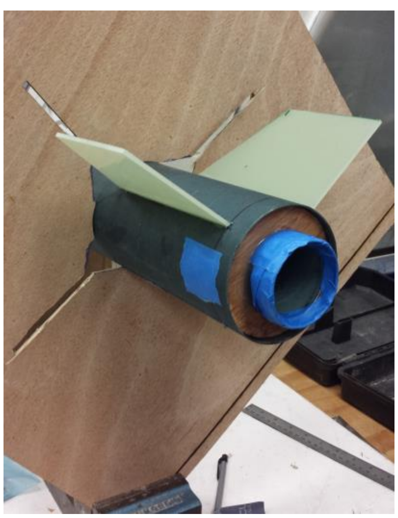

**Figure 9. Rocket prepared for fin attachment.**

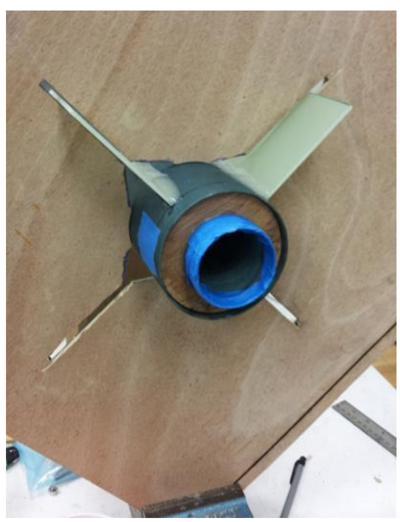

**Figure 10. Rocket with outside fin epoxy fillets.**

**Figure 11. First set of outside fin epoxy fillets.**

Once all four sets of outside epoxy fillets were complete and dry, the inside fillets that attach the fins to the motor mount tube were done. These fillets were also done two at a time, with four sets total, with at least 6 hours of drying time between each set. To get the epoxy inside the rocket, two holes of size 3/32 in. in diameter were drilled next to the fins as seen in Figure 12. Then a syringe was used to push epoxy into the holes as seen in Figure 13. After the epoxy was in the holes and all excess epoxy was removed with rubbing alcohol, the rocket was tilted to allow the epoxy to spread evenly along the fin length. The rocket was then set to dry. This process was repeated three more times to complete the inside fillets.

**Figure 12. Drilling holes for inside fillets.**

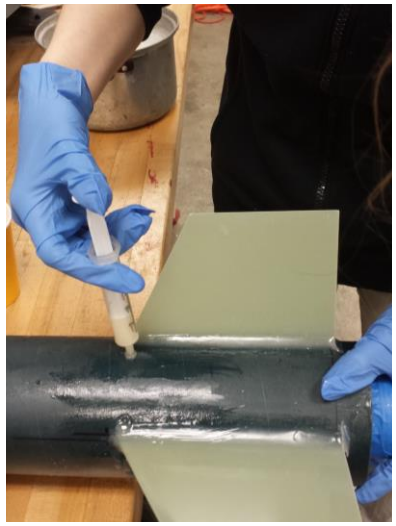

**Figure 13. Putting epoxy into rocket using syringe.**

**1.3 Stability Analysis**

Based on the OpenRocket predictions with our design changes in place, the rocket has a stability caliber of 3.08 on the pad. The stability will then increase as the motor burns and the CG shifts towards the nose cone, reaching a maximum value of 4.44 calibers. A graph of the stability of the rocket can be seen in Figure 14, without the active drag. The team believes this model is slightly underestimating the stability of the rocket throughout its flight, which leads to the discrepancies between the stated stability margins. In either situation, the stability margin is still above the required minimum (and below the maximum) throughout the entire flight.

