



# Preliminary Design Report

---

High Power Rocketeers

University of Minnesota Duluth

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

Advisor: Dr. Ryan Rosandich

3/20/2015

## Table of Contents

Executive Summary .....	4
Introduction.....	5
Rocket Mechanical and Electrical Design .....	5
Dimensional Specifications .....	5
Booster Dimensions and Specifications.....	6
Dart Dimensions and Specifications .....	5
Recovery System Design Specifications .....	7
Booster .....	8
Dart .....	7
Propulsion System Specifications.....	8
Avionics Systems Design Specifications.....	9
Planned Construction Solutions and Techniques.....	11
Booster Construction Procedures and Techniques .....	11
Dart Construction Procedures and Techniques.....	11
Structural Analysis of Custom Built Parts .....	12
Structural analysis of mirror device .....	12
Structural Analysis of Booster Transition Section.....	12
Structural Analysis of Dart Tail Cone .....	13
Structural Analysis of Booster Fin.....	13
Structural Analysis of Dart Fin.....	14
Structural Analysis of Fiberglass U-Bolt Mount .....	14
Risk Mitigation Analysis .....	14
Predicted Performance .....	15
Simulation Assumptions .....	15
Launch Analysis.....	15
Flight Analysis .....	15
Recovery Analysis .....	15
Stability Analysis .....	17
Environmental Conditions Analysis .....	18

	3
Innovation .....	18
Safety .....	19
Designed for Safe Flight and Recovery .....	19
Documented Material-Handling Procedures.....	20
Planned Assembly Procedures .....	20
Planned Pre- & Post-Launch Procedures .....	21
Pre-flight Checklist .....	21
Post-flight Checklist.....	22
Budget .....	23
Booster .....	23
Dart .....	23
Miscellaneous .....	23

## Executive Summary

The 2015 Space Grant Midwest High-Power Rocket competition requires each team to design a boosted dart that will reach maximum altitude and be recovered safely and in flyable condition. To design our booster and dart we used a combination of hand calculations and simulations using OpenRocket. The booster has an overall length of 58 cm, has an outer diameter of 5.8 cm, and has a target weight of 1280 grams. The dart has an overall length of 80 cm, has an outer diameter of 3.2 cm, and has a target weight of 730 grams. The body diameters were chosen from commercially available high power body tubes. The booster body diameter is the minimum necessary to fit the motor required by the competition, and the dart body tube is the smallest diameter available that still fit our electronics. We wanted to minimize the diameters, therefore minimizing the weight of the booster and the drag on the dart. The competition guidelines require teams to have an onboard down looking video footage as well as measure and record rotation about the x, y, and z axis. We accomplished this requirement by housing a USB video camera in a custom designed tail cone fitted to the dart that records downward looking footage. We also designed a unit to record rotation by wiring an Arduino controller to an inertial measurement unit. The booster and dart are designed to be stable in all phases of the flight, and to be recovered safely and in flyable condition. Recovery will be accomplished by using an altimeter to deploy a parachute from the dart just after apogee, and by using motor-based ejection to deploy a parachute from the booster shortly after apogee. Propulsion will be provided by a Cesaroni I445 motor as required by the competition. The motor provides an average thrust of 445 newtons for 1.1 seconds and has a total impulse of 475 newton-seconds. Based on our simulations it is predicted that the booster will reach an apogee of 830 meters (2723 ft.) and the dart will reach an apogee of 1,470 meters (4820 ft.).

## Introduction

The Space Grant Midwest High-Power Rocket Competition supplies student teams to show case their engineering and design skills. Our team conceived and designed the following rocket to fulfill this year's competition objectives. This year's objectives are to design and construct a boosted dart that will be recovered safely. We are to predict the flight performance, collect down looking video footage from the dart and construct a non-commercial on-board data collection package for the dart that will record its rotation in the (x,y,z) over time. Another objective of the competition is to maximize the altitude of the dart while also maximizing the separation between the booster and dart at apogee. To achieve this we first designed a booster with minimum weight and a dart with minimum drag. We then determined the optimum weight of the dart using simulations and mass was added to the dart to reach this optimum weight. Our designs were done using a combination of hand calculations and simulations using OpenRocket. Custom designed components were designed and analyzed using SolidWorks. The following report documents our preliminary design of the booster and the dart as well as the predicted performance of our design.

## Rocket Mechanical and Electrical Design

The rocket consists of two stages, a powered booster and an unpowered dart, that will separate immediately after motor burnout. The basic dimensions of the rocket are shown in Figure 1, and further details are provided below, beginning at the top of the rocket and working downward.

## Dimensional Specifications

### Dart Dimensions and Specifications

The dart is composed of four major sections, the nose cone (10 cm), the parachute bay (28 cm), the electronics bay (36 cm) and the tail cone (6 cm). The nose cone is made of hollow plastic and is an ogive shape. The parachute bay is constructed of 29 mm Blue Tube (32 mm OD) and will house an ejection canister and an 18 in. elliptical parachute. The electronics bay is also made of 29 mm Blue tube and will house the inertial measurement unit, the data acquisition device, the parachute deployment altimeter, the flight recording altimeter, and the required power supplies. The electronics bay will be provided with breather holes to allow the altimeters to accurately measure the barometric pressure. The electronics will all be mounted on a strip of 1.6 mm fire retardant Garrolite that will be attached to a plywood bulkhead that will separate the electronics bay from the parachute bay. The bulkhead will also carry an eye bolt to anchor the recovery system shock cord and an adjustable mass to optimize the weight of the dart. The tail cone is a custom designed 3D printed part that provides a streamlined housing for a down-looking video camera that will have a view straight out of the tail of the dart. The dart fins are

made of 1.6 mm fire retardant Garrolite and have a root chord of 6 cm, a tip chord of 4.5 cm, a height of 2.2 cm, and a sweep angle of 65 degrees. The fins will be keyed into slots in the body tube, attached with epoxy, and reinforced with epoxy fillets.

