Flight Readiness Report

High Power Rocketeers

University of Minnesota Duluth

Tessa Bakken, Jordan Gaytan, Cody Graupmann, Erik Klevar, Jade Lecocq, Curt Myers, Joel Stomberg, Chase Warnecke

Advisor: Dr. Ryan Rosandich

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Executive Summary

The 2015 Space Grant Midwest High-Power Rocket competition requires each team to design a boosted dart that will reach maximum altitude and be recovered safely and in flyable condition. The booster has an overall length of 48 cm, has an outer diameter of 5.8 cm, and has a weight of 1240 g. The dart has an overall length of 88 cm, has an outer diameter of 3.2 cm, and has a weight of 680 g. We were able to do a test launch of our boosted dart on Sunday April 22, here we found that our simulations were very close to the actual launch. Our dart reached an altitude of 1712 meters and our dart reached 856 meters. The competition guidelines require teams to have onboard down-looking video footage as well as measure and record rotation about the x, y, and z axis. We accomplished this requirement by housing a USB video camera in a custom designed tail coned fitted into the dart. We also designed a unit to record rotation by wiring an Arduino controller to an inertial measurement unit. During our test flight, we did not record rotation about the x, y, and z axis due to a coding error. However, we were able to calculate the rotation about the z axis from the camera footage. The booster and dart are designed to be stable in all phases of the flight and to be recovered safely. After this flight, we found a few issues with our system that we plan to fix before the competition flight. We plan on changing the code for the Arduino to ensure we can record data during flight, downsizing the booster's parachute to ensure it doesn't float too far away, and enlarging the mirror doghouse device to ensure that we can record down looking footage alongside the booster.

Figure 1: Booster and Dart on Launch Pad

Rocket Mechanical and Electrical Design

The rocket consists of two stages, a powered booster and an unpowered dart, that will separate immediately after motor burnout. The basic dimensions of the rocket are shown in Figure 4, and further details are provided below, beginning at the top of the rocket and working downward.

Dart Dimensions and Specifications

The dart is composed of four major sections, the nose cone (10 cm), the parachute bay (32 cm), the electronics bay (40 cm) and the tail cone (6 cm). The nose cone was purchased from Apogee Rockets, it is made of hollow plastic and is an ogive shape. The parachute bay is constructed of 29 mm Blue Tube (32 mm OD) and houses an ejection canister and an 18 in. elliptical parachute. The electronics bay is also made of 29 mm Blue tube and houses the inertial measurement unit, the data acquisition device, the parachute deployment altimeter, the flight recording altimeter, and the required power supplies. The electronics bay has been provided with breather holes to allow the altimeters to accurately measure the barometric pressure. The electronics are all mounted on a strip of 1.6 mm fire retardant Garrolite that is attached to a steel coupling that provides mass for the dart and connects the parachute bay to the electronics bay. The coupling also carries an eye bolt to anchor the recovery system shock cord. The tail cone is a custom designed 3D printed part that provides a streamlined housing for a down-looking video camera that has a view straight out of the tail of the dart. The dart fins are made of 1.6 mm fire retardant Garrolite and have a root chord of 6 cm, a tip chord of 4.5 cm, a height of 2.2 cm, and a sweep angle of 65 degrees. The fins are keyed into slots in the body tube, attached with epoxy, and reinforced with epoxy fillets.

Booster Dimensions and Specifications

The booster is composed of four major sections, the transition section (13 cm.), the altimeter bay (3 cm.), the parachute bay (16 cm), and the motor section (16 cm). The transition section is topped by a custom designed 3D printed transition cap (see Fig. 2) which mates to the tail cone of the dart and couples into a section of body tube. The body tube is 54 mm Blue Tube (58 mm OD) and also houses a custom designed mirror device. This device allows the video camera in the dart to see downward along the booster body tube prior to separation. The mirror device sits on top of a plywood bulkhead that separates the transition section from the altimeter bay. The altimeter bay is constructed of 54 mm OD coupler tube and sits up against the aforementioned plywood bulkhead. It is enclosed on the bottom with another plywood bulkhead that is attached to the upper bulkhead with threaded fasteners to allow access to the altimeter within. This lower bulkhead also carries a U-bolt that provides an anchor point for the recovery system shock cord. The altimeter bay has been provided with breather holes to allow the altimeter to accurately measure the barometric pressure. The parachute bay is also constructed of 54 mm Blue Tube and houses a

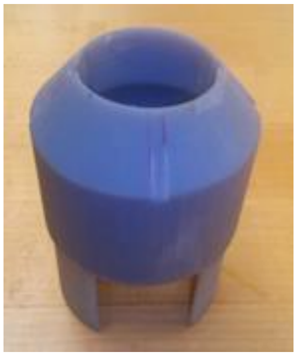

Figure 2: Booster Transition Cap

30 in. elliptical parachute. The parachute bay is separated from the motor section by a custom designed mounting ring, made of ¼ in. aluminum, which is designed as an attachment point for a U-bolt that will be used as an anchor point for the recovery system shock cord. The mounting ring has a generous opening in the center to allow the motor-based ejection charge to deploy the parachute. The motor section is also made of 54 mm Blue Tube and is capped on the bottom by a motor retainer. The booster fins are made of 1.6 mm fire retardant Garrolite and have a root chord of 12 cm, a tip chord of 10 cm, a height of 6.5 cm, and a sweep angle of 60 degrees. Since the motor section must be smooth inside, the fins are surface mounted to the booster body tube with epoxy, reinforced with epoxy fillets, and further reinforced with fiberglass overlays that overlap both the fins and the body tube (see Fig. 3).

