Women in Aerospace

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1. Rocket Specifications

1.1 Rocket Design

1.1.1 *Overall Dimensional Specifications*

The total length of the rocket is 6.41 ft with an outer diameter of 4.01 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 motors, is 14.59 lbs with one motor and 14.01 lbs with the other. The center of pressure is denoted by a red dot on Figure 1 and is located 5.22 ft from the tip of the nose cone, or 1.18 ft from the base. The center of gravity is denoted by a blue and white dot on Figure 1. The center of gravity is dependent on time due to mass loss from the motor burning. Additionally, since each motor that has a different mass, the center of gravity is dependent on motor choice. The motors that have been chosen are the Aerotech J415W and Aerotech K1103X.

Using the J415W motor, which has a launch weight of 2.64 lbs, the center of gravity prior to motor burnout is located 4.36 ft from the tip of the nose cone, or 2.03 ft from the base of the rocket. Once motor burnout occurs at 3.50 seconds, the center of gravity shifts to 4.04 ft from the tip of the nose cone, or 2.36 ft from the base. After motor burnout occurs, the location of the center of gravity remains constant during flight before the recovery device deploys.

For the second launch, the K1103X motor will be used, which has a slightly greater launch weight of 3.22 lbs. The center of gravity using this motor is initially located 4.40 ft from the tip of the nose cone, or 2.00 ft from the base before motor burnout. Once the motor burnout occurs at 1.71 seconds, the center of gravity moves to 4.04 ft from the tip of the nose cone, or 2.36 ft from the base. Comparing the two results, it can be noted that the weight of the two motors was intentionally chosen to be very similar so that the center of gravity does not drastically change between launches. Additionally, the centers of gravity after each motor burnout match at 4.04 ft from the tip of the nose cone, ensuring our simulations are accurate.

