NASA's Space Grant Midwest High Power Rocket Competition

2014-2015

Preliminary Design Report

University of Minnesota - Twin Cities

Freshman Team

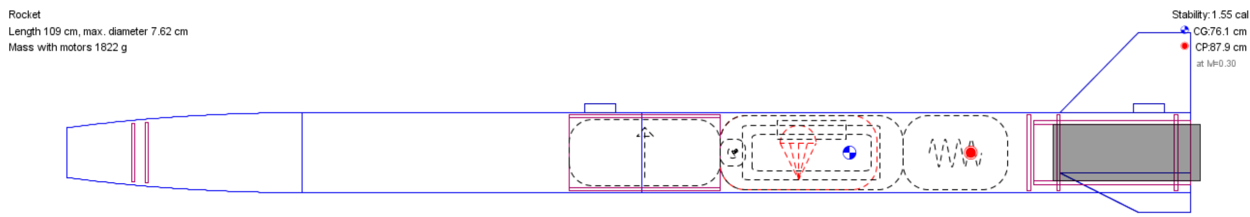
5/4/2015

Table of Contents

Recap of Rocket Design

Booster

Design and Dimensions:



Length = 42.9”

Body Diameter = 3.00”

Mass (with preflight motor) = 64.3 oz = 4.02 lb

Center of Gravity (from tip of “nosecone”) = 30.0”

Center of Pressure (from tip of “nosecone”) = 34.6”

Static Margin = (34.6” - 30.0”)/3.00” = 1.55 (<u>Stable</u>)

The booster body tube is a 3” diameter Blue Tube coupler tube. A coupler tube was chosen so we could have the option of using main body tube as a form-fitting shape for the potential airbrakes later on. Other notable features of the booster include:

-three 10.5 sq. in., ⅛” fiberglass fins

-a cut-off nosecone as to accommodate the dart

-centering rings within the nosecone that keep the dart in place

-a large amount of empty space between the AV bay and the nosecone that was left for airbrake mechanisms

-a 5.75” long AV bay made from 3” LOC Stiffy Tube that holds a Raven altimeter, a radio beeper, and the Altimeter 2

Construction Techniques:

The booster was constructed using a series of progressively sized tubes. A full length coupler tube was used as a body tube, while a LOC Stiffy tube was used as the coupler/AV bay. This will allow the addition of flap-style air brakes if such a thing remains doable. In general, the booster from the nose cone and back was constructed fairly normally, using a motor mount tube with centering rings and slotted fins. For this competition, our team acquired a fit slotting machine that allowed us to slot our own fins accurately using a router. The nosecone was cut off 3” from the tip, and was then slotted as to accommodate the dart, using a dremel. Two centering rings of differing sizes to hold the dart were laser cut to fit into the nosecone and hug the tail cone of the dart.

Stability Analysis:

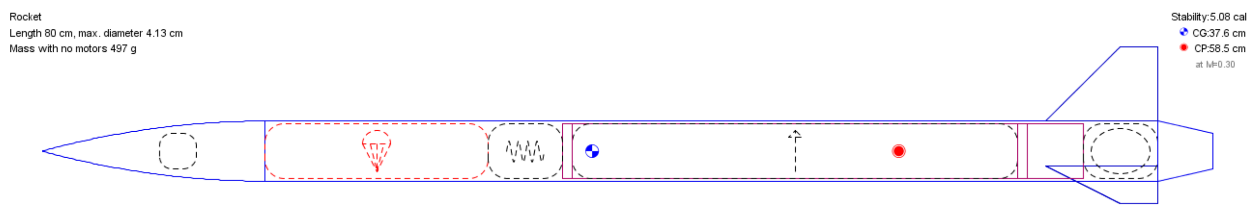
The static margin of the booster is 1.55, which is right in the middle of the stable zone. Without accounting for the time when the booster and dart are together, the booster needs no alterations to change stability according to that figure. However, questions remain as to how well modelling software is able to account for the presence of a large hole in the center of the nose cone, so further testing may indicate the need for larger fins or a different weight distribution to try to counteract this problem.

Constructed for a Safe Flight and Recovery:

For the most part, the booster is a very simple rocket, and does not have too much danger associated with it. An altimeter-triggered ejection charge, as well as a motor eject as a backup should ensure the safe separation and recovery of the booster. The only notable safety concern for the booster is the fact that the sizable hole in the nose cone after separation adds an element of unpredictability to its flight. To try to mitigate risks from this, we will fiberglass over the nosecone in order to stiffen it and avoid bending or even breaking of the nose cone. The booster's fins may also be enlarged to move the center of pressure back and stabilize the rocket as well.

Dart

Design and Dimensions:



Length = 31.5"

Body Diameter = 1.63"

Mass = 17.5 oz = 1.10 lb

Center of Gravity (from tip of nosecone) = 14.8"

Center of Pressure (from tip of nosecone) = 23.0"

Static Margin = (23.0" - 14.8")/1.63" = 5.08 (<u>Overstable</u>)

The dart body tube is a 38mm diameter, 24" long carbon fiber body tube. Other notable features of the dart include:

-three 4 sq. in., 1/16" fiberglass fins

-a 1.5” long, drag-reducing tail cone that also acts as a retention system for an onboard Mobius Camera

-a 12” long AV bay that contains a Raven altimeter, an Arduino Nano with microSD card shield, and a 9 degree of freedom IMU

-a hollowed out nosecone that holds a radio beeper and the Altimeter 2

Construction Techniques:

The 24” carbon fiber body tube was received as is, with 1” slots to allow for partial slotting of the fins. G10 fiberglass fins were cut using a bandsaw to fit the required dimensions, as is the case with the booster as well. Another notable construction project for the dart was the creation of the tail cone. The cone was formed using a dremel and a lathe from a full size solid conical nose cone, and was hollowed out manually as to hold the Mobius Camera.