Figure 3: Lower booster body and fins

Recovery System Design Specifications

Dart

The dart recovery system parachute is a CFC-18 Chute from Fruity Chutes, an 18 in. (46 cm) elliptical chute with an estimated coefficient of drag of 1.55. It has 8 shroud lines rated for 330 lb. It was chosen since it was estimated to be the most effective chute that would fit in the dart. The Kevlar shock cord used is rated for 300 lb., with a total length of 300 cm. It is anchored at one end to the nose cone and at the other to the body of the dart via an eye bolt. The chute is protected by a 6”x6” square of Nomex wadding which will be attached to the shock cord. The parachute will be deployed at apogee by a black powder ejection canister that will be fired by a Stratologger CF altimeter. This recovery system was designed to provide a dart landing velocity of 6.5 m/sec.

Booster

The booster recovery system parachute is a CFC-30 Chute from Fruity Chutes, a 30 in. (76 cm) elliptical chute with an estimated coefficient of drag of 1.55. It has 8 shroud lines rated for 330 lb. each. It was chosen to provide a terminal velocity between 5 and 6 m/sec. for the booster. The Kevlar shock cord used is rated for 1500 lb., with a total length of 300 cm. It is anchored at one end to a U-bolt mounted on the altimeter bay and at the other to the body of the booster via another U-bolt. The chute is protected by a 9”x9” square of Nomex wadding which is attached to the shock cord. The parachute will be deployed shortly after apogee by the motor-based ejection charge. This recovery system was designed to provide a booster landing velocity of 5.5 m/sec.