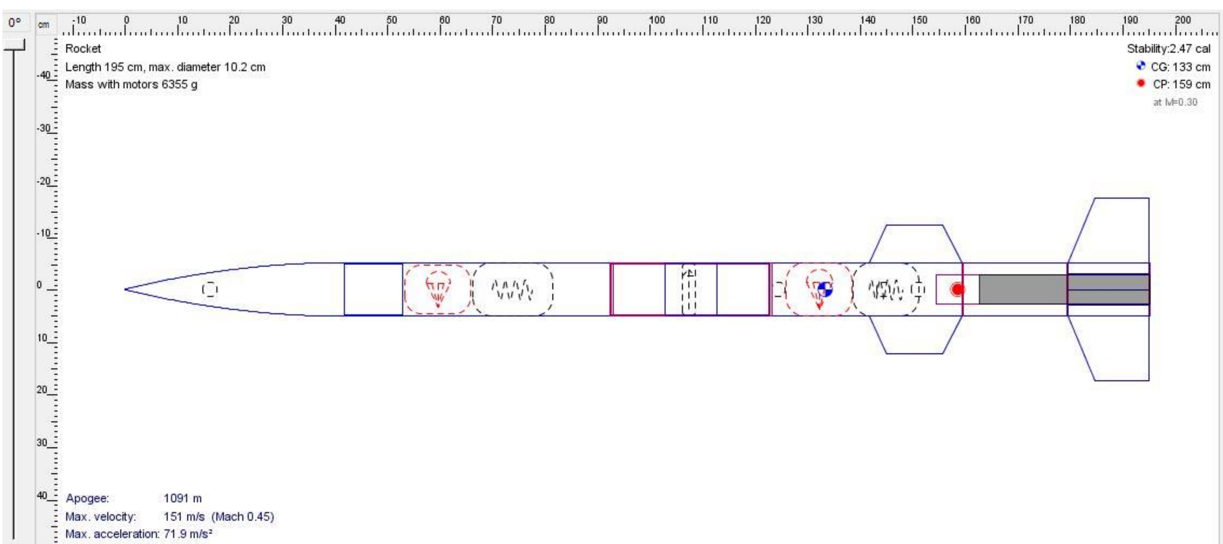

Figure 1. OpenRocket diagram of rocket before J415W motor burnout

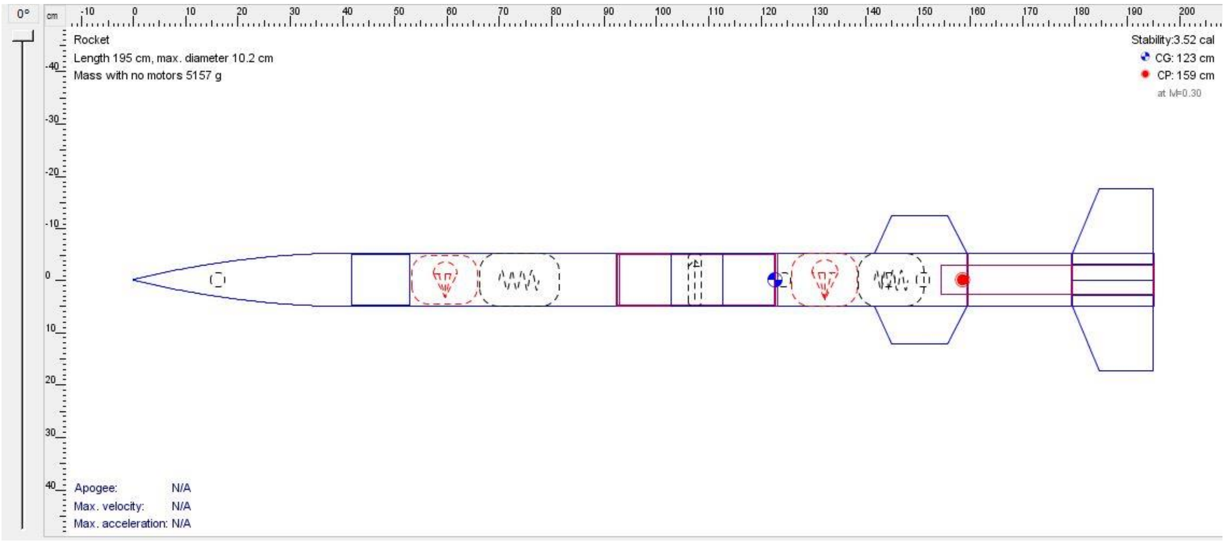

Figure 2. OpenRocket diagram of rocket after J415W motor burnout

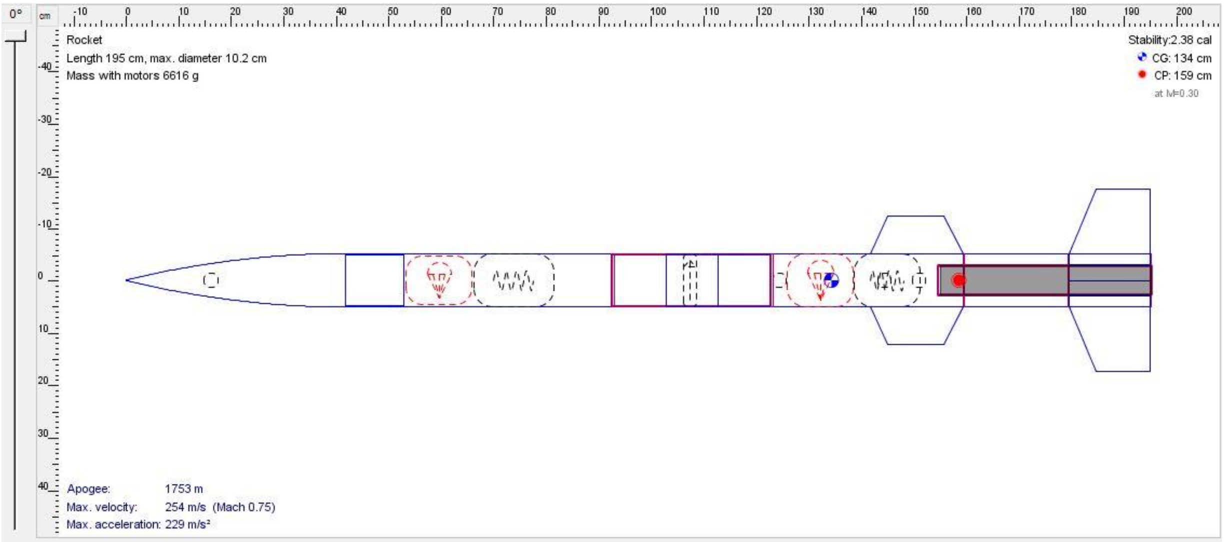

Figure 3. OpenRocket diagram of rocket before K1103X motor burnout

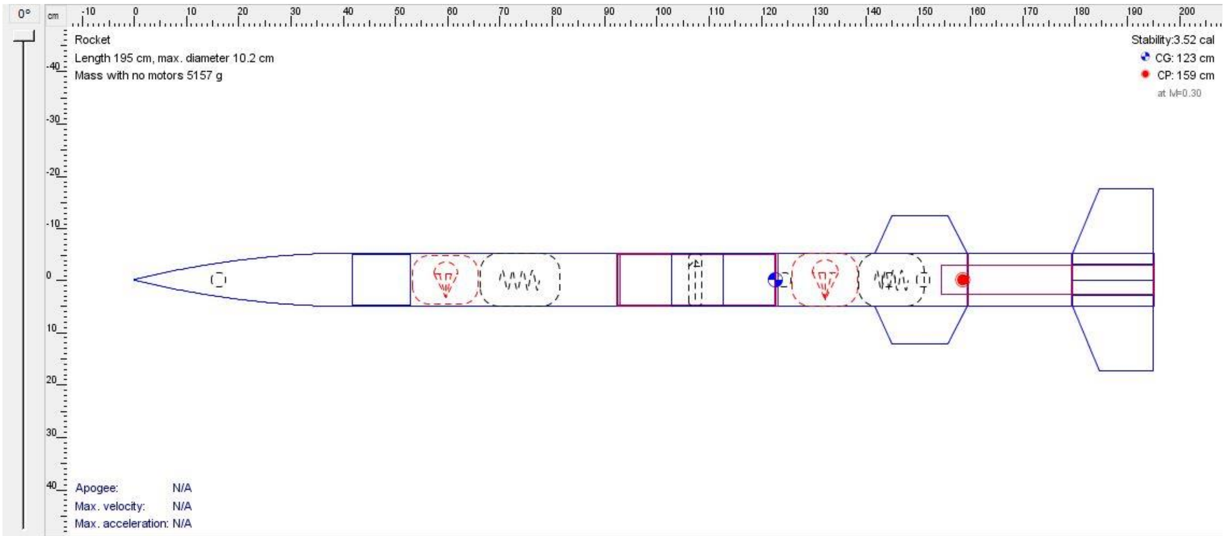

Figure 4. OpenRocket diagram of rocket after K1103X motor burnout

1.1.2 *Mechanical Design Features*

After careful analysis of rocket motors in class “J” and “K”, the motors that were ultimately chosen for competition were the Aerotech J415W and K1103X as they yield the highest figure of merit without the availability of Cesaroni motors. The Aerotech J415W is a reloadable motor that is 54 mm (2.13 in.) in diameter and 326 mm (12.83 in.) in length. It has a burn time of 3.37 s and a maximum ejection charge delay of 6 s. It has an average thrust of 355 N and a maximum thrust of 552 N occurring at 0.030 s. The thrust curve can be seen below in Figure 3. The total impulse is 1201 Ns. The launch mass of the motor is 2.64 lbs and the mass after burnout is 1.19 lbs. The thrust curve can be seen below in Figure 5.