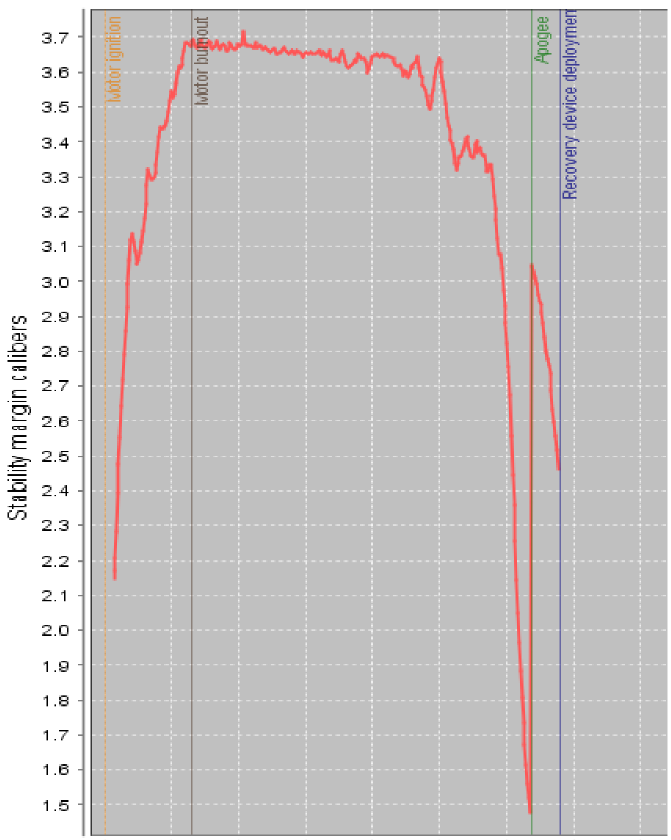


**Figure 14. Stability vs time for the flight without active drag.**

For the flight with the active drag enabled, the center of pressure will no longer be located in the same position as when the fins were not deployed. The deployment of these fins will cause an increase in the normal drag on the rocket and thus raise the CP towards the deployed fins. However, the CP will never increase past the drag fins, and with the CG being above the drag fins, the rocket will stay stable throughout the whole flight.

**1.4 Safety**

The rocket was designed for maximum safety during construction, flight, and recovery. During launch, the speed of the rocket at 6 ft up the rail exceeds the minimum requirement significantly, and the exit rail velocity exceeds the standard minimum exit velocity to ensure the rocket flight is vertical. The rocket has been designed such that the stability margin is an acceptable value for stable flight throughout the entire flight. The parachutes will be deployed at optimal times to ensure the landing speed is safely under 24 ft/s. To make sure that the vehicle can be located after flight, a GPS tracker was attached to the rocket to obtain the exact landing location of the rocket.

During all stages of construction, a variety of safety hazards were present. Various hazardous materials such as the flammable motor, epoxy, black powder charges, and fiberglass were used. At least one team member has experience with each of these hazardous materials. The team member(s) with experience in the handling procedures taught the rest of the team proper techniques. Flammable materials were always handled according to their instructions, keeping any possible flame source out of the range of the flammable materials and a fire extinguisher on hand in case of emergency. For handling epoxy and other possible skin irritants, gloves were worn at all times. Pieces that had not fully cured were labeled as such to avoid anyone unknowingly coming in contact with epoxy. Black powder was stored safely with all necessary precautions and was measured precisely. Fiberglass was handled with eye glasses, gloves to prevent fiberglass splinters, and masks to prevent the inhalation of fibers during cutting. Other than hazardous materials, many of the team members are experienced in using necessary power tools and have shown newer members proper techniques and safety precautions that must be taken into account when operating these tools.

Since all assembly during the competition will be under time constraint, it is vital that all members of the team know how to assemble the rocket prior to the competition so that no mistakes are made that could compromise the safety of the team or others in attendance. Before both the competition and test launch, the team will go over the assembly slowly ensuring that all steps are carefully explained, and practice assembling the rocket until it can easily be done. Prior to assembly, a checklist was made describing in detail all the steps and including all of the parts needed. The checklist was used during assembly at the test launch and will be reused for future launches as a guide to make sure nothing is left out or forgotten and to make sure all assembly steps are performed in the right order. Additionally, each person involved in assembly had specific tasks assigned to them to streamline the process. However, all team members are able to assemble the whole rocket in case of absence of one or more team members.

Prior to and after the launch of the rocket, team members will use precaution and follow predetermined procedures and safety codes. The team will first take inventory of all components to ensure everything is present. The team will then begin assembling the rocket, being careful that all components are safely secured and in the proper position. After everything has been assembled properly, the rocket will launch. After launch, the team will first make sure that the launch area is clear before going to recover the rocket. The GPS tracker on the vehicle will be used to determine the location of the rocket. Once the rocket has been retrieved the landing site will be surveyed to check for any parts that may have come loose on impact. Once all parts have been recovered, the team will make their way back to the setup area to begin the process again for the second flight.

