Flight Readiness Report

InVenTs Slinging Slashers:
High Powered Rocketry Team

Organization:
InVenTs Living Learning Community

Funded By:
Virginia Space Grant Consortium

Written:
May 4, 2015

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EXECUTIVE SUMMARY

NASA's Space Grant Midwest High-Power Rocket Competition states that a high-power rocket be constructed in the form of a boosted-dart. Unlike a conventional, single-stage rocket, a boosted-dart system requires at least two stages. The booster stage propels the entire weight of the boosted-dart system using a motor. Once the motor reaches burnout, the unpowered upper stage or "dart" continues to travel upward, relying only on its own momentum to carry it in an upward motion. At the same time, the drag tries to decelerate it, causing the booster stage to separate from the boosted-dart and allowing the parachutes to deploy.

The primary objectives for the competition are to ensure the rocket meets all safety standards and is safe to fly. Other goals include but are not limited to: maximizing separation distance between the boosted-dart and booster stages, achieving maximum boosted-dart apogee, and having the rocket safely return to the ground in a suitable condition to be relaunched later at a different occasion. In addition, the team will have to predict the rocket's flight performance, collect video footage during ascent, and construct an avionics package for more data collection.

The performance of the lower and upper booster sections as well as the lower and upper dart sections was calculated using rocket simulators under three different wind speeds to better understand its performance under multiple conditions that may be encountered in the competition, and to insure the safety of the participants. These simulations were calculated using the approximate longitude, altitude, and latitude of Minneapolis to compare to the similar conditions to those expected during flight. The initial rocket design was implemented for both the booster and dart. Once constructed, the New River Valley Rocketry Team conducted a safety inspection on the rocket. Changes based on their recommendations were made afterwards. Unfortunately, bad weather prevented the intended April 25th launch and the attempt on May 2nd could not be carried out due to an incompatible motor ordered by the team's sponsor.

The purpose of this report is to provide a detailed description of flight readiness steps and processes implemented by the inVenTs High Powered Rocketry Team: the inVenTs Slinging Slashers, in the construction and testing of a high-power, boosted-dart rocket.

BUDGET ANALYSIS

The budget for this project was one of the first things to be drafted. It was based on preliminary estimates based on design objectives and estimated travel costs. Table 1 shows the layout for the estimated budget. It includes projections for how much the general parts for the rocket would cost as well as the estimates for travel and lodging and the $400 registration fee.

Item	Cost ($)
Construction Expenses	1090
Test Launch Costs	
Model Rocket Kit	30
2X H-Class Motors	160
Electronics	
Arduino	40
Sensors	40
Camera	55
Rocket Body Construction	800
Travel Costs(Flying)	**5375**
Rental Car(s)	600
Gas	80
Hotels	1320
Food	900
Flight	2175
Shipping(Rocket)	300
Registration	**400**
Total	**6900**

Table 1: Estimated Budget

This analysis was based on the assumption that the team would be flying five of its members to Minneapolis, MN and shipping the rocket to the competition. It also assumes that the rocket will be subjected to two flights. The costs for the parts needed to construct the rocket were taken from preliminary research overviewing the options present for each category. The same was applied in estimating costs for travel. This budget was approved and funded by the NASA Virginia Space Grant Consortium.

Table 2 displays the current budget analysis with more details on what specific parts will be ordered based on the final design of the rocket. It also features an updated estimate on travel costs. The team decided that it would be best to travel by car to Minneapolis to allow more of its members to have the experience of competing in a competition. It was estimated that eight people would attend the competition.