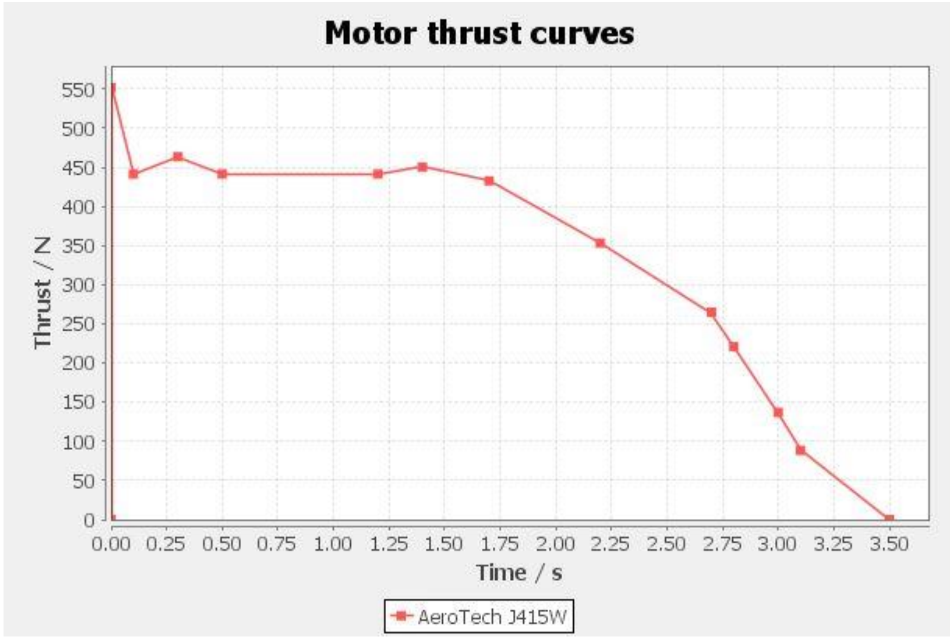

Figure 5. Aerotech J415W thrust curve

The Aerotech K1103X is a reloadable motor that is 54 mm (2.13 in.) in diameter and 401 mm (15.79 in.) in length. It has a burn time of 1.65 s and a maximum ejection charge delay of 17 s. It has an average thrust of 1099 N and a maximum thrust of 1620 N occurring at 0.028 s. The thrust curve can be seen below in Figure 6. The total impulse is 1810 Ns. The launch mass of the motor is 3.22 lbs and the mass after burnout is 1.39 lbs. The thrust curve is shown in Figure 6.

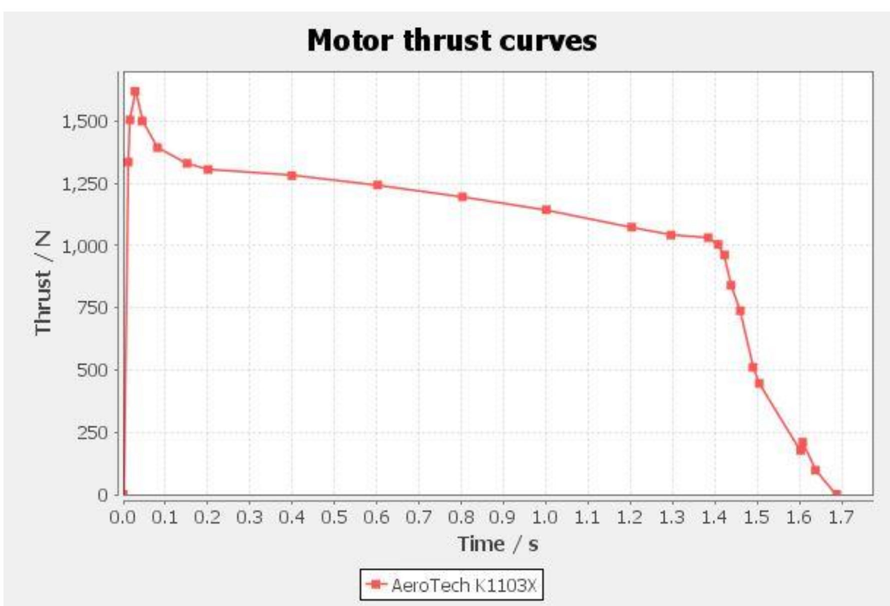

Figure 6. Aerotech K1103X thrust curve

The Aerotech J415W provides the rocket with a rail exit velocity of 59.06 ft/s at 8 ft off the ground which is greater than the 45 ft/s requirement. The J415W is projected to produce an altitude of 3569.55 ft.

