Preliminary Design Report

NASA's Space Grant Midwest High Power Rocket Competition

2014-2015

University of Minnesota - Twin Cities

Freshman Team

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Executive Summary

The boosted dart rocket will be comprised of two sections: the lower part, otherwise known as the booster, and the upper part, referred to as the dart. The booster will be of a thicker diameter than the dart, and will have some form of air brake device to assist in the separation of the booster and the dart during the coast phase of the flight. There are two preliminary designs for these braking mechanisms, the “Flaps” and “Streamers” designs. Both provide advantages and disadvantages as to their reliability and effectiveness during the flight, and further testing will need to be done until one final design is implemented in the final booster design. The design of the dart will include an avionics bay that will contain essential equipment for data collection about the flight and an altimeter to ensure deployment of a parachute at the apogee of the dart. Every component of this rocket is expected to be stable to overstable at all points in the flight.

There is an expected separation between the apogees of the booster and the dart of about 944 ft, without the airbrakes. It is anticipated that the booster will reach a height of 3277 ft with a maximum acceleration of 828 ft/s^2 (or 26.7 G’s), while the dart reaches apogee at 4221 ft and has a maximum acceleration of 828 ft/s^2 (or 26.7 G’s). The booster reaches apogee around 13 seconds after liftoff, and the dart reaches apogee around 2 seconds later.

The budget for this project is $3000, and it is being allocated in the purchase of rocket parts, paying competition fees, travel to launches and funding other necessary aspects of the design and build process.

Design Features of the Rocket

The Booster

The booster will be 75mm in diameter, made out of a 26" long Blue Tube body tube, an 8.25" long plastic nose cone that has been cut to 7.15" to accommodate the release of the dart, and three 10.5 square inch trapezoidal 1/16" thick fiberglass fins. The body tube will hold the provided VMax motor, as well as a mirror system that will redirect the camera view so that it points downward.. An airbrake system that has yet to be fully developed will be housed on the exterior of the booster body tube as well. The entire booster will weigh around 36 oz., not including the provided motor, and will be weighted for stability throughout both segments of the flight. The surface of the booster will be optimized to provide the maximum amount of drag so the booster will attain the minimum possible altitude. The airbrake system, mentioned above, will take on one of the two forms described below:

1. Flaps - The air brakes will be attached by hinges between each set of fins, giving three total air brakes. The flaps themselves will lay along the rocket body, with the hinge connecting at the lowest point of the flap. The top of the flap will be connected by a wire which runs along the side of the rocket up to the payload section of the booster, where they will then enter the booster. Inside, each wire will connect to a piece of nichrome wire, which is in turn connected to the payload section of the dart. If it becomes too difficult to electronically link the booster and dart, additional avionics will instead be installed in the booster in order to control the trigger the airbrakes. At the moment the motor burns out, the avionics in will electronically signal an Arduino to send current through nichrome wire and the nichrome wire will break, releasing the tension on the

airbrakes, allowing them to open due to the force of the air on them as the rocket travels upward. They will open outwards past 90 degrees relative to the rocket body, and come to a rest, providing additional drag to decelerate the booster section.

Figure 1: A preliminary model of "the Flaps" airbrake design

2. Streamers - Similarly to the flaps design, streamers made of flexible material will be connected at the base of the rocket, and will extend along the length of the rocket up to the payload section, where they will attach. The release mechanism will either be nichrome wire or the physical separation of the dart from the booster. When released, the streamers will be pulled away from the rocket, and will trail the rocket, providing

additional drag to decelerate the booster section. The streamer material will be selected to have as little drag as possible on the outside face so that the section of the booster that they cover will have a less drag during the boosted portion of the flight only. The section of the booster covered by the streamers will have a very high coefficient of friction to further increase the booster's drag after separation. This could be accomplished by applying a rough coating of some kind.

Figure 2: A preliminary model of "the Streamers" airbrake design

Above the section of the booster containing the air brakes, there will be the 48 inch diameter nylon parachute, which will be released by the payload section of the booster, or, as a reserve, by the motor eject, which will be left inside the motor for redundancy. Above the payload section will be a modified plastic 8.25” ogive nose cone, cut to 7.15” with slots so that the booster fins can sit inside. We may also fill the transition section with hard foam to increase its strength. Additionally, there will be a system of mirrors angled such that the camera view will redirect the camera view through a section of clear acrylic in the body tube, and still get downward facing video of the boosted portion of the flight.