### 1.5 Recovery

The drogue parachute is 18 in. in diameter. It is attached to a 15 ft piece of shock cord by a quicklink. The shock cord is then attached to the bottom bulkhead of the coupler with an eye bolt and a quicklink, and to the top of the motor mount with an eye bolt and quicklink. There is a parachute protector of appropriate size to wrap the drogue in during flight. The drogue is set to deploy at apogee. Three 4-40 nylon shear pins are used to secure the booster tube to the coupler, and 1.75 g of black power is used for the ejection charge. The main parachute is a 60 in. Fruity Chutes IRIS Ultra parachute, with a coefficient of drag of 2.2. With this parachute the descent rate was predicted by OpenRocket to be 18.2 ft/s; however in the test flight it was found that

OpenRocket slightly underestimates the descent rate for this rocket. The main parachute is attached to a 20 ft piece of shock cord with a quicklink. The shock cord is then attached to the nose cone and to the top bulkhead of the coupler with an eye bolt and a quicklink. The main parachute is set to deploy at an altitude of 500 ft. Four 4-40 shear pins are used to hold the nose cone to the upper airframe, and 1.75 g of black powder is used for the ejection charge.

### 1.6 Design Changes

The largest design change was an increase in the length of the coupler section, adding 5 in. to both the coupler and the switchband to allow more room for the avionics and active drag. Within the avionics another change was to use only one Stratologger instead of two due to the limited space within the avionics bay. The system used in mounting the active drag fins changed as well. While the system originally used a small wooden mounting block located along the centerline of the rocket to support the rods of the fins, the system now uses the plastic mounting piece that encompasses the entire cross section of the body tube. The change resulted in order to decrease unwanted movement of the system as well as providing more support to the fins to protect both the fins themselves as well as the body tube from damage. The camera to take video of the active drag deploying and retracting was moved to the outside of the upper airframe for easier access before and after flights. Due to the increase in size and weight of the rocket, a larger parachute was used to achieve a safe descent rate. To account for the larger weight, the shear pin size was increased from 2-56 nylon shear pins to 4-40 nylon shear pins so less shear pins were necessary.

## 2. Rocket Operation Assessment

The rocket was tested in preparation for the competition in order to ensure proper flight. Specifications of the rocket as prepared for the test flight in addition to flight characteristics are shown in Table 1 followed by an analysis of the flight in the following sections.

**Table 1. Flight Characteristics of the Rocket for the Test Flight**

| Flight Characteristics | |
|---|---|
| Mass (on the pad) | 312 oz |
| Motor | K-500 |
| Max Altitude | 2771 ft |
| Max Velocity | 501 ft/s |
| Time of Flight | 63 sec |
| Landing Descent Rate | 29 ft/s |

### 2.1 Launch and Boost Analysis

The rocket launched and boosted according to plan. The rocket went straight off the launch pad at a safe speed of 56 ft/s. The flight path was fairly straight, with a few deviations but nothing near unsafe levels.

**2.2 Coast Phase Assessment**

The rocket also had a few deviations in a straight flight path during the coast phase, most likely due to the active drag system, but remained stable all throughout flight.

**2.3 Drag System Assessment**

The active drag system was successfully built and put into the rocket for the test flight. However, during the test flight one of the fins prematurely opened slightly before motor burnout. This was caused by the set screw of the spur gear slipping along the aluminum rod. This will be fixed for the next launch by drilling a hole into the aluminum rod for the set screw to go into so that it cannot slip. Due to the fin deploying prematurely, the final altitude of the rocket was not what the team expected. In addition to the premature deployment, the fin was also unable to retract before apogee. Despite the errors, the team did collect data that allows for the calculation of the Cd for this flight case, along with data that will help determine how effective this active drag system is in slowing down the rocket. This flight also showed that the rocket will remain stable during the entire flight, with the deployment of just one fin being the worst case scenario for stability.

**2.4 Recovery System**

The drogue deployed at apogee, as programmed by the Stratologger. However, due to the unexpectedly low altitude, the motor ejection charge went off later than would have been desired if the lower altitude had been taken into account. The main deployed when it was programmed to by the Stratologger at 500 ft AGL. The rocket landed at 29ft/s, which is higher than the maximum landing velocity so a larger main parachute will be used for the competition. The rocket drifted less than 500 feet from the launch site. The team was able to clearly see where the rocket landed and it was not necessary to use the tracker to find the rocket. However, the GPS tracker was working and could have been used if necessary.