The K1103X provides the rocket with a rail velocity of 106.63 ft/s at 8 ft which is greater than the 45 ft/s requirement. The K1103X is projected to produce an altitude of 5748.03 ft without the utilization of the active drag. In addition, the short burn time of 1.65 s will allow the active drag system an estimated 15.75 s window of operation.

The upper airframe is composed of the nose cone, velocity measurement package, 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 0.675 lbs (306 g). The Blue Tube attached to the nose cone is 2.00 ft long and 0.80 lbs. In the Blue Tube is the main parachute, shock cord, and parachute protector with an eye bolt at the base of the upper airframe to attach the shock cord and parachute.

Outside of the rocket, the cameras fit into a slot in the Blue Tube of the airframe. The two cameras will be placed in opposing directions to capture both up and down views of the rocket during flight. They will be secured to the inside of the Blue Tube with duct tape to prevent separation from the rocket during flight.

Below the upper airframe is the coupler section that consists of one 11.89 in. section of Blue Tube. There is a Blue Tube switchband centered on the outside of the coupler measuring 3.89 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. 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.

At the base of the rocket is the booster airframe that consists of a Blue Tube section with a 4 in. diameter measuring 2.71 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 4.84 in. measuring 4.02 in. at the tip and 5.98 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 23.5 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 23.5 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 a nut. The ejection charges are located on the sides of the bulkheads facing out of the coupler. The ejection charge for the drogue and main parachute use 2 g of black powder each.

1.1.3 *Electronic and Payload Design Features*

The two avionics bays, plywood sheets to hold avionics, are housed in the nosecone and in the coupler section. The sled in the nose cone is 8 in. in length and spans the width of the nosecone with edges being chamfered as necessary. The sled in the coupler is 5 in. in length and spans the width of the coupler tube. They are protected from separation charges in the upper airframe and booster section by bulkheads. The sleds are attached to the nosecone and coupler by zip ties through which two threaded rods are inserted. The upper bay rods are secured to the bulkhead in the nosecone and the lower bay rods go through the entire coupler section. This allows the sleds to easily be inserted and removed from their housings. Nuts will be placed on the rods to prevent the sleds from sliding during flight.

The upper avionics bay houses an Arduino Uno, SD card reader, pressure transducer, and 9V battery. Tubing links the pressure transducer to the pitot static probe mounted at the tip of the nose cone. Pressure data is recorded in the SD card and will be analyzed post-flight using the isentropic equations to obtain velocity.

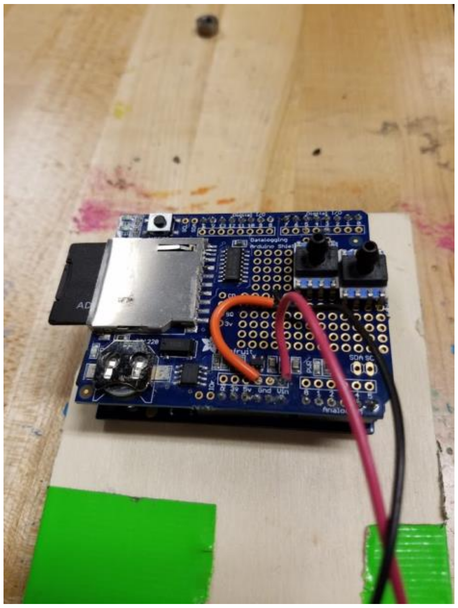

Figure 7. Image of upper avionics bay

On the lower avionics bay, one Stratologger altimeter and one 9V battery are secured 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, an Arduino Uno, 11.3 V LiPo battery, and pressure sensor are used to control the solenoids which control the active drag. The solenoids are directly wired to the Arduino. Power runs from the Li-Po battery to a switch located on the switchband and then to the Arduino. The layout of the components are shown in Figure 8.

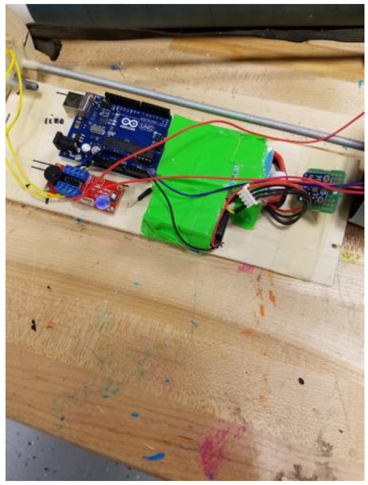

Figure 8. Image of lower avionics bay

The active drag system consists of two rotating fins located 21 in from the base of the rocket. The fins are a trapezoidal shape with a root chord of 7 in and tip chord of 5 in. They are 2.7 inches wide and are constructed out of fiberglass that is 0.125 in thick. The rotation point of the fins is located about 5 in below the center of gravity of the rocket after motor burnout for both motors.

When not activated, the fins are stowed such that they run parallel to the rocket body in order to reduce drag. The drag system will be activated after motor burnout and will be deactivated and returned to initial configuration before apogee. Upon activation, the fins will pivot 90° on their center axis becoming aligned perpendicular to the body tube. This will increase the surface area and consequently the drag on the rocket. The fins and attachments are sturdy enough that they will not fracture or tear off the rocket body when activated. Each fin of the active drag system is attached to a rod running into the rocket and attached along the centerline of the rocket to a 3D printed “doughnut”. Each rod has three protrusions offset by 90°. These protrusions will be used in conjunction with solenoid locks to rotate the fins in 90° intervals. Torsion springs will help facilitate the rotation of the rods in opposing directions. This will prevent the rocket from drifting laterally and, more importantly, from tumbling about the lateral axis as the fins rotate. By turning the fins in opposite directions, stability will be maintained and the rocket will not break apart as the active drag is applied. The solenoids are secured to the outside of the booster frame. When motor burnout occurs, the bottom solenoid will be released to permit the rod to rotate 90° and be stopped by the top solenoid. At apogee the bottom solenoid will be activated again and the top released. This will once more allow the fins to rotate 90°. The solenoids are powered by the Arduino and the solenoid releases will be triggered by altitude data derived from pressure sensor readings.