Components	Price ($)		Travel	Price ($)		SubTotal ($)
Motor Cartridge (2 for testing)	105.98		Gas	525		6212.45
Motor Casing Closure	39.95		Food	2880		
Ejection Delay Adjustment Tool	29.37		Hotel	810		**Approx (5%) Tax ($)**
BlueTube Body Tube (Booster)	23.95		Tolls	40		263.37
Fiberglass Body Tube (Dart)	20.95		Registration	400		
Aero Pack 54 mm Retainer	40.66		**Travel Total**	4655		**Combined Total ($)**
Polystyrene	13.5					6475.82
Camera	50					
Arduino Nano 3.0 (Microcontroller Board)	25.95					**Leftover ($)**
Transmitter	30					424.18
RF Button	7					
Reciever	5					
Ejection Charge Canister (for dart)	18					
Rail Buttons	3.07					
Kevlar Cord	27.6					
CTI 54mm 1-Grain Motor Casing	55.12					
ULTEM 9085 Components	1000					
Shipping (Combined Shipping From All Sites)	61.35					
Components Total	1557.45					

Table 2: Current Budget and Expenditures

As can be seen above, the list of the components for the rockets is longer and more detailed than the original estimates. The additional parts, which were mostly ordered from Wildman Rocketry and Apogee Components©, caused the significant rise in the total cost for the rocket components ($1556.45). More than enough money to account for the price change was saved by switching from flying to driving. The cost for driving the 8 members to Minneapolis was determined by first finding the approximate distance for a round trip from North Carolina to Minneapolis, MN. Two V6 2007 Toyota Highlanders would be used during this trip. These cars have a highway mileage of 25 mpg. Therefore, driving 2588 miles at 25 mpg with 2 cars at approximately $2.50 per gallon gave $525 total dollars. To feed the 8 members at approximately $60 dollars per day for 6 days would cost $2880. The cost for the hotels was determined using $90 per night for 3 nights and 3 rooms coming to a total of $810. Additionally, $40 dollars were allotted for possible toll roads. Altogether, the combined total comes out to be around $6475.82 with $424.18 leftover from the original $6900 budget.

CONSTRUCTION

The rocket was designed using both standard and advanced, technology-based methods. The lower booster section was printed using digital ABS and incorporates three NACA 0001 airfoiled fins, the lower rail button, and the motor mount all into one component. An Aeropack 54mm motor retainer was epoxied onto the bottom of the lower booster section. The upper booster section was constructed using Blue Tube. The Blue Tube was cut using an electric angle grinder. The symmetrical NACA 0030 airfoiled rail button on the upper booster section was printed out of ABS plastic using a standard FDM 3D printer. The polystyrene transition piece was cut using a CNC machine in three different sections. These three sections were then epoxied together and coated in a plastic-safe epoxy to increase the hardness of the foam. The rear nose cone, dart fins, and front nose cone of the dart stage were also printed using digital ABS plastic. The dart stage's body tube is constructed from 29mm filament wound fiberglass. The fiberglass body tube was cut into two segments using an angle grinder. The lower section houses the electronics bay while the upper section holds the recovery system. The coupler is epoxied into the lower dart section so the parachute can eject from the mid section. The front nose cone contains a 200 gram lead weight that was created from lead pellets that were melted within a custom mold. Both body tubes were bored with small holes to balance out the pressure for more accurate altimeter readings.

The rocket will ultimately be painted orange for the body tubes and maroon for the other components. The body tubes were coated with three coats of black primer and sanded using a variety of sandpaper grits until semi-glossy. The first two coats of orange paint have been applied, and will be finished after the application of four coats of paint. Finally, one or two coats of clear coat will be applied over the paint. The same process follows for the other components.

SUMMARY OF ROCKET DESIGN

The current iteration of the high powered rocket closely resembles the initial plans presented in the preliminary design report, with the exceptions presented herein. The overall length of the rocket is 1640mm. The length of the dart is 881mm. The total mass, including the motor, adds up to 1934g. Current stability is 3.47 calibers.

Despite negotiations about pricing, ULTEM 9085 proved to be a cost prohibitive material. Further examination of a free sample prototype part also revealed some of the hidden weaknesses that were not immediately apparent. Although the thermoplastic is very strong and provided a desirable factor of safety with regards to stresses and strains, the material surface finish was not smooth. This subtle flaw was not correctable based on the available manufacturing techniques. The option was then to either go ahead with the expensive material and coat it with a finish to smooth out the surface, or alternatively, choose a cheaper substitute. Consequently, other alternatives were explored. Further design revisions and investigations evidenced Digital ABS as an effective candidate. Subsequent design iterations incorporated Digital ABS as the replacement. Digital ABS is readily available at the Aerospace machine shop on the Virginia

Tech campus. Although the density of the new ABS material was higher and led to a heavier rocket, this change was accounted for by making the walls of the booster thinner and adding pillars to improve rigidity under compression.