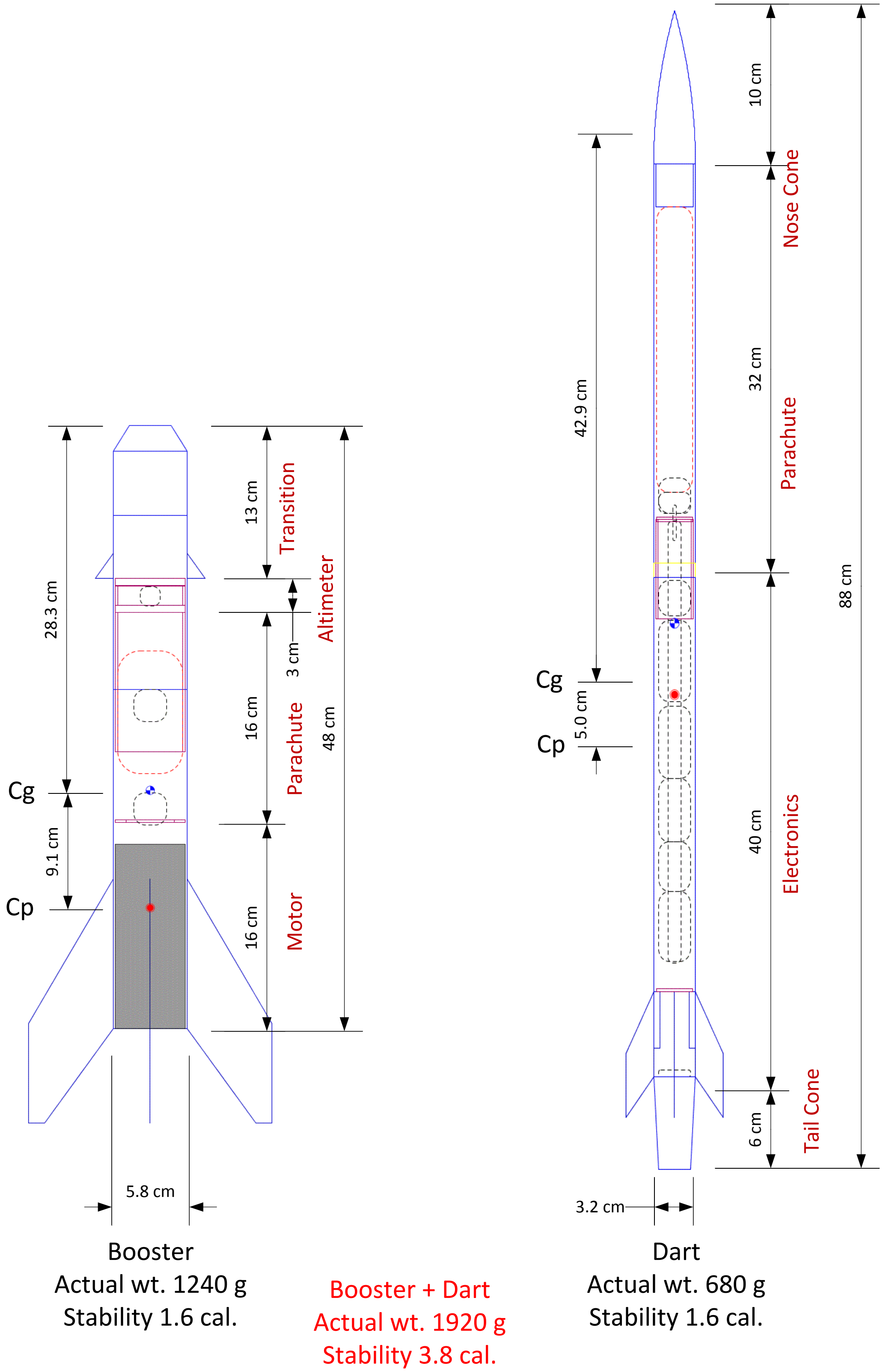

Figure 4: Booster and Dart Actual Dimensions

Booster Construction Techniques

The booster's body tube was created out of 54mm Blue Tube. This durable material has the same inner diameter as the outer diameter of the motor casing to reduce weight and drag. Inside the blue tube are the motor case, altimeter bay, parachute, U-bolt, Kevlar shock cord, and doghouse with mirrors to see outside the booster. Construction starting from the bottom of the rocket begins with the fins. The fins are made out of a strong fireproof material called Garolite. The fins are bonded to the booster with epoxy, hardened putty used as fillets, and fiberglass matting with resin to ensure the fins are securely fastened. This method of holding the fins proved to hold up to the large acceleration of the rocket during the test launch. The motor casing is secured to the booster with an aluminum ring threads that are bonded to the booster using epoxy. Above the motor is an aluminum disk with a U-bolt and a large hole to allow the motor charge to force the booster apart. The disk is epoxied to the tubing. A U-bolt is attached to a wood bulkhead that is fastened to another bulkhead by two bolts. The U-bolt is attached using two nuts on the backside. In between the two bulkheads is the altimeter which is attached to the bottom bulkhead of the altimeter bay using Velcro. The shock cord is connected to both separate parts of the booster at the U-bolts. The two separate parts of the booster are held together by a friction fit. The coupler tube is epoxied to the lower outer tube allowing the top tube to slide off. The doghouse is a snug fit inside the upper tube and is epoxied to ensure it will not come loose. This mirror holding device and the transition section were created on a 3D printer. The transition section is fastened to the tube by four nylon pins.

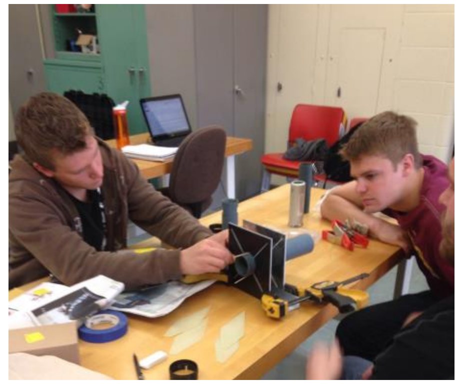

Figure 5: Booster Construction

Changes to Booster Design

Not many changes were made to the booster from the original design. The U-bolt mount above the motor was originally to be made from fiberglass, but we found that an aluminum U-bolt mount would withstand the forces better than the fiberglass and was easier to manufacture. During the test flight, we found that the mirrors did not extend far enough beyond the booster to see the launch pad before separation. We extended the mirror casing to allow a sight line along the booster.

Dart Construction Techniques

The body tube of the parachute bay and electronics bay are composed of a material call Blue Tube. A PNC Ogive shaped nose cone caps the fore end of the parachute bay and is friction fitted into the parachute bay to allow the parachute to eject. The aft end of the parachute bay fits over a section of the steel coupler. This overlap is 3 cm. These two sections are attached by set screws, not epoxy because of the need to have easy access to ejection charge lying beneath the parachute. The coupler connection joins the recovery bay to the electronics bay along with holding a strip that all the electronics are attached to. The coupler is 7 cm in length and is machined from a steel rod. The coupler has two grooves on opposite sides which allow wires to run from the recovery bay to the electronics bay. At the fore end of the coupler connection lies an eye bolt that attaches the to the parachutes shock cord. The coupler section weight can be increased by adding washers to the hollowed out aft end. Attached to the aft side coupler section bulkhead is an aluminum L-bracket to attach a Garrolite strip. This strip of Garrolite is 31 cm in length and serves as a surface to mount the electronics to. The electronics are fastened to the Garrolite using strips of Velcro tape, fast setting epoxy, and silicone glue. The strip and the electronics are inserted in the electronics bay. Having all the electronics on a removable strip allows easy access to any of the components that need to be armed before flight. The electronics bay and the coupler connection have a 3 cm overlap, like the parachute bay, and are attached using set screws. At the base of the electronics bay, four fins are mounted. The fins were cut from Garrolite. The tabs on these fins are inserted into slots on the body tube. The front tabs of the fins stick up into the electronics bay, allowing for greater surface area and better stability of the fins. Aluminum jigs were cut to maintain fin alignment while epoxying the fins. The tail cone, of our own design, houses the downward looking camera which is inserted into the aft end of the body tube and is attached using four nylon pins.

Figure 6: Dart Construction

Changes to Dart Design

The couple section was originally composed of 29mm Blue Tube coupler with coupler bulkheads. After simulation, the ideal mass of the dart was found to be significantly greater. To accommodate this weight increase, the couple section was machined from a steel rod. The coupler section was designed to have a shoulder to help assist in distributing the force that is experienced during the launch.

Constructed for Safe Flight and Recovery

FEA analysis provided useful information about where stress concentrations exist on the rocket. The analysis and test flight prove that the components can handle the acceleration. The fins would most likely fail towards the bottom of the fin if they were to fail. For the booster, the bottom of the fin is placed against the aluminum that threads onto the rocket. For the dart the fins have tabs that go inside the body tube. A preflight checklist was created to ensure every step was taken into consideration before flight. The booster and dart are stable both combined and individually. The ejection charge for the booster was set to a time delay of 12 seconds. The dart's ejection charge used a full ejection canister of black powder to guarantee the chute is deployed.

The boosters parachute was originally 30 inches. This large parachute took a long time to descend the booster. A new parachute that is 24 inches will replace the old chute to guarantee that the booster gets to the ground faster and does not drift. A tracking device is added to the dart so it can be found very quickly.

