Preliminary Design Report

inVenTs Slinging Slashers:
High Powered Rocketry Team

Organization:
inVenTs Living Learning Community

Funded By:
Virginia Space Grant Consortium

Written:
March 1, 2015

Table of Contents

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 it is safe to fly. Other goals include: to maximize separation distance between the boosted-dart and booster stages, to achieve maximum boosted-dart apogee, and to have 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.

As a result, the inVenTs High Powered Rocketry Team was assembled. Composed of members of various academic levels and majors, ranging from Aerospace Engineering to Electrical Engineering to Physics, living in the inVenTs Living Learning Communities, every member supplies a variety of technical skills and experiences that facilitates the development of the rocket components. The application of computer-aided design software has allowed for the integration of 3D-printed parts into the design. Flight and performance simulators such as OpenRocket and Rocksim have enabled design flaws to be diagnosed early in the design stage allowing for design alternatives to be implemented. In addition, physical and mathematical limitations as well as other constraints, such as budget and time management, restricted access to materials, and competition guidelines, have been taken into great consideration throughout the design process.

The purpose of this report is to provide a detailed description of the design processes implemented by the inVenTs High Powered Rocketry Team, the inVenTs Slinging Slashers, in the construction of a high-power, boosted-dart rocket. It is important to note that this report is preliminary in nature, and information within the report is subject to change.

ROCKET DESIGN

The high-power, boosted-dart rocket features a modular design for easier disassembly and maintenance. The rocket consists of lower and upper sections on both the booster and the dart. Figure 1 shows the location and division of the rocket's four sections.

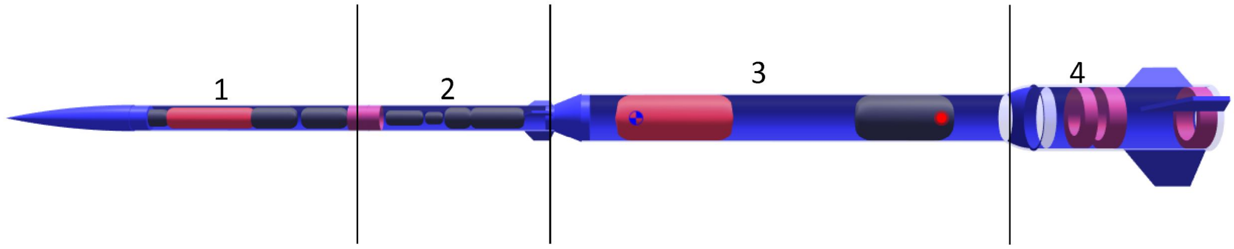


Figure 1: Breakdown of booster and dart

The length of the assembled rocket is estimated to be around 1420 millimeters. The rocket's stability is estimated to be around 2.2 calipers with a loaded motor. The center of pressure should be a distance of approximately 1110 millimeters away from the top while the center of gravity should be approximately 936 millimeters away from the top. With an empty motor, the rocket's stability is estimated to be approximately 4.58 calibers. The center of pressure is expected to be about 1110 millimeters from the top of the rocket while the center of gravity is expected to be about 749 millimeters from the top of the rocket. The dart's stability is estimated to be around 2.07 calibers with a center of pressure approximately 296 millimeters away from the top of the dart and a center of gravity approximately 230 millimeters away from the top of the dart. The total mass of the rocket with a loaded motor is expected to measure 1850 grams, while the mass of the dart stage is expected to measure 548 grams. The booster stage is expected to have 1.91 calibers of stability, a center of pressure located 624 millimeters away from the top of the booster stage, and a center of gravity located 473 millimeters away from the top of the booster stage. Refer to Figure 2 for visual representations of the center of gravity and center of pressure locations.

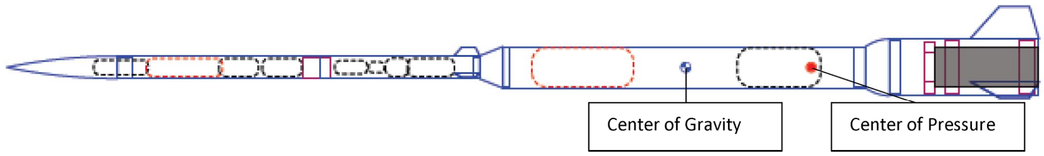


Figure 2a: Rocket with labeled center of gravity and center of pressure for a loaded motor.

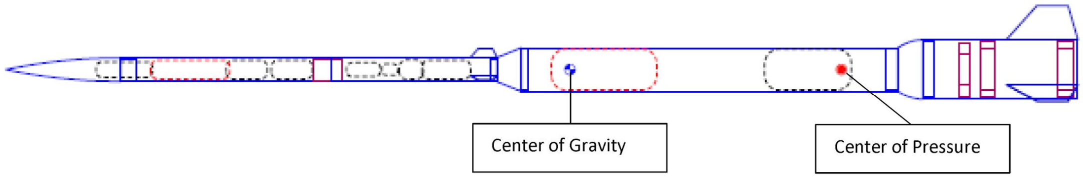


Figure 2b: Rocket with labeled center of gravity and center of pressure for an empty motor.

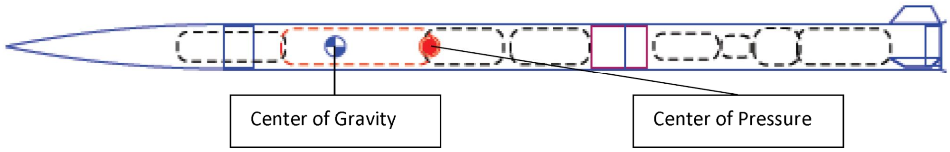


Figure 2c: Dart stage with a labeled center of gravity and center of pressure.

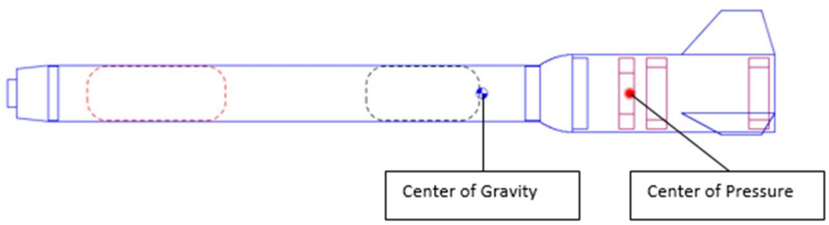


Figure 2d: Booster stage, with an empty motor, with a labeled center of pressure and center of gravity.

Figure 2: Layout of booster and dart created through Open Rocket, center of pressure and gravity labeled

Lower Booster Section

The lower booster section was created using a computer automated design (CAD) program known as Autodesk Inventor. The CAD model was then 3D-printed using ULTEM 9085, a thermoplastic known for its high strength-to-weight ratio and flame, smoke, and toxicity rating (FSM). [8] The lower booster section is unique in that it integrates a motor mount, threaded body tube coupler, and fin set into one part. The motor mount was designed to accommodate the Cesaroni 54 millimeter one grain motor casing. The integrated motor mount will allow approximately 6.4 millimeters of the motor to protrude out of the base of the rocket so that an Aeropack 54 millimeter flanged motor retainer may be installed. A smaller diameter hole extends from the top of the motor through the threaded body tube coupler to allow the ejection charge to reach the upper booster stage. This is useful for proper recovery device deployment. The threaded body tube coupler is located at the top of the integrated, dome-shaped transition. This screws into a threaded ring secured to the bottom of the upper booster section. Refer to Figure 3 to view the internal, integrated motor mount.