At first glance, the overall dimensions of the rocket appear unchanged. However, upon further investigation, it is clear that the length of the booster has been slightly shortened and the length of the dart has been marginally extended. The changes in the body tube lengths are a result of the optimization analysis. The booster was shortened to increase apogee. A shorter booster reduced the amount of 3D printed material present and minimized weight. This also changed the location of the center of gravity on the booster, thereby reducing the static margin, effectively decreasing the stability of the overall paired boosted dart system. To overcome this drop in stability, the length of the dart was increased, further separating the center of gravity from the center of pressure. In addition, this change meant that the weight needed to be reduced in the nosecone in order to decrease the moment experienced at the transition piece. Had the weight in the nosecone not been reduced, the transition piece would have experienced stresses that would have ripped it apart.

Other changes include the elimination of a dual deployment system. This was first implemented into the design due to concerns about landing zone hazards such as railroad tracks, flowing water in a river, and a military arsenal near the planned test launch site. The team elected to forgo this addition in order to save weight in the rocket and avoid unnecessary complexity with regards to the electronics. Since the competition launch site is a wide, open field, the team is confident that the potentially long drift distances will not be an issue.

The addition of 3D printed rail buttons eliminated concerns of drilling into the fiberglass and ensuring that rail buttons lined up flush with each other. This also removed concerns for human error with the use of heavy machinery. In order to secure the electronics within the dart, a housing unit was printed with standard ABS plastic. Difficulties with the transmitter have caused it to be withheld from the current payload. Consequently, the current payload includes a dual deployment altimeter, which emits a high-pitched sound to assist in the recovery of the rocket.

PLANNED CHANGES AND IMPROVEMENTS

After continued analysis and meetings with a Tripoli RSO and many other Tripoli certified people at different levels, there are a few changes that should greatly improve the high powered boosted dart. With each individual, the design was broken down and explained why some aspects were chosen over different alternatives. After each meeting it was concluded that the team had made the right general design choices. A few small details were missed, details that one learns after countless hours building and launching rockets.

The most important changes are going to be made in the dart. One of the biggest changes that is going to be done is increasing the overall length of the dart. This change needs to occur because the length of shock cord used needs to be increased dramatically. After parachute deployment in the dart section, the two pieces are separated by a shock cord three feet in length.

This is not enough. While falling back to the ground, it will be quite easy for the densely packed nose cone to dent the lower part of the dart. With this information gained, the new length of shock cord separating the two dart sections will be between 10 to 15 feet. The length of each section in relation to the parachute will also be uneven, doing this will make sure that there are no collisions between dart sections. Safe wadding will also be implemented in order to protect the parachute. In order for the altimeter to correctly record data, holes need to be drilled in order to make up for the pressure differential. Although some say two hole would be fine for the altimeter in the dart, a third hole is going to be drilled to ensure accuracy. Another way the accuracy of the altimeter is going to be increased is by increasing the diameter of the holes. The last issue in the dart is that the force required to separate the nose cone and the body tube is too low. If this force is not increased the nose cone could rip the parachute out at way too high of speeds. This change will easily be done by increasing the overall diameter of the bottom of the nose cone ever so slightly. Wires needed to be threaded from one end of the dart, through the coupler, and then connected again on the other side of the dart. This left a hole through the coupler that would easily allow the ejection charge to push through and destroy all of the electronics and flow through the holes used for the altimeter. This hole can easily be patched up with a sort of clay or epoxy and will be done for launch. One last issue is the electronic bay, the initial design was much bulkier than expected. This meant that a longer overall dart length was needed, meaning the apogee of the dart decreased. All of the parts for the electronics bay can be individually assembled and then put together in different orientations to make sure the optimal length is met.