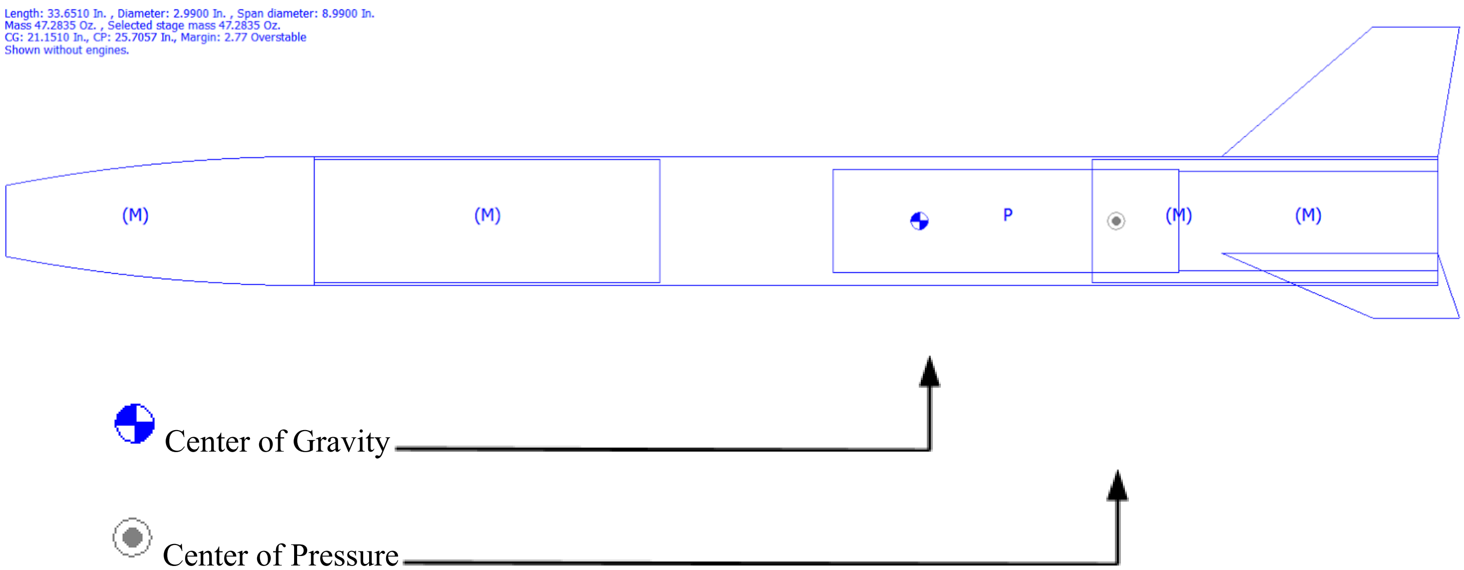

Figure 3: A full RockSim model of the booster and all of its components. Masses have been added to simulate the various mechanisms within the rocket, including the fully expended motor. The dimensions and statistics on the booster are as shown below:

Length	33.7”
Diameter	2.99”
Span Diameter	8.99”
Mass	47.3 Oz.
Center of Gravity	21.2” (from tip of the nose cone)
Center of Pressure	25.7” (from the tip of the nose cone)
Static Margin	2.77

The static margin of 2.77 indicates slight overstability, which may cause the booster to veer into the wind slightly. This will not be a problem, and may in fact help us, because the altitude of the booster's flight will be negatively affected.

The Dart

The dart will be 38mm in diameter and will be made of a 24" long carbon fiber body tube, a 7.5" long 5:1 Von Karmen fiberglass nose cone, and three 4 square inch trapezoidal ⅛" thick fiberglass fins. There will be slots built into the dart fuselage for part of the length of the fins to allow these fins to be partially inserted inside the body for support and rigidity. The body tube will contain avionics to measure and record the attributes of the dart in flight, including the z-axis rotation of the dart. A plastic, 1.64" long boat tail, fashioned from a conical 6" long nose cone, will be placed on the back end of the body tube to reduce drag on the dart after separation. The surface of the entire dart will be sanded and machined thoroughly to give it the lowest possible drag, and it will be weighted such that it is stable in all stages of flight. In the bottom section of the dart, a Mobius camera will be mounted partially inside of the boat tail, facing downward to record video of the flight. The coupler section of the dart will contain the payload section with the avionics. Above this will be the 30 inch diameter nylon parachute, which will be ejected at apogee by the Raven3 altimeter in the payload section.