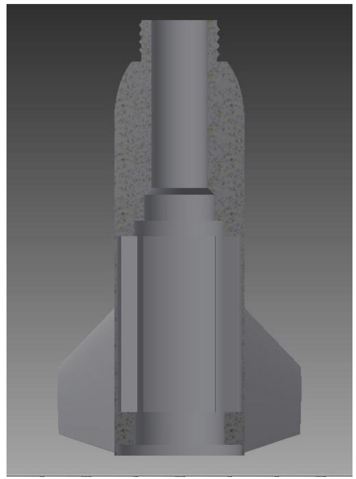


Figure 3: cross-section view of lower part of booster section

The lower booster stage contains three equidistant fins. The fins were printed as part of the lower booster section to eliminate potential human error caused by unequal spacing and weakness at the fins' mounting points. Each fin was created using a NACA 0005 symmetrical airfoil. The fins have root chords of 95 millimeters, tip chords of 41.2 millimeters, heights of 95 millimeters and sweep angles of 42.1 degrees. To reduce the risk of damage to the fins upon impact, the fins are swept away from the base of the rocket. This is an added preventative measure in the event the base of the rocket strikes the ground on impact due to the shifting center of gravity of the booster stage assembly with a now empty motor. A sketch of the lower booster section and find design is shown in Figure 4.

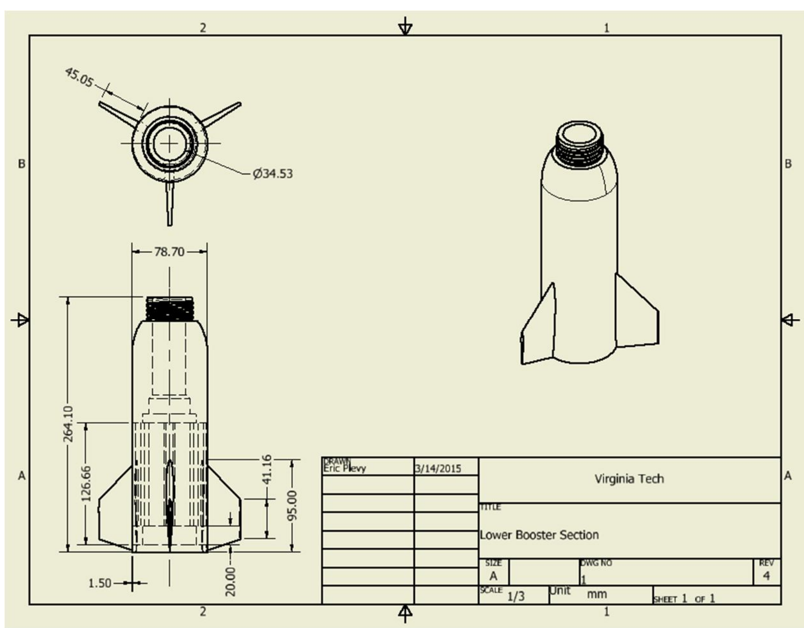


Figure 4: Views and drawings of lower section of booster

Upper Booster Section

The upper booster section consists of a 54 millimeter body tube, with a threaded ring at the bottom of the body tube, a transition coupler at the top of the body tube. The booster stage assembly's recovery system is contained within the body tube (refer back to section 3 of figure 1). The body tube consists of a vulcanized fiber-like material known as Blue Tube. The material is less expensive than fiberglass and is more durable than phenolic kraft tube. The 3D-printed threaded coupler ring will allow the lower booster section to screw into the upper booster section. The conical transition coupler, located at the top of the upper booster section, will be constructed from polystyrene. A conical cavity, located at the fore end of the conical coupler, will secure the dart stage assembly to the booster stage assembly. For increased durability, the polystyrene coupler will be coated in a resin. The booster stage's recovery system will consist of a 36 inch diameter, ripstop nylon parachute. The parachute will be attached to a tubular nylon shock cord. An altimeter will be attached to the shock cord using a segment of non-flammable Kevlar string.

Lower Dart Section

The dart stage assembly, like the booster stage assembly, can be divided into two main sections. The lower dart section houses the electronics and fins while the upper dart section holds the recovery system and nosecone. The lower dart section will be constructed out of 29 millimeter diameter wound filament fiberglass, which will be cut to a length of approximately 220 millimeters. Fiberglass has a higher density (1.85 grams per cubic centimeter) than ULTEM 9085 (1.34 grams per cubic centimeter) and Blue Tube (1.3 grams per cubic centimeter), which increases stability. The bottom of the lower dart section features a conical polystyrene boat-tail with a small opening to allow room for the camera. Directly above the boat-tail, a 3D-printed fin assembly is secured to the fiberglass body tube. Three symmetric airfoil cross-sectioned fins are evenly spaced around a ring that slides onto the body tube and is secured in place with adhesive. The fins have root chord lengths of 35.4 millimeters, tip chord lengths of 18.8 millimeters, heights of 12 millimeters, and are swept from the top at an angle of 41.1 degrees. As with the fins on the lower booster section, they are also swept away from the base of the dart to reduce the risk of damage upon impact.

Upper Dart Section

The upper dart section uses a 280 millimeter segment of wound filament, 29 millimeter diameter, fiberglass body tube. This section houses the dart's recovery system: an 18- inch diameter, ripstop nylon parachute, which deploys via an ejection charge capsule. The parachute deploys out of the bottom of the upper dart section as opposed to the top. A 3D-printed, ULTEM 9085, tangent, ogive nose cone is secured at the top of the body tube. The tangent, ogive nose cone has a horizontal length of 152 millimeters, a base diameter of 31 millimeters, and whose profile was created from the segment of a 1469 millimeter diameter circle. A hollow cavity extends approximately a third of the length of the nose cone to allow for the addition of a lead counterweight with an approximate mass of 275 grams to increase stability.

AVIONICS

Microcontroller system

The boosted dart features a microcontroller to act as the onboard flight computer. The microcontroller is responsible for the data collection during the flight and parachute deployment at apogee. The microcontroller is an Arduino Micro, which measures 48mm x 18mm x 13mm. As with all onboard electronics, the largest dimension will be oriented vertically within the boosted dart with the smaller dimensions fitting within the small dart diameter. The Arduino Micro was chosen for its small size and its ability to communicate through the I2C interface. In addition, it can be powered off an independent power supply (it does not need a computer connection to run). A 9V DC battery powers the microcontroller and external components. [3] The Micro connects to a sensor, which is responsible for taking measurements of rotation during the flight. A three-axis gyroscope/accelerometer combination instrument, the MPU-6050, was selected. The sensor communicates with the Arduino through an I2C connection. [6] Since the Arduino Micro only contains 1 kb of EEPROM memory, an additional memory chip is required to store the flight data. A 256 kb I2C EEPROM external memory chip is connected to the Arduino to store the flight data. [1] The Micro will also be connected to a small, short range 315 MHz RF receiver, which acts as an input. When the microcontroller receives the input signal that was sent to the receiver, it activates the electronics before launch. The last part of the microcontroller system is a digital output pin on the Micro connected to the tracking transmitter. Just before launch, the Micro activates an electronic relay, activating the tracking transmitter.