Stability Analysis:

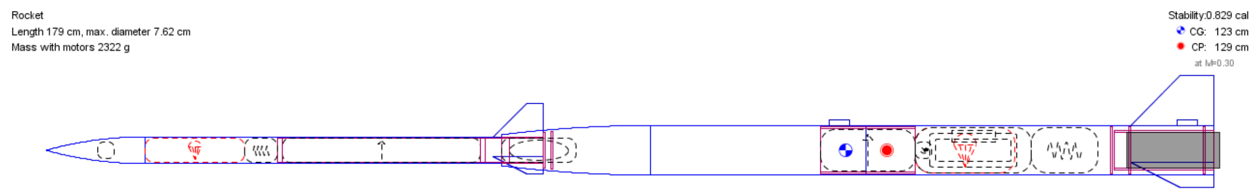
The dart has a static margin of 5.08, which is quite overstable. This is not desirable, but we have decided to air on the side of overstability for the dart. We hope that by the time of separation, the dart’s trajectory will be set to the point that it won’t veer into the wind much due to its overstability. If we decide that the overstability will be a problem however, we have the option to simply cut the existing fins into a smaller shape.

Constructed for a Safe Flight and Recovery:

Once separated from the booster, the dart becomes a very simple projectile, similar to ones our team has experience with. An altimeter triggered ejection charge will go off at apogee, releasing a parachute that will bring the dart safely to the ground. The sturdy carbon fiber and fiberglass exterior of the dart should avoid any problems caused by the stresses of flight.

Booster and Dart Together

Design and Dimensions:



Length = 70.5”

Maximum Body Diameter = 3.00”

Mass = 81.9 oz = 5.12 lb

Center of Gravity (from tip of nosecone) = 48.4”

Center of Pressure (from tip of nosecone) = 50.8”

Static Margin = (50.8” - 48.4”/3.00” = .83 (<u>Understable</u>)

The booster and dart fit together using three fin-slots in the booster nosecone, as well as a series of centering rings in the booster nosecone that provide a stable place to sit for the dart.

Stability Analysis:

The booster-dart combination has a static margin of .83, which indicated slight understability. This is definitely not desirable. In our flight tests thus far, this has possibly manifested itself in some somewhat veering and wobbling flights. This will definitely be a problem that we want to fix before the competition. We can either somehow add on the booster fins, shrink the dart fins, or move or add weight to the front of the booster or to the dart in order to remedy this problem.

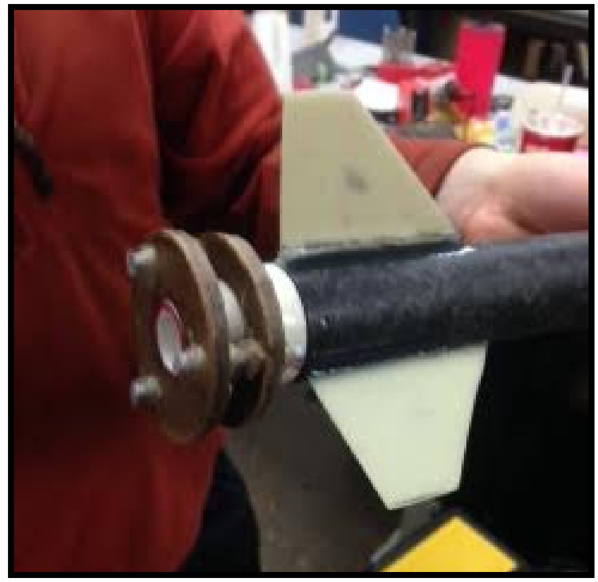
Discussion of Changes since the Preliminary Design Report:

Since the PDR, the general dimensions of the booster and dart only changed slightly, but there were many smaller additions and revisions to each design over the course of the build process. Notably, in both rockets, the fins were given a simpler shape, and the placement of the interior components of the rockets were rearranged. The dart now separates at the nose cone, as opposed to the previous model that had it separate in in the middle the body tube.

Rocket Construction Process

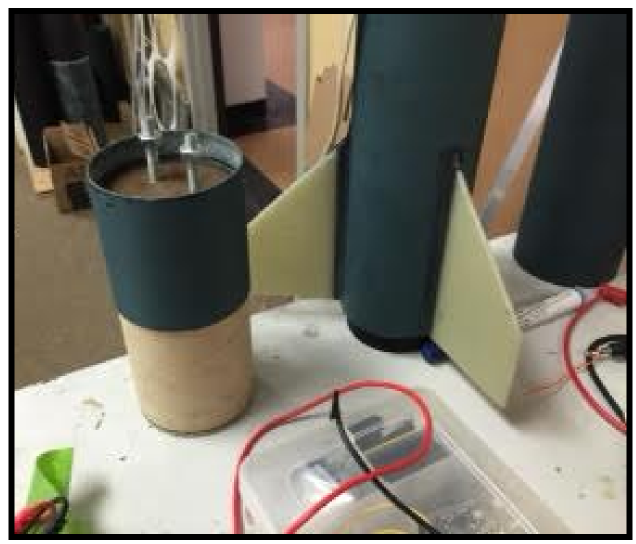
Using a rocket slotting mount we slotted our fins using a router. The slotter adjusts to the diameter of the body tube. A ⅛” bit was used to cut slots to the thickness of the fiberglass fins.