Stability Analysis

Centers of gravity were checked before the test flight with all the components in the booster and dart separately. The center of gravity was very close to the calculated centers of gravity using OpenRocket software. The centers of pressure were found using the same software. Using a tape measure, the team measured all the crucial points on the rocket for the booster, the dart, and the combination of the two for the test launch. All the points were color coded and labeled on the rocket before flight. The center of gravity for the dart and booster combined is 89.1 cm from the tip of the nose cone. The center of pressure is 113 cm from the nose cone. This gives the dart and booster combined a stability of 3.8 body diameters. The center of gravity for the dart alone is 46.8 cm from the nose cone. The center of pressure is located 57.9 cm from the nose cone. This makes the stability of the dart to be 1.6 body diameters. The booster has a center of gravity of 28.5 cm from the transition section. The center of pressure is 37.4 cm from the transition section. The overall stability of the booster is 1.6 body diameters.

Avionics Design

Down-looking video is collected by a miniature self-contained digital video camera that will be mounted in the dart tail cone. The on-board data collection package for measuring rotation includes the use of an Aduino Pro-micro microcontroller that has an ATmego32U4 processor on board as a data acquisition device and a three-axis gyro inertial measurement unit (IMU) as a measurement device. The purpose of these components together is to read, process, and record the angular rates of rotation about the roll (x), pitch (y), and yaw (z) axes. The avionics package also includes a Stratologger and Altimeter Two. All of the electronic devices and power sources will be mounted in the electronics bay to a Garolite strip. Rocket Operation Assessment

Launch and Boost Assessment

The booster and dart left the launch pad at an angle as shown in figure 7 to the right. This was caused due to the booster and dart having too loose of a connection at the transition connection. This caused the dart to wobble during the boost phase since the thrust was not aligned with the center of mass. The boost phase lasted 1.1 seconds until motor burnout; the dart reaches an altitude of 106 meters. According to our Stratologger in the dart, our rocket had a peak acceleration at 0.6 seconds into our boost phase of 23.64 Gs. The data taken from the booster's Altimeter

Figure 7: Test Launch

Two shows a peak acceleration of 23.1 Gs which is the maximum the Altimeter can handle, the Altimeter Two shows that average acceleration was 19.8 Gs.

Coast Phase Assessment

The motor burns out 1.1 seconds after launch. After which both the booster and dart are in the coast phase. The booster coasts for 10 seconds and 532 meters, reaching an apogee of 856 meters. The motor ejection charge ejects the booster parachute 12 seconds after motor burnout. The dart travels for another 1391 meters, reaches an apogee of 1715 meters 16 seconds after burnout. If we add roughly 50 more grams to the dart, we could reach a higher altitude.

Separation Assessment

The dart is designed to purely drag separate from the booster without any mechanical system, such as an airbrake. The dart's 3D printed tail cone fits within the booster's 3D printed transition section. When the booster motor reaches burnout, the dart separates from the booster due to momentum and a lower drag coefficient. According to our Jolly Logic Altimeter Twos the booster apogee was 856 m and the dart apogee was 1712 m. This is a separation of 856 m, the dart flew double the height of the booster. From analyzing the Stratologger data, we found that separation occurred at 1.15 seconds, right at motor burnout. This is excellent separation, we don't plan on changing how the dart separates from the booster.

Booster Recovery System Assessment

The booster recovery system used a 30 in classic elliptical Fruity Chute with the motor ejection 12 seconds after burnout. The parachute is attached to the booster with a 1500 lb rated Kevlar shock cord. The 30 in. parachute seemed ideal for our booster which is around 1 kg. During simulations, terminal descent velocity of 4.8 m/s was calculated with an apogee of 830 meters; this is based on the parachute coefficient of drag of 1.6. During the test flight, the booster's recovery system deployed as planned, however it descended far more slowly than calculated. Winds during the test launch were less than five miles per hour, but if they would have been higher the booster would have travelled a great distance before touchdown. To mediate this we have purchased a 24 inch elliptical Fruity Chute which will help the booster come down closer to the launch pad and also fit within the booster's parachute bay better than the 30 inch parachute.

Dart Recovery System Assessment

The dart recovery system uses an 18 inch classic elliptical Fruity Chute with ejection at apogee using a black powder ejection charge that is controlled by a Stratologger altimeter. The parachute is attached to the dart using 300 lb. rated Kevlar shock cord. Based on the simulation a terminal descent velocity of 6.5 m/s was expected from an apogee of 1453 m. This is based on the parachute's estimated coefficient of drag of 1.55. During the test flight, the dart's recovery system deployed as planned, at apogee, According to the Stratologger data from the dart, the descent rate began at 8.4 m/s from an apogee of 1706 m. This remained approximately constant for the first 92 seconds, and then the descent rate fell to 7.5 m/s for the last 113 seconds. This rate seemed large at first but with the altitude the dart is reaching this descent rate helped keep the dart from floating too far from the launch pad.

Pre- and Post- Launch Procedure Assessment

For the test launch we used pre and post launch procedure checklists as can be seen in the appendix. The initial procedures worked well and were then approved upon as we went through the day.