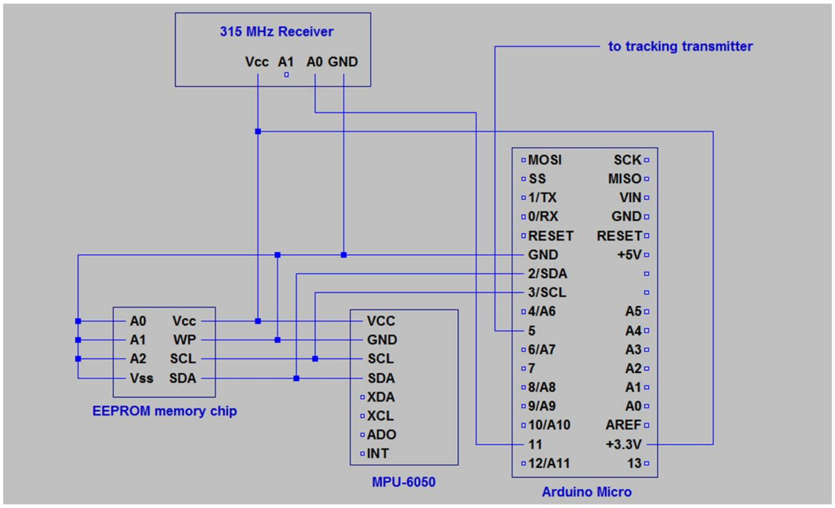


Figure 5: microcontroller system block diagram

Transmitter/receiver

The tracking transmitter (Figure 6) is responsible for outputting a signal so that the boosted dart can be tracked and recovered after launch. Commercial transmitters with several miles of range can cost more than $100. As the large range is not required for the recovery of the dart, a smaller, cheaper 108 MHz adjustable transmitter was selected. The 108 MHz transmitter has a minimum range of ⅛ mile in vegetation with a maximum range of 1 mile in ideal conditions. This is sufficient for finding the boosted dart after if lands. The receiver is a simple variable FM receiver. The antenna height and a potentiometer can be adjusted to change the receiver's strength. The signal is strongest when the antenna has a clear path to the transmitter. It is weaker when the signal is being blocked. [4]

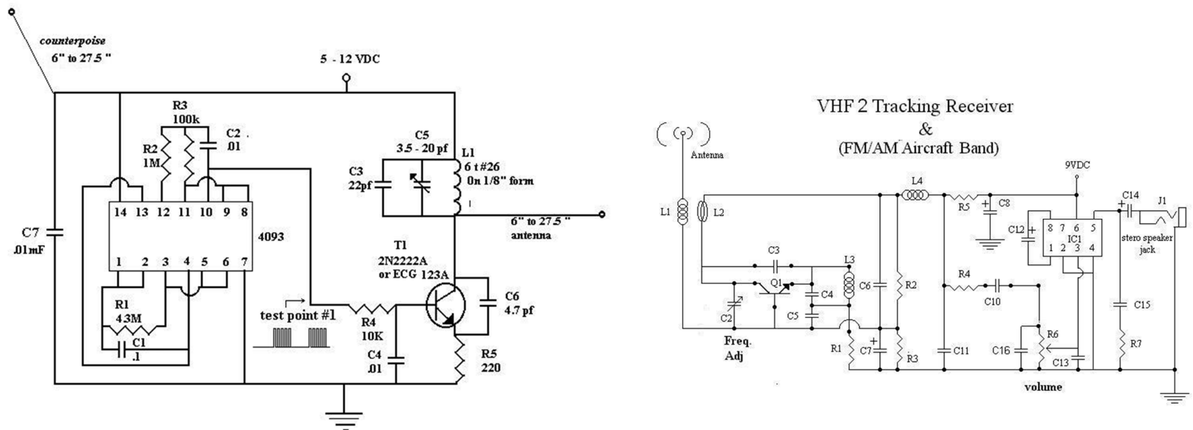


Figure 6: left: transmitter schematic; right: receiver schematic

Camera

The main consideration when selecting a camera to record downward video from the dart was that the camera must be small enough to fit into the 1" diameter dart body tube. In addition, the camera must be a closed system to reduce complexity, run off its own battery, and store the video. It was also desirable for it to have a high frame rate and a decent resolution. Several options were considered, including snake tube cameras, tiny digital cameras, and spy cameras, as well as scavenging for cameras from products that used them. After sifting through many different options, the latter method was deemed the most effective means of acquiring a decent functional camera. The 808 Keychain camera from Apogee Components© was selected. A microUSB port on the device allows the flight video to be easily downloaded onto a computer post flight. [2] While it is a significantly more expensive piece, it is believed to be of better quality and still within the allotted budget.

Software

After the rocket is situated on the flight pad, a signal is sent to the Arduino's receiver. The purpose of the signal is to activate the electronics when the rocket is stationary on the flight pad. This is an extra precautionary measure to prevent false data caused by moving the rocket from triggering events in the microcontroller. After the Arduino receives the signal, it proceeds to initialize the sensor and begin testing the system. First, the Arduino tests the memory chip by storing and retrieving sample data. Next, the program tests the sensor by checking that it returns appropriate values for sitting stationary on the launch pad. At this point, the Arduino has verified that all components are working properly and activates the tracking transmitter. If the tracking receiver does not pick up a signal, then there is an issue with the electronics. The launch is then aborted. The electrical components are then analyzed to diagnose the issue. After the issue has been resolved, a launch is then reattempted. If the electronics are working properly, and the tracking transmitter is activated, the program continues into pre-launch mode where it waits for the motor ignition. Before the launch, the Arduino requests the accelerometer and gyroscope data from the sensor. When the accelerometer detects a large instantaneous acceleration in the vertical direction (i.e. a launch), the Arduino records the flight time as t = 0. The Arduino then focuses on collecting, processing, and storing the gyroscope data. During launch, the Arduino does not request the data from the accelerometer as the data is not be required during the flight. With the Arduino only requesting the gyroscope data, the rate of data collection and storage increases compared to when the Arduino requested both acceleration and gyroscopic data. During the flight, the Arduino requests the gyroscope data from the sensor. It then processes it to determine if the dart has reached apogee. The second method of parachute deployment is based on the timer. Should the gyro fail to set off the parachute, and if a certain flight time has been reached, the microcontroller deploys the parachute as a safety measure. If the Arduino detects that the dart has passed apogee and is pointed back towards the Earth, then the parachute will be deployed. Throughout the flight, the Arduino stores the flight time in addition to the gyroscope data in the external memory chip.

ANTICIPATED PERFORMANCE

Rocket simulations were performed under three different wind speeds to ensure safe flight under multiple conditions (Tables 1, 2, and 3). All simulations were calculated using the approximate latitude, longitude, and altitude of the launch site located outside of Minneapolis, MN. The highest dart apogee is estimated to be approximately 1651 meters and would be achieved under no wind. Under more probable launch conditions, with winds averaging 2.68 meters per second, the estimated dart apogee is approximately 1649 meters. Under higher winds of 5.36 meters per second, the estimated dart apogee is approximately 1644 meters. The booster's apogee, however, is affected more greatly than the dart's apogee with different wind conditions. The booster's apogee is estimated to occur at approximately 981 meters with no wind, 970 meters with winds of 2.68 meters per second, and 659 meters with winds of 5.36 meters per second. The significant decrease in the booster's apogee with greater winds can be attributed to the booster's larger surface area, as compared to the dart's surface area. The rocket's maximum velocity and maximum acceleration both remain 247 meters per second and 286 meters per second- squared, respectively, despite changes in wind conditions. The dart's impact velocity remains unaffected by changes in wind conditions and is expected to be roughly six meters per second. The booster's impact velocity is estimated to be approximately 4.5 meters per second with no wind, 4 meters per second with winds of 2.68 meters per second, and 4.3 meters per second for winds of 5.36 meters per second. For all three wind conditions, the times from launch to ejection for the dart and booster stages, respectively, were chosen to occur at 19.1 seconds and 17.2 seconds. Both ejection times are slightly longer than the optimized ejection times as this ensures both stages are past apogee before ejection occurs.