**2.5 Pre-Launch Procedure**

First, the team made a checklist before going to the launch site of all the things that need to be taken to the launch. Once all the necessary items were collected, the team carefully packed them and drove to the launch site ensuring no components got damaged in transit. Once the team arrived at the launch site all items were again accounted for and prepared for rocket assembly. The team then ensured the wiring was all still intact on the avionics bay. When the electronics were in place, the parachutes were folded and wrapped in the parachute protectors. While the parachutes were being wrapped, a GPS tracker was attached to the shock cord of the main parachute. The shock cords were then bundled and wrapped lightly in rubber bands to avoid entanglement. The parachutes and shock cords were packed in the rocket. While the parachutes and shock cords were being prepared, the charge cups were filled with the correct amount of black powder, filled with wadding, wire inserted, and taped over to hold everything in place. Once the charges were prepared, the rocket pieces were assembled and shear pins and screws were put in their respective places to hold the rocket together. The motor delay was drilled out to account for the lower altitude expected from the active drag. The motor was then put in the rocket and the rocket was brought to the launch pad. The center of gravity was next checked and marked to ensure safe flight. Once the rocket was slid onto the launch rail, the igniter was inserted and the wires attached to the igniter. The team then moved a safe distance away from the rocket.

**Figure 15. Inserting shear pins into the booster and coupler sections.**

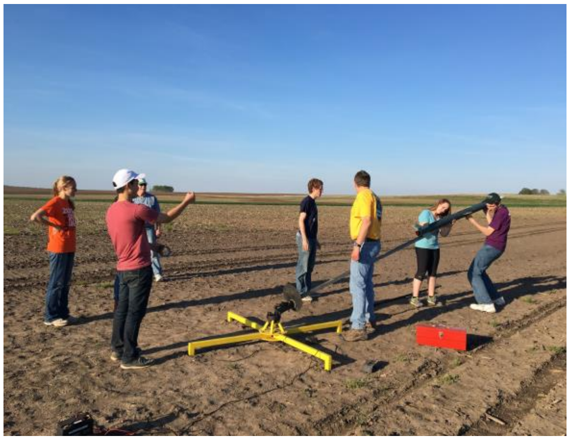

**Figure 16. Attaching rocket to launch rail.**

**Figure 17. Turning the Stratologger switch on.**

### 2.6 Post-Launch Procedure

After the launch, the team recovered the rocket. As previously stated, the landing position could be clearly seen so using a tracker was not necessary. Upon arriving at the landed rocket, the parts were all collected and checked to make sure nothing was lost during flight. After listening to the Stratologger to determine the rocket's peak altitude, the electronics were turned off. Once the rocket was brought back, the coupler section was opened to determine why the active drag fin deployed before motor burnout. Based on the state of the active drag system, it was determined that the set screw holding the active drag fin slipped during launch, causing the early deployment.

## 3. Test Launch Analysis

### 3.1 Peak Altitude

The rocket reached a peak altitude of 2771 ft AGL. This altitude was lower than expected due to the early deployment of the active drag fin. The team believes that with the proper deployment of the active drag system, the desired altitude can be reached. The plots of the altitude and velocity of the flight can be seen below in Figure 18.