Test Launch Actual Vs Predicted Performance

Table 1. Boost Phase Performance

Quantity	Simulation	Stratologger	Alt. Two (booster)	Alt. Two (dart)
Thrust duration (s)	1.1	1.1	1.1	1.1
Max. acceleration (g)	27.7	23.6	23.1	23.0
Average Accel. (g)	21.7	14.0	19.8	
Max velocity (m/s)	234.8	217.0	40.0	219.0
Altitude at burnout (m)	105.0	76.2		
Apogee	1451 (dart) 830 (booster)	1711	856	1712

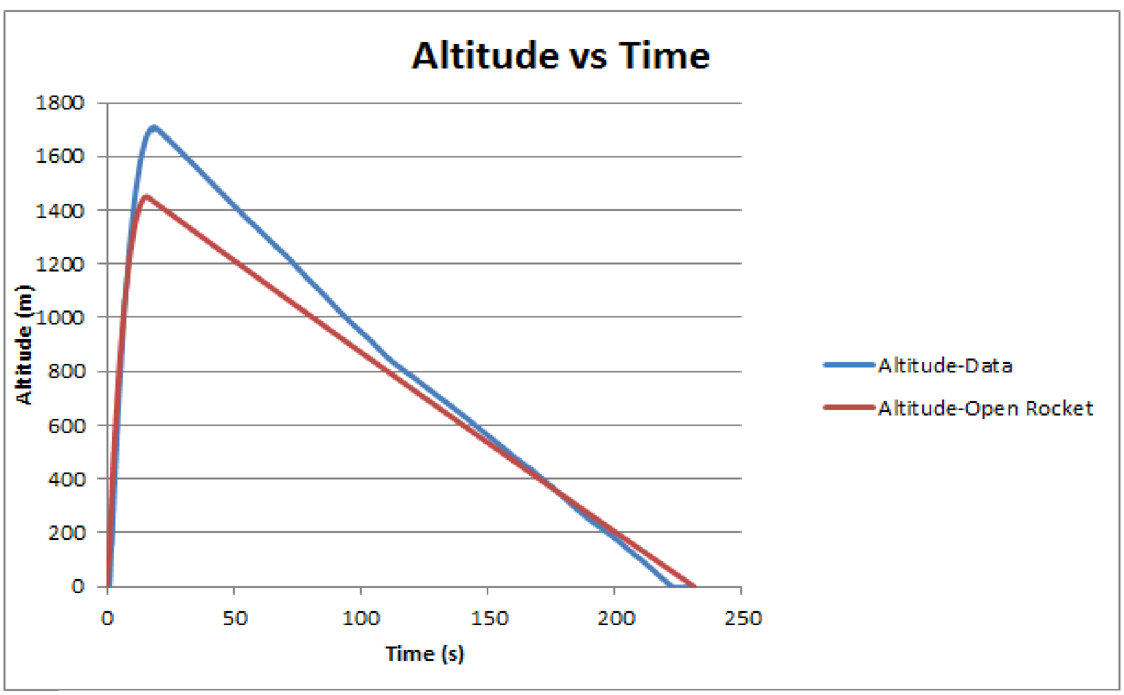

Figure 8: Altitude vs time

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he simulated peak altitude was 1451 meters, the stratologger data recorded an apogee of 1708 meters, and the Altimeter Two gave us an apogee of 1706 meters. Simulated apogee of the dart was 830 meters and it actually went 856 meters during the test flight. The simulated and actual apogees are vastly different. This may be a combination of many contributing factors. By nature, simulations are imperfect; the coefficient of drag in OpenRocket could have been very different from the actual situation, especially for the dart after separation. It was not possible to properly simulate the dart tail cone after separation, and the missing tail cone would significantly increase the coefficient of drag for the dart. Another factor could have been the environmental conditions. Our test launch was in ideal conditions, 65 degrees Fahrenheit, Clear skies, and 4 mph winds, while our simulations were set up for more normal conditions.

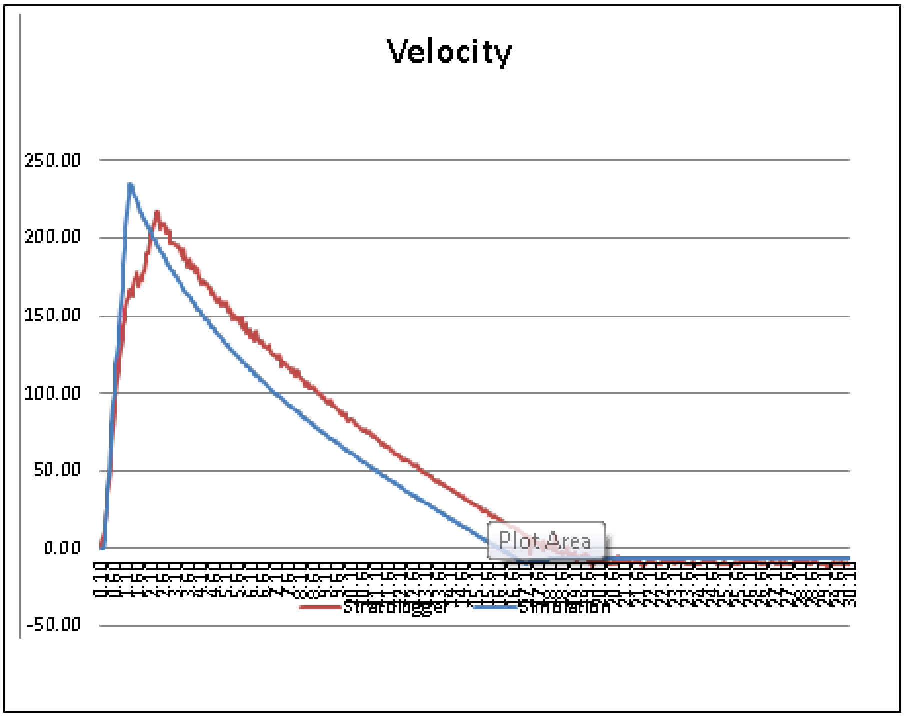

Figure 9: Velocity vs time

The simulated peak velocity was 235 m/s at 1.0172 seconds, the Stratologger shows a peak velocity of 233 m/s at 1.9 seconds. The Altimeter Two showed a peak velocity of 218 m/s. The Stratologger data showed a large dip in velocity for 0.1 seconds at 1.4 seconds. We believe this dip is due to a large pressure change in the dart at the dart separated from the booster. We believe this could be mediated by drilling more breather holes to equalize any data altering pressure changes. Figure 9 above shows the data after the erroneous data was removed and the data was smoothed.