No Wind (0 m/s)	
Dart Apogee (m)	1651
Booster Apogee (m)	981
Max Acceleration (m/s^2)	286
Max Velocity (m/s)	247
Dart Impact Velocity (m/s)	6
Booster Impact Velocity (m/s)	4.5
Dart Time of Ejection (s)	19.1
Booster Time of Ejection (s)	17.2

Table 1: Rocket data, no wind

Average Wind (2.68 m/s)	
Dart Apogee (m)	1649
Booster Apogee (m)	970
Max Acceleration (m/s^2)	286
Max Velocity (m/s)	247
Dart Impact Velocity (m/s)	6
Booster Impact Velocity (m/s)	4
Dart Time of Ejection (s)	19.1
Booster Time of Ejection (s)	17.2

Table 2: Rocket data, average wind

High Wind (5.36 m/s)	
Dart Apogee (m)	1644
Booster Apogee (m)	659
Max Acceleration (m/s^2)	286
Max Velocity (m/s)	247
Dart Impact Velocity (m/s)	6
Booster Impact Velocity (m/s)	4.3
Dart Time of Ejection (s)	19.1
Booster Time of Ejection (s)	17.2

Table 3: Rocket data, high wind

SAFETY/RISK ANALYSIS

There were many factors to take into account when designing the rocket, the most important of them being safety. It was essential that the rocket and all its components would not harm any bystanders present during launch, and would return safely and intact, ready to be launched again after flight. Therefore, ULTEM 9085, a high heat resistant thermoplastic, was chosen to be used for the aft part of the booster so that the high heat produced by the motor would not destroy the body/structures mounting it. This ensures a smaller chance of the motor shooting out of the rocket and possibly causing harm to a bystander or the environment.

Additional concerns for safety included the overall stability of the rocket. This was improved by increasing the static margin -- the distance between the center of gravity and the center of pressure. A larger distance between these two points increases general tendency to maintain a linear trajectory. It was important that each section of the rocket was individually stable. A steady dart eliminates the fear of launching a heavy mass on an unpredictable flight path. Overall stability when the dart and booster sections are attached is critical to accomplish design objectives. This will ensure that the dart is released on a predictably straight flight path and achieve maximum apogee.

Another safety concern is the weight that the rocket will take off. A major safety concern at takeoff is that the maximum weight of the rocket must be less than 1/3rd of the average thrust produced by the motor. Using the motor specifications listed by Apogee, the average thrust is 445 N [9]. Using the data from the OpenRocket file, the approximate weight of the rocket at takeoff is 1850 g (1.850 kg). So to check safety, it can be observed that the rocket should not be unsafe because of the weight of the rocket at takeoff. Therefore:

$$1.850\,kg\ *\ 9.81\,m/s^2\ <\ (1/3)\ *\ 445,$$
$$18.1485\text{ N} < 148.33\text{ N}$$

STRUCTURAL ANALYSIS OF PARTS

The team performed a structural analysis of regions where possible deformation was likely to occur. One of the areas of interest were the fins. The analysis performed was the calculation of the maximum shear stress experienced at the intersection of the fins on the booster to the booster body. To find the force acting on the fins, the assumption was established that the force would be equal to the drag force.

To calculate the maximum drag force, OpenRocket was used to find the maximum speed and the resulting value of the coefficient of drag, Cd, for a single fin, which were 247 m/s and 0.04, respectively. The drag force was found using equation (1).

$$D\ =\ (1/2) * rho * V^2 * S_{ref} * Cd \qquad (1)$$

where D represents the drag force, rho represents the density of the air, V represents the velocity of the rocket, and Sref represents the reference area.

The value of density in the equation is 1.1901 kg/m^3, which is the approximate density for the altitude of the competition launch site, which is 250 m above sea level. The reference area was used by taking the total area of a single fin obtained from OpenRocket and dividing it by 2 (to get just one side) and also dividing by 1.02 (to take into account the curvature of the leading edge included in the total area) in accordance with the equation:

$$S_{ref}\ =\ S\ *\ (1/(2 * 1.02)) \qquad (2)$$

where S represents the total area as obtained from OpenRocket.

Once the reference area was found, all values are plugged into the drag equation to find the drag experienced on the wing, which was found to be approximately 4.4296 N. Knowing the force, all that was needed to calculate the shear stress was the area of contact between the fin and the body. Autodesk Inventor was used to get a value for the area, which was found to be 466.48 square millimeters. Then shear stress was calculated using the following formula:

$$\text{Tao} = P/A \qquad (3)$$

where Tao represents the shear stress, P represents the reaction force, and A represents the area.

The shear stress between a fin and its connection to the booster body tube was calculated to be .009496 MPa. Using the material properties page provided by Stratasys for the thermoplastic ULTEM 9085 [8], it was found that the failure shear stress of the material was 57 MPa. Since the maximum value of shear stress is much less than the materials failure stress, the fins are highly unlikely to fail during the rockets ascent.

DOCUMENTED MATERIAL-HANDLING PROCEDURES

The Cesaroni motor's propellant and black powder pellet must be handled and stored with caution. The motor is classified as an explosive article for shipping and transportation purposes. Although the chemicals contained in the motor are chemically stable under standard temperatures and pressures, exposure to temperatures of 280 degrees Celsius or greater will cause auto-ignition. Direct exposure to an open flame will also result in ignition. Static electricity, friction, and impact may also result in an unintended ignition. In case of fire, a dry chemical, chemical foam, or alcohol-resistant foam type fire extinguisher should be used. Water may also be used to extinguish a fire. The motor must be stored in a cool, dry location. For health-related concerns associated with the motor, refer to Table 4.

Health Concerns	Probability of Route Exposure	First Aid
Eyes	unlikely	Flush eyes for at least 15 minutes, with water. Seek medical attention.
Skin	unlikely	Rinse with soap and water for at least 15 minutes. Remove all contaminated clothing. Seek medical attention if irritation occurs. For burns, treat using standard, first aid procedure.
Ingestion	unlikely	Do not induce vomiting. If conscious and alert rinse mouth and drink 2- 4 cupful of milk or water.

Inhalation	unlikely	Remove from exposure and bring to an area with fresh air. Use artificial respiration if not breathing. Give oxygen for difficulty with breathing. Seek medical attention.

Table 4: Safety information for the Cesaroni motor propellant and black powder pellet. [5]

PRE-FLIGHT AND POST-FLIGHT PROCEDURES

Before the launch of this rocket, there are several procedures that have to be followed to ensure a safe and optimal flight. Below is a list of required actions.

Pre-Flight Checklist:

1. Ensure the electronics are activated and are secure in the rocket.
    a. Turn on both competition altimeters, securing one in the booster and one in the dart.
    b. Turn on the dart camera, securing it at the bottom of the dart.
    c. Download the flight program to the microcontroller, ensuring everything is connected and working properly.
    d. Secure the microcontroller system inside the dart.
    e. Secure the tracking transmitter inside the dart, connecting the relay to the microcontroller.
2. Test the security of the motor in the rocket.
3. Verify the timing of the ejection charge in the booster.
4. Verify that the correct amount of black powder, 0.9 g, is in the ejection canister in the dart.
5. Place flame resistant wadding separating the ejection charge devices from the payload components in the booster and the dart sections.
6. Gently coat the two parachutes, one for the dart and one for the booster sections, with baby powder (to prevent it from sticking to itself). Fold the parachutes neatly and secure them in the rocket.
7. Inspect the fins for possible cracks forming around the intersection at the body tube.
8. Confirm the connecting ring for the fins of the dart section is securely attached to the dart.
9. Verify that the nose cone is secured to the dart
10. Check to make sure the top section of the booster is securely connected to the bottom half.

11. Verify that the dart is properly aligned with the booster and has a snug fit inside the transition piece.
12. Get the rocket inspected and approved for flight by the regional safety officer, or RSO, to make sure that the rocket is in compliance with the safety codes and regulations.
13. Move the rocket onto the launch rail, connecting the motor to the launch system.
14. Activate the microcontroller by sending a signal to the system.
15. Listen for the signal from the onboard transmitter. If the transmitter is activated, the rocket is ready for launch. If not activated, launch is aborted and the electronics issue is diagnosed and fixed.

Post Flight Checklist:

1. When the area is clear, as determined by the RSO and the team, the booster and dart will be recovered using the tracking transmitter.
2. Ensure all payload components were recovered and examine for any possible damage.
3. Examine the rocket for any possible damage.
4. Download the video from the camera.
5. Download the flight data from the microcontroller system.
6. Deactivate the camera, microcontroller system, and transmitter.
7. If rocket is in flyable condition, prepare for next flight.