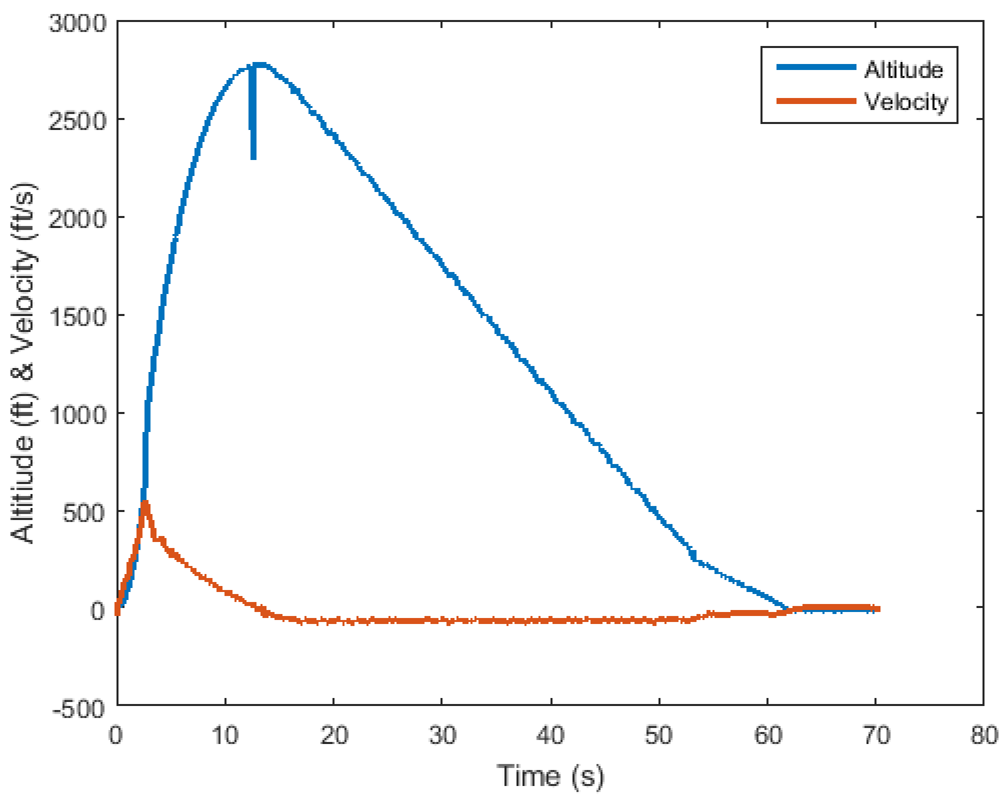


**Figure 18. Altitude and velocity of the test flight.**

Using the OpenRocket software, the expected altitude, velocity, and acceleration can be seen in Figure 19 for a flight without the active drag system deployed.

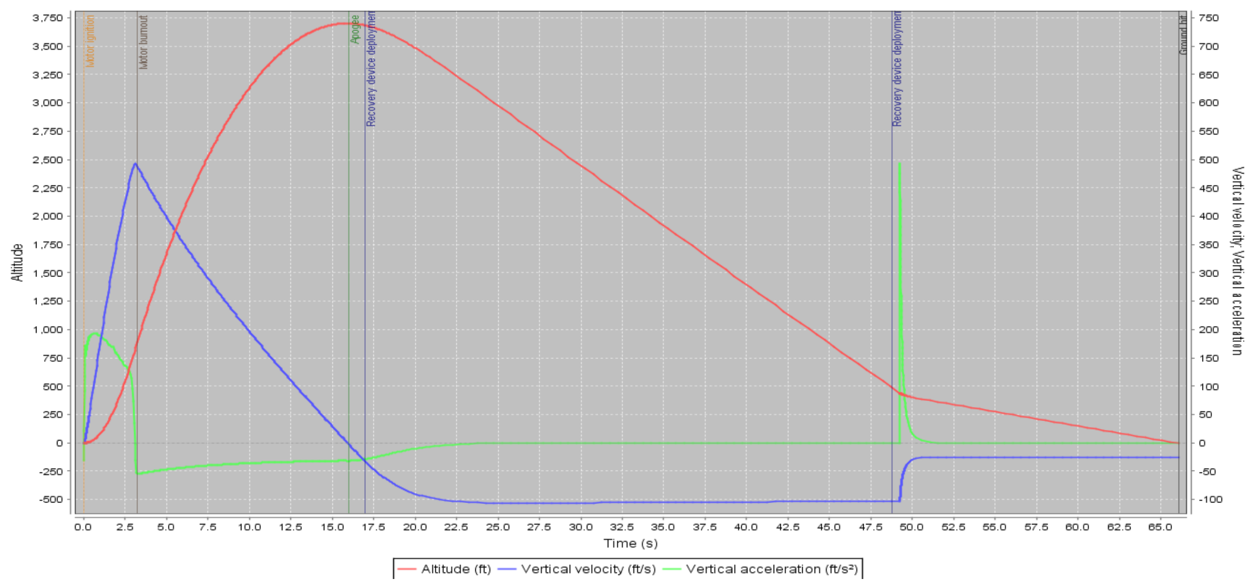


**Figure 19. Plot of the predicted altitude, velocity, and acceleration without active drag activated.**

### 3.2 Coefficient of Drag

The coefficient of drag for the rocket was studied using the data obtained from the Stratologger during flight. Unfortunately, the off the shelf data collection system was not implemented for the test flight thus the Stratologger data was used. The coefficient of drag was calculated using the equation