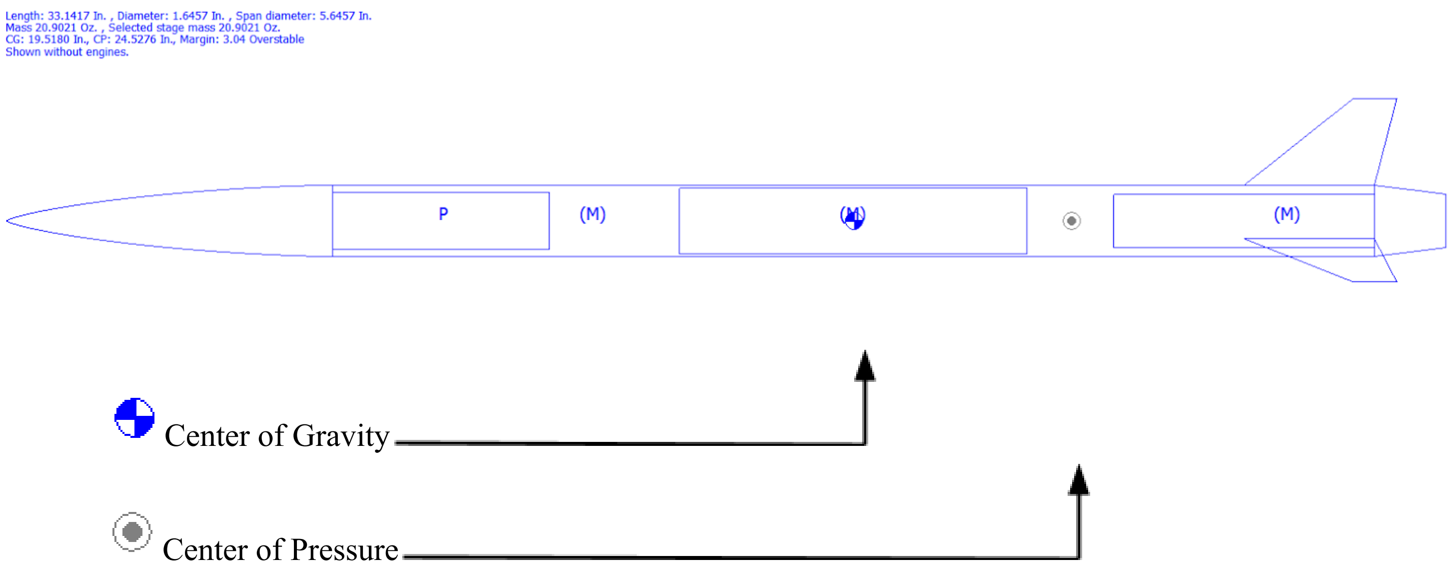

Figure 4: A full RockSim model of the dart and all of its components. Masses have been added to simulate the various mechanisms within the dart.

The dimensions and statistics on the dart are as shown below:

Length	33.1417”
Diameter	1.6457”
Span Diameter	5.6457”
Mass	20.9021 Oz.
Center of Gravity	19.518” (from tip of the nose cone)
Center of Pressure	24.5276” (from the tip of the nose cone)
Static Margin	3.04

The static margin of 3.04 indicates overstability, which could cause the dart to veer into the wind. This is not desirable as it could limit altitude, but due to concerns about the fins becoming too small, the size will not be decreased unless further testing indicates the advantage of doing so.

Design Features of Payload System

The payload of our dart is focused on the measurement of the dart's behavior in flight and the deployment of the dart's parachute. The payload is to be contained in a cylinder that is 8 inches in length and 1.5 inches in diameter. This is a very small space for including all the components. However, we used CAD modelling (shown below) to determine that an Arduino Nano (with microSD and ethernet shield), 9-axis inertial measurement unit (IMU), Raven3 altimeter, and two 9-volt batteries will fit.We plan to attach each component to a G10 fiberglass sled and to then attach the sled to threaded rods. The threaded rods will allow the avionics section to be easily removed so that work can be done on it. The arduino, shield, and IMU will measure the dart's rotation, acceleration, and attitude with 3 degrees of freedom for each quantity. This data can be written onto the SD card for post-flight analysis and used in-flight to trigger more accurate ejection events. The Raven3 altimeter will give an accurate measurement of altitude with time, allowing the optimal parachute ejection (at apogee).