Above: Epoxying The motor retention system to the bottom of the booster.



Above: The dart mounting system that was later installed in the booster nosecone.

The dart's downward looking camera resting inside its hollow boat tail.



The booster's avionics bay with metal reinforcement rods protruding.

Test Flight 1 Report

Our first full system test flight was Sunday, April 26. The full configuration of booster and dart were launched, the only exceptions being the planned mirror and airbrake systems were not flown, and the camera was not flown due to a design oversight in the mounting process that was quickly corrected for future flights.

Launch and Boost Analysis:

Left: Vertical Off of the rail

Right: Vertical into the flight

Our launch was vertical, and the booster/dart combination appeared stable in flight, moving vertically for the entire duration.

Coast and Separation Assessment:

The coast continued vertically, and the drag separation occurred almost immediately after the end of the motor burn. The dart continued upwards, and the booster quickly decelerated. Both appeared stable in flight, although the dart was invisible soon after separating from the booster. There did not appear to be any issues with the separation of the two systems.

Recovery Systems Analysis:

Neither altimeter-controlled ejection charge fired, but the motor eject backup did fire in the booster, saving it and returning it only a few feet from the launch pad. The booster sustained no damage. Unfortunately, no such backup existed for the dart, and it managed to bury itself to its fins the the soft ground. Using a shovel and our hands, we were able to recover the dart, which fortunately had minimal damage to its structure. The camera had not been mounted, but the boat tail was unharmed. In the digging process, a fin was damaged, but not severely, and was quickly repaired. The nose cone of the booster was mostly undamaged, but was still replaced for future flight due to some compression at its base, and some difficulties removing the radio beacon from it. The primary issue that resulted from the rapid deceleration of the dart was in the avionics bay. The arduino, IMU, Raven altimeter, and two 9V batteries were damaged well beyond repair or function, and any data they may have carrier was lost. These components required replacements for future launches.

Pre-Post Flight Procedure Assessment:

There were clear issues with our pre-launch procedure. The Ravens were not correctly understood before being used, and the beep patterns had been misinterpreted before and during the launch, leading to their failure to successfully recover either component. Overall, the first test flight was a learning experience for the team, and forced caution and better oversight into our future plans so that another disaster, possibly much more damaging that this one, could be avoided.

Test Flight 1 Performance:

The data recovered from the Altimeter 2 gave an indication into how the dart flew.

Max Altitude: 3068 ft

Top Speed: 387 ft/s

Thrust Time: 1s

Peak Acceleration: 22.0 g

Average Acceleration: 17.6 g

Flight Duration: 31s

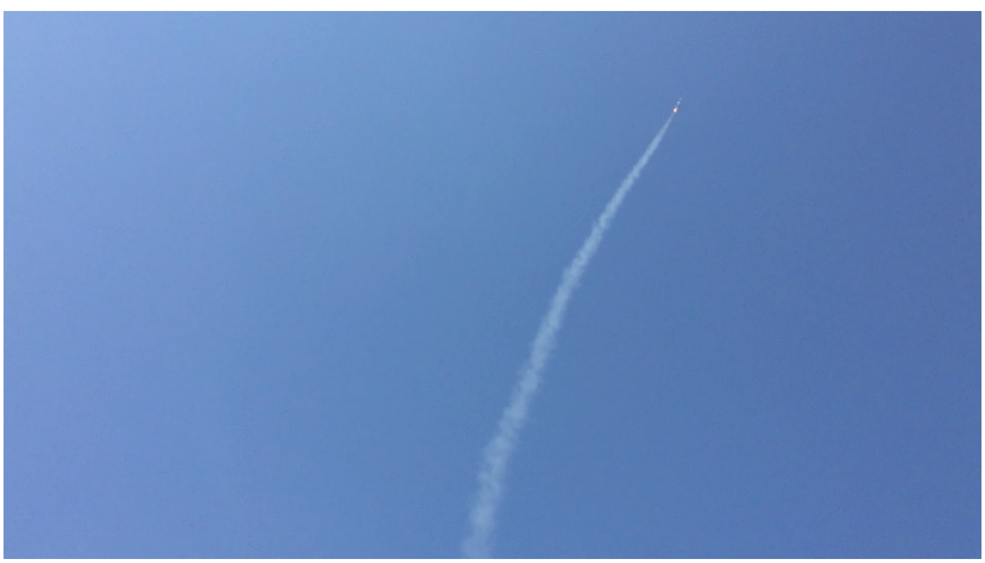
From this data we can deduce that the dart actually flew as expected, reaching near the expecting apogee.

Test Flight 2 Report

Launch and Boost Analysis:

Above: Vertical Takeoff

Right: Rotating onto its angled flight



Left: On its

Angled Path

At the time of launch, there was a slight swirling wind that frequently changed directions. Because of this, it was a bit hard to pin down exactly how, or even if, the rocket reacted to the wind. Upon launch the booster-dart combination veered south and took off at approximately a 60^{o} angle from horizontal. Once it reached this angle, followed this angled path all the way through the boost phase. As stated before, it was difficult to decipher what exactly the quick southward veer indicated because of the shifting winds. With the knowledge that the booster-dart combination is understable, it seems quite possible that the rocket was simply not going fast enough for stable flight upon leaving the rail guide. For this reason, it began to tilt toward the horizontal until it reached a more stable speed, at which point it followed a straight path.