1.2 Construction Techniques

1.2.1 *Upper Airframe Construction*

Construction of the upper airframe began with the assembly of the pitot probe in the nose cone and attaching the shock cord to the nose cone. In order to fit the probe into the nose cone, a drill was used to make a hole in the tip of the nose cone that was of slightly larger diameter than the probe. A dremel was then used to remove the bottom of the nose cone so that the team could easily set up and access the probe. This, of course, created the issue of where to attach the shock cord in a secure, safe fashion. To overcome this problem, team members 3-D printed a bulkhead that would fit into the bottom of the nose cone and that could be attached to the rocket body using a threaded rod through the center with two nuts on the outside of the entire rocket body. This allowed the nose cone to be securely attached to the rocket body so that the shock cord had a sturdy surface to attach to. The nose cone assembly is shown in Figures 9 and 10 below.

Figure 9. Fully assembled nose cone in airframe

Figure 10. 3-D printed bulkhead

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 of 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.

1.2.2 *Coupler Section Construction*

To allow for easy installation and removal of the parachutes, a combination of eye bolts and quick links was 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 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 coupler was inserted into the upper aircraft and booster sections. Four evenly spaced holes were drilled through the coupler and airframe for the shear pins.

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 sized to ensure a tight fit in the rocket. Once the components were marked out on the plywood, holes were drilled for the Arduino and Stratologger. Duct tape was used temporarily for the test flight to secure the batteries to the sled.

Black powder charges were used to eject the parachutes. On each bulkhead, there were two ejection canisters and a terminal block. To test the black powder ejection charges, 2 g of black powder in a cardboard tube was secured 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. Once the canister for the drogue was safely filled, the same procedure was done for the main parachute using 2 g of black powder. The team tested the black powder charges prior to the test flight and both ejection charges were successful.

1.2.3 *Booster Section Construction*

The motor mount was assembled as the first step in the construction of the rocket. First, 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 and the middle ring aligned with the top of the fins. The bottom ring would be inserted after the attachment of the fins. 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. Following the attachment of the fins, outlined in Section 1.2.4, the third centering ring was epoxied flush with the base of the fins.

The active drag system will also be housed in the booster section. This process will involve drilling two holes through the rocket an inch above the top of the motor mount. Four solenoids will be epoxied on the outside of the airframe, one above and below each hole. This will serve as the location for the active drag system.

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 roughed up with sandpaper and an exacto knife to allow for better adhesion between the fiberglass and epoxy. 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 designed to leave room in the inner corners for the epoxy fillets on the outside of the rocket. The fin jig can be seen in Figure 11.

Figure 11. 3-D printed fin jig

Once the fin jig was created, the team began to epoxy the fins on. The outer fillets were done two at a time, each set epoxied at least 6 hours apart to allow proper drying time. This way we avoided the epoxy dripping all over and ensured the most secure bond possible. The fins are shown in Figure 12 drying in the fin jig.

Figure 12. Rocket with epoxy fillets setting

1.3 Stability Analysis

OpenRocket was used to simulate stability margin caliber for the flight when the active drag is stowed. With the J415W, the lowest stability margin is 1.87 and occurs at launch rail clearance at 0.28 s. This is still well above the minimum stability margin of 1.00 to fly safely. The highest stability margin is 3.02 and occurs at motor burnout. This stability margin is well below the maximum stability margin of 5 required for safe flight. With the K1103X motor, the lowest stability margin is 2.04 at 0.16 s and the highest is 3.11 at motor burnout. After motor burnout the stability margin slowly decreases, until a sharp drop near apogee, where the stability margin drops to 1.1. This phenomenon is most likely a result of a discontinuity in the simulation, not the physical features of the rocket, and therefore not likely an accurate prediction for stability near to apogee. The values of the stability margin throughout the flight can be seen in Figures 13 and 14.