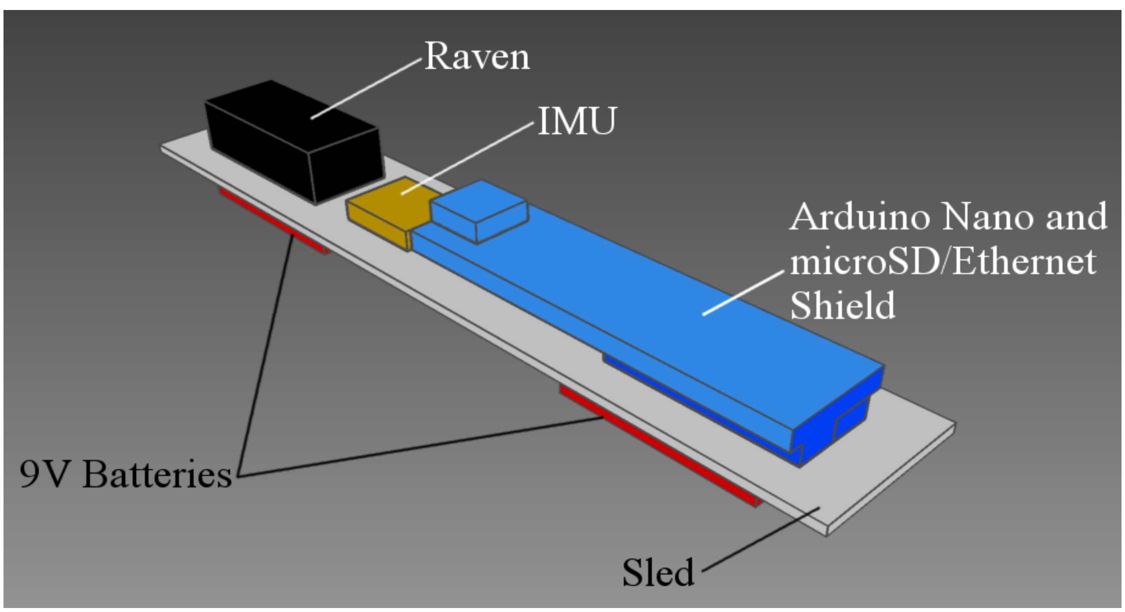

Figure 5: A CAD rendering of the dart's avionics

The payload of the booster is centered around the deployment of air brakes and the optimal deployment of the parachute. The plan is to include a Stratologger altimeter, allowing the booster to deploy its parachute immediately upon reaching apogee. If we select the flap air brakes described above, our current plan is to keep the air brakes retracted by wiring them together with nichrome wire. The nichrome wire will be connected to the avionics of the booster, which will run a current through the nichrome wire when the motor burns out. This current will cause the nichrome to break, releasing the air brakes. The streamer air brakes could possibly use the same release mechanism or may be mechanically deployed by the separation of the dart and booster.

Combined Boosted Dart Design

The combined boosted dart will consist of the booster and the dart as one larger rocket. The boat tail and a small length of the fins of the dart will be inserted into the slots in the transition section (truncated nose cone) of the booster in order to keep the two pieces together until the desired separation. This separation will occur as soon as acceleration due to the motor has ended, because the more aerodynamic dart will decelerate at a slower rate than the booster, which has a higher coefficient of drag, as well as deployed airbrakes.