Coast Phase Assessment:

The period of time in which the booster and dart were together and coasting was very short and almost unnoticeable from the ground. As far as can be told however, it appeared that the booster and dart remained on the straight, 60^{o} from horizontal path that was established during the boost phase all the way up until separation. This short period seemed rather uneventful.

Separation Assessment:

As stated in the coast phase assessment, the booster and dart separated almost immediately after burnout. Upon separation, the dart appeared to continue on the path that the full booster-dart combination was travelling upon, and the booster fell back due to its greater drag. Using the onboard video, as well as a slight change in the flight of the booster, this drag separation seemed to occur very quickly and without any interference imparted upon the dart by the booster. Due to its small size and speed, the dart was quickly out of view, but the booster remained easy to follow. After the dart pulled away from the booster, the booster began to wobble fairly significantly. This wobble did not appear to be strictly due to instability in the proportions of the booster, but rather seemed indicative of the inflow of air that was entering the booster's hollow nose cone. It never appeared as though the booster was going to tumble, but the flight was definitely not as stable as desirable and remained in a wobbling state until apogee. On the other hand, the booster came to reach apogee very quickly, especially compared to the dart, potentially due to the loss of energy from the wobbling. While we feel confident that the booster is stable enough to fly repeatedly, based on the imperfect flight, we hope to improve this stage of the flight. This can be done increasing the static margin of the booster by either making the fins larger or adding weight near the front, both of which would also help stabilize the booster-dart combination.

Recovery System Analysis:

Left: Recovering the Dart

Upon reaching apogee, the booster ejected its 45" parachute and began its descent. A couple seconds into the descent, a puff of smoke could be seen from the lower half of the booster. We determined that this was the motor ejection charge going off, which would indicate that the altimeter-triggered ejection charge indeed ejected the parachute. This suspicion was confirmed upon recovery of the booster when both charges were found to be set off. In addition, the booster came down slowly and had not sustained any damage upon reaching the ground.

The 30” parachute of the dart could be seen very faintly in the distance, so we knew that the altimeter had also triggered the ejection event in the dart. The dart went out of view while still high in the air, and ended up drifting more than a mile away from the launch site. We later found based on our altimeter data that the dart had a descent rate of 13.9 ft/s, which would explain the far drift. The desired descent rate is in the range of 20-25 ft/s, so we may decrease the size of our parachute in future flights. Other than the far drift, the rocket was in perfect shape upon recovery, and the ejection from the altimeter was confirmed.

Pre- & Post-Launch Procedure Assessment:

Unfortunately, in the days leading up to this launch, our team was too focused on the build and forgot to prepare a procedure for flight day. Fortunately, this did not hurt us, as the only thing that we forgot to do was turn on the alarm on the booster’s shock cord, and since the booster came down within sight, this was not a problem. It did however, prove to us that a checklist will be necessary in future flights, because similar oversights could be devastating.

Without the use of a checklist, we still ran through a mental procedure that served us well enough for this flight. It consisted of the following major steps:

Pre-flight:

-confirm that avionics in both booster and dart are in working order and set up correctly

-place all avionics in both booster and dart

-tie and pack parachutes

-assemble and secure the pieces of the rocket bodies with rivets, shear pins, etc.

-install the booster's motor

-confirm that avionics are still in working order while in each AV bay (by listening to the beep pattern of the Ravens)

-setup the full rocket on the rail

-turn on the electronic for the final time and make sure once again that everything is beeping correctly

-confirm that the radio beeper in each part of the rocket is transmitting

-connect the motor and launch

Post-Flight:

-follow both components of the rocket visually as best as possible (assign people to track each part)

-find both the dart and the booster, using the radio beeper if necessary

-once found, confirm that the flight went as planned and there is no damage on the found half of the rocket

-find both halves of the rocket before recovering

-bring both parts of the rocket back to the base camp and check the avionics for damage

-check the Altimeter 2 data to get a rough idea of how the flight went

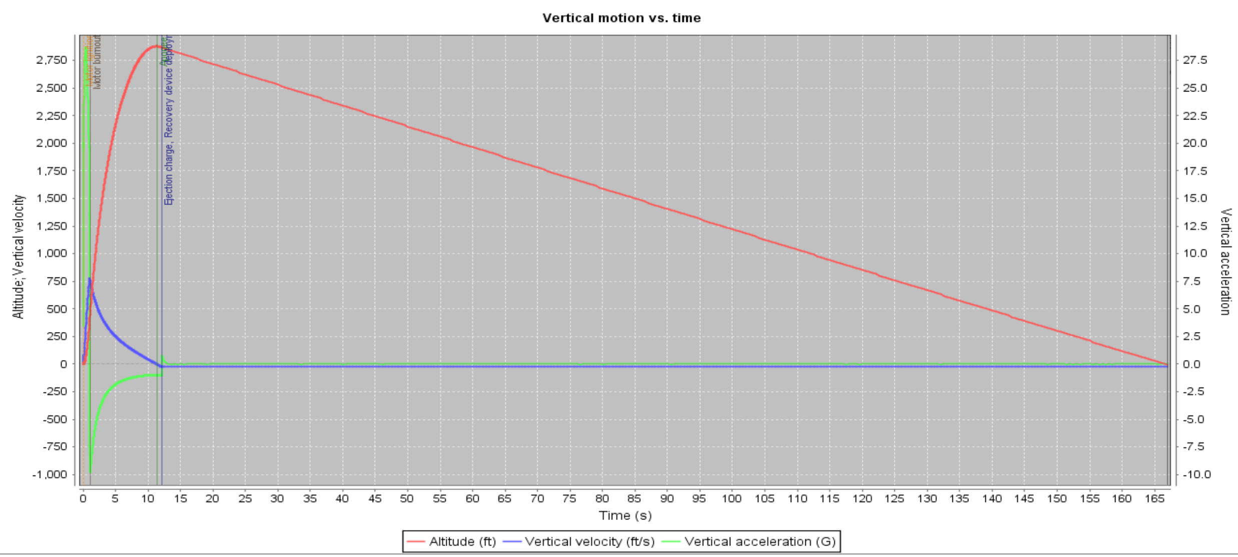
-if possible, view more extensive altimeter and IMU data