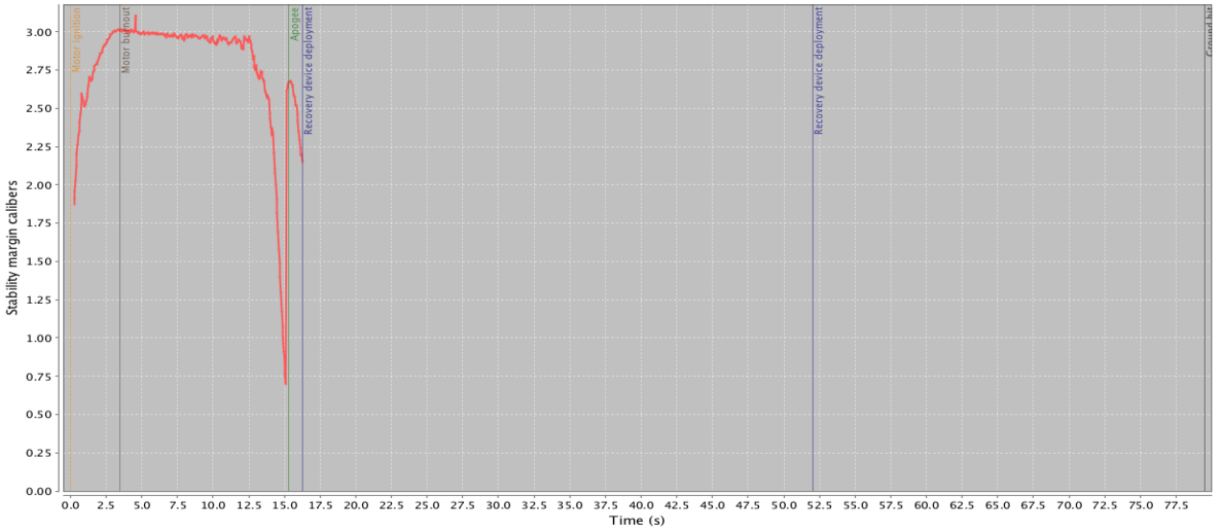

Figure 13. Stability margin versus time with J415W motor.

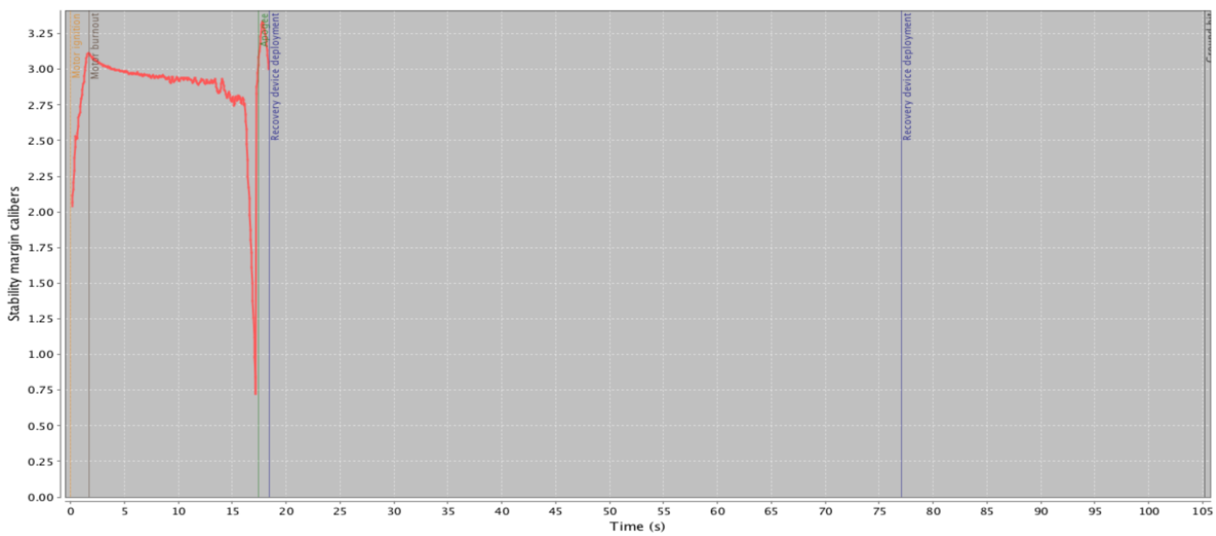

Figure 14. Stability margin versus time with K1103X motor.

1.4 Safety

The rocket has been designed with safety in mind at all times, especially during the flight and recovery processes. During launch, the speed of the rocket when it is 8 ft up the rail far exceeds the minimum requirement for a safe launch. Similarly, the exit velocity of the rocket off the rail is greater than the minimum speed requirement, allowing for a stable, vertical flight and minimizing risk due to an unpredictable flight path. The parachutes will be deployed at appropriate times to ensure that the landing speed is safely under 24 ft/s. A radio tracker will allow the team to locate the rocket after flight in a timely manner, ensuring an efficient launch and recovery.

Hazardous materials have been used during construction, testing, and launch of the rocket and proper handling of these components was imperative. The materials that presented the greatest hazards were the flammable motor, epoxy, black powder charges, and fiberglass, all materials which at least one team member has experience working with. The experienced team member(s) taught the rest of the team the proper handling techniques and safety procedures; they also oversaw the team's use of these materials. Flammable materials were always handled according to their specific instructions and were carefully kept away from any source of open flame or other potential spark. A fire extinguisher was kept on hand at all times. Gloves were worn whenever the team was working with epoxy or other potential skin irritants. Any parts that have been epoxied and are drying were labeled as such and kept in a separate area to avoid any accidental contact with the chemicals. Black powder was stored carefully and according to specifications; extra precautions will be taken when measuring to ensure precision. Fiberglass was always handled with gloves to avoid splinters and masks were worn during cutting to avoid inhalation of fumes or particles. Safety glasses were on hand at all times for protection when necessary.

Prior to and after launch of the rocket, team members will take precautions and adhere to the predetermined procedures and safety codes. The team will first go through all of the components and ensure that each part is present and in working condition. After the preliminary check, the team will begin assembly of the rocket, taking extra care to implement all of the parts safely and securely. The team will then survey the launch area to account for any unevenness in the ground and counteract it to ensure a safe, vertical flight. Once launch is complete, the team will scan the area to confirm that it is safe and then recover the rocket. The aforementioned radio tracker in the rocket will allow the team to quickly locate the rocket. Upon finding the rocket, the team will check for any parts that may have come loose during flight, or on impact, and secure them before bringing the rocket back to the setup area. At this point, the team will then begin the procedure again for the second flight.