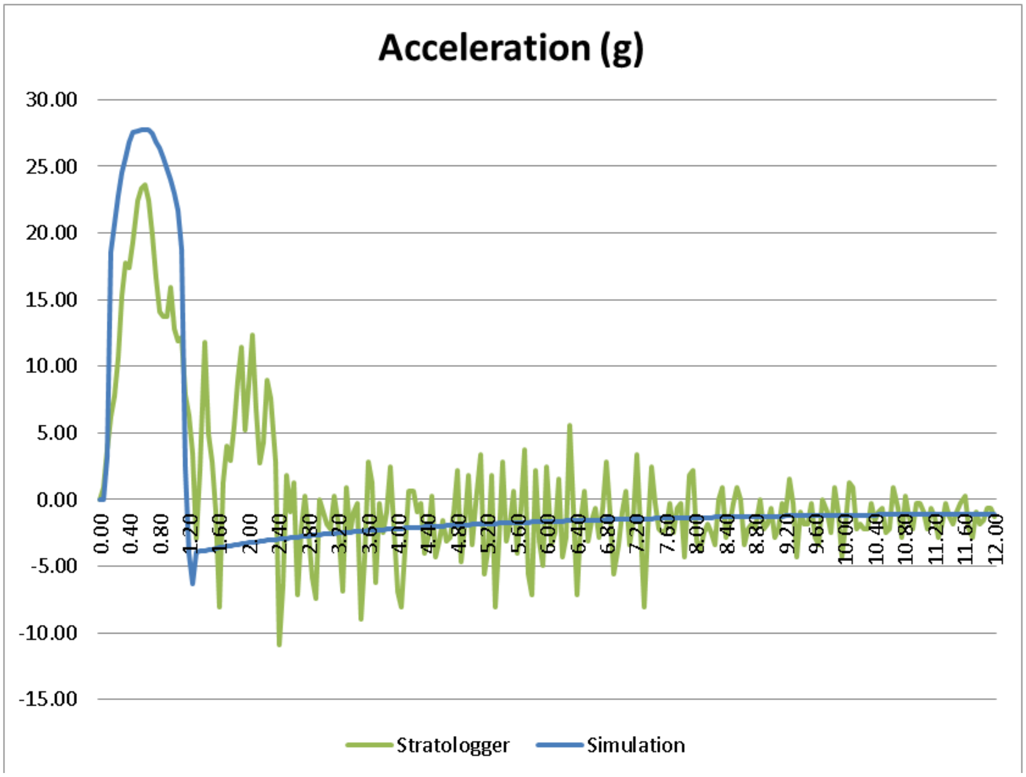

Figure 10: Acceleration vs time

The acceleration is where our data begins to differ. The peak acceleration according to the simulation is 27.5 Gs, where the stratologger recorded a max acceleration of 48 Gs, and the Altimeter Two had a max acceleration reading of 23 Gs. We believe these accelerations of so different because of a large pressure wave when the dart separated from the booster. During separation, where the stratologger data shows a large negative acceleration data, air would have been pushed into the hole in the tail cone of the dart creating a pressure wave. This is also shown in the stratologger's velocity data; during separation there is a large dip in velocity data. We know that the dart couldn't have slowed way down and then sped up, so we must assume this is a false reading. The Altimiter Two only showed a max acceleration reading of 23 Gs because this is the largest reading it can read. By maxing out the acceleration reading, our Altimeter Two also shows that the parachute was deployed 20 ft. above the ground and 11 seconds before apogee, neither of which were true. In figure 10 above, we removed the erroneous data and smoothed the raw data as much as possible; this showed a graph more in line with our simulations. However, this data still shows an increase in acceleration right at separation. We believe this is due to the decrease drag when the dart leaves the booster.

Video and Rotation Data Logging Performance/Comparison

3-axis rotation data-logging was done by the use of a 3-axis gyroscope (IMU) which measures the angular rates of rotation about the roll (X), pitch (Y), and yaw (Z) axes. The IMU was controlled by using an Arduino Pro Micro, which is provided to code and data output deliverance. Since the Preliminary Design Report, several changes have been made. The addition of two buttons on the Arduino has been made to enable functions for “Start” and “Output” of the data. The code currently works by first calculating its zero position, as stated by finding the DC Offset for XYZ, and it uses this value to determine the amount of noise/initial variation in movement. Secondly, three arrays are created to hold the data. According to the Arduino Pro Micro, based on the amount of SRAM in the chip, the max array size is about 150. Any more causes loss of data during data collection. A push-button at pin 7 on the Arduino, is programmed to start data collection. This meaning once the code has been uploaded to the Arduino and the battery is in place, there has to be a way for the Arduino/IMU to know when to start recording data. After the button is pressed, an LED on the Arduino blinks five times, thus signaling the user that the initial button has been pressed and that data collection is about to begin. The data is set to continuously record from the IMU until the array is filled, and after that, data collection is set to stop. Once the rocket has been safely recovered after flight, the Arduino is the plugged into the computer, and the second button is pressed, which then outputs the data onto the serial port of the computer, making the flight rotational data able to be collected.