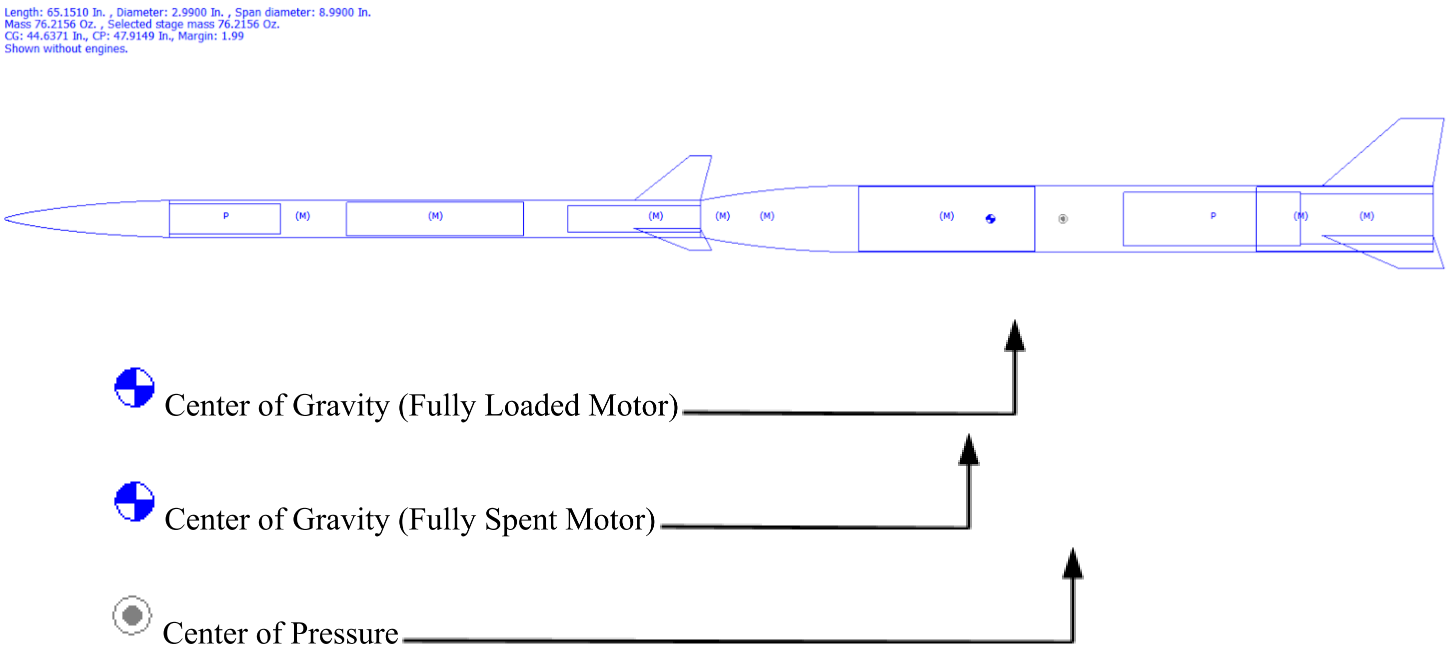

Figure 6: A full RockSim model of the combined boosted dart and all of its components. The full design is essentially the individual booster and dart pieces slide together, the boat tail and a small length of the fins of the dart entering the nose cone of the booster. Masses have been added to simulate the various mechanisms within the booster and dart.

The dimensions and statistics on the combined boosted dart are as shown below:

Length	65.2”
Maximum Diameter	2.99”
Span Diameter	8.99”
Mass (Fully Loaded Motor)	76.2 Oz.
Center of Gravity (Fully Loaded Motor)	44.6” (from tip of the nose cone)
Center of Pressure (Fully Loaded Motor)	47.9” (from the tip of the nose cone)
Static Margin (Fully Loaded Motor)	1.99
Mass (Fully Spent Motor)	67.7 Oz.
Center of Gravity (Fully Spent Motor)	42.5” (from tip of the nose cone)
Static Margin (Fully Spent Motor)	3.29

The static margin of 1.99 at the beginning of the launch indicates stability, which should result in a vertical launch. At the end of the boosting phase, the static margin will be 3.29, which indicates overstability. This should not be a problem because, if all else goes as planned, the dart and booster should separate soon after acceleration has ceased, leaving little time for the full rocket combination to veer into the wind.

Analysis of the Anticipated Performance

Combined Motion

The motion of the combined rocket was estimated using a RockSim model of the booster-dart combination. It was assumed that the booster and dart would separate soon after burnout, so the simulated data was stopped at that point. While together, the booster-dart combination reaches:

Maximum Acceleration	828.2 ft/s^2 (26.7 G's)
Maximum Velocity	697.5 ft/s
Altitude	371.3 ft

