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# UMD Flying Bulldogs: Design Report


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## Executive Summary

The Wisconsin Space Grant Consortium (WSCG) and its counterpart, the Minnesota Space Grant Consortium (MnSGC) put on the Regional Rocket Design Competition for higher education institutions across the Midwest. The Flying Bulldogs team at the University of Minnesota Duluth was formed among like-minded students interested in the aerospace industry and in design challenges. The Flying Bulldogs team is designing a high-powered rocket for competition April 25 and 26, 2014, in North Branch, MN. The goal of the competition is to design a rocket to reach an apogee of 3,000 feet. The rocket cannot exceed 84 inches in length, with a body diameter between 4 and 6 inches. It will utilize a motor of the design team's choosing, from a list specified by the competition. The flight performance must be evaluated using two independent methods of measurement. The recovery system must include an electronic dual-deployment system as well as a motor ejection backup system, and the rocket must be recovered in flyable condition. Teams must evaluate the rocket for safety and must provide analysis of the safety and performance of any parts not "pre-qualified" by the competition.

The rocket designed by the Flying Bulldogs has a 4 inch diameter and is 70.5 inches in length. The rocket is designed to overshoot the targeted altitude of 3,000 feet, and its mass will be adjusted based on conditions the day of launch in order to hit the targeted altitude. The flight performance will be measured by an altimeter and by a Pitot-static tube located in the nose cone, as well as by a G-Force sensor and temperature probe. The dual-deployment system for the rocket has been designed using two pistons that will be detonated by the StratoLogger altimeter. The first piston will deploy a 30 inch nylon drogue chute at apogee, followed by piston deployment of the 72 inch main chute, which will deploy when the rocket's descent reaches an altitude of 500 feet. As a back-up, the top of the motor will also set off a time delayed blast to deploy the drogue chute, ensuring that the rocket won't "lawn dart". The motor chosen was the Cesaroni J357, as it was determined the best fit for the proposed 4 inch diameter rocket design. Based upon the simulations, the mass is estimated at 3 kg and should reach an altitude of just over 3,500 feet under normal conditions. The mass will be increased based on our test data and meteorological conditions the day of the launch to reach precisely 3,000 feet.

The rocket will be fully assembled by April 13th for ground testing of electronics and dual-deployment during the week of April 13th in preparation for a test launch on April 19th. Additional engineering design decisions may be made post-launch and will be outlined in the presentation and in the post-flight performance analysis.

The Flying Bulldogs team has a design that meets or exceeds all parameters of the competition, will be thoroughly tested for safety and performance, and will perform as planned on the date of the competition.

# Introduction

## *Flying Bulldogs Team Summary*

University of Minnesota Duluth Department of Mechanical and Industrial Engineering
Duluth, MN

Trevor Wilcox, Project Manager

Adam Broderius, Mechanical Design Engineer

Tyler Carlson, Mechanical Design Engineer

Donna Carpenter, Control Systems Engineer

Rylan O'Brien, Simulation Engineer

Nathan Wise, Quality Assurance Engineer

## *Competition Parameters*

Flight Mission

- Two or more types of measurement systems
- Speed vs. Altitude
- Acceleration vs. Altitude

Flight Apogee Requirements

- Target: 3,000 feet
- Range: 2,500 – 3,500 feet

Parachute Deployment

- Electronic dual deployment
- Motor ejection backup

Model Rocket Demonstration Flight

- Purchase, assemble, fly, and recover a model rocket
- Submit pictures of the team at launch site with rocket before and after launch

Rocket Design and Safety Reviews

- Each team must participate in a safety review the day before the competition launch
- Include analysis of non "pre-qualified" components
- Rocket must pass Range Safety Officer's Inspection on launch day

Educational Outreach

- Each team must share information pertinent to aerospace with a group or audience

## *Design Constraints*

Body Diameter

- Minimum: 4 inches
- Maximum: 6 inches

Length

- Maximum: 84 inches

Motor Selection

- 38 mm: I540, J285, J316, J357
- 54 mm: K400, K445, K454, K530
- Provided by competition

Competition Flight Data Recorder

- Raven III Altimeter
- Inserted at time of competition

## *Successful Flight Characteristics*

- Launch
- Attain an altitude of at least 2,500 feet, not to exceed 3,500 feet at apogee
- Parachute recovery must be electronically deployed
- All parts of the rocket must be recovered together
- Rocket must be recovered in flyable condition

