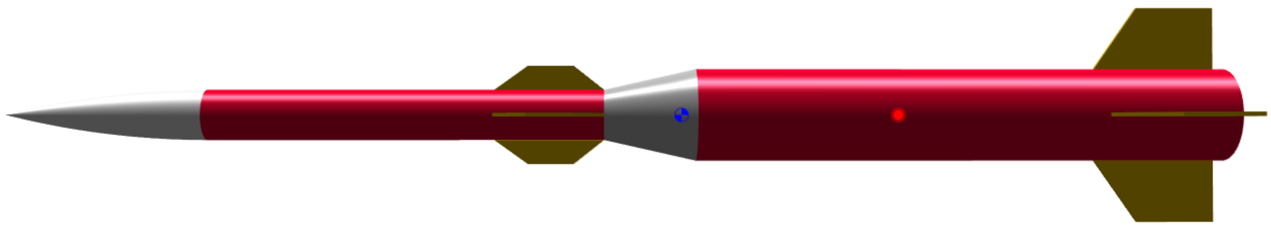

Flight Readiness Report

NASA Space Grant Midwest High-Power Rocket Competition

The Ohio State University Rocket Team

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Summary of Design

The rocket is divided into three main sections that separate at some point in flight. These are the booster stage, the dart, and the transition piece and are shown along with some of their significant sub-components in Figure 1 on page 4. The dart will separate from the rest of the rocket at motor burnout, and the transition piece will remain attached to the booster stage until the parachute ejection charge fires.

The booster stage is the largest section of the rocket, with 7.6 cm diameter body tube, and a length of 46.7 cm. A 54mm motor mount from Apogee Components will be placed inside two centering ring at the base of the booster stage. The booster stage also contains a 61 cm diameter parachute that will deploy when the ejection charge in the motor is fired. Para cord is used to connect the parachute to the booster stage, with one end attached to the uppermost centering ring and the other being attached to the transition piece. Finally, one set of four fins is attached 0.8 cm above the base of the booster. The fins are trapezoidal with a surface area of 41 cm^2.

The transition piece is the middle section of the rocket and keeps the booster and the dart together as well as holding all of the electronics for the booster. The transition piece is made of a cylindrical tube at the bottom, closest to the booster, and a cone at the top. The cylinder is 7.6 cm in length and has a diameter of 7.6 cm, the same diameter of the booster, while the cone has a length of 7.6 cm, an aft diameter of 7.6 cm, and a fore diameter of 4.18 cm. At the fore of the cone is an ogive shaped depression into the cone for 3 cm with the top of the cone containing 4 slits where the fins from the dart will fit into. The uppermost section of the cylinder is used as an airbrake with two slots cut into the walls of the cylinder. Once the dart separates from the booster, two fins will be deployed through these slots via servos that rotate the ends of the fins outwards. The wires of these servo motors lead down through a quarter inch bulkhead into the electronics section. Inside of the electronics section is an altimeter, accelerometer, and gyroscope. The electronics compartment is made up of two bulkheads connected and supported with bolt screws. A screw hook at the bottom of the lowermost bulkhead is used to attach the other end of the para cord to the transition piece. After apogee, the motor ejection charge will separate the transition piece from the booster section and the parachute will be pulled out of the booster stage and deploy.

The dart is the uppermost stage of the rocket. It will separate from the booster at motor burnout using the air brakes from the transition section. The dart consists of a nose cone, a body tube, fins and a boat tail. The boat tail is ogive and has size of 3 cm in length and was designed to fit loosely into the transition piece and hold the dart in place until separation. The body tube has length of 44.4 cm and an outer diameter of 4.18 cm. The nosecone of the dart is ogive of length 16.8 cm with a base diameter of 4.18 cm. The dart has four fins with a surface area of 12.8 cm^2. The dart has an electronics compartment, an ejection charge, a parachute, and a rip cord. The electronics compartment is on top of the boat tail and consist of two bulkheads connected by thin balsa wood supports and is screwed into the walls of the dart. The electronics compartment contains an altimeter, an accelerometer, and a gyroscope. Attached to the topmost bulkhead is an ejection charge for the dart recovery system that is made of 1 gram of gunpowder and a small copper thimble. A rip cord of length 1.33m connects the dart to the parachute and nose cone of the dart.