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. Figure 5 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.

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.

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 5: Estimated Budget

Table 6 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 8 people would attend be attending.

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 6: 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 parts were mostly ordered from Wildman Rocketry and Apogee Components©. This is reflected in the significant rise in the total cost for the rocket components ($1556.45). This was made possible since more than enough money 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, it would be $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.

REFERENCES

1. 24AA256/24LC256/24FC256 Data Sheet. (January 1, 2013). Retrieved March 8, 2015, from <http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Components/General%20IC/34979_SPCN.pdf>

2. 808 Keychain Camera. (March 7, 2015). Retrieved March 7, 2015, from <https://www.apogeerockets.com/Electronics_Payloads/Cameras/808_Keychain_Camera>

3. Arduino Micro. Accessed March 7, 2015, from <http://arduino.cc/en/Main/arduinoBoardMicro>

4. Jerry Baumeister. Tracking Transmitter XFM1. (March 5, 2015). Retrieved March 8, 2015, from <http://www.jbgizmo.com/page30.htm>

5. Material Safety Data Sheet ProX Rocket Motor Reload Kits and Fuel Grains. (August 1, 2010). Retrieved March 10, 2015, from <http://www.pro38.com/MSDS/MSDS--ProX--ver3-0.pdf>

6. MPU-6000 and MPU-650 Product Specification Revision 3.4. (August 19, 2013). Retrieved March 11, 2015, from <http://www.invensense.com/mems/gyro/documents/PS-MPU-6000A-00v3.4.pdf>

7. Pro54 475I445-16A. (May 20, 2009). Retrieved March 2, 2015, from <http://www.pro38.com/products/pro54/motor/MotorData.php?prodid=475I445-16A>

8. Ultem 9085 Resin. (January 1, 2014). Retrieved March 1, 2015, from <http://www.stratasys.com/~/media/Main/Secure/Material Specs MS/Fortus-Material-Specs/Fortus-MS-ULTEM9085-01-13-web.ashx>

9. Technology, C. (2009, 06 28). Cessaroni I445. Retrieved from thrust curve.org: http://www.thrustcurve.org/motorsearch.jsp?id=704

APPENDICES

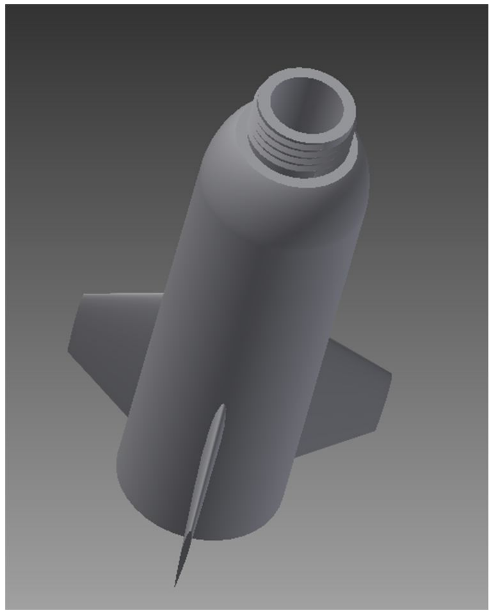


Figure A1: Image of the computer automated design model of the lower booster section

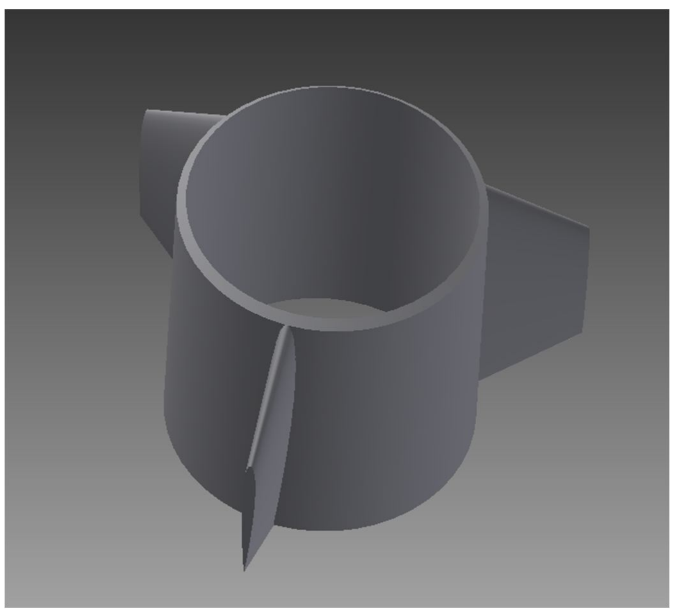


Figure A2: Image of the computer automated design model of the dart fin assembly.

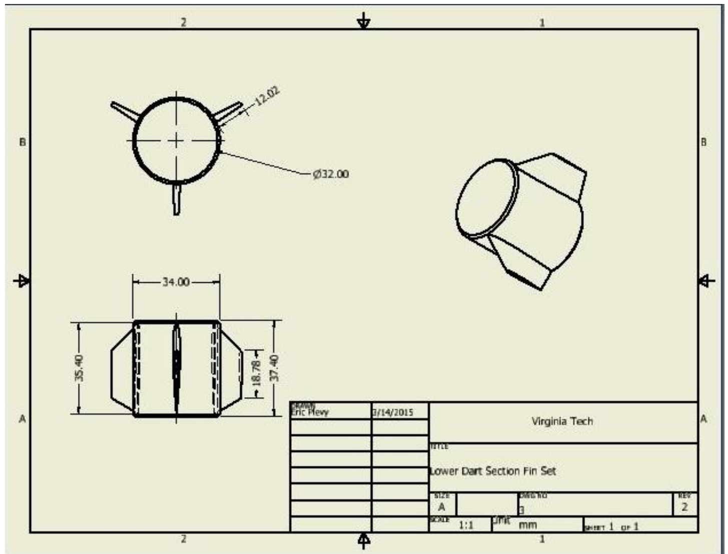


Figure A3: Views and drawings of the lower section of the dart fin assembly.

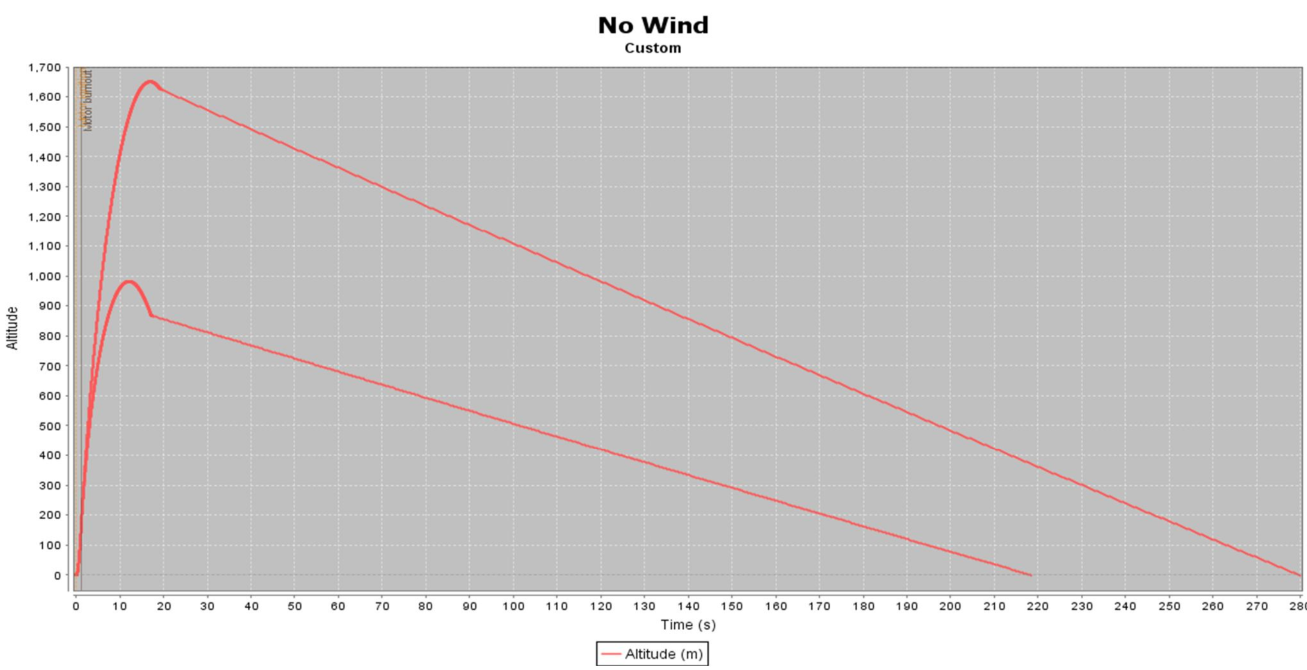


Figure A4: Graph of time (in seconds) versus altitude (in meters), with no wind.