Problems during our flight were encountered. The code worked great, although the only code telling the IMU to record data is that of a delay. Therefore, we are relying on a delay of 15 minutes before we know that data is being recorded, and as a result, once the first button is pressed, if the rocket isn’t launched at exactly 15 minutes after, then the wrong data will be collected.

The results are gathered in degrees per second. According to the results from our test flight, data was gathered before launch, and the launch window was not hit. 150 data points for XYZ were recorded and properly outputted as arrays. The only failure for the test launch was the 3-axis rotation data-logging. Many changes in the code need to be made prior to competition flight. Mainly, code will be written so that a delay launch window will no longer need to be relied upon, meaning that there will be a motion detection statement written that controls the parameters for exactly when the data will be recorded. Physical changes will not be made to the Arduino/IMU because the problem solely lies in the code that was written. A Micro SD Shield with Micro SD card would have been used to record the data; however, there is insufficient space in the dart/electronics housing for the addition of an SD shield, thus it was decided not to use one in this process.

Camera analysis

The camera, housed in the tail cone of the dart, was able to capture the video footage of the flight. The dart completed about 20 revolutions before apogee and deployment of the parachute. The peck of angular velocity was between 2 and 4 seconds where it is spinning at 2.5 revolutions per second. As the dart gains altitude, the angular velocity consistently drops to almost .5 revolutions per second.

Potential design Improvements

During the test flight only a few things did not operate as expected. The rocket flew slightly sideways, thought to be caused by the dart not seating correctly in the transition section. The video was slightly obstructed by the interior of the rocket before separation. The Arduino did not collect data during the flight due to a timing issue. The booster coasted for a long distance due to having a large chute. The data collection on the altimeter was not correct, thought to be caused by not allowing enough atmosphere exposure. The dart to transition section will be slightly modified to insure a secure fit, and achieve greater stability of the rocket. This will be done by adding a slight amount of epoxy clay and molded to the edge of the transition section, creating a more snug fit. The mirror device will be altered to capture better video of the flight before dart separation. To insure better video the mirror device will be elongated so the line of sight is no longer obstructed by the interior of the rocket. The arduino will have a while loop programed in to insure that it will detect a launch and record the data when expected. The booster coasted a long ways and did not descend fast enough, which caused a long recovery process. This will be corrected by reducing the chute size from a 30” to a 24” Fruity Chute, ensuring a faster descent and a speedy recovery. The altimeters did not collect all of the data accurately, this may have been due to the fact that they were not exposed to enough atmosphere or that the rocket was exposed to more Gs than the altimeters could withstand. The altimeter bays will have more and larger breather holes to provide adequate atmosphere.

Budget

The budget was calculated using the construction cost of the booster, $333, and the dart, $298, and the other costs for miscellaneous materials, $140, and launch-related costs, $1,464. This leads to a total budget of $2,236. The details are shown below

Booster

Item	Cost	Weight (g)	Qty	Unit	Total Cost	Total Weight
Body Tube 54 mm	$0.08	3.08	42	cm	3.30	129.4
Coupler Tube 54 mm	$0.45	2.78	12	cm	5.37	33.3

Bulkhead 54 mm	$2.65	9.00	2	ea	5.30	18
Motor Retainer 54 mm	$31.03	110.10	1	ea	31.03	38.5
Fins	$0.01	0.30	320	sq. cm	2.46	89.1
Parachute	$72.62	77.20	1	ea	72.62	77.2
Motor Case	$42.75	110.10	1	ea	42.75	110.1
Rail Buttons	$1.54	1.90	2	ea	3.07	3.8
Shock Cord	$0.03	0.10	300	cm	9.05	19.4
Wadding	$7.44	18.90	1	ea	7.44	18.9
Altimeter Two	$69.95	9.70	1	ea	69.95	9.7
Mirror Device	$0.00	13.20	1	ea	0.00	13.2
Anchoring Ring	$0.00	10.00	1	ea	0.00	10
U-bolt	$2.99	10.50	2	ea	5.98	21
Hex Nut 1/4-20	$0.03	1.10	8	ea	0.24	8.8
Screw, 8-32X1.25	$0.12	3.10	2	ea	0.24	6.2
T-nut 8-32	$0.73	1.50	2	ea	1.46	3
Transition Section	$0.00	100.00	1	ea	0.00	100
Fasteners and adhesices	$20.00	85.00	1	lot	20.00	85
Motor Reload	$52.99	465.00	1	ea	52.99	465
				Total:	$333.25	1.2596 kg

Dart

Item	Cost	Weight	Qty	Unit	Total Cost	Total Weight
Body Tube 29 mm	$0.10	1.76	65	cm	$6.71	114.4
Steel coupler	$0.00	320	1	ea	$0.00	320
Eye-bolt 1/4-20	$3.01	10	1	ea	$3.01	10
Nose Cone	$4.32	9.6	1	ea	$4.32	9.6
Fins	$0.01	0.3	60	sq. cm	$0.46	20
Tail Cone	$0.00	25	1	ea	$0.00	25
Parachute	$54.57	46.9	1	ea	$54.57	46.9
Shock Cord	$0.02	0.0012	300	cm	$4.82	3.5
Black Powder			6	g		6
Wadding	$7.37	4.5	1	ea	$7.37	4.5
Ejection Cannister	$1.80	2.7	1	ea	$1.80	2.7
Arduino ProMicro	$19.95	1.1	1	ea	$19.95	1.1
IMU	$12.95	0.6	1	ea	$12.95	0.6
Altimeter Two	$69.95	9.7	1	ea	$69.95	9.7
Stratologger	$49.46	10.2	1	ea	$49.46	10.2
Battery holder AA	$0.47	4.2	1	ea	$0.47	4.2
Battery holder 1/2 AA	$2.10	4.1	1	ea	$2.10	4.1