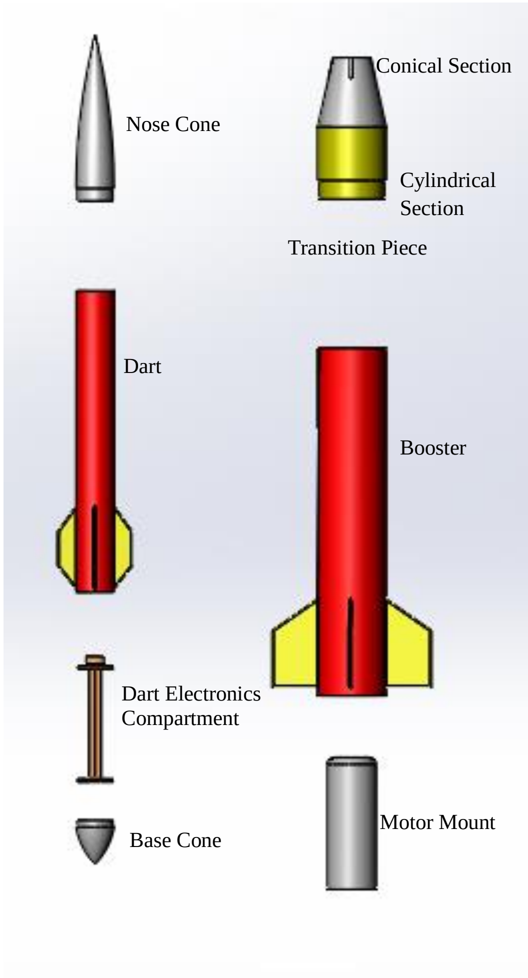

Figure 1: Components of Final Rocket Design

Budget

Current budgeting estimates are projected to cover only the costs of materials to create two versions of the current rocket design: the flight-test prototype and the competition rocket. Price estimates of individual components have been based off of past material costs for past projects of The Ohio State University's Rocketry Team as well as maximum pricings for necessary electronic components to be included in dart and booster sections. Travel expenses for the team as well as overlapping budgeting for tools and equipment are not included in the below tables.

There were only three changes in our budget as seen below. They are the last three items in table 1: the replacement nosecone, the retainer ring and several bolts and screws. Due to lost or broken material from the test launch this budget may increase significantly over the coming weeks.

Table 1: Projected Budget of Midwest Competition

Minnesota Competition Budget Projections			
	Unit Price	Units	Total Price
1 Fiberglass Sheets Fins	$120.00	1	$120.00
Custom electronics	$150.00	1	$150.00
Hobby Grade Altimeters	$150.00	1	$150.00
Fiberglass Body Tubes costs	$200.00	1	$200.00
Parachute Modules	$120.00	2	$240.00
Composite Nose Cone	$80.00	1	$80.00
Camera System	$65.00	1	$65.00
Motor Casing	$54.00	1	$54.00
Motors for Test Launches	$53.00	2	$106.00
Hotel 3 Nights (2 rooms)	$200.00	3	$600.00
Van Rental Fees			$1,600.00
Nose Cone	$36.73	1	$36.73
Assorted Screws, Nuts and Bolts	$14.47	1	$14.47
Retainer Ring	$75.58	1	$75.58
Total Cost			**$3491.78**

Table 2: In Kind Costs of Competition

In Kind Costs			
Sources	Rate	Estimated Cost	Reasoning
OSU Campus Lab 1 (Bolz 112)	$10/hr	$1,500	25 weeks, 6 hours a week
OSU Campus Lab 1 (Bolz 114)	$10/hr	$1,500	25 weeks, 6 hours a week
Faculty Advisor (Time support)	$40/hr	$1,000	25 hours at $40/hr
Lab Tool use/Maintenance	$50/Semester	$100	2 semesters
	Total	$4,100	

Construction of Rocket

The body tubes of the rocket, the booster, the body of the dart and the cylindrical part of the transition piece, were made by cutting cardboard tubes to the designed size. These cardboard tubes were then wrapped in three layers of epoxy soaked fiberglass and allowed to harden. Excess fiberglass was removed with a dremel and by hand sanding the tubes. Centering rings and fins for the booster were made by laser cutting quarter inch wood. The two centering rings were secured using epoxy at the top and bottom of where the fins would eventually be. The booster fins were layered in two layers of epoxy soaked fiberglass, and, after hardening, were sanded down to their appropriate size. A thin fiberglass motor mount was then put in the booster stage by gluing it to the centering rings with epoxy. The booster stage had 4 slots cut into the base of the body tube using a dremel, and the fins were placed into these slots and epoxied to the motor mount and the sides of the booster. Finally, the rip cord for the recovery system was epoxied to the top of topmost centering ring.

Figure 2: Body Tube Coated in Fiberglass Drying

The transition piece was made from the top down. It began by designing the shape of the cone section of the transition piece and 3-D printing it. Following this the airbrake system was built initially as part of the body tubes wrapped in fiberglass. Two 120 degree slots were then cut out of the tube that the fins would come out of. A laser cut bulkhead was epoxied below the slots and two servo motors that were attached to their laser cut fins were epoxied in so that when the motors were activated, the fins would rotate out of body tube and cause extra drag on the rocket. Just below the airbrake is the electronics compartment for the booster. Still housed in the fiberglass body tube, the electronics compartment consists of the two bulkheads that are connected with two parallel bolt screws. This allows the compartment to be opened right before launch and for the electronics to be placed inside. At the bottom of the bottommost bulkhead is a crew hook where the other end of the para cord is connected to.