$$C_d = 2 * F_d/(\rho u^2 A)$$

where $C_d$is the coefficient of drag, $F_d$is the force due to drag, $\rho$is density of air, $u$is the velocity of the flow, and $A$ is the frontal area exposed to the flow. The force of drag was calculated using the mass and acceleration of the rocket. The mass of the rocket was assumed to be linearly decreasing during the burn time, and constant following motor burnout. The acceleration was calculated using an 8th order finite difference scheme over the velocity profile obtained from the Stratologger. The data was smoothed using a moving average smoothing technique covering a 3.5 s range. This large smoothing range removed much of the noise from the acceleration data.

The density was calculated assuming an inverse square atmosphere from a starting density of 1.225 kg/m$^2$. The area assumed for the body of the rocket was calculated as the cross sectional area of the rocket body as well as bottom and deployable drag fins. This was parametrized as a function of time based on the deployment state of the fins shown in the onboard video.

Since the active drag deployed prior to the period after motor burnout and before the rocket slowed to velocities before Mach 0.1, the coefficient of drag should remain relatively constant over this timeframe. As can be seen from the data, the coefficient of drag is generally increasing with a small slope over the timeframe. The inaccuracies in the data have been attributed to the placement of the pressure tap holes for the altimeter which was below the fins. In order to account for any inaccuracies in the data, the average value of coefficient of drag over the relevant period was calculated. This value was found to be 1.898, which is large though not physically impossible. The plot of the real calculated and average values of drag coefficient can be seen in Figure 20 below.

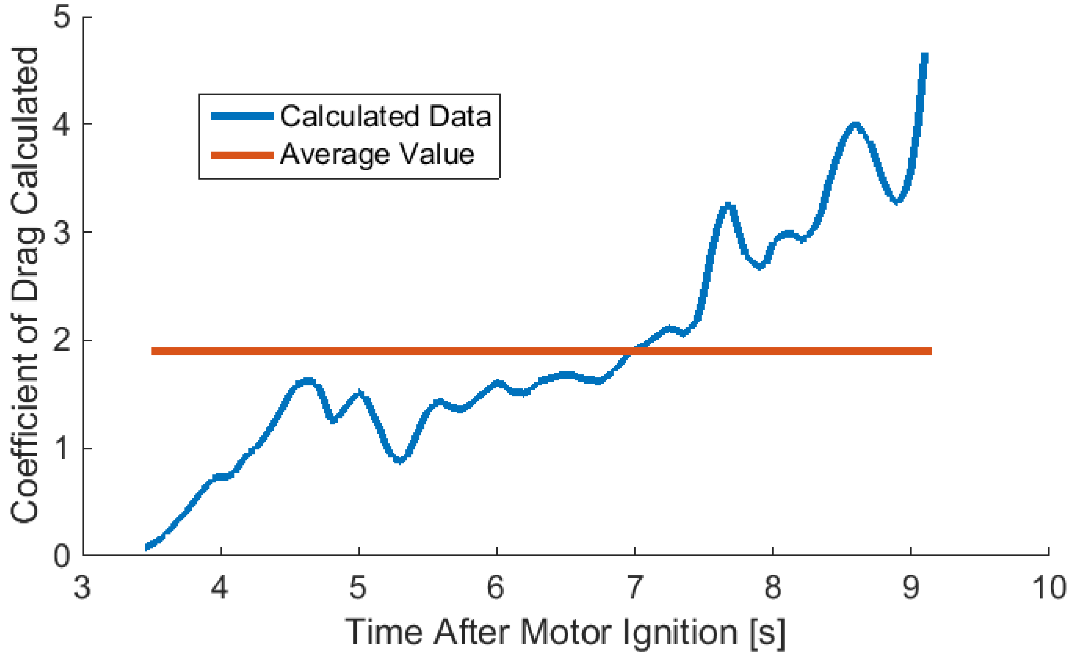


**Figure 20. Drag coefficient as a function of time during the unpowered ascent phase of flight.**

There is room for improvement in the estimation of the coefficient of drag. It is expected that with measures being taken to fix the pressure tap location will allow for more accurate velocity data. In addition, for the competition flight, an accelerometer will be functional to aid in the calculation of the coefficient of drag. This device will allow for a more accurate measurement of the acceleration on the vehicle than can be provided by using a finite difference scheme on the data.