-confirm that everything was recovered, and pack up

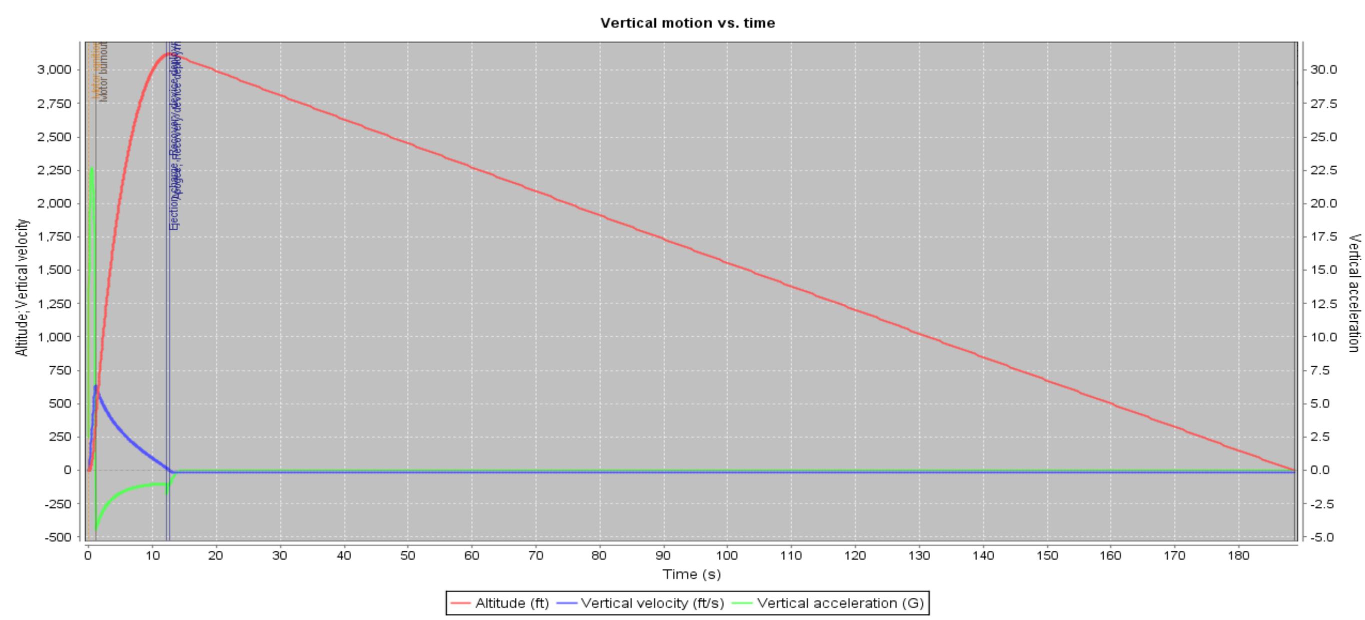
Test Launch 2: Actual vs. Predicted Performance

Projected Flight Performance

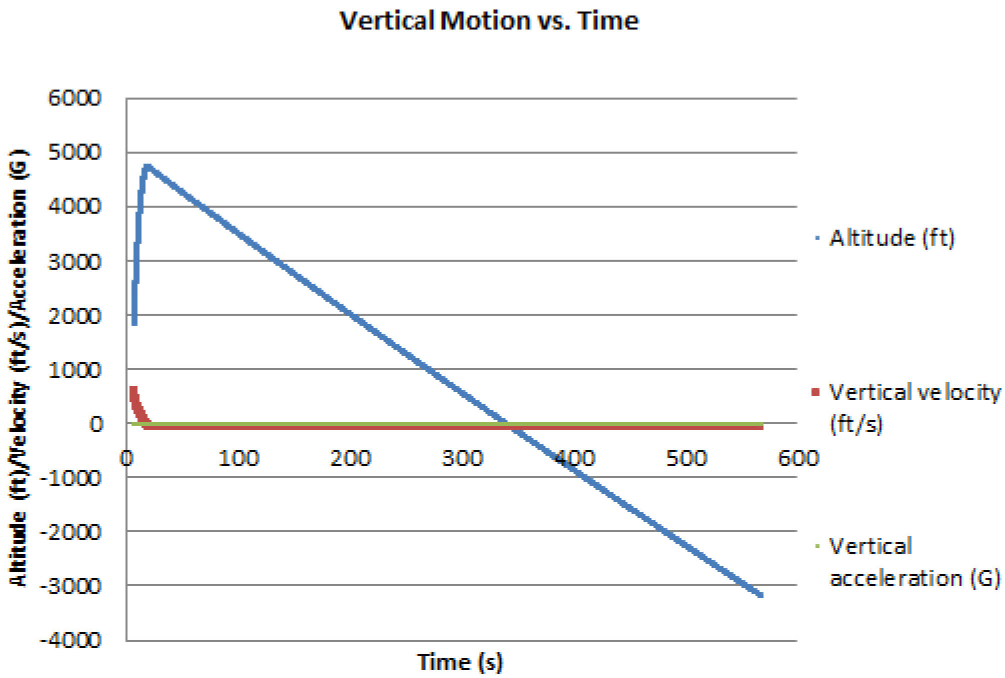
Booster-Dart Combination (no separation):