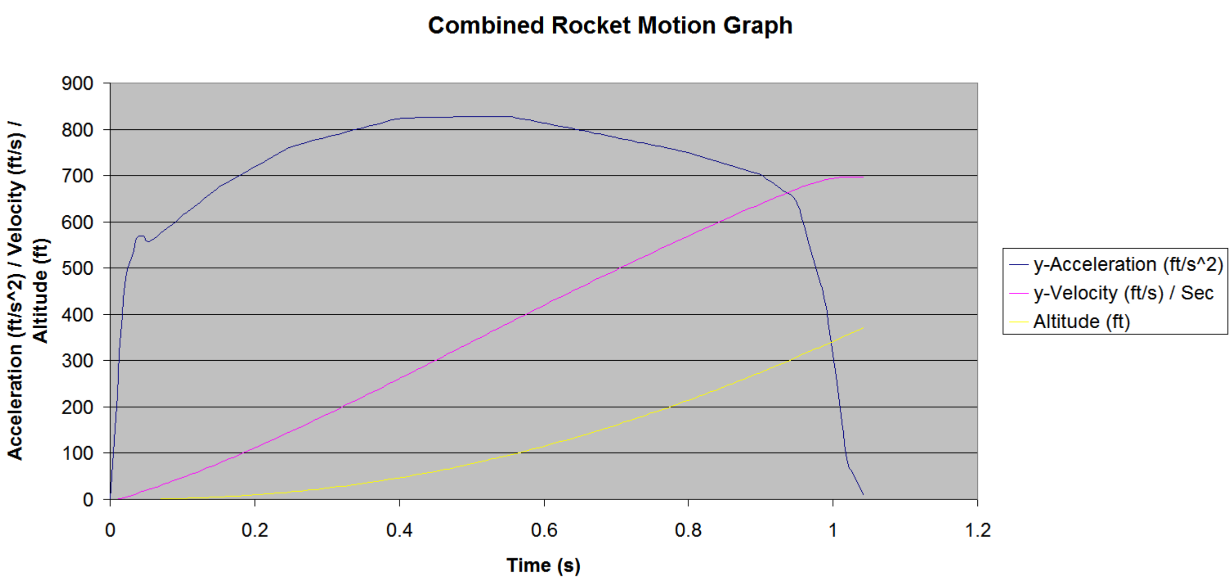

Figure 7: Graph of the upward acceleration and velocity, and altitude of the full rocket combination, up until the point of separation at burnout

Booster Motion

The motion of the booster was simulated using a RockSim model of the booster on its own, in conjunction with the data obtained for the combined flight. The velocity of the booster at the point of separation was found, and for all times after that velocity was reached, the booster alone simulation was used. For all points before, the combination simulation was used. Due to the difficulty of modelling airbrakes, the simulations could only be run as if the airbrakes did not deploy. If the airbrakes were to have deployed, a much stronger negative acceleration, and a much lower maximum altitude could be observed. However, with this consideration, from lift-off to apogee, the booster reaches (notice that the maximum acceleration and velocity were obtained while the booster and dart were together):

Maximum Acceleration	828.2 ft/s^2 (26.7 G's)
Maximum Velocity	697.5 ft/s
Maximum Altitude	3277.2 ft