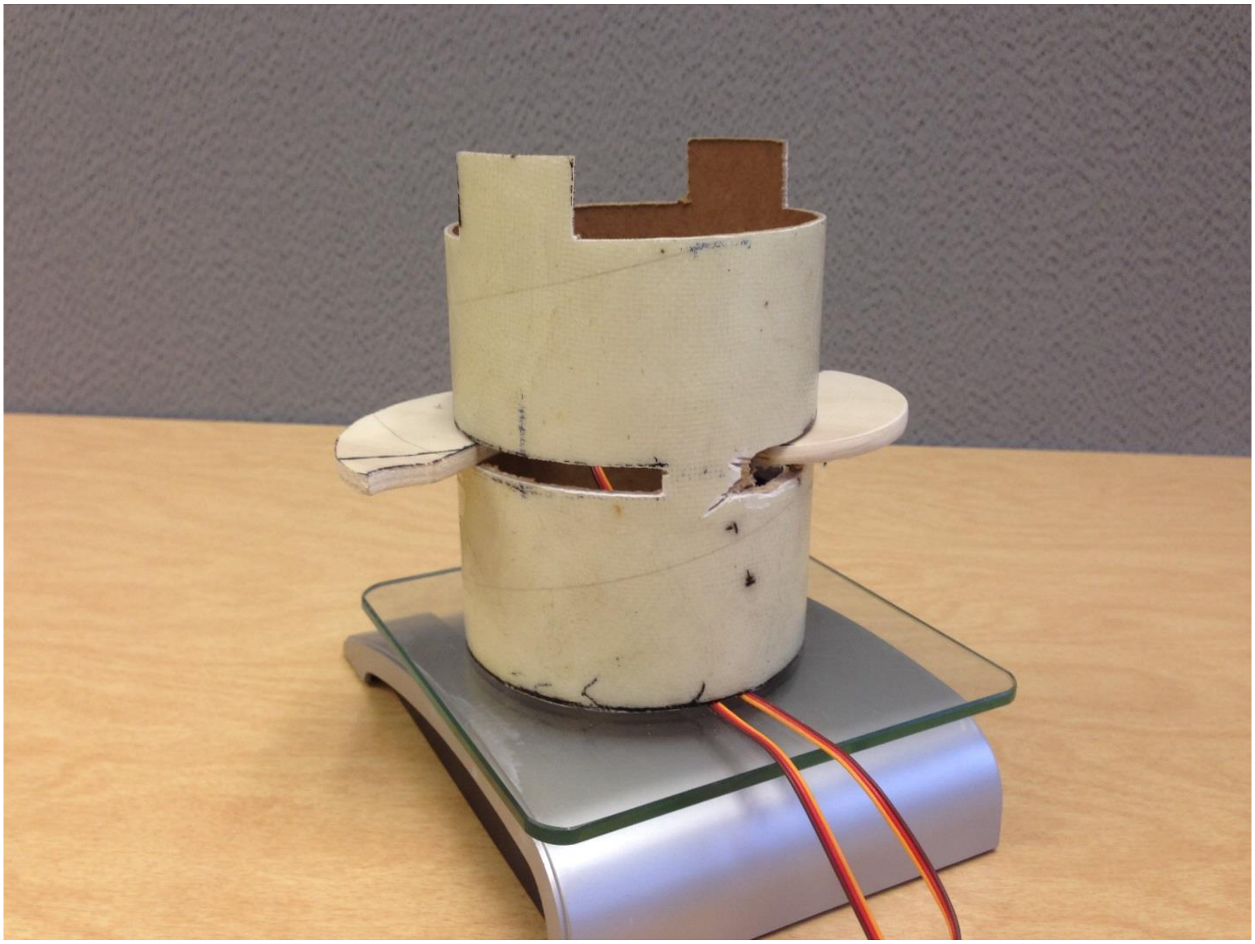

Figure 3: An Early Prototype of the Transition Piece with Fins Deployed

The dart of rocket was made from the bottom up. The boat tail of the dart was designed in conjunction with the transition cone and was 3-D printed. Four fins were laser cut out of quarter inch wood and were layered with two layers of epoxy soaked fiberglass. Along with the fins, three rings with additional slots for fins were laser cut. These rings were fit over the body tube and held the fins in place while they were epoxied to the tube. The electronics compartment was made by epoxying 2 half inch bulkheads to the base cone. Two balsa wood struts were cut from dowel rods and epoxied to the bulkhead attached to the base cone. Finally, the last bulkhead was attached with epoxy to the other end to the struts. The electronics compartment was attached to the body tube of the dart by drilling two holes in the base of the body tube and then screwing them together. This allowed easy access to the electronics compartment. An ejection charge was placed on top of the electronics compartment by drilling a small hole through the copper container, used to hold the charge, and the bulkhead and screwed into place. The rip cord for the parachute was attached to the top bulkhead and led to the 61cm diameter parachute and continued until it attaches to the nosecone. The nosecone was purchased from Apogee Components and sits on top of the dart with only friction holding it in place. 300 grams of lead shot and epoxy were added to the nose cone to bring the center of gravity up as designed.