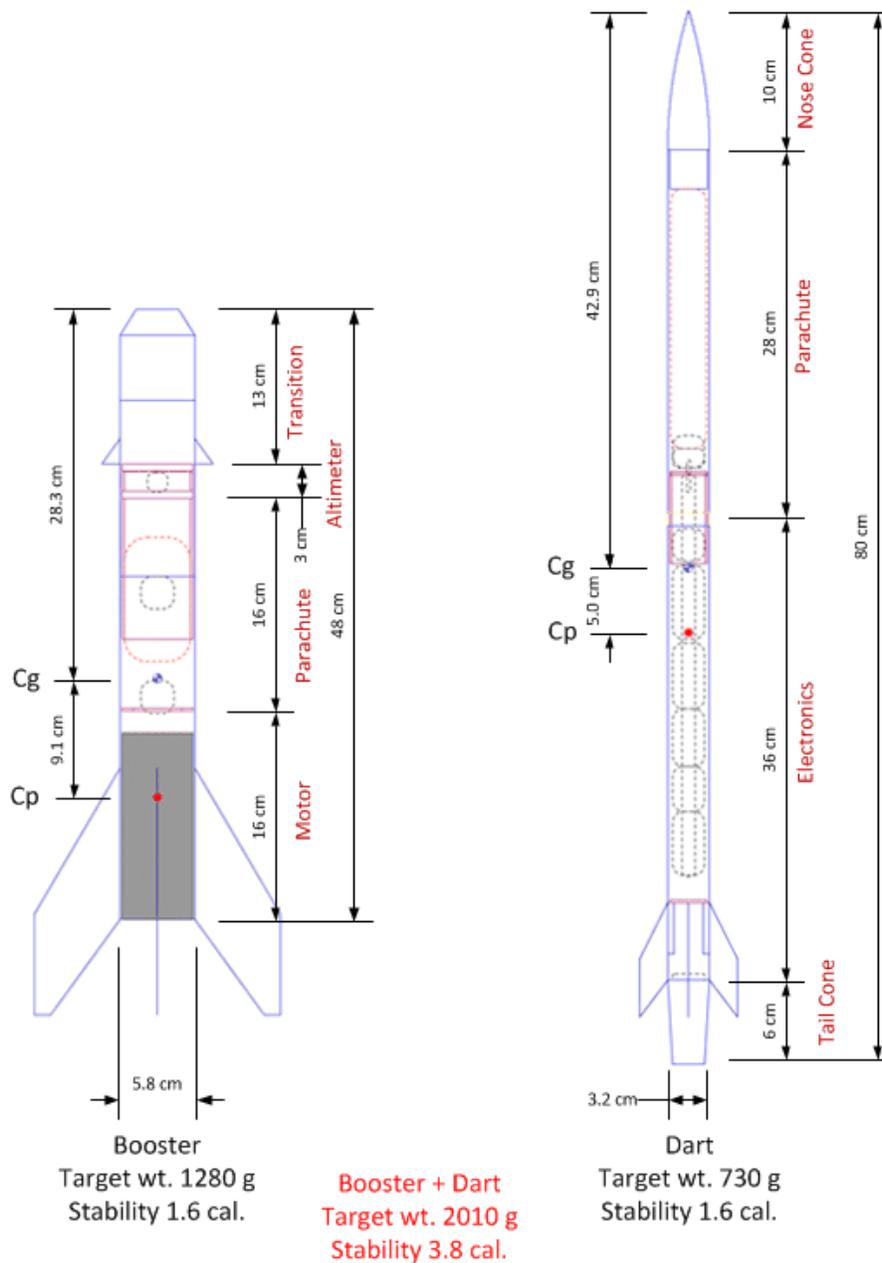


Figure 1: Booster and dart dimensions

## **Booster Dimensions and Specifications**

The booster is composed of four major sections, the transition section (13 cm.), the altimeter bay (3 cm.), the parachute bay (16 cm), and the motor section. The transition section is topped by a custom designed 3D printed transition cap which will mate to the tail cone of the dart and will couple into a section of body tube. The body tube will be 54 mm Blue Tube (58 mm OD) and will also house a custom designed mirror device. This device will allow the video camera in the dart to see downward along the booster body tube prior to separation. The mirror device will sit on top of a plywood bulkhead that separates the transition section from the altimeter bay. The altimeter bay will be constructed of 54 mm OD coupler tube and will sit up against the aforementioned plywood bulkhead. It will be enclosed on the bottom with another plywood bulkhead that will be attached to the upper bulkhead with threaded fasteners to allow access to the altimeter within. This lower bulkhead will also carry a U-bolt that will provide an anchor point for the recovery system shock cord. The altimeter bay will be provided with breather holes to allow the altimeter to accurately measure the barometric pressure. The parachute bay is also constructed of 54 mm Blue Tube and will house a 30 in. elliptical parachute. The parachute bay will be separated from the motor section by a custom designed mounting ring, made of 3.2 mm Garrolite, which is designed as an attachment point for a U-bolt that will be used as an anchor point for the recovery system shock cord. The mounting ring has a generous opening in the center to allow the motor-based ejection charge to deploy the parachute. The motor section is also made of 54 mm Blue Tube and is capped on the bottom by a motor retainer. The booster fins are made of 1.6 mm fire retardant Garrolite and have a root chord of 12 cm, a tip chord of 10 cm, a height of 6.5 cm, and a sweep angle of 60 degrees. Since the motor section must be smooth inside, the fins will be surface mounted to the booster body tube with epoxy, reinforced with epoxy fillets, and further reinforced with fiberglass overlays that will overlap both the fins and the body tube.

## **Recovery System Design Specifications**

### **Dart**

The dart recovery system parachute will be using a CFC-18 Chute from Fruity Chutes, an 18 in. (46 cm) elliptical chute with an estimated coefficient of drag of 1.55. It has 8 shroud lines rated for 330 lb. It was chosen since it was estimated to be the most effective chute that would fit in the dart. The Kevlar shock cord used is rated for 300 lb., with a total length of 300 cm. It will be anchored at one end to the nose cone and at the other to the body of the dart via an eye bolt. The chute will be protected by a 6"x6" square of Nomex wadding which will be attached to the shock cord. The parachute will be deployed at apogee by a black powder ejection canister that will be fired by a Stratologger CF altimeter. It is estimated that this recovery system will provide a dart landing velocity of 6.0 m/sec.

## Booster

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

## Propulsion System Specifications

The required Cesaroni I445 motor will provide an average thrust of 445 newtons, with a maximum thrust of 526.2 newtons, for the booster during the boost phase of the launch. The burn will last for 1.1 seconds, providing a total impulse of 474.9 newton-seconds. The dimensions of the motor are 54.0 mm in diameter, and 143 mm in length. The total weight of the motor will equate to 575 grams with 213 grams of propellant weight. This type of motor is reloadable and will be provided by the host of the competition.

The Cesaroni I445 is considered a high-powered rocket motor and requires a minimal diameter of cleared area of 50 feet with a minimal personal distance of 100 feet, 200 feet for complex rockets. The thrust curve for this motor is shown below and obtained from the following link: <http://www.thrustcurve.org/simfilesearch.jsp?id=1609>.