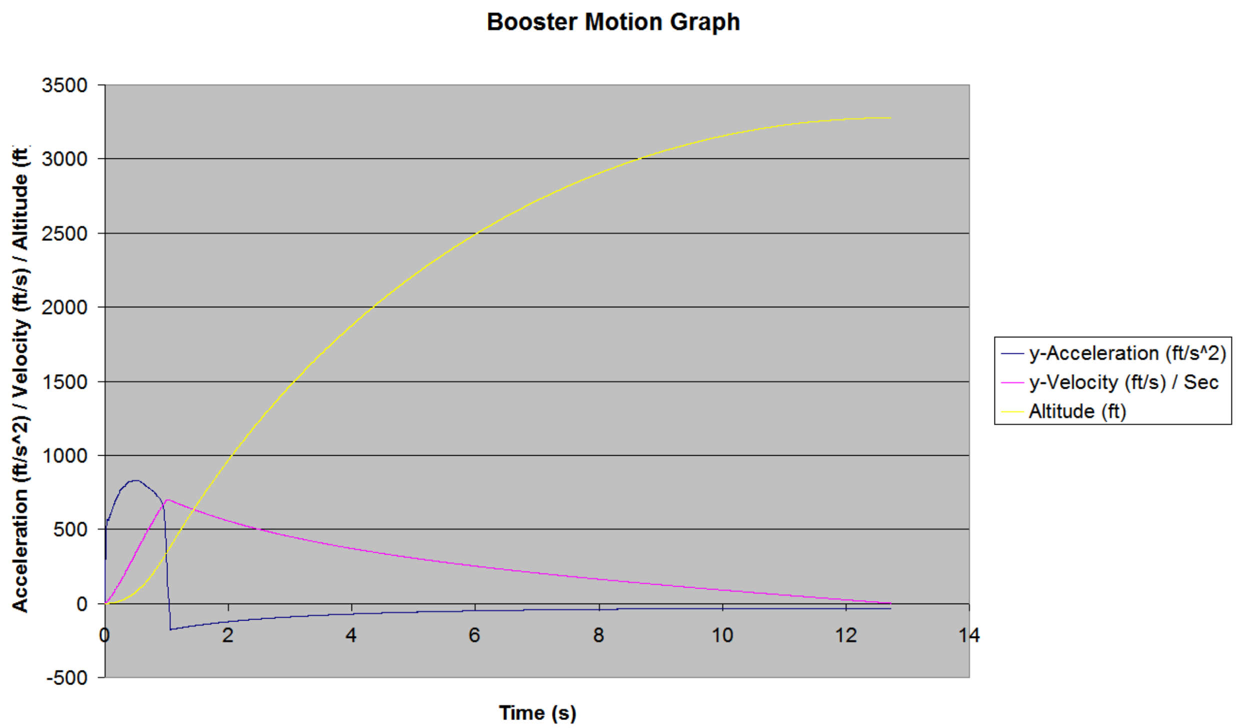

Figure 8: Graph of the upward acceleration and velocity, and altitude of the booster, until apogee. Notice that the first approximately 1 second of the booster's motion is as part of the full rocket combination

Dart Motion

The motion of the dart was simulated using a RockSim model of the dart on its own, in conjunction with the data obtained for the combined flight. The velocity of the dart at the point of separation was found, and for all times after that velocity was reached, the dart alone simulation was used. For all point before, the combination simulation was used. From lift-off to apogee, the dart reaches (notice that the maximum acceleration and velocity were obtained while the booster and dart were together):

Maximum Acceleration	828.2 ft/s^2 (26.7 G's)
Maximum Velocity	697.5 ft/s
Maximum Altitude	4220.9 ft

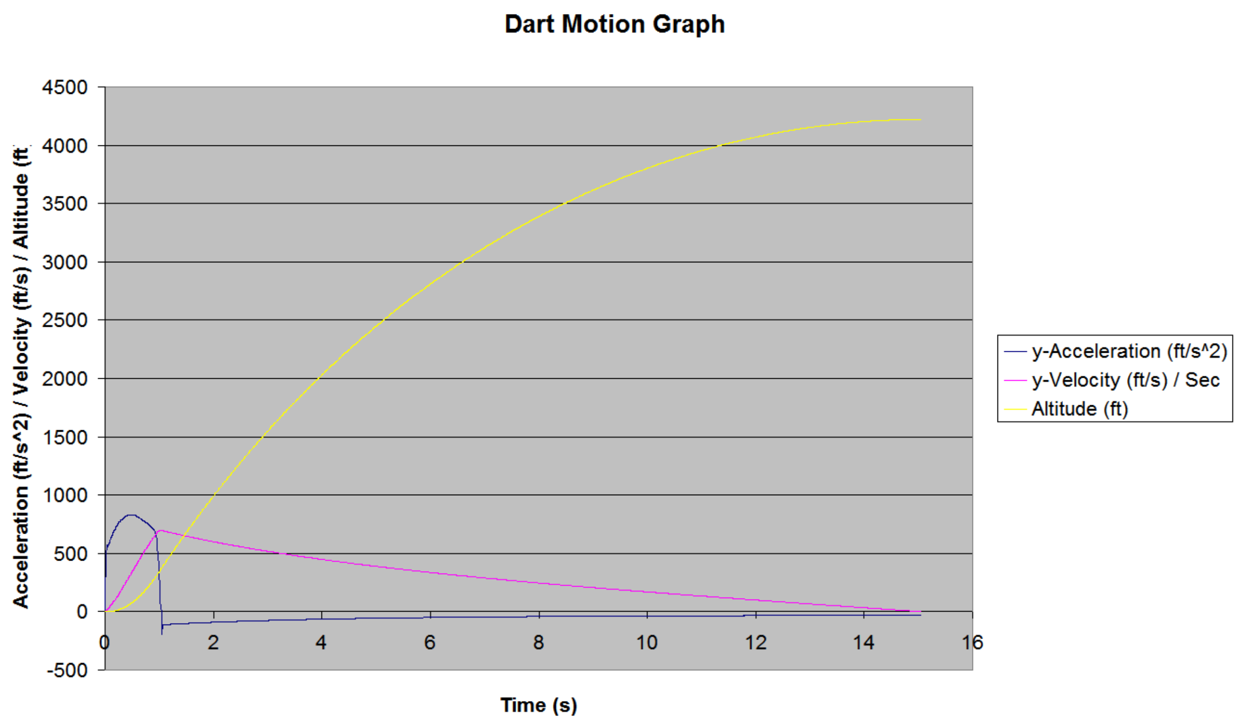

Figure 9: Graph of the upward acceleration and velocity, and altitude of the dart, until apogee. Notice that the first approximately 1 second of the dart's motion is as part of the full rocket combination

According to this data, the dart would reach a maximum altitude of 4220.9 ft which is 943.8 ft higher than the no-air brakes booster apogee. With airbrakes (or streamers), we expect the apogee separation to be larger still. We will continue to test and attempt to discover more accurate figures for the booster's flight with the inclusion of airbrakes.