Figure 4: Complete Dart atop the Transition Section

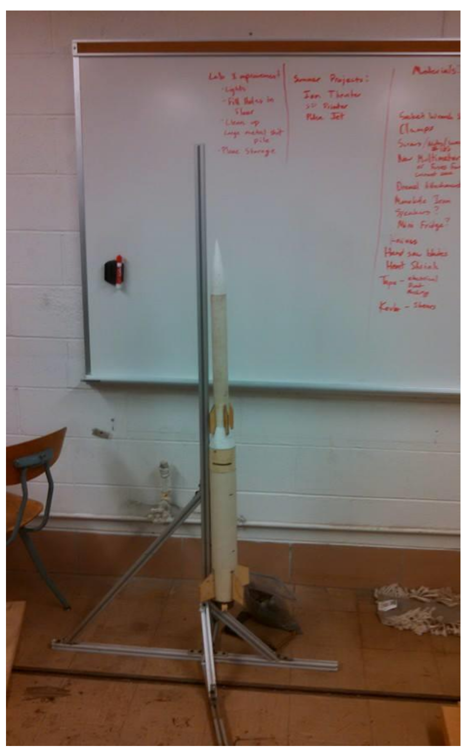

Figure 5: Fully Assembled Rocket

Stability and Safety

The stability of the rocket was determined using Open Rocket software. Open Rocket uses two methods to calculate the static and dynamic stability of the rocket. The first, static, is found in the main construction of the aircraft and represents the static margin between center of gravity and center of pressure in terms of diameters of rocket. As long as the center of pressure remains behind the center of gravity, any displacement of the rocket from its flight path will create a corrective moment to reorient the rocket towards the direction it's moving. However, for the rocket to be able to reorient in a time that the thrust from the motor does not significantly affect the velocity vector of the rocket, while not correcting so quickly that it overcorrects the other way. The generally accepted value for this is 1 to 2 diameter lengths between the Cp and the Cg. Before launch our rocket has a stability of 1.29 and after launch value of 3.24. However, at this point, the rocket separates into two pieces and the dart has a stability of 1.95 while the booster has one of slightly greater than 1. Open Rocket models the dynamic stability inside a flight simulation. The plot below shows lateral distance, stability margins and pitch rate from the Open Rocket simulation of the flight. The lateral distance remains small throughout flight indicating that it remains stable through flight and accelerates vertically. The pitch rate always returning to 0 and the static margins remaining around 1-2 show that the rocket is dynamically stable in flight.

Preparing the rocket for launch will include the packing of the parachutes into the body tube sections with protective wadding. Once assembled, the rocket motor will be slid into the aluminum motor housing and secured into the motor tube. After the rocket is secured to the launch rails, the electronics devices will be armed to prepare for data collecting. Only after the rocket has been secured to the launch rails will the rocket ignitor be placed inside the motor and discharge leads connected to the launch station. The custom IMU recorder will be set to record data following the thrust of the motor start up and will record until they have sensed that the rocket has returned to the ground. Upon completion of the launch, the rocket will be recovered and the saved data log file will be recorded to a computer for analysis and comparison to estimated results. The motor tube will be extracted from the booster upon cooling down and will be cleaned with rubbing alcohol in preparation of the next anticipated launch as the electronics batteries are recharged and memory reset.

Recovery systems of the current design include the same equations of motion used for the ascent but will be using the design drag coefficient of the included parachutes chosen. During descent, the rocket must achieve a safe landing speed that will not damage components of the rocket so it may be reused in another launch. The dart and booster parachute design holds a Cd value of 0.8 and a reference area of 0.2831 square meters. Computing the descent of the rockets components with their respected masses at apogee (where initial conditions for the ODE system are at apogee and zero velocity) will result in the computation of the darts velocity at zero altitude. Below are figures produced by Open Rocket using these methods. Both the booster and the dart landing velocities fall within 15 to 18 feet per second which are considerably safe velocities in regards to the structural integrity of the rocket.