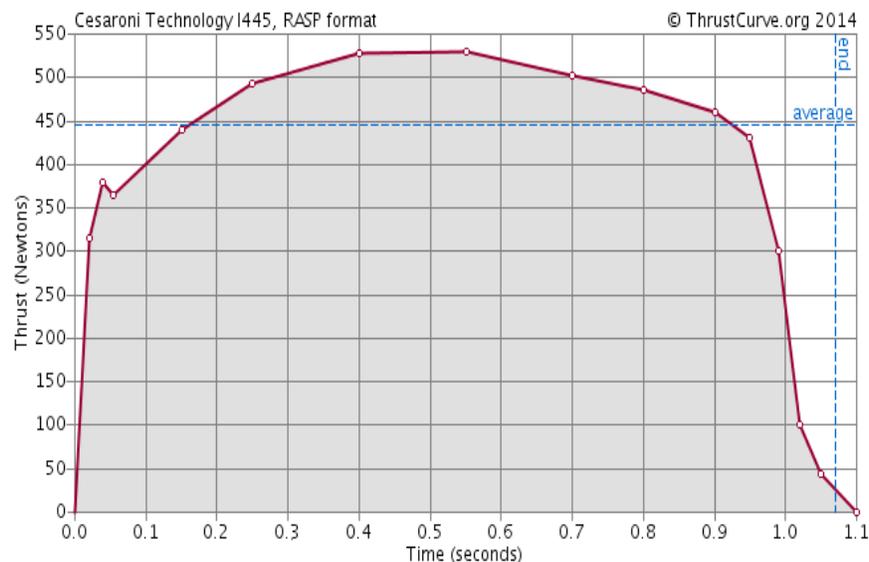


Figure 2: Thrust curve vs. time for the I445 rocket motor.

The unique aspect of the booster design is that the motor will not be housed by a traditional motor casing. The booster body tube will be the motor casing, and the motor will be held in by a motor retainer that will be attached to the bottom of the body tube. This decision was made primarily to minimize the weight of the booster.

### Avionics Systems Design Specifications

As stated in the competition parameters, part of the flight mission is to “collect look-down on-board video from the dart (during ascent configuration), and construct a non-commercial on-board data collection package for the dart that will characterize its rotation in the X, Y, and Z axes over time.” The on-board video footage collected and rotational data will then be compared together to get an accurate representation of the rotational forces (pitch, roll, and yaw) experienced by the rocket during flight.

Down-looking video will be collected by a miniature self-contained digital video camera with recording capability that will be mounted in the dart tail cone. This camera is powered by an internal battery and can record up to two hours of video on a micro SD card. The camera is interfaced and recharged via a standard USB connection.

The on-board data collection package that was decided upon for measuring rotation will include the use of an Arduino Pro-Micro microcontroller that has an ATmega32U4 processor on board as a data acquisition device, and a three-axis gyro inertial measurement unit (IMU) as a measurement device. These two components together will read, process, and record the angular rates of rotation about the roll (X), pitch (Y), and yaw (Z) axes. This specific Arduino board was chosen for various reasons. The small form factor was ideal for our overall rocket design because space and weight need to be kept to a minimum. The system voltage is 3.3V running at 8MHz, and this is also ideal since the unit can operate off of a single 3.6 v lithium battery. The Pololu IMU was chosen due to its compact design and easy compatibility with the Arduino interface. It has many configurable options such as, three selectable angular rate sensitivities, seven selectable output data rates, and a programmable external interrupt signal. The three angular velocity readings are available through a digital interface (Arduino), which operate in I<sup>2</sup>C mode. Conveniently, the IMU operates on 3.3 VDC which will be provided by the Arduino. The carrier board includes a circuit that shifts the two I<sup>2</sup>C lines to the same logic voltage level as the supplied input voltage (VIN), making it simple to interface the board with the acquisition system. The Arduino and IMU will be connected as shown in Figure 3.

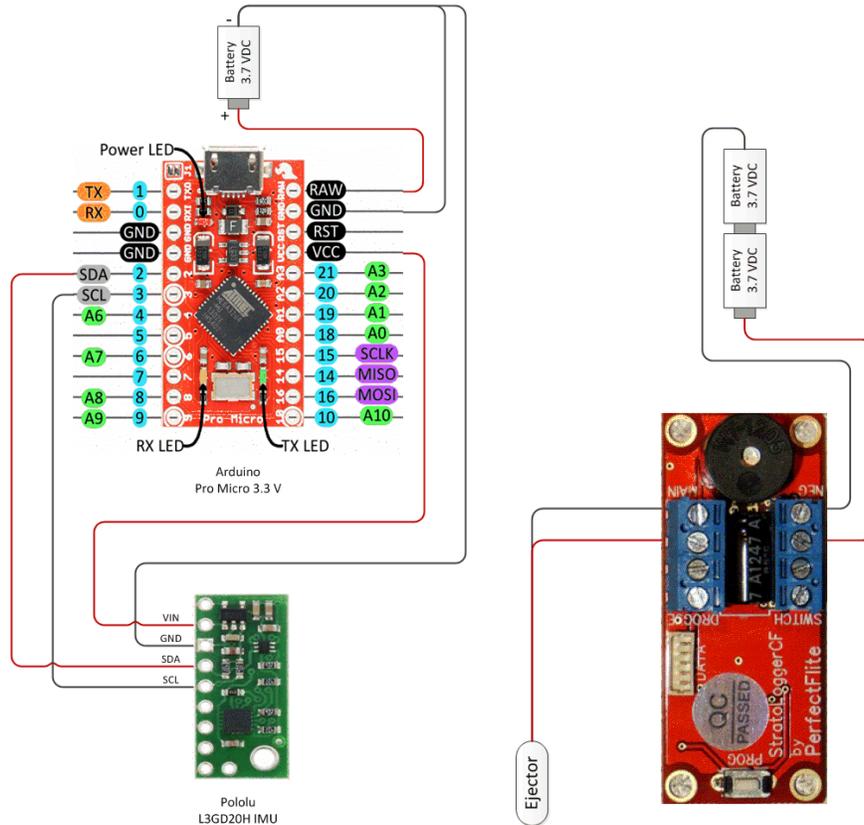


Figure 3: Avionics electrical schematic.

In addition to the video camera and the Arduino/IMU the avionics package will also include a Stratologger altimeter to deploy the parachute, and the Jolly Logic Altimeter Two required as a flight recorder by the competition. The Stratologger will be powered by two 3.6 V lithium cells in series, and the wiring connections are shown in Figure 3. The Altimeter Two is self-contained and will simply be mounted in the avionics bay. All of the electronic devices will be mounted in the avionics bay to a Garrolite strip using Velcro attachments.