The booster section of this design had much fewer and smaller issues. One of the issues that really stuck out was the way to attach part of the shock cord. One side of the shock cord is attached to the transition piece, but the lower part does not have anywhere to obviously connect too. The attempt to attach it to the motor mount was made, but it interfered far too much with the motor itself to be successful. It was decided that using a coupler would be the best alternative. The shock cord will be wrapped around the coupler, pushed into place and then bonded on. This will ensure a tight and stable fit so there is no way the shock cord will be ripped out at one end. The overall length of the booster body tube will also be shortened.

APPENDICES

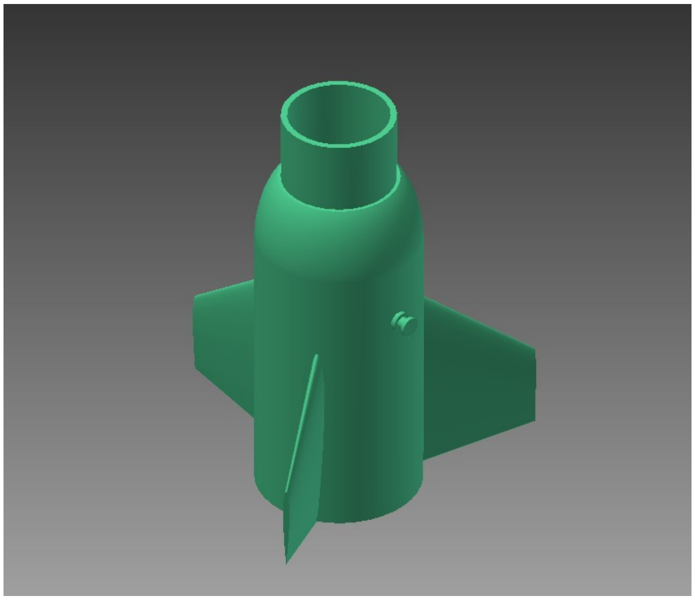

Figure 1: Final lower booster section.

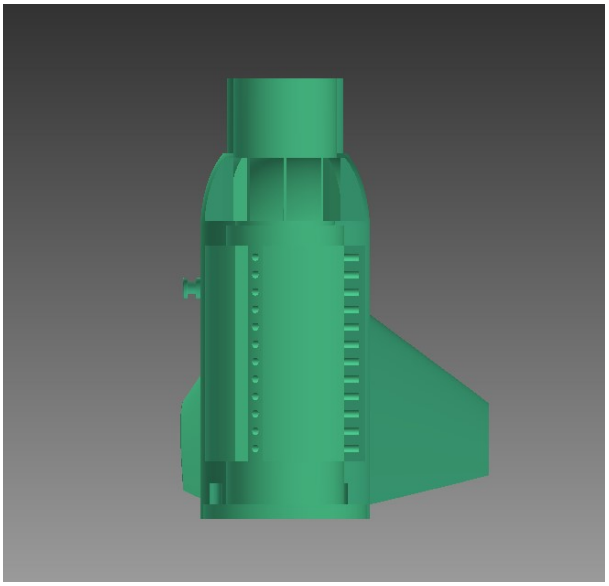

Figure 2: Cross- section view of the final lower booster section.