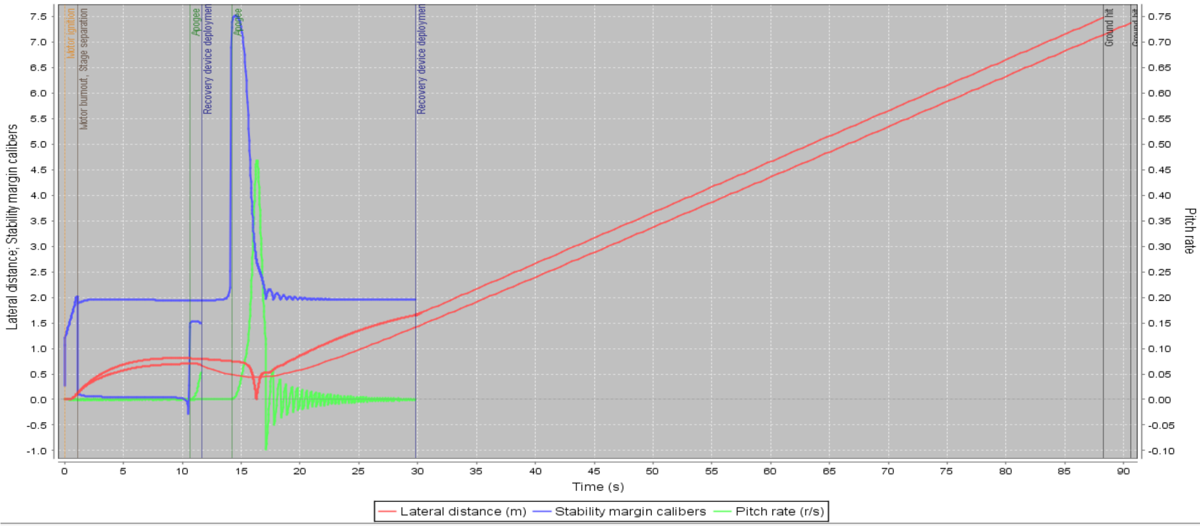

Figure 6: Dynamic Stability Graph

Changes from Previous Design

Very few changes were made in regards to the initial design of the rocket. The major change is that the airbrake system was selected. The group, without being able to perform tests of each system, decided to make the conservative choice to choose a fin deployment system where small fins were rotated out of the rocket by servo motors, through slots in the side of the rocket to slow down the booster during and after separation, until retracting when the parachute deploys.

Test Flight Results

The test flight results were different that than the simulated results for both the booster and dart. First, it should be noted that the electronics for the dart, the dart, and the booster were not recovered after testing. After the test launch, the dart and booster (that was separate from the parachute during the ejection charge) was searched for but was never found and recovered. Therefore, there is no data for the dart after the separation of the booster with the dart. Importantly, the transition piece held the electronics for the booster, and this was the only component recovered after the test launch.

An analysis of the recovered data proved promising for the booster apogee reached. The simulated apogee for the booster component was 1200m, while the actual apogee was recorded at 1100m. Such small difference in results with the quickly gusting wind suggests both positive and negative consequences. First, a higher apogee for the booster would suggest that the dart also reached a higher apogee, which is one of the aims of the project. However, it is not possible to make this conclusion because the dart and its corresponding electronics data were never recovered. Next, a higher apogee for the booster also suggests that the air brake system was not as effective as simulated. It is thus possible that the final score for the separation of the apogee of the dart and booster would be lower than expected because the air brake system did not lower the apogee as much as intended. Though, it was noted that five minutes before the launch the air brake system was tested and worked as programmed, therefore it is unlikely that the system failed to deploy altogether during launch.

Figure 7: Test Rocket upon Launch

The vertical acceleration graph shows that the motor burnout occurs at about 1 second, as expected. The vertical acceleration seems to be much too small compared to the other data for the booster section though the data appears to have approximately the right shape as its peaks are all about in the right location. The error seen in the acceleration graph is likely just a sensitivity issue that will need to be corrected between the test launch and the competition. During this same time period the velocity spikes upwards rapidly and the rocket rises quickly in altitude. These three graphs show that the rocket launched successfully during the first second.

The booster proceeds to coast on a parabolic arc to its maximum altitude of 1100m with an acceleration starting to make its way to one G as the drag force falls since the speed of the rocket falls. Additionally, the velocity of the falls linearly until it reaches a value of 0 at 16 seconds. Once again, the booster performs as expected.

The separation of the booster and dart are hard to measure considering that the dart data is missing. However, it can be presumed, though not proven, that the dart separated correctly from the booster. Since the dart was not found with the transition piece it must have separated at some point. The two most likely times for this is when the airbrakes deploy and create the most drag for the booster relative to the dart and the ejection charge of the booster. If the latter was the case the dart would have been found near the transition piece, which it was not, or would be between the transition piece and the launch area since the booster parachute, which was designed for a much larger weight, only had to carry the transition piece and thus would have drifted further. The launch team searched the 1.5 km between the launch area and where the transition piece was recovered thoroughly and the dart was not found. Because of this, it is likely that the dart separated properly.

For the booster it is clear that the recovery system did not work properly. The rip cord broke off from the booster section and it can be presumed that the booster plummeted to the ground. The parachute for the booster section did properly deploy as the launch team kept visual contact with it until it landed. Once again, it cannot be known if the dart recovery system deployed but it can be presumed since the dart was not found anywhere in the area and the parachute deploying would have carried it far away.