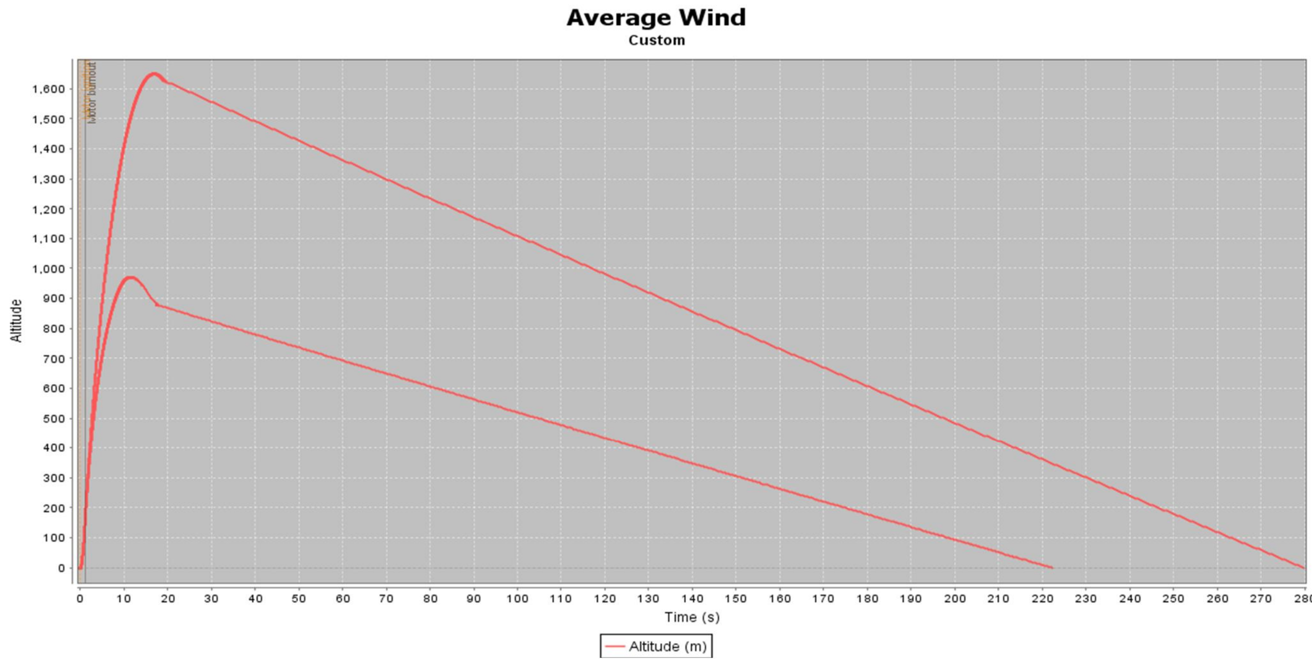


Figure A5: Graph of time (in seconds) versus altitude (in meters), with average wind.

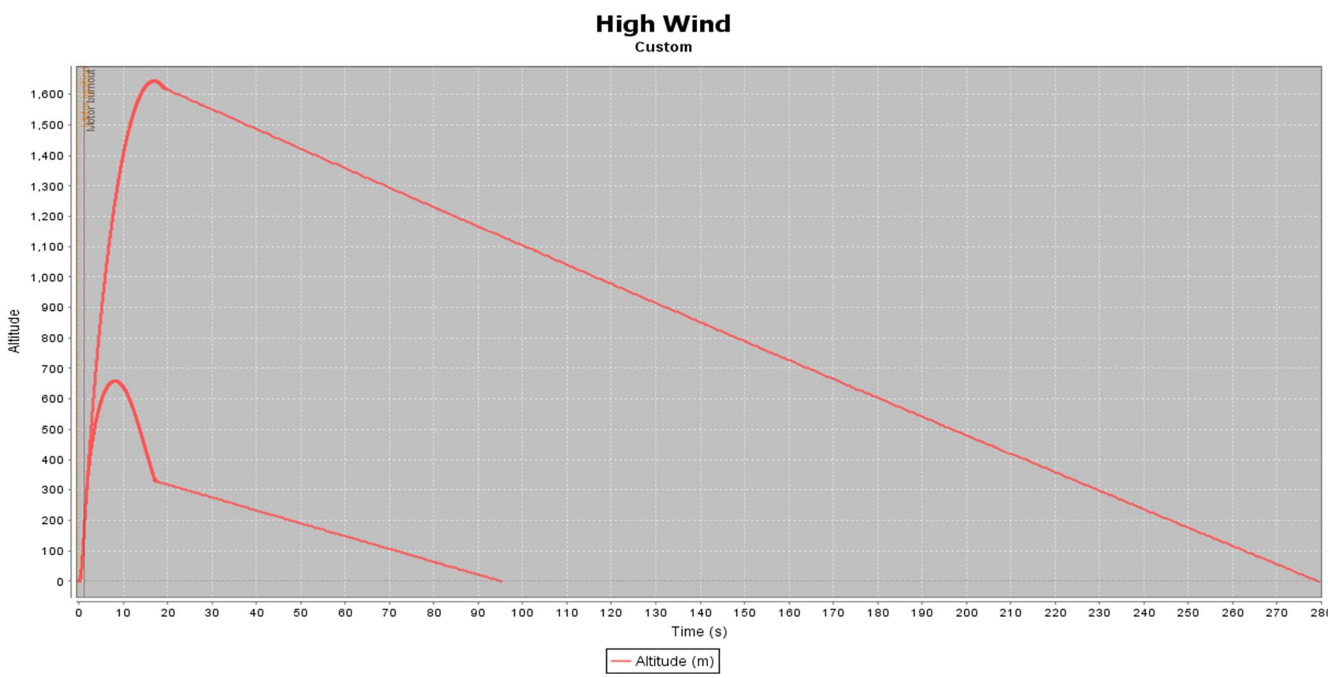


Figure A6: Graph of time (in seconds) versus altitude (in meters), with high wind.