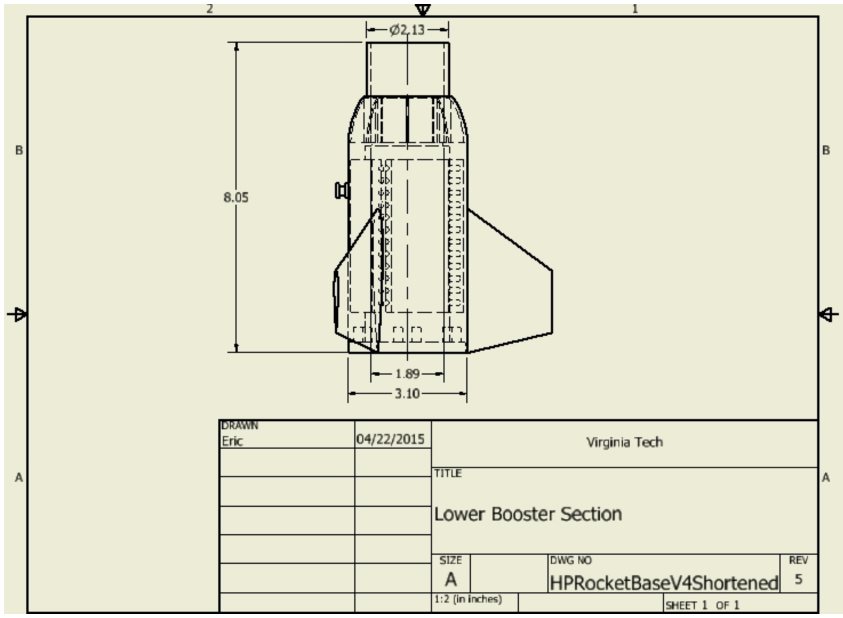

Figure 3: Sketch of the lower booster section with the main dimensions.

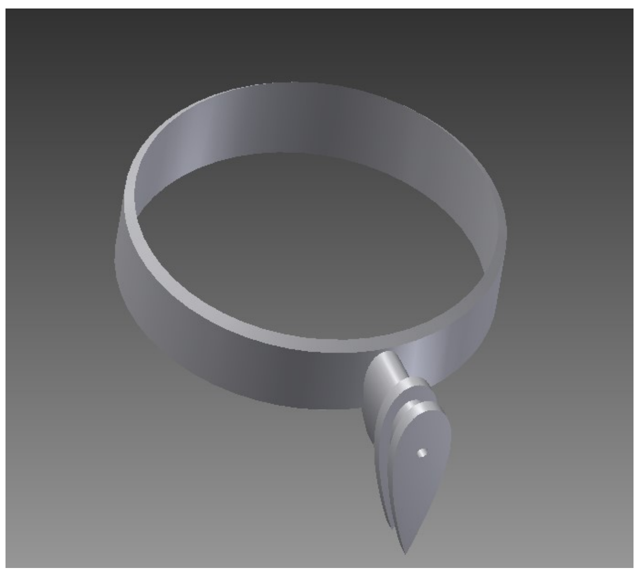

Figure 4: Inventor CAD model of the upper booster rail button. Airfoil is a NACA 0030.

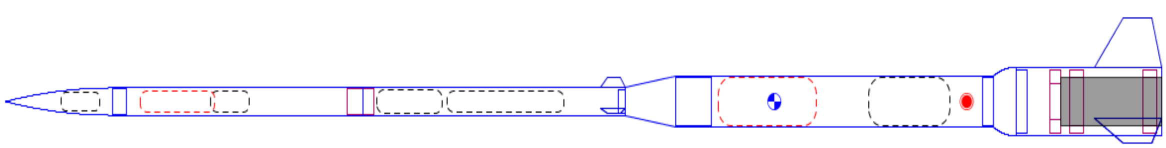

Figure 5: Open Rocket model with the center of gravity denoted by the blue and white dot (1090 mm from top) and the center of pressure denoted by the red dot (1370 mm from top).