Results of Flight

Figure 8 below shows the simulated altitude vs time for the booster only. On the day of the test launch, there were occasional gusts of strong wind. One of these gusts hit right as our group launched which should cause a significant amount of error as the rocket corrects itself by turning into the wind. With this in mind our rocket performed well and was just slightly below our simulation in results. The major difference between the recorded and simulated results is due to the ejection delay charge being set too high in the simulation. The max delay charge for the I-445 is 16 seconds. The recorded data indicates that the motor correctly fired its ejection charge after 16 seconds, and the descent rates from the recorded and simulated results are equal.

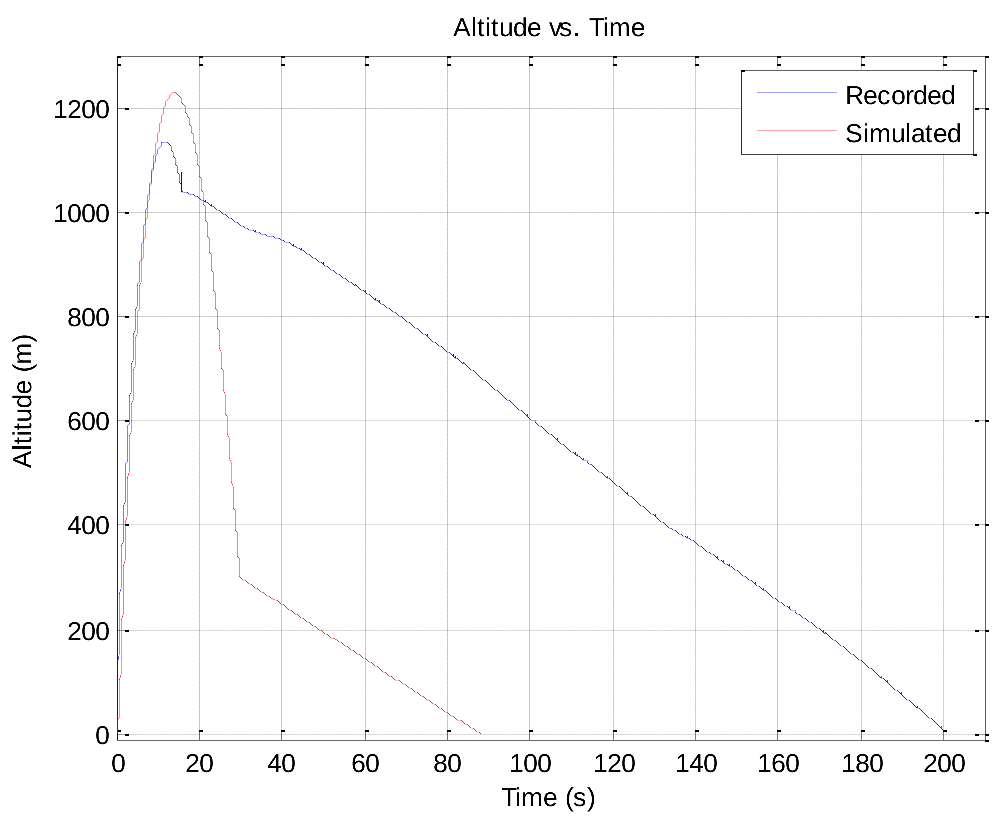

Figure 8: Altitude Real and Simulated

As mentioned previously, the data gathered from the vertical acceleration data seems to be off by several powers in magnitude. However, the accelerometer did record the spikes in acceleration at launch; parachute deployment and landing that were expected of it. This indicates that the error in the accelerometer is merely a sensor problem.