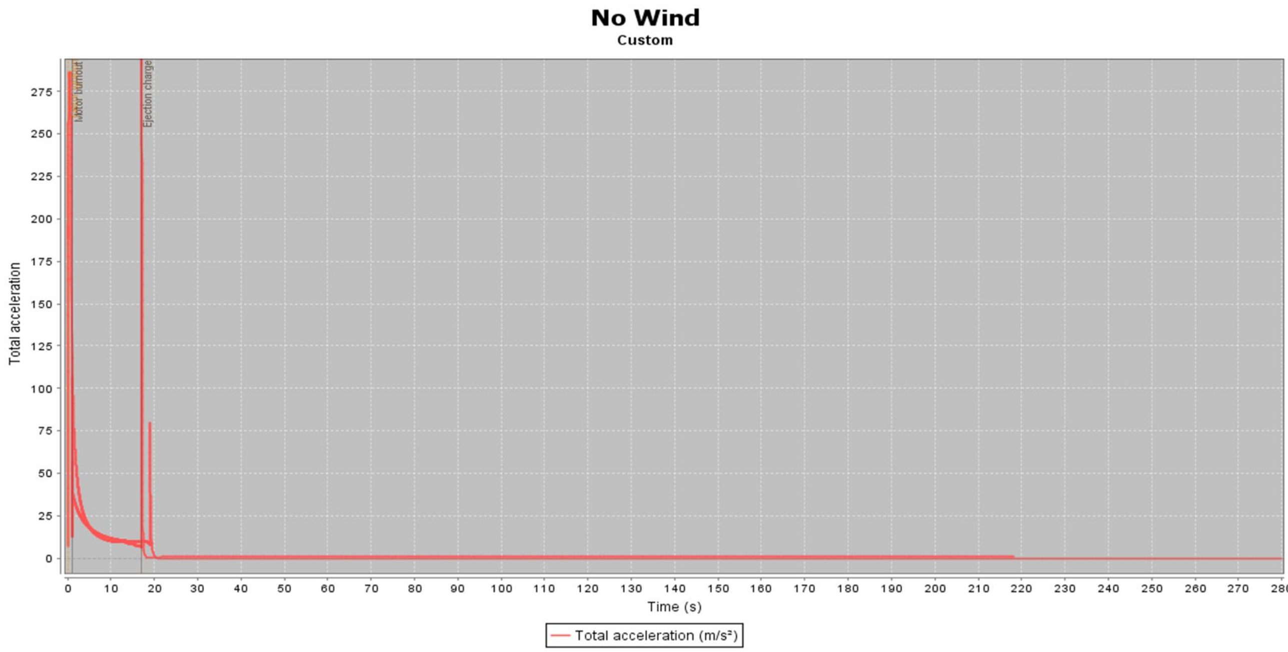


Figure A7: Graph of time versus total acceleration (in meters per second-squared), with no wind.

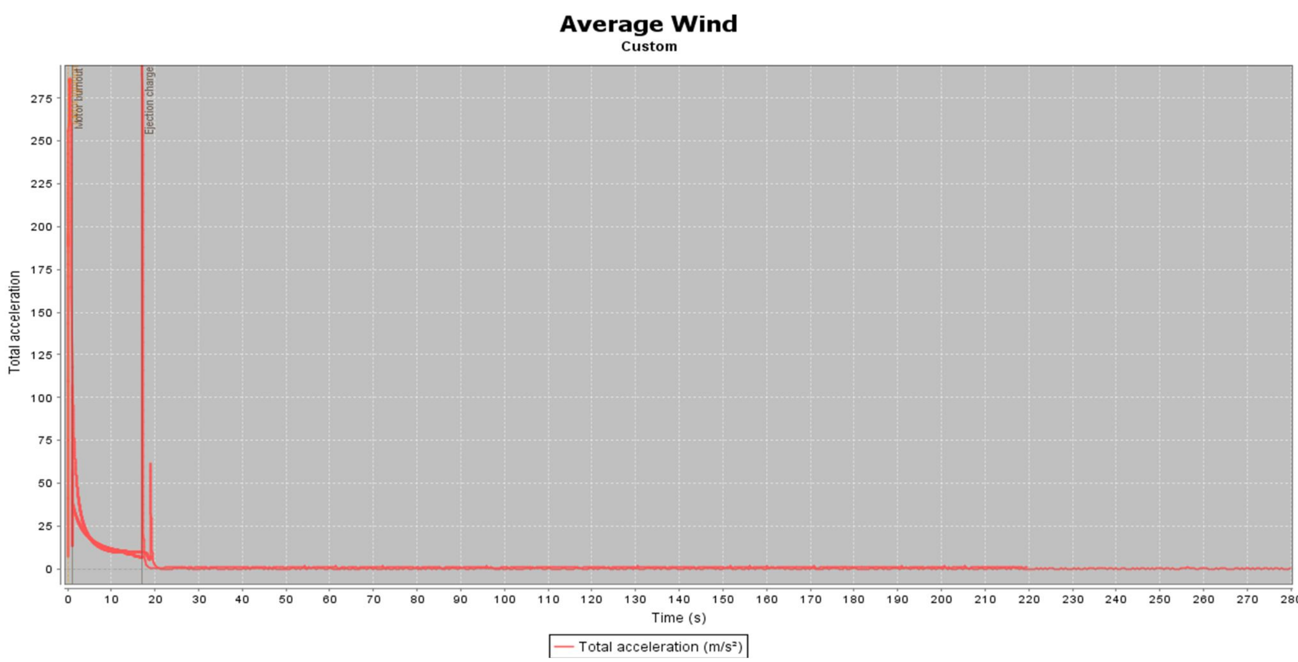


Figure A8: Graph of time versus total acceleration (in meters per second- squared), with average wind.