**3.3 Peak Velocity**

The stratologger shows that the peak velocity for the flight was 501 ft/s or Mach 0.44. The peak velocity occurred 3.1 s after motor ignition, almost 0.1 s before motor burnout. With the peak velocity being below Mach 0.5, supersonic flow across the body is unlikely. There may be isolated spots of transonic flow, but the rocket was constructed to withstand these flows.

**3.4 Video and Data Logging**

A few images from the onboard camera from the test flight can be seen in Figures 21-23. These images were taken from the full length collected video that can be seen at https://www.youtube.com/watch?v=wWoAvLN5uU8. This video accurately shows the deployment of one of the drag fins and how the rocket remains stable throughout the flight.

Figure 21. Active drag fin before deployment.

Figure 22. Active drag fin partially deployed.

Figure 23. Active drag fin fully deployed.

## 4. Future Work

A few small design changes will be implemented to improve the performance of the rocket. To stop the set screws from slipping and releasing the active drag early, new holes will be drilled to screw in the active drag fins instead of pinning them in, therefore not allowing them to slip. The team will also be looking into a new way of determining when the active drag system should be deployed, and for how long. This may involve the implementation of an altimeter instead of an accelerometer attached to the Arduino. The location of the camera located on the outside of the upper airframe may also be moved towards the nose cone to get a better view of the fins.

## 5. Budget

Project budget was tracked throughout design and construction and is shown in Table 2. Parts already owned by the team or mentors are not included. Most of these pre-owned components are miscellaneous parts such as nuts and jumper wires, as well as components that are easy to obtain from previous rockets such as altimeters and parachutes.

**Table 2. Women in Aerospace Space Grant Team Planned Budget**

| Component | Price |
|---|---|
| eye bolts | $15.76 |
| 4" Blue Tube Coupler | $21.90 |
| Blue Tube 4" diameter | $77.90 |
| Nose Cone | $21.95 |
| K500 | $225.90 |
| Motor Case | $84.69 |
| Linear actuator | $108.99 |
| 12V Battery | $29.99 |
| Actuator controller | $13.82 |
| Fiberglass for fins | $51.42 |
| Shock cords (mentor allowed team to borrow) | $0.00 |
| 1/4" threaded rod | $13.44 |
| 1/4" nuts for threaded rod | $4.74 |
| Camera | $8.19 |
| Arduino | $9.89 |
| Accelerometer | $13.99 |
| Balsa wood block (for shroud) | $13.80 |
| Paint (Pink) | $7.76 |
| Paint (Silver) | $11.36 |
| Plywood for sled | $3.99 |
| Micro SD adapter for camera | $5.59 |
| Quick Links | $5.40 |
| Terminal Blocks | $9.75 |
| 9V Battery | $8.00 |
| Battery Leads | $3.24 |
| Blue Tube motor mount | $23.95 |
| 54mm Motor Retainer | $31.03 |
| Rotary Switch | $28.38 |
| Epoxy | $44.99 |
| Epoxy Pumps | $12.99 |
| Bulkheads | $16.20 |
| 1515 Rail Buttons | $4.43 |

| | |
|---|---|
| Gear Rack | $25.39 |
| Spur Gear | $45.64 |
| Shear Pins | $8.85 |
| Aluminum Rods | $5.02 |
| Mirrors (bought but did not use) | $2.99 |
| Registration Fee | $400.00 |
| Travel Costs | $1000.00 |
| **Total Project Cost** | **$2,421.32** |

## 6. Conclusions

Since the preliminary design submitted in March, various design changes were made in order to improve rocket construction during the building process and to improve flight performance. Throughout the construction and testing process, proper safety measures were followed by all team members. The rocket with drag system activated has been tested to identify areas of improvement and confirm the capabilities of both the rocket as a whole as well as the active drag system. While the active drag system did not perform exactly as desired, valuable information was gained from the test results and necessary measures are being taken to prevent errors from occurring in future flights.