## Planned Construction Solutions and Techniques

### Dart Construction Procedures and Techniques

The dart is composed of four major sections, the nose cone, the parachute bay, the electronics bay and the tail cone. The nose cone will be friction-fit to the top of the parachute bay, and the tail cone will be friction-fit to the bottom of the electronics bay. To make the parachute bay and the electronics bay, body tubes and coupler tube will be cut to the required lengths. A 1 cm section of body tube will be cut and epoxied in the middle of the coupler tube. The fins will be aligned and epoxied onto the body tube using water- jet cut fin jigs for precision, ensuring that the fins are square and are allowed to cure in the correct location. Epoxy filler will be used to fillet the fins to the body tube creating a smooth transition. The electronics will be mounted as follows:

- A hole will be drilled in a piece of aluminum angle for the eyebolt.
- Holes will be drilled in the bulkhead for the eyebolt and small holes will be drilled for electrical wires.
- The aluminum angle will be fastened to the bulkhead using the eyebolt, nuts, and epoxy.
- The Garrolite strip will be attached to the aluminum angle
- The bulkhead will be epoxied 1 mm within the coupler tube.
- The electronics will be attached to the Garrolite strip using Velcro tape.

### Booster Construction Procedures and Techniques

The booster will be made up of several components: Upper body tube (blue tube), mirror device (ABS plastic), altimeter bay, Bulkhead (wood), Coupler tube (blue tube), Parachute bay, U-bolt (aluminum), Hex nut (aluminum), fire retardant ring (Fiberglass), motor casing (aluminum), Booster fins (fiberglass), Lower body tube (blue tube), end cap and thrust nozzle(plastic). They will be constructed as follows:

- The body tubes and coupler tubes will be cut to length.
- The upper body tube will have a slot cut through it to fit the mirror device dimensions, allowing it to slide through.
- The two wooden bulkheads will be drilled out to fit the U-bolt.
- The fiber glass ring and upper most bulkhead will be epoxied into place.
- The U-bolt will be installed on the fiberglass ring in the lower body tube section.
- The bottom bulkhead and top bulkhead will be spaced out by a piece of coupler tube and U-bolted together using two hex nuts; one on top of the upper most bulkhead and the other on the underside of the bottom bulkhead, sandwiching the coupler tube in-

between. The bottom bulkhead will not be epoxied, making it removable so the altimeter is accessible.

- The mirror device will be epoxied on top of the upper bulkhead to secure it into place.
- The coupler tube in-between the upper and lower body tube sections will be epoxied on the lower body tube section only. This will allow the upper body tube section to be blown off by the motor charge, causing the parachute to eject.
- The parachute will be attached to both U-bolts with shock cord and protected with wading, insuring that the booster comes down safely and together.
- The fins will be aligned and epoxied onto the lower body tube section using two water-jet cut fin jigs for precision, ensuring that the fins are square and stay in the correct location. Epoxy filler will be used to fillet the fins to the body tube creating a smooth transition. Fiberglass strips will then be impregnated with epoxy and laid over the fillets for reinforcement.
- The motor retainer inner ring will be epoxied on the outside of the lower body tube section. The outer retainer ring will thread onto the inner retainer ring.

## Structural Analysis of Custom Built Parts

### Structural analysis of mirror device

This analysis was done with worst case scenario to insure that the structure would hold up in the worst possible conditions. The tensile strength of this material and process is found to be 13 MPa, according an article on “Anisotropic material properties of fused deposition modeling ABS”. The results are a displacement of  $2.083e-.003$  mm (2.06866 mm) with a force of 30 G’s ( $294.3 \text{ m/s}^2$ ) acting on the structure. The part only displaced 7.73032 mm under a load of 32.6525 N. These are minor displacements and will not degrade the structural integrity. The maximum stress found on this structure is 8.801MPa from the drag force of 32.6N. This gives a factor of safety of 1.48. The calculations validate that this is a safe structure and could be placed in the rocket.

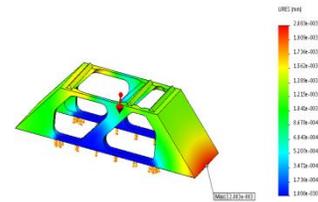


Figure 4. Displacement due to 30 G’s ( $294.3 \text{ m/s}^2$ ) of force acting on the structure in thrust phase

### Structural Analysis of Booster Transition Section

The FEA for the booster transition section was done under a worst case scenario, ensuring that the VeroBlue material will hold up during the least favorable conditions. The tensile strength of this material is 55 MPa, the maximum stress found on the section from 30 G’s of force is found to be

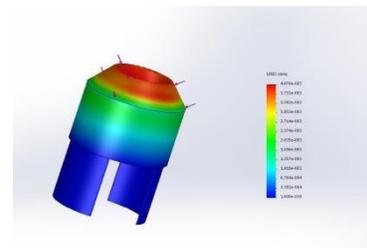


Figure 5: Displacement due to the drag force of 52.7 N at the max velocity of 250 m/s

0.06103 MPa and the maximum stress found on the section from the drag force of 52 N is 2.8841 MPa . This gives a factor of safety of 19.1. The maximum displacement is 4.070e-003 mm. This is a minor displacement that will not affect the performance or safety of the part. This analysis confirms that this is a safe transition section. All of the results above prove that the transition section can withstand the forces being applied to it, showing that this transition section is safe to use during flight.

## Structural Analysis of Dart Tail Cone

The FEA for the dart tail cone was done under a worst case scenario, ensuring that the VeroBlue material will hold up during the least favorable conditions. This material has a tensile strength of 55 MPa according to the material specifications. The maximum stress on this part due to 30 G's is found to be 5.802e004 N/m<sup>2</sup> or .05802 MPa, this stress will not affect the integrity of the tail cone. This gives a factor of safety of 947, well above any allowable limit. There is a maximum displacement of 1.458e-004 mm with a force of 30 G's (294.3 m/s<sup>2</sup>) acting on the tail cone's center of gravity. Deflection can be neglected due the small value. All of the results above prove that the tail cone can withstand the forces being applied to it, showing that the tail cone is safe to use during flight.

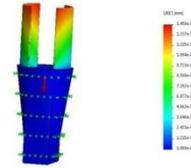


Figure 6: Displacement due to 30 G's (294.3 m/s<sup>2</sup>) of force acting on the tail cone during the thrust phase

## Structural Analysis of Booster Fin

The booster fin is a very crucial element to a successful flight. If the fins fail, the flight will not be successful. The fins would most likely fail under the large acceleration during the boost phase. The analysis results in a shear stress between the epoxy and Garolite fin material. Assuming that the fins are bonded properly, this failure is unlikely to occur. The result for stress location is at the rear root tip of the fin and is well below the predicted 310 MPa yield strength of the material. The stress is 252 KPa at this location. This large stress will be reduced in the final design with epoxy fillets and extra support in this region. The displacement of 0.006 mm is very small during this simulated acceleration and should not be of concern. A crash analysis was conducted as well and produced stress zones in the same region of the part.