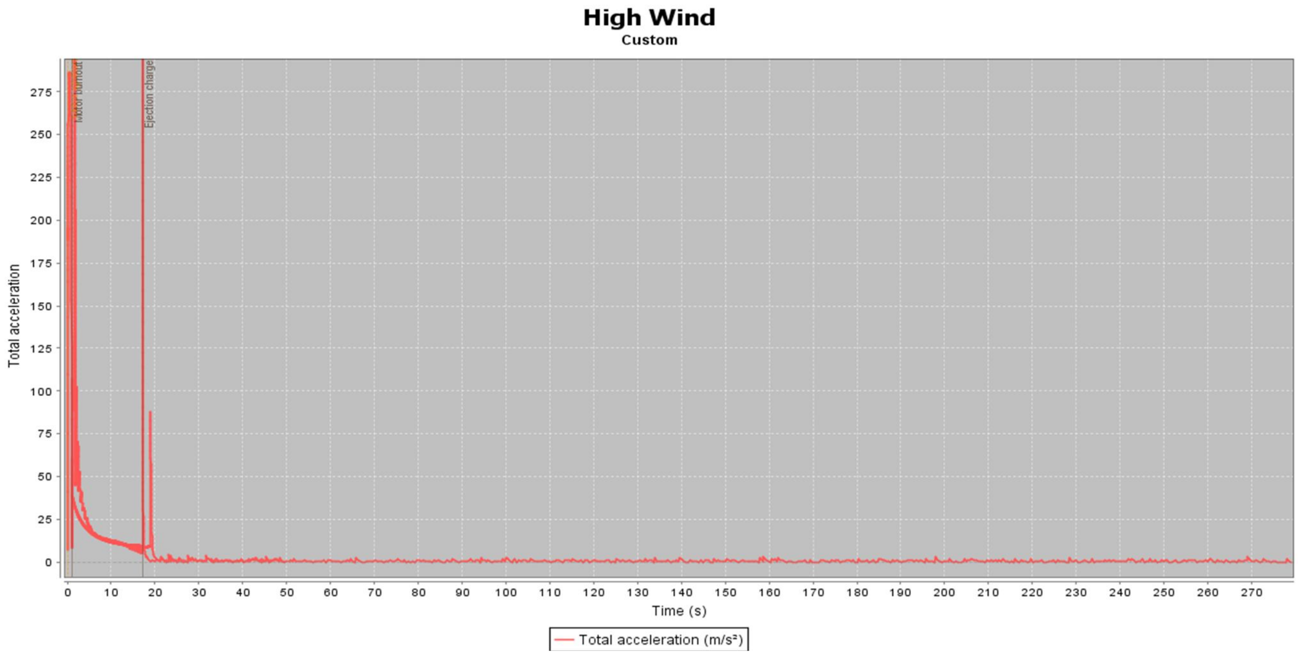


Figure A9: Graph of time versus total acceleration (in meters per second- squared), with high wind.

```
function[D] = ParachuteDiameter(m)
%%calculates parachute diameters necessary to slow a rocket to acheive
%impact velocities of 3, 3.5, 4, 4.5, and 5 m/s for both true-dome and
%parasheet parachutes
%%diameter of parachute output in cm, mass of rocket (m) entered in kg

rho = 1.22; %in kg/m^3
v1 = 3; %in m/s
v2 = 3.5; %in m/s
v3 = 4; %in m/s
v4 = 4.5; %in m/s
v5 = 6; %in m/s
V = [v1 v2 v3 v4 v5];
cd_sheet = 0.75; %approximate coefficient of drag for a parasheet
cd_dome = 1.5; %approximate coefficient of drag for a true- dome shape
g = 9.81; %m/s^2

numr = 8*m*g;
den_sheet = (pi*rho*cd_sheet).*(V.^2);
den_dome = (pi*rho*cd_dome).*(V.^2);
Dp_s = sqrt(numr./den_sheet);
Dp_d = sqrt(numr./den_dome);
Dpsheet = Dp_s.*100; %in cm
Dpdome = Dp_d.*100; %in cm
D = [Dpsheet;Dpdome]; %first row is diameters for parasheet for different
%velocities
%second row is diameters for true- dome shape
%both rows arranged in diameters from lowest to highest impact velocities
end
```

Figure A10: Code, written in MATLAB, used for calculating parachute diameter to achieve given impact velocities.

Pro54 475I445-16A

Motor Data

Brandname	Pro54 475I445-16A	**Manufacturer**	Cesaroni Technology
Man. Designation	475I445-16A	**CAR Designation**	475-I445-16A
Test Date	1/5/2009		
Single-Use/Reload/Hybrid	Reloadable	**Motor Dimensions mm**	54.00 x 143.00 mm (2.13 x 5.63 in)
Loaded Weight	575 g (20.28 oz)	**Total Impulse**	474.9 Ns (106.76 lb.s)
Propellant Weight	212.7 g (7.50 oz)	**Maximum Thrust**	526.2 N (118.29 lb)
Burnout Weight	333 g (11.75 oz)	**Avg Thrust**	442.7 N (99.52 lb)
Delays Tested	16 - 6 secs	**ISP**	227.6 s
Samples per second	1000	**Burntime**	1.07 s
Notes	Vmax™		

Representative CMT Thrust Curve

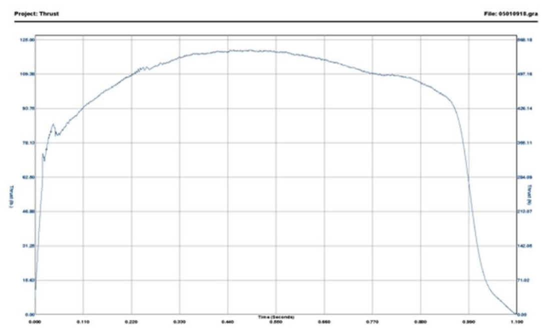
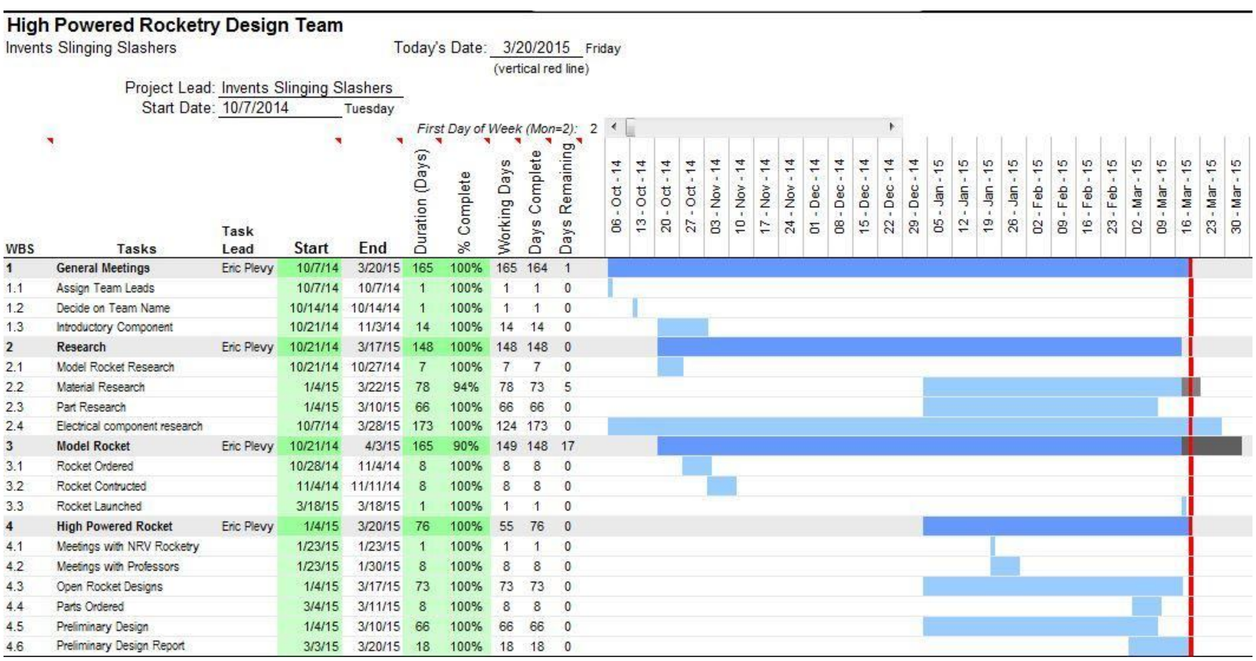


Figure A11: Cesaroni Pro 54 motor specifications and thrust curve graph. [7]



High Powered Rocketry Design Team

Invents Slinging Slashers

Today's Date: 3/20/2015 Friday
(vertical red line)

Project Lead: Invents Slinging Slashers
Start Date: 10/7/2014 Tuesday

First Day of Week (Mon=2): 2

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**General Meetings**	Eric Plevy	10/7/14	3/20/15	165	100%	165	164	1
1.1	Assign Team Leads		10/7/14	10/7/14	1	100%	1	1	0
1.2	Decide on Team Name		10/14/14	10/14/14	1	100%	1	1	0
1.3	Introductory Component		10/21/14	11/3/14	14	100%	14	14	0
2	**Research**	Eric Plevy	10/21/14	3/17/15	148	100%	148	148	0
2.1	Model Rocket Research		10/21/14	10/27/14	7	100%	7	7	0
2.2	Material Research		1/4/15	3/22/15	78	94%	78	73	5
2.3	Part Research		1/4/15	3/10/15	66	100%	66	66	0
2.4	Electrical component research		10/7/14	3/28/15	173	100%	124	173	0
3	**Model Rocket**	Eric Plevy	10/21/14	4/3/15	165	90%	149	148	17
3.1	Rocket Ordered		10/28/14	11/4/14	8	100%	8	8	0
3.2	Rocket Contructed		11/4/14	11/11/14	8	100%	8	8	0
3.3	Rocket Launched		3/18/15	3/18/15	1	100%	1	1	0
4	**High Powered Rocket**	Eric Plevy	1/4/15	3/20/15	76	100%	55	76	0
4.1	Meetings with NRV Rocketry		1/23/15	1/23/15	1	100%	1	1	0
4.2	Meetings with Professors		1/23/15	1/30/15	8	100%	8	8	0
4.3	Open Rocket Designs		1/4/15	3/17/15	73	100%	73	73	0
4.4	Parts Ordered		3/4/15	3/11/15	8	100%	8	8	0
4.5	Preliminary Design		1/4/15	3/10/15	66	100%	66	66	0
4.6	Preliminary Design Report		3/3/15	3/20/15	18	100%	18	18	0

Figure A12: Gantt Chart