Camera	$25.59	18.5	1	ea	$25.59	18.5
Batteries	$2.48	9.2	3	ea	$7.43	27.6
Memory card for camera	$14.70	0	1	ea	$14.70	0
Electronics strip	$0.01	0.3	50	sq. cm	$0.39	16.6
L-bracket	$1.74	5	1	ea	$1.74	5
Fasteners and adhesives	$10.00	15	1	lot	$10.00	15
				Total:	$297.79	675.2g

Miscellaneous

Item	**Qty**	**Cost**
Model Rocket Kit	3	$42.03
Model Rocket Motors	3	$8.77
Epoxy	3	$31.52
JB Weld	2	$12.34
Repair Stick	1	$12.48
Fiber Glass Strip	1	$10.63
Blade Set	1	$10.98
Knife Set	1	$11.86
	Total:	$140.61

Launch

Item	**Cost**
Launch fee	$400.00
Motor Reload	$52.99
Travel	$431.25
Meals	$200.00
Hotel	$380.00
Total:	$1,464.24

Appendix

Pre-Launch Procedures

Name: ___________________________ Date: ______________ Time: __________ Launch #: ___

Temperature	**Relative Humidity**	**Barometric Pressure**	**Wind Speed**

Initial Inspection

1. Inspect all four shock cord connection points.
2. Inspect all wiring connections and velcro attachments in dart lower payload.
3. Check all battery levels (some require voltmeter).
   Altimeter Two (1 - Booster):____%
   Altimeter Two (2 - dart):____%
   Stratologger:____V (9V)
   Arduino:____V (9V)
4. Ensure the Camera, Altimeters, Stratologger, and Arduino are **OFF**.

Dart Inspection

5. Inspect and fold dart parachute
6.Install shock cord, parachute, and nose cone into the parachute bay
7. MAKE SURE POWER IS OFF! Install dart chute blast cap filled with black powder and wadding **MAKE SURE TO DOUBLE CHECK WIRING CONNECTIONS AS THEY EASILY COME LOOSE!**
8. secure parachute bay to coupler
9. Connect the Statologger and Arduino 9V batteries.
10. Inspect & install electronics strip.
    a. Turn on and arm Altimeter Two (3), will display **READY**
11. Secure electronics bay to coupler
12. Arm arduino and IMU
13. Place radio transmitter in electronics bay
14. Turn on camera
15. Install and secure tail cone into dart

Booster Inspection

16. Arm Altimeter Two, will display **READY**

17. Secure altimeter bay in booster
18. Check that mirrors are clean
19. Install transition section
20. Inspect and fold booster parachute
21. Install shock cord, and parachute into booster parachute bay
22. Install dart into booster

Launch Pad Inspection

23. Record motor type and full mass.
    Mass:________g
24. Install motor.
25. Place rocket on launch rail.
26. Arm Stratologger altimeter.
27. Listen for correct beep sequence as follows:
    2 short beeps (Preset 2)
    Long Pause
    5 short beeps (Describing an altitude of 500 ft. for dart deployment)
    Short Pause
    10 short beeps
    Short Pause
    10 short beeps
    Long Pause
    A sequence of beeps and short pauses (Describing altitude of last flight)
        Altitude:___________ft
    A sequence of beeps and a short pause followed by another sequence of beeps (Describing battery voltage as X.X Volts)
        Voltage:_______V
    Long Pause
    A non-stop pulse of 3 beeps (This indicates that the chute is are connected properly. **IF A PULSE OF 1 OR 2 BEEPS, THEN THE CHUTE IS NOT CONNECTED. DO NOT LAUNCH!!!**)
28. One last visual inspection
29. Photograph(s) of rocket on pad
30. Launch

Post-Launch Procedures

Name: ___________________________ Date: ______________ Time: __________ Launch #: ___

Temperature	Relative Humidity	Barometric Pressure	Wind Speed

1. Approach the booster and dart with ***caution***, and inspect from afar to verify all separation has occurred
2. Take a picture of all components on the ground

Dart Inspection

3. Stratologger Altitude and Voltage:
    - Remove electronics strip
    - Download IMU matrix
    - record Altimeter Two data
4. Turn off electronics:
    - Stratologger
    - Altimeter Two
    - Arduino & IMU
5. Turn off Camera
6. Collect all components of dart
7. Return to Judges booth and wait for booster recovery team

Booster Inspection

8. Record data and Turn off booster electronics:
    - Altimeter Two
9. Collect all components of booster
10. Return to judges booth and wait for dart recovery team

Judges Inspection

11. Present booster and dart to judges for inspection of rocket and collection of data
12. Return electronics if not doing another launch
    - Altimeter Two (2)

Our Inspection

13. Inspect booster
    - Motor securement
    - Reducer and its securement
    - Shock cord and securement of both ends
    - Booster parachute

Body, fins, piston, and remaining hardware

14. Inspect dart
    Nose and tail cone
    Electronics strip
    Shock cord and securement of both ends
    Dart parachute
    Body, fins, and remaining hardware
15. Download/collect data from dart
    Stratologger
    Arduino/IMU
    Camera