## *Timeline*

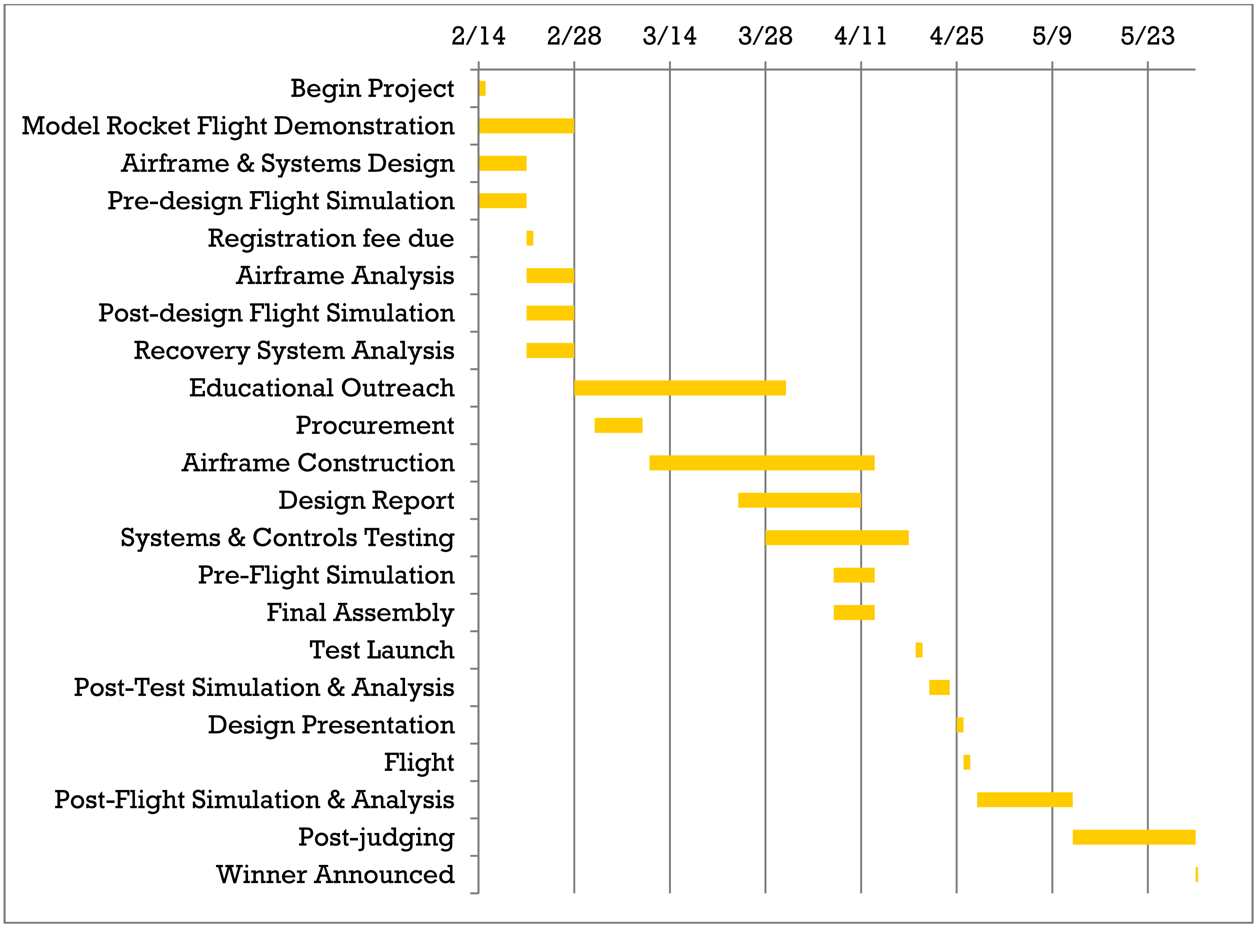


**Figure 1: Project Schedule**

Figure 1 shows a Gantt chart of the project schedule. As of the submission of the report, the final assembly and testing of the rocket and its components still need to be completed. There is a test launch is scheduled for April 19, 2014. Once the test launch is completed, data will be gathered and used to make any repairs or modifications to the rocket as required.

## *Demonstration Flight*

An Estes Alpha model rocket kit and three B-4 engines were purchased and constructed by the Flying Bulldogs. The rocket was launched on February 26th, 2014 on the campus of the University of Minnesota Duluth. Photographs of the rocket construction and the assembled rocket, a video of the launch, and a map of the rocket's launch site and recovery site were submitted to the judges on February 28, 2014.

### *Educational Outreach*

Members of the Flying Bulldogs delivered three 20-minute lectures on the rocket design and competition for prospective students at the University of Minnesota Duluth and their parents. These students were participating in Admitted Students weekend, designed for students who have been admitted to the University but who have not yet accepted. Flying Bulldogs team members explained the competition parameters as well as the educational opportunities provided by the competition. After the planned presentation, team members answered questions about the competition and the University from students and parents.

## Design Features of Rocket

### *Components*

Once the design of the rocket was completed, procurement and construction of the rocket began. Shown below, Table 1 outlines the different components that make up the Flying Bulldog's rocket.

**Table 1: Rocket Components**

| Rocket Component Details | | |
|---|---|---|
| Component | Manufacturer | Material |
| Airframe | Always Ready Rocketry | Blue Tube |
| Couplers | Always Ready Rocketry | Blue Tube |
| Bulkheads | Apogee | Plywood |
| Centering Rings | Apogee | Plywood |
| Motor Mount | Always Ready Rocketry | Blue Tube |
| Motor Casing | Cesaroni | Aluminum |
| Motor Retainer | Aeropack | Aluminum |
| Drogue Chute | Fruity Chutes | Ripstop Nylon |
| Main Chute | Fruity Chutes | Ripstop Nylon |
| Nose Cone | Heavenly Hobbies | Plastic |
| Nose Cone Chassis | - | RGD240 |

## *Motor*

The team had to choose from a list of approved motors provided by the competition. The Cesaroni J357 motor was selected because it was the motor with the maximum amount of thrust for a J-size motor. A more powerful motor would have required a significant increase in mass and drag, resulting in a larger diameter rocket design. In order to optimize the ease of rocket mass adjustability a 4 inch diameter was chosen. The specifications for the J357 are shown below in Table 2.

**Table 2: Properties for Cesaroni J357 Motor**

| Cesaroni J357 Properties | |
|---|---|