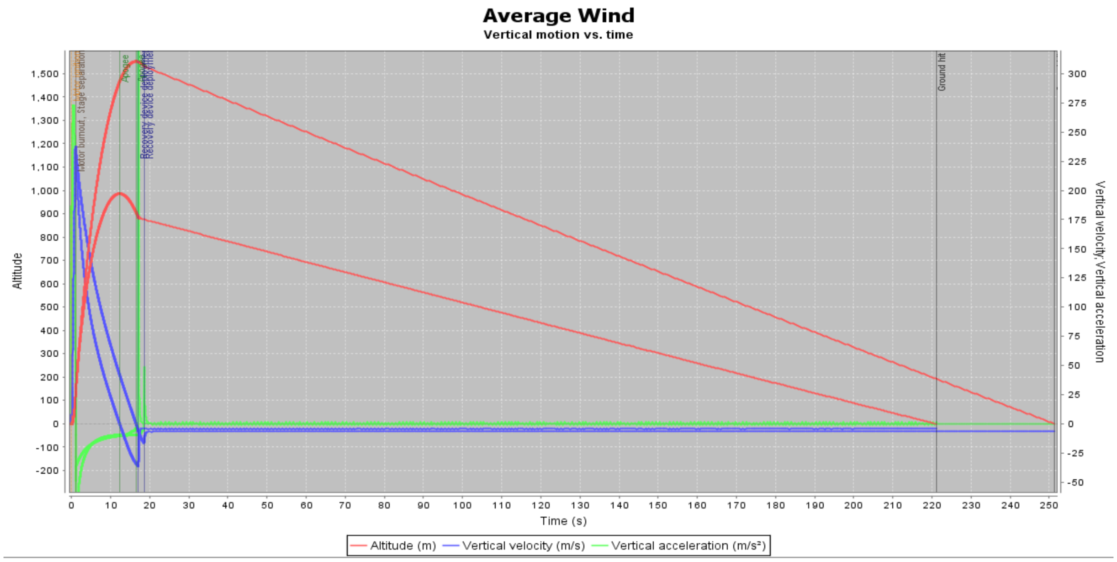

Figure 6: Open Rocket simulation for average wind conditions. Expected apogee is 1553 meters.

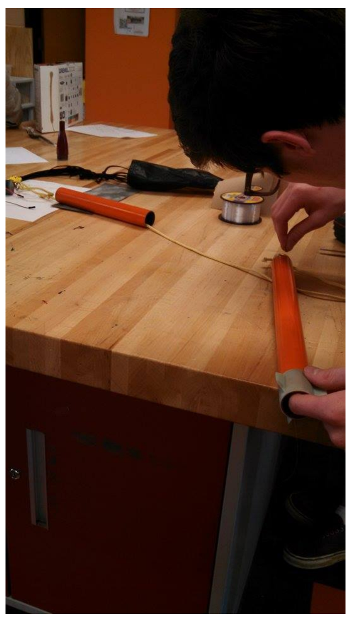

Figure 7a: Fishing line was used to run wires from the electronics bay to the ejection charge in the dart stage.

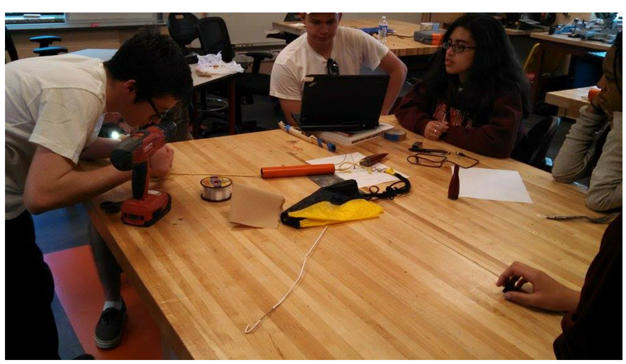

Figure 7b: A hole was drilled in the coupler for the dart to run wires from the electronics bay to the ejection charge.

Figure 8a: The rocket in its two primary components. The booster stage is on the top, and the dart stage is in the bottom.

Figure 8b: The assembled rocket.

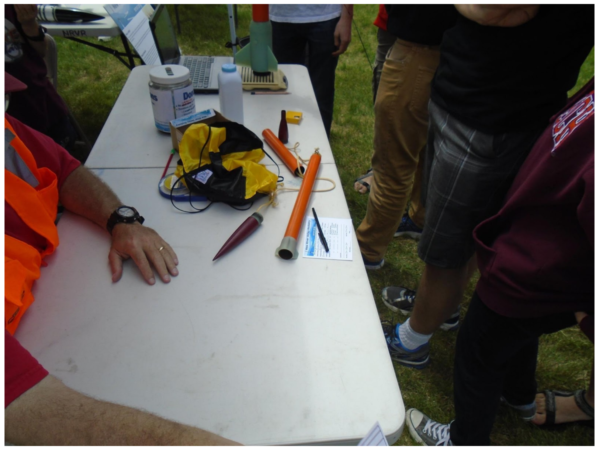

Figure 9: The team at launch day only to find out the wrong motor was ordered..