Budget

Rocket Components

Date Ordered	Company Name	Quantity	Part Number	Description	Unit Price	Total
3/12/15	LOC Precision	2	PNC-1.52	1.52" plastic nose cone	$13.81	$27.62
3/12/15	LOC Precision	1	PNC-3.00	3" plastic nose cone	$20.74	$20.74
3/12/15	Banggood	2	SKU191992	G4-85...9DOF IMU	$9.85	$19.70
3/12/15	Banggood	1	SKU191993	+ Expedited Shipping	$12.03	$12.03
3/12/15	Performance Hobbies	1	n/a	38mm 5:1 Von Karmen Nosecone	$39.00	$39.00
3/12/15	Performance Hobbies	1	n/a	3" ogive fiberglass nose cone	$30.00	$30.00
3/12/15	Rocketry Warehouse	2	FWCF-38M-24	38mm Carbon Fiber 24" tube	$52.00	$104.00
3/12/15	Rocketry Warehouse	3	FWCF-38M-25	+ Slotting Charge	$5.00	$15.00
3/12/15	Robot Shop	2	RB-Gra-01	Arduino Nano v3	$34.99	$69.98
3/12/15	Robot Shop	2	RB-Gra-05	Nano Ethernet w/ micro SD	$39.95	$79.90
3/12/15	Apogee Components	3	14152	1/8" G10 fiberglass (1 square ft)	$25.71	$77.13
3/12/15	Apogee Components	2	14150	1/16" G10 fiberglass (1 square ft)	$14.29	$28.58
3/12/15	Apogee Components	1	13156	LOC 38mm Coupler	$2.04	$2.04
3/12/15	Apogee Components	1	12070	38mm to 29mm adapter	$10.95	$10.95
3/12/15	Apogee Components	25	30327	Kevlar Shock Cord (1 foot)	$0.92	$23.00

3/12/15	Apogee Components	1	11010	54mm Motor Mount tube 34"	$8.09	$8.09
3/12/15	Apogee Components	1	35522	Airframe Slotting Jig	$245.75	$245.75
3/12/15	Apogee Components	1	13114	75mm blue tube coupler 48"	$31.95	$31.95
3/12/15	Apogee Components	2	13172	75mm Stiffy tube 6"	$5.78	$11.56
3/12/15	Apogee Components	1	10504	75mm blue tube 48"	$29.95	$29.95
3/12/15	Featherweight Altimeters	2	Raven3 +/- 706/356	Raven3 Altimeter	$155.00	$310.00
3/12/15	Off We Go Rocketry	1	P29-CL	Pro29 Rear Closure	$17.99	$17.99
3/12/15	Off We Go Rocketry	1	P29-1G	Pro29 1 Grain Case	$19.99	$19.99
3/12/15	Off We Go Rocketry	1	HAMR-54-SET	54mm HAMR motor retainer	$32.95	$32.95
3/12/15	Off We Go Rocketry	3	475I445-16A Vmax	Cesaroni I445 Vmax motor	$52.99	$158.97
3/12/15	Off We Go Rocketry	2	56F120-14A Vmax	Cesaroni F120 Vmax motor	$17.99	$35.98
3/12/15	Off We Go Rocketry	15	n/a	E-Match	$2.00	$30.00
3/12/15	Off We Go Rocketry	1	FOAM-EXP-8	2-part expanding foam	$15.95	$15.95
					TOTAL	**$1,508.80**

Additional Expenditures

1/30/15	MN Space Grant Consortium	1	n/a	Registration Fee	$400.00	$400.00
5/19/15	n/a	1	n/a	Travel Expenses	~$400.00	~$400.00
					TOTAL	**~$800.00**
		TOTAL (INCLUDING ROCKET COSTS)				**$2308.80**

Along with the items listed above, we intend to further use our budget of $3000.00 to pay for more parts as our design evolves and as parts get damaged through our pre-competition test flights. This money will also go towards paying for travel to and from launches, the cost of which is yet to be determined, but will most likely be close to $400 for gas and rental of University of Minnesota transportation.