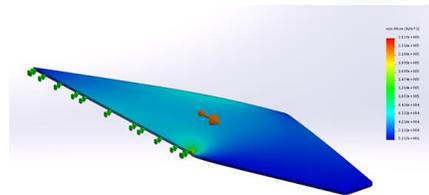


Figure 7: Stress on booster fin

## Structural Analysis of Dart Fin

The dart fin is not as large as the booster fin so it has a lower mass. This fin also rests on a transition section during the boost phase. This allows for extra support and ensures that the fins will not fail due to the large acceleration of takeoff. The stress is located in the same region as the booster fin. The stress for this zone is at a maximum of 52 Kpa and the greatest displacement is 0.0005 mm. These values seem to be of no major concern. Extra reinforcement should be added at the highest stress zone to ensure that this zone will not fail. A crash analysis was also conducted and the same stress zone was a problem. Adding extra support here will make the design much safer all around.

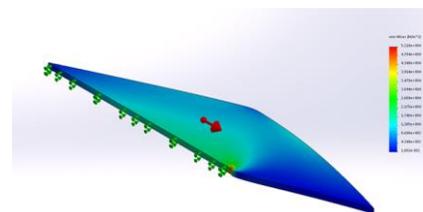


Figure 8: Stress on Dart fin

## Structural Analysis of Fiberglass U-Bolt Mount

Finite Element Analysis (FEA) was conducted on the fiberglass U-bolt mount, shown in Figure 9. A static analysis was conducted to ensure the structural integrity of the parachute mount for a worst case scenario. The mount will be epoxied to the booster body tube and for the simulation the epoxy is assumed to not fail. The fasteners were also excluded from the analysis, for they have a load rating. The U-bolt mount material is a flame-retardant multipurpose garolite (G-10/FR4), and the material ply properties were modeled after a WovenGI/Epoxy. The yield strength is 255 MPa. The maximum stress experienced by the mount is 102 MPa and is located on the inside of the mounting holes, Figure 9, which is well below the yield strength of 255 MPa. The resulting safety factor is 3.79.

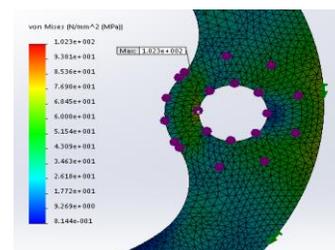


Figure 9: Maximum stress for the fiberglass U-bolt mount with a yield stress of 255 MPa.

## Risk Mitigation Analysis

Safety of the rocket is a primary concern. Many factors such as stability of the booster, the dart, the overall combined rocket, and the reliability of parachute deployment and booster/dart separation are receiving great attention to detail. All custom designed parts have been analyzed, and will be further subjected to physical testing to insure that they will perform safely. The stability of both the booster and dart have been closely examined (see stability analysis on p. 18). The use of a redundant ejection charge for deploying the dart parachute is being considered to ensure parachute deployment. Extensive ground testing will be done to test the electronics, parachute deployment, and booster/dart separation. A test launch will also be conducted in late April to test all systems in flight conditions.

## Predicted Performance

Estimation of the booster and dart performance were done using OpenRocket. OpenRocket was also used to perform a rocket optimization. The optimization determined the optimal dart weight that would result in the maximum apogee altitude, while maintaining a minimum stability of one caliber.

## Simulation Assumptions

- Launch Rod is a total of 1.83 meters long.
- Separation of the dart from the booster occurred at motor burnout.
- Both the dart and booster parachute deployed 2.00 seconds after apogee.
- Parachute drag coefficient equals 1.55.
- Average wind speed of 2.00 meters per second.
- Wind speed standard deviation 0.20 meters per second.
- Wind turbulence intensity 10.0 percent.

## Launch Analysis

The launch time was recorded from the time of motor ignition to motor burnout. During the launch phase the dart and the booster stayed in contact for a total of 1.10 seconds, which is when motor burnout occurred and the two components separated. At the end of the launch phase both the dart and the booster were traveling at a vertical velocity of about 220 meters per second, and reached an altitude of 130 meters.

## Flight Analysis

Flight time started after motor burnout and stopped 2.00 seconds after apogee, which is when the parachutes were triggered to deploy. The dart traveled a total of 1,340 meters in 15.0 seconds to reach apogee during the flight phase, resulting in a maximum altitude of 1,470 meters from the launch site. After burnout, the booster traveled another 700 meters in 10.00 seconds and reached an apogee height of 830 meters.

## Recovery Analysis

The recovery phase of the launch started 2.00 seconds after apogee and ended when a ground-hit was detected. The dart was equipped with a 46.0 centimeter parachute, and contacted the ground at 6.70 meters per second. The recovery phase lasted about 200 seconds resulting in a total flight time of 220 seconds. The booster was equipped with a 76.0 centimeter parachute, and contacted the ground at 4.80 meters per second. The recovery phase lasted about 170 seconds resulting in a total flight time of 180 seconds.

Table 1 compares the maximum altitude and the peak acceleration between the dart and the booster, and shows the launch rail guide departure velocity. Figure 10 shows the altitude,

velocity, and acceleration for the entire flight. Figure 11 shows the estimated acceleration of the dart from the time of motor ignition to the time of the parachute deployment, and Figure 12 shows the acceleration of the booster.