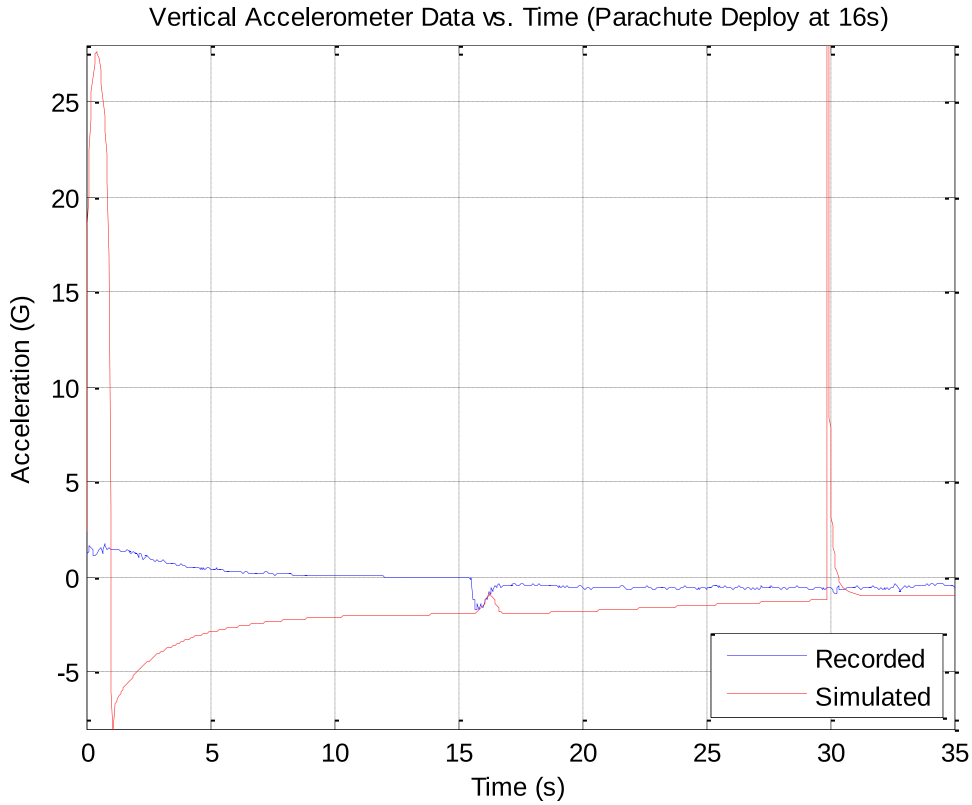

Figure 9: Vertical Acceleration Recorded and Simulated

The vertical velocity of the booster closely followed the simulated results until it hits 16 seconds which is when the recovery system deploys. At this point it experiences a massive spike both positive and negative and then almost immediately jumps to a few meters per second. The massive spike is explained by the shock of the ejection charge firing, having the booster ripped away from the para cord and the parachute deploying. Because the booster fell off of the transition piece, the parachute had much less weight to carry as it fell to Earth. So it is logical that the recorded velocity falls slows down much faster than expected.

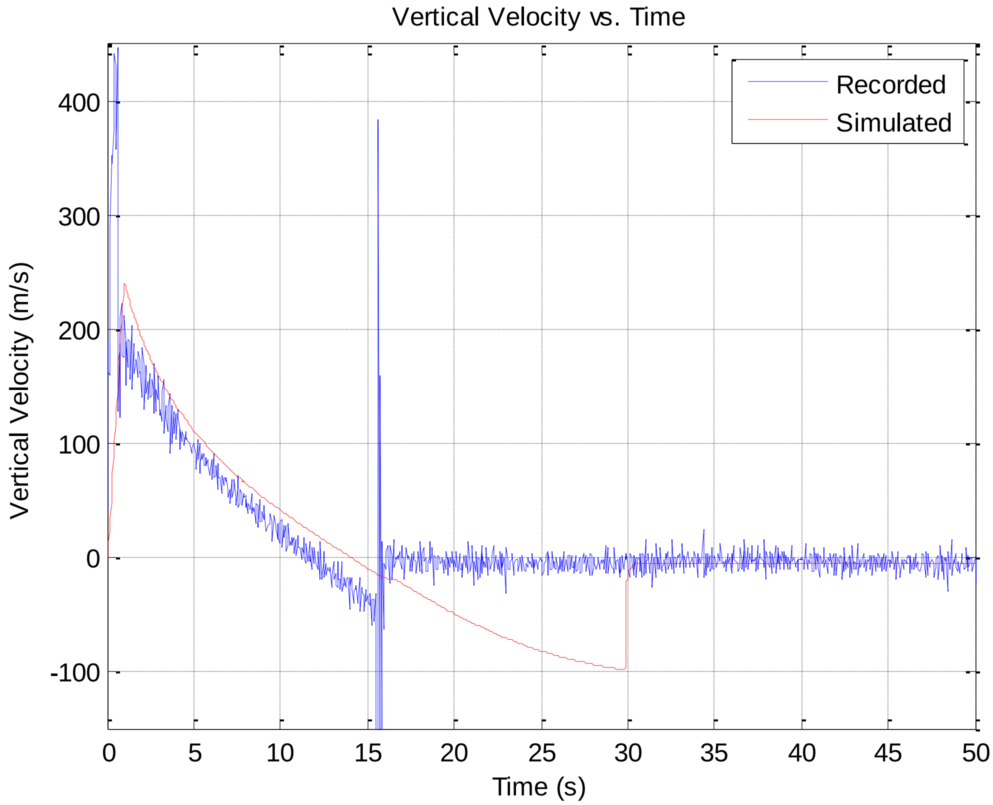

Figure 10: Vertical Velocity Recorded and Simulated

The down facing camera data was not recorded for this launch. The team had plans to rebuild the dart after the test launch so the aerodynamic shield and camera were not placed in until the final version. The three axis rotational data was taken during flight and wasn't stopped till the transition piece was recovered. The graph shows two large spikes in rotation the first being launch, during the acceleration dampens and when the parachute deploys.