1.5 Recovery

The drogue parachute is 23.5 in. in diameter. It is attached to a 20 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. Four 4-40 nylon shear pins are used to secure the booster tube to the coupler, and 2 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 14.87 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 bulkhead 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 2-56 shear pins are used to hold the upper airframe to the coupler, and 2 g of black powder is used for the ejection charge.

1.6 Design changes

The largest design change was within the avionics, where only one Stratologger will be used instead of two due to lack of necessity. The Raven3 altimeter will also not be used, but rather a pressure sensor to trigger the releases of the solenoids. The shear pins used were also changed from the originally planned 2-56 to the 4-40. This was due to the large predicted force on the booster section when the active drag fins are activated.

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 rocket for test flight

Flight Characteristics	
Mass (on pad)	192 Ounces
Motor	J415W
Max Altitude	3868 ft
Max Velocity	650 ft/s
Time of Flight	99 s
Landing Descent Rate (w/out main parachute)	40 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 55 ft/s. The flight path was very straight with minimal deviations from vertical flight.

2.2 Coast Phase Assessment

During the coast phase the rocket gradually transitioned into a horizontal flight path until deployment of the drogue. This was a characteristic coast phase for most rockets.

2.3 Recovery System

The drogue deployed at apogee, as programmed by the Stratologger. The main however did not deploy at 500 ft AGL. Upon inspection post-flight, the ejection charge had gone off at 500 ft, but the force was not enough to separate the coupler from the upper airframe, despite successful separation during ground testing. This was likely due to leak in the upper airframe that will not be present during the competition. There is a hole for a rotary switch in the upper airframe for the upper avionics bay. Since that avionics package was not being flown however, there was nothing plugging the hole, so the pressure was not allowed to build up and separate the stages. The rocket landed at 29 ft/s, which is higher than the maximum landing velocity, but this is due to the lack of deployment for the main parachute. 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.

2.4 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 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 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. Team with rocket on launch rail, prior to launch

Figure 16. Rocket post-flight for test flight.

2.5 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, team members opened the coupler section to assess damage and to determine why the parachute had not deployed. It was determined that there was a leak in the upper airframe, an issue that will be remedied for the next launch. The other issue that was discovered post-launch was that the pitot probe had been bent upon impact. Fortunately the electronics themselves had not been damaged. The probe itself is very inexpensive, so the team will have backup probes for the future that can replace a potentially damaged probe post-flight.

3. Test Launch Analysis

3.1 Peak Altitude

The rocket reached a peak altitude of 3868 ft AGL. The plots of the altitude and velocity of the flight can be seen below in Figure 17. This is well above the 3000 ft minimum before heavy penalties are applied to the score during competition. The maximum altitude was predicted to be 3572.2 ft using OpenRocket, which is slightly below the actual altitude from the test flight. This is likely due to OpenRocket accounting for the stowed drag fins causing additional surface friction to slow down the rocket and decrease apogee, when in reality these fins were not on the rocket during test flight. The predicted altitude and velocity plots are shown in Figure 18 below.