Table 1: Anticipated Performance

	Maximum Estimated Altitude (m)	Peak Estimated Acceleration (m/s <sup>2</sup> )	Launch guide (1.83 m) velocity (m/s)
Dart	1470	260	28
Booster	830	260	28

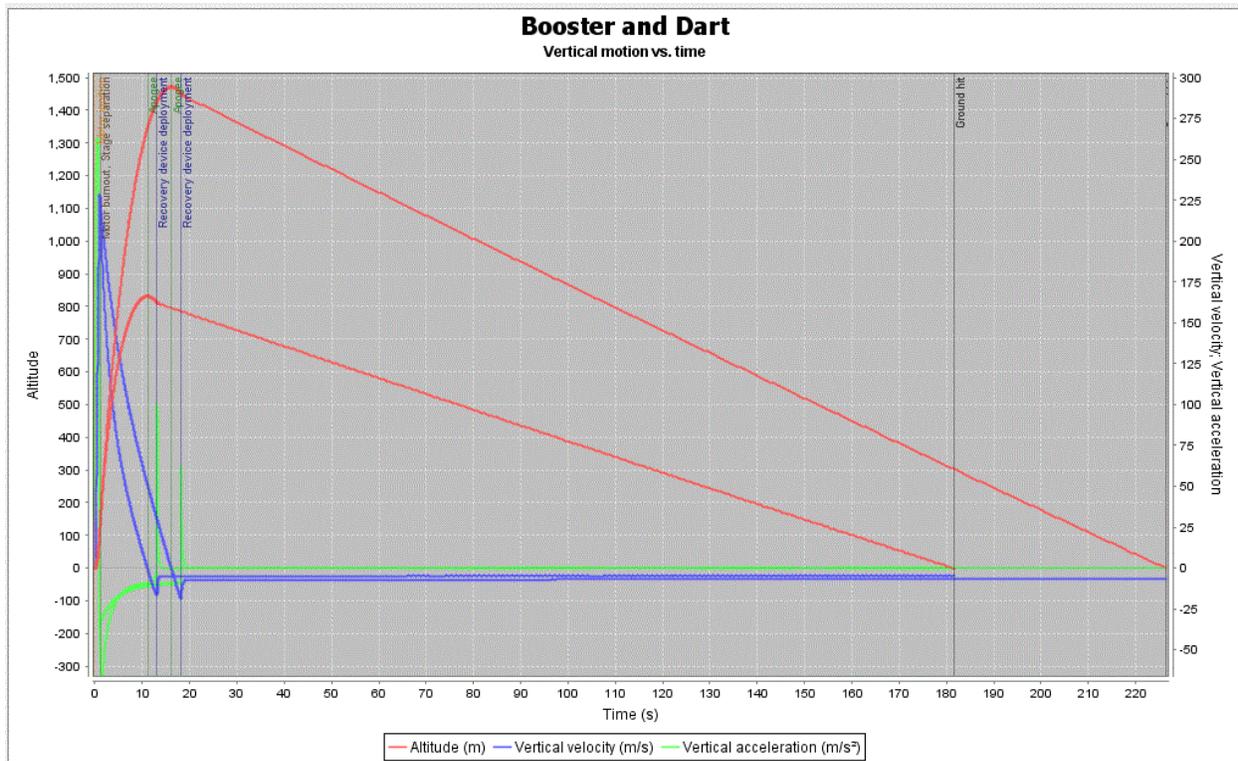


Figure 10: Plot of flight

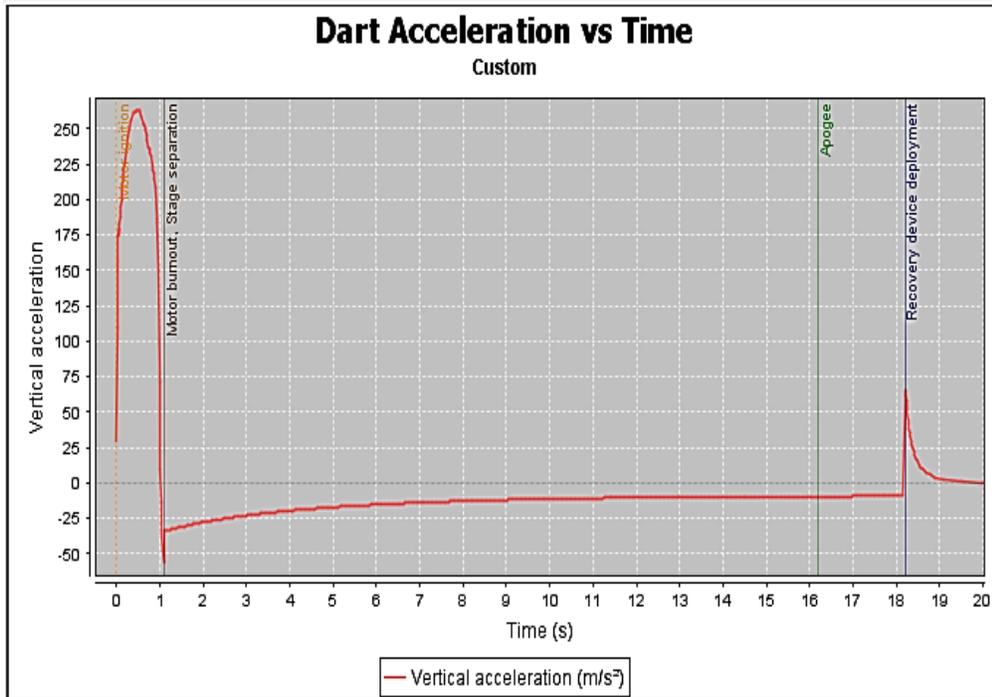


Figure 11: Dart acceleration vs. time from the time of motor ignition until parachute deployment

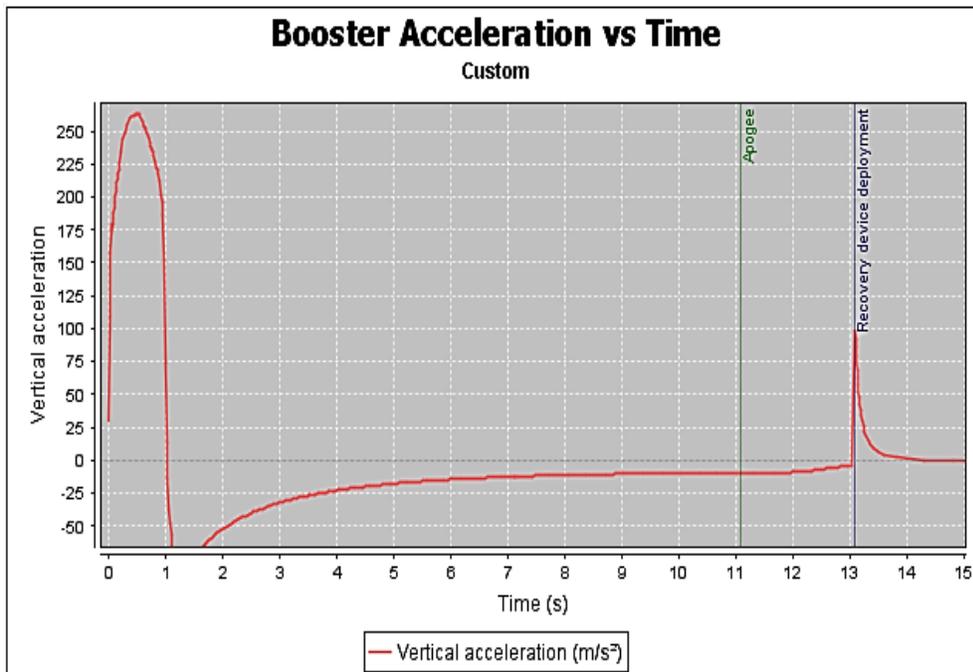


Figure 12: Booster acceleration vs. time from the time of motor ignition until parachute deployment.