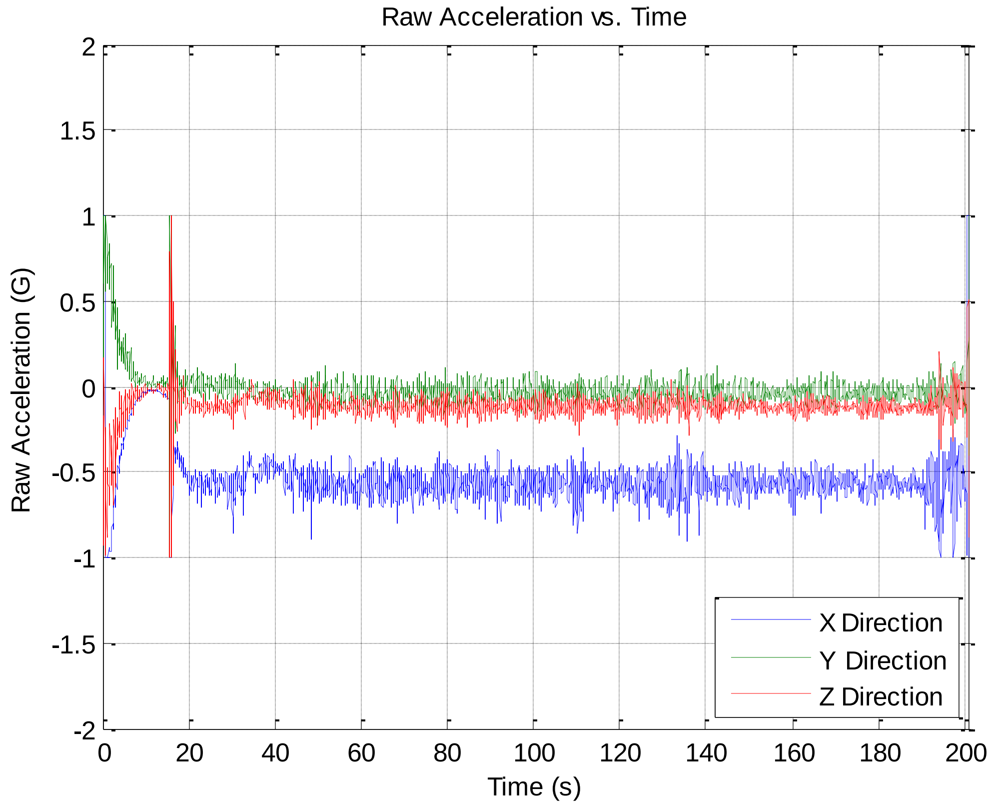

Figure 11: Roll Acceleration over Time for All Three Axes

Table 3: Flight Characteristics

Mass Initially	1859g
Mass Final	1617g
Mass Propellant	333g
Average Thrust	446N
Burn Time	1.07s
Initial Stability	1.29
Dart Stability at End	1.95
Dart Length	61.2 cm
Booster and Transition Length	60.5 cm
Location of Center of Gravity from nose	82.1 cm
Location of Center of Pressure from nose	91.9 cm

Findings and Future Work

The test flight was a perceived success, with a stable launch and flight data collected for the booster. However, the rocket traveled farther than expected in both altitude and lateral distance. After extensive searching, the only section recovered from the launch was a transition piece that connected the booster and dart. Although much of the rocket needs to be rebuilt from scratch, many of the findings discovered during construction and testing can now be applied to the final design.

The first finding was that the booster traveled much higher and farther than expected. The predicted lateral distance traveled for the booster was 75m on a slightly windy day, the actual lateral distance the transition piece covered was 1500m. Although the booster was no longer attached to the transition piece like it was intended, the actual value for lateral distance covered was much greater than anticipated. However, the fact that the booster was no longer attached to the transition piece and parachute means that there was less weight under the parachute. This was the most likely factor that contributed to such a large lateral distance covered by the transition piece.

The second finding was that the method used to secure the booster, transition piece, and parachute together needs to be reworked. For the test flight the method used to secure the booster to the transition piece and parachute chord was a large amount of epoxy. In the final design, a hole will be drilled into the centering rings within the booster and then the parachute chord will be threaded through, tied multiple times, and then epoxied. The final result would be a stronger connection between each part and a stronger possibility that the booster and transition piece will both be recovered safely at the competition.

The third finding was that GPS will be a requirement in all future rocket designs that are to be launched. Consequently, we will not have to deal with the trouble of losing major components of the rocket if launches do not perform according to plan.

The fourth finding was that the entire rocket needs to be remade minus the transition piece and the electronics associated with the booster. Thus, many improves will be added to the design and other aspects will be modified to enhance the quality of the rocket. First, the dart will be remade longer so that it will be more stable in flight due to a higher CG relative to the CP. Also, a longer dart will enable a larger housing for electronics, the addition of GPS components, and additional mass to be placed within the dart.