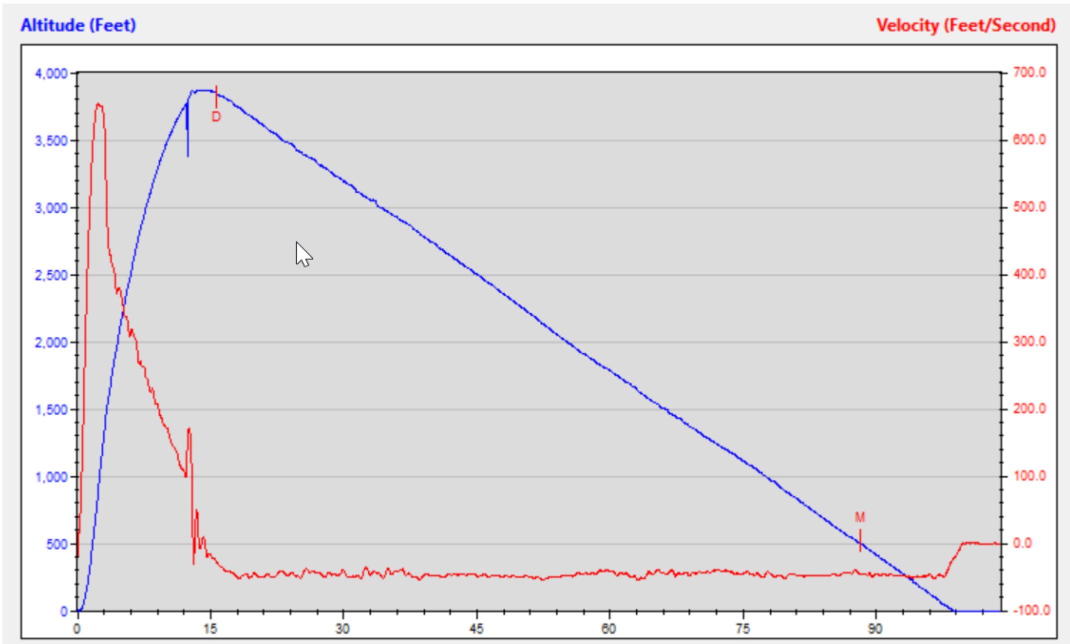

Figure 17. Altitude and velocity of the test flight

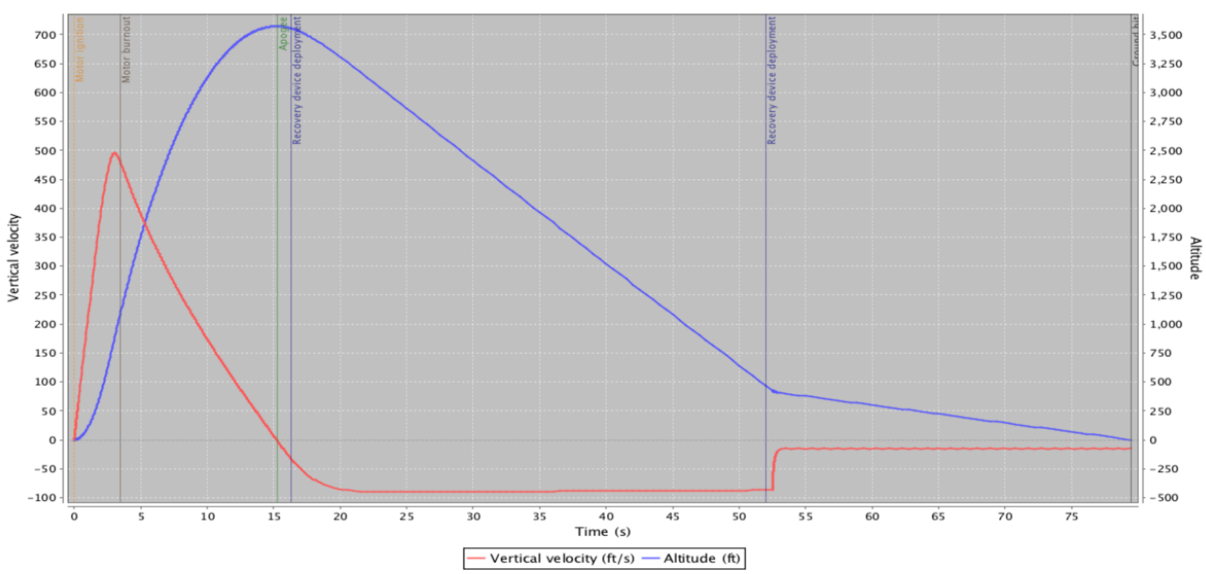

Figure 18. Predicted altitude and velocity for test flight

3.2 Peak Velocity

The Stratologger shows that the peak velocity for the flight was 650 ft/s or Mach 0.58. The peak velocity occurred 3 s after motor ignition. With the peak velocity being below Mach 0.6, supersonic flow across the body is unlikely. There may be isolated spots of transonic flow, but the rocket was constructed to withstand these flows. The OpenRocket maximum predicted velocity directly after motor burnout was 495.43 ft/s. Therefore, it can be seen that the rocket not only flew to a greater altitude than predicted, it also reached a much higher peak velocity. This is likely because the rocket prepared for test flight did not include the active drag package, and was therefore lighter and had less surface drag than what was predicted in OpenRocket.

4. Future Work

The active drag and velocity measurement package still need to be integrated into the rocket prior to the competition, along with the up and down view cameras. Most of the rocket's weight that will be flown at the competition was present during the test flight, so a major shift in the cg is not expected. Otherwise, the rocket had a very good test flight and the team sees little that needs to be improved on apart from what still needs to be implemented.

5. Budget

The project budget includes parts that the team needed to buy and that were used. Parts that were already owned by the team or mentors and parts that were purchased but not used 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. The budget is shown in Table 2.

Table 2. Women in Aerospace Space Grant Team Budget

Component	Cost
Eye bolts	$21.12
Blue tubes	$77.90
Nose cone	$21.95
Aerotech K1103X	$112.99
Aerotech J415W	$92.99
Coupler tube	$21.90
bulkheads	$17.50
Pitot probes	$32.76
Pressure transducer	$41.33

Arduinos	$36.20
Stratologger	$49.46
Epoxy	$38.25
Centering Rings	$17.02
Terminal Blocks	$10.23
Canister Caps	$6.30
Fiberglass	$81.00
9V batteries	$14.89
11.3V LiPo batteries	$20.90
Plywood	$10.39
Parachute protectors	$16.30
Balsa wood	$9.00
Rail buttons	$4.65
Rotary switches	$29.79
Battery leads	$0.74
24 gauge wire	$17.99
Paint	$13.96
Rods	$14.00
Torsion springs	$10.00
Solenoids	$39.80
Shear pins	$9.30
Rear closure	$42.75
Aft closure	$48.15
Motor retainer	$31.03
Motor mount tube	$23.95
Motor casing	$128.40

Reload adapter system	$58.84
Registration fee	$400.00
Travel Costs	$1000.00
Total Project Cost	$2623.73

6. Conclusions

Since the preliminary design was submitted in March, various design changes were made in order to improve rocket construction during the building process and to improve flight performance. The largest change was switching motors due to the supplier shortage, although fortunately this had a relatively small effect on the overall design of the rocket. Throughout the construction and testing process, proper safety measures were followed by all team members in order to minimize injury. While the active drag and velocity measurement systems were not flown, the barebones rocket performed exactly as desired save for the deployment of the main parachute. Valuable information was gained from the test results and necessary measures are being taken to prevent errors from occurring in future flights.