## Stability Analysis

The assumptions used for this analysis are that a stable rocket has a stability margin between the center of gravity and center of pressure of at least one body diameter (caliber), and that a margin of three or more calibers is considered over-stable.. The combined rocket of both the dart and the booster is over-stable. When the motor is full, the combined rocket's center of gravity is at 81 cm, and its center of pressure is at 103 cm, with a stability of 3.8 calibers, causing it to be somewhat over-stable. When the motor is burned out and empty, the center of gravity moves up to 67.3cm, causing the stability to increase to 6.4 calibers, which is very over-stable. On its own, the booster with a full motor has a center of gravity at 28.3cm and a center of pressure at 37.4cm, with a stability of 1.6 calibers. This is a good level of stability. When the motor in the booster is empty however, the center of gravity moves up to 18.8cm, increasing the stability to 3.2 calibers, leading it to be slightly over stable. The dart has its center of gravity at 42.9 cm and its center of pressure at 47.9 cm, with a stability of 1.6 calibers, well within the stable region.

## Environmental Conditions Analysis

The historical temperature for May 19 in North Branch is estimated to be a high of 69 degrees Fahrenheit, a low of 45 degrees Fahrenheit, and a mean of 58 degrees Fahrenheit. There is a predicted 0.10 inches of precipitation. Winds are unknown; however Minneapolis is predicted to have a high of 65 degrees Fahrenheit, so wind could be expected to come from the south. May 19, 2011 had similar temperatures to those estimated, a high of 71 deg F and low of 44 deg F, and received 4 mph winds in a ENE direction, with a max wind speed of 10 mph and a max gust speed of 16 mph. Due to the similarity in temperatures, it can be expected for the wind to also be similar.

## Innovation

A unique mirror device was designed to allow the video camera mounted in the tail of the dart to see around the booster during the boost phase of the flight. This device will be mounted in the booster so it does not add drag to the dart. After separation, the camera will have a clear view looking straight down. The device is shown in Figure 13. As depicted by the arrows, the camera viewpoint will be reflected using two parallel mirrors positioned at a 45-degree angle. This enables the camera to be safely secured in the dart and still be able to capture the first few moments of the flight. A third "dummy" mirror is added to the opposite end of the device to balance the weight and drag of the unit. The structure of the mirror device was thinned to make it lightweight, but not enough to affect the structural integrity of the device. The mirrors themselves add great rigidity to the structure. The outer faces where it will protrude from the booster body are solid ABS plastic, except for the under face allowing the view for the camera.

This allows for a higher strength where the drag force will be acting, as well as improving aerodynamics while it is in flight.

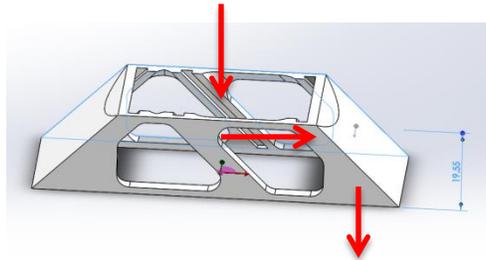


Figure 13: Camera view through mirror device.

## Safety

### Designed for Safe Flight and Recovery

- Calculate center of gravity for Booster – Dart combination with full motor
- Calculate center of gravity for Booster with empty motor
- Calculate center of gravity for Dart
- Calculate center of pressure for Booster – Dart combination
- Calculate center of pressure for Booster
- Calculate center of pressure for Dart
- Design for at least one body diameter between the center of gravity and pressure throughout each stage of flight
- Thrust aligned with center of gravity on the central axis by carefully balancing parts therefore preventing instability
- Fins are mounted to a flat milled surface on the body tube to ensure good contact and alignment with epoxy and matrix fillets on the sides
- The booster parachute is deployed by the charge of the motor
- The dart parachute is deployed by an altimeter that measures differential pressure
- Fireproof wadding is used to protect the dart parachute from the black powder
- U-bolts are used to secure shock cords to the centering ring
- Multiple simulations were created with Openrocket and Excel sheets

## **Documented Material-Handling Procedures**

During construction and launch of our rocket, materials must be stored and handled with care. A few materials that we will be using during construction may be hazardous to our health; this includes the epoxy and any paint we will be using. We will construct our rocket in a well ventilated area in order to dissipate any fumes that could cause health issues. Another potentially dangerous material we will be using is the black powder used for the ejection charge for the dart. The black powder should not be handled in areas of excessive heat or an open flame. While loading the ejection canister, be certain that the igniter is not connected to any live power supply until the rocket is loaded and ready on the launch pad. Always wear eye protection when handling ejection charges. The rocket motor must be stored in a cool dry place until placed in the rocket is ready for launch.

## **Planned Assembly Procedures**

Each individual part was weighed on a scale and taken into account during simulation. The team decided it was important to apply counterweights to the rocket where needed to keep the center of mass as closely to the rocket's central axis. Having the center of gravity in the middle of the rocket makes it more stable. Fins are planned to be designed last to ensure the center of pressure will not change during assembly. If the center of gravity indeed changes, the fins can be adjusted to have at least one body diameter of separation with the center of pressure towards the tail of the rocket. Fins will be mounted to the rocket using a straight edge following a milled path on the blue tube. Water jet cutting will be used to cut certain components in the system. A few custom parts will be created with a 3-D printer and thereafter analyzed. These properties can be added to a finite element analysis program to determine if any parts will fail under flight conditions. A strong epoxy will be used to mount internal parts to the airframe. An acrylic paint will be used to coat the rocket and give it a smooth surface. The paint will also reduce drag on the rocket. The parachutes will be carefully folded and placed into the booster with fireproof wadding to ensure the parachute will not burn during ejection.