Booster:



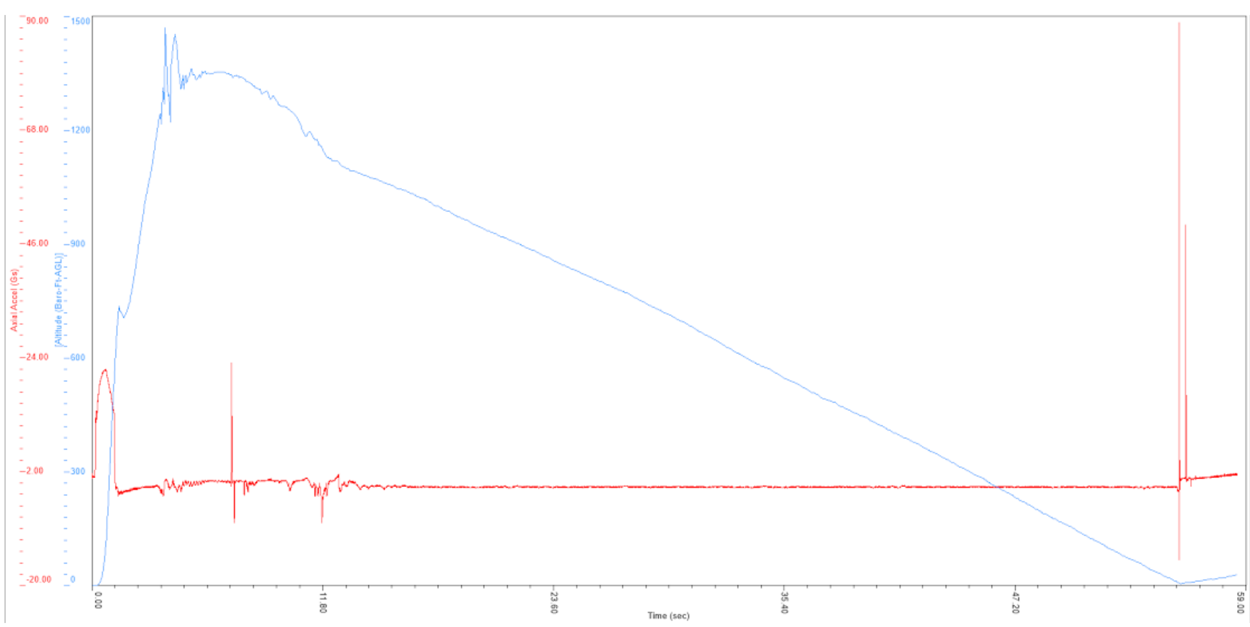
Dart (after separation):



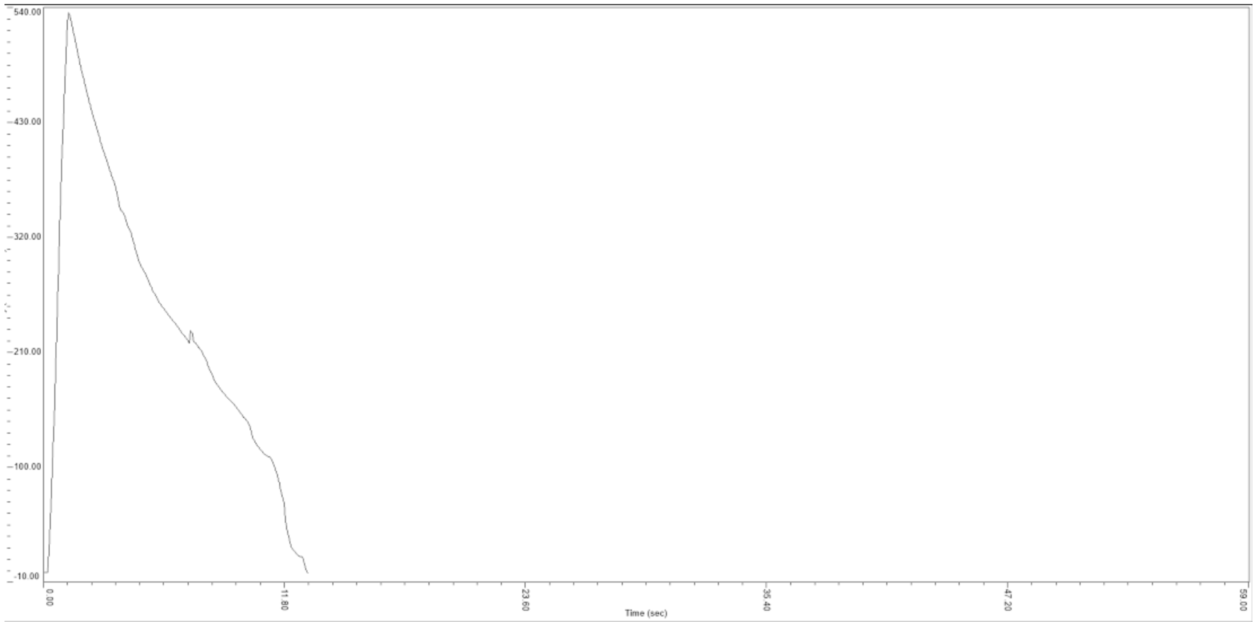
Actual Flight Performance

Booster:

Acceleration and Altitude:

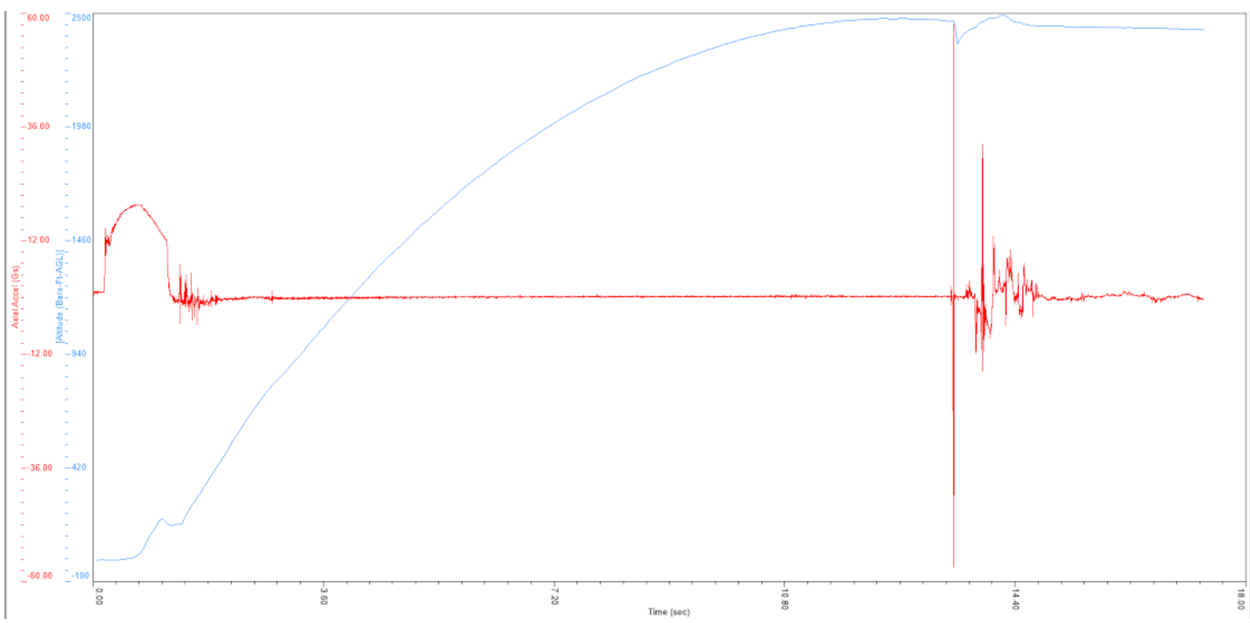


Velocity:

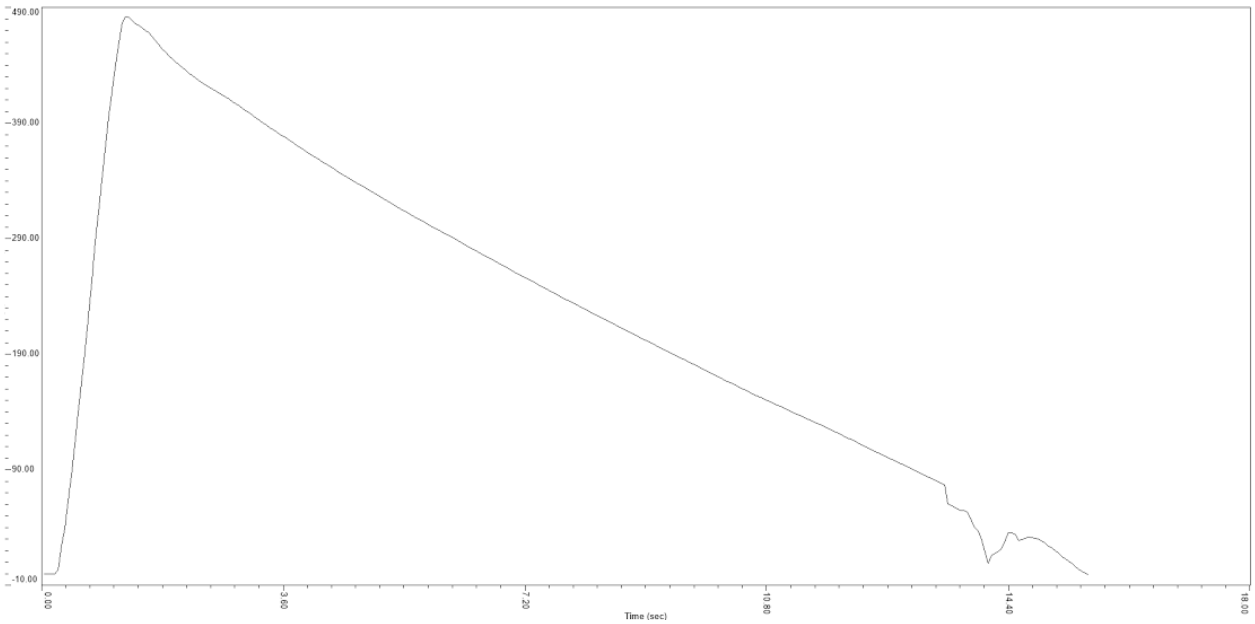


Dart:

Acceleration and Altitude:



Velocity:



Peak Altitude Comparison:

Projected Booster Peak Altitude = 3147’

Actual Booster Peak Altitude = 1361’

Projected Dart Peak Altitude = 4796’

Actual Dart Peak Altitude = 2493’

Peak Acceleration Comparison:

Projected Booster Peak Acceleration = 28.2 G

Actual Booster Peak Acceleration = 22.9 G

Projected Dart Peak Acceleration = 28.2 G

Actual Dart Peak Acceleration = 23.6 G

Peak Velocity Comparison:

Projected Booster Peak Velocity = 756.1 ft/s

Actual Booster Peak Velocity = 537.0 ft/s

Projected Dart Peak Velocity = 756.1 ft/s

Actual Dart Peak Velocity = 486.2 ft/s

Across all of the figures, the projected values appear to be from 20% to around 100% higher than the actual values. This could be due in part to the fact that the figures measured here are all vertically oriented, as were the flight projections, but the actual flight was not perfectly vertical. The flight projections also seemed to have a difficult time modelling the hole in the nosecone of the booster and the spinning of the dart, both of which limit altitude, velocity, and acceleration.

Video and Rotation Data Logging Performance/Comparison:

For the purpose of data logging, an Arduino microcontroller was among the avionics aboard the dart. A 9-axis inertial measurement unit (IMU) was attached to the Arduino along with a shield that afforded us the ability to record the IMU data on a microSD card.

For the test flight on May 2, 2015, the Arduino was programmed to read and record the acceleration and angular velocity data for all three axes. We then intended to analyze the data in Excel and pinpoint the launch by finding the instances when acceleration peaked. To this end, we were somewhat successful. The data collected by the Arduino provided us with proof-of-concept for the Arduino code and design. However, the largest peak in acceleration observed by the Arduino was less than 2.5 times the gravitational acceleration on the surface of the earth. This is a significant deviation from our expectations; during the boost phase of the flight, we expected the accelerometer to report its maximum value of 16 g. There is a possibility that the code did not properly compensate for the accelerometer sensitivity, though ground testing before the flight suggested that acceleration data was being interpreted properly. The angular velocity data (as provided by the IMU's gyroscope) from the period shortly after the peak g-force is similarly anomalous. Two of the axes were expected to have relatively low angular velocity measurements when compared to those of the third axes. To a reasonable degree, this was observed in our data as the X and Z axes had far less angular velocity than the Y-axis. We would therefore expect the Y-axis to exhibit either a consistently positive or consistently negative angular velocity shortly after the peak acceleration. Unfortunately, the data do not show such a trend. The sign (+/-) of the Y-axis angular velocity values inverts repeatedly.

Before the next flight, a sizable quantity of ground testing will be performed to better prepare the data for post-flight analysis. This ground testing will inevitably include many revisions of the Arduino's code, including (but certainly not limited to) increasing the rate at which data is collected and re-evaluating the data collection processes for each component. Additionally, the inclusion of data from the IMU's magnetometer is planned and expected to provide supplementary rotation data.

Based solely on the video however, there was an extremely high amount of rotation in the dart, particularly after separation from the booster. Rotation was extreme enough to the point that it was often impossible to comprehend the video being received at all. We still are not quite sure why some much rotation occurred, but we hope that after further ground testing with the Arduino will allow us to better understand the rotation of our dart during the next flight, possibly allowing us to remedy the problem before the competition launch.

Findings and Future Work

Key Findings:

Having a successful practice flight was a very beneficial experience for our team overall, despite the shortened timeline that it forced us into. There were many crucial findings that we had that we would not have been able to discover without flying ahead of the competition. Some of the most principle of these are the following:

-The dart's parachute is unnecessarily large and only will make recovery more difficult and loading the dart more tight

-The hole in the front of the booster causes instability in the booster despite the stable static margin

-The slightly understability of the booster-dart combination is significant enough to cause both parts of the rockets to veer off of vertical

-The previous two points provide very strong reasons to make the booster (and thus the full rocket) more stable

-The dart spins quite a bit upon separation from the booster, which could potentially be a large waste of energy. This should be remedied if possible

-It will be extremely beneficial to create a pre- and post-flight checklist for future flights

Potential Design Improvements:

Based on these key findings, and the goals we have yet to achieve, the following are some potential design improvements that we have yet to apply:

-Make the booster more stable

    -Add weight near the top of the booster

-Add canard fins near the base of the booster

-Extend the fins of the booster

-Make it possible to achieve full-flight camera footage

-Devise a system of mirrors that directs the camera view to the exterior of the booster while the booster and dart are together

-Use improved rotational data to keep the dart from spinning so much

-Replace the dart’s 30” parachute with a 24” parachute

-If there is time and it seems beneficial, add air brakes to the booster