## Planned Pre- & Post-Launch Procedures

### Pre-flight Checklist

- 1. Inspect all shock cord connection points for dart and booster.
- 2. Inspect all wiring connections in altimeter bay.
- 3. Inspect all wiring connections and Velcro attachments.
- 4. Test all battery voltages.
- 5. Connect batteries to the internal controls.
- 6. Inspect static pressure ports in altimeter bay.
- 7. Turn camera on and make sure is properly mounted in tail cone
- 8. Listen for the correct vibrations to verify camera is on
- 9. Securely mount camera into the tail cone
- 10. Install dart chute blast cap (top end) on top of altimeter bay with a full cap of black powder topped off with a small amount of wadding and a strip of electrical tape over the top.
- 11. Insert top section of body tube and fasten to altimeter bay.
- 12. Make sure the top rail guide is aligned with the bottom rail guide.
- 13. Inspect and fold main parachute into dart body.
- 14. Insert nose cone into dart body
- 15. Fold booster parachute into the body tube
- 16. Make sure all special components are secured surely (dog house, transition cone, etc)
- 17. Record motor type and full mass.
  - Type: \_\_\_\_\_
  - Mass: \_\_\_\_\_g
- 18. Install motor.
- 19. Place rocket on launch rail.
- 20. Arm Stratologger altimeter 1.
- 21. Arm Stratologger altimeter 2.
- 22. Listen for correct beep sequence as follows:
  - 2 short beeps (Preset 2)
  - Long Pause
  - 5 short beeps (Describing an altitude of 500 ft. for main deployment)
  - Short Pause
  - 10 short beeps
  - Short Pause
  - 10 short beeps
  - Long Pause
  - A sequence of beeps and short pauses (Describing altitude of last flight)

- Altitude:\_\_\_\_\_ft
- A sequence of beeps and a short pause followed by another sequence of beeps  
(Describing battery voltage as X.X Volts)
  - Voltage:\_\_\_\_\_V
- Long Pause
- A non-stop pulse of 3 beeps (This indicates that main chute is connected properly.)
- 23. Visual inspection
- 24. Photograph(s) of rocket on pad.
- 25. Launch
- 26. Maintain visual of rocket.

### Post-flight Checklist

- 1. Locate Booster and Dart
- 2. Inspect rocket for any damage
- 3. Take a picture of the rocket
- 4. Disarm altimeters
- 5. Cover pilot hole
- 6. Remove camera from dart
- 7. Turn off camera
- 8. Disconnect battery from electronics
- 9. Retrieve all flight Data
- 10. Record empty motor mass

## Budget

The budget was calculated using the estimated construction cost of the booster (\$334) and dart (\$305), and the other costs for miscellaneous materials (\$141) and launch-related costs (\$1518). This leads to a total budget for the project of \$2300. The details are below

## Booster

Item	Cost	Weight (g)	Qty	Unit	Total cost	Total weight
Body Tube 54 mm	\$0.08	3.08	42	cm	\$3.30	129.4
Coupler tube 54 mm	\$0.45	2.78	12	cm	\$5.37	33.3
Bulkhead 54 mm	\$2.65	9.0	2	ea	\$5.30	18.0
Motor Retainer 54 mm	\$31.03	38.5	1	ea	\$31.03	38.5
Motor case	\$42.75	110.1	1	ea	\$42.75	110.1
Rail Buttons	\$1.54	1.9	2	ea	\$3.07	3.8
Fins	\$0.01	0.3	320	sq. cm	\$2.46	106.4
Parachute	\$72.62	77.2	1	ea	\$72.62	77.2
Shock Cord	\$0.03	0.1	300	cm	\$9.05	19.4
Wadding	\$7.44	18.9	1	ea	\$7.44	18.9
Altimeter 2	\$69.95	9.7	1	ea	\$69.95	9.7
Mirror Device	\$0.00	13.2	1	ea	\$0.00	13.2
Anchoring ring		10.0	1	ea	\$0.00	10.0
U-Bolt	\$2.99	10.5	2	ea	\$5.98	21.0
Hex Nut 1/4-20	\$0.03	1.1	8	ea	\$0.24	8.8
T-nut 8-32	\$0.73	1.5	2	ea	\$1.46	3.0
Screw, 8-32 x 1.25 in.	\$0.12	3.1	2	ea	\$0.24	6.2
Transition Section		100.0	1	ea	\$0.00	100.0
Fasteners and adhesives	\$20.00	85.0	1	lot	\$20.00	85.0
Motor Reload	\$52.99	465.0	1	ea	\$52.99	465.0
					<b>\$333.24</b>	<b>1276.9</b>

## Miscellaneous

Item	Cost
Model Rocket Kit	\$42.03
Model Rocket Motors	\$8.77
Epoxy	\$43.86
Repair Stick	\$12.48
Fiber Glass reinforcement	\$10.63
Blade Set	\$10.98
Knife Set	\$11.86

**\$140.61**

## Dart

Item	Cost	Weight (g)	Qty	Unit	Total cost	Total weight
Body Tube 29 mm	\$0.10	1.76	65	cm	\$6.71	114.4
Coupler tube 29 mm	\$0.35	1.41	8	cm	\$2.79	11.3
Coupler Bulkhead 29 mm	\$4.31	1.0	1	ea	\$4.31	1.0
Eye bolt, 8-32 x 1 in. w/nut	\$0.19	5.9	1	ea	\$0.19	5.9
Adjustable mass		360.0	1	ea	\$0.00	360.0
Nose cone	\$4.32	9.6	1	ea	\$4.32	9.6
Fins	\$0.01	0.3	60	sq. cm	\$0.46	20.0
Tail cone		25.0	1	ea	\$0.00	25.0
Parachute	\$54.57	46.9	1	ea	\$54.57	46.9
Shock Cord	\$0.02	0.012	300	cm	\$4.82	3.5
Wadding	\$7.37	4.5	1	ea	\$7.37	4.5
Ejection cannister	\$1.80	2.7	1	ea	\$1.80	2.7
Arduino ProMicro	\$19.95	1.1	1	ea	\$19.95	1.1
IMU	\$12.95	0.6	1	ea	\$12.95	0.6
Stratologger Altimeter	\$49.46	10.2	1	ea	\$49.46	10.2
Battery holder AA	\$0.47	4.2	1	ea	\$0.47	4.2
Battery holder 1/2 AA	\$2.10	4.1	1	ea	\$2.10	4.1
Battery	\$2.48	9.2	3	ea	\$7.43	27.6
Altimeter 2	\$69.95	9.7	1	ea	\$69.95	9.7
Video Camera	\$25.59	18.5	1	ea	\$25.59	18.5
Memory Card for camera	\$14.07	0	1	ea	\$14.07	0.0
Electronics mounting strip	\$0.01	0.3	50	sq. cm	\$0.39	16.6
Fasteners and adhesives	\$15.00	30	1	lot	\$15.00	30.0
					<b>\$304.69</b>	<b>727.4</b>

## Launch

Item	Cost
Launch fee	\$400.00
Motor Reloads (2)	\$105.98
Travel	\$431.25
Meals	\$200.00
Hotels	\$380.00

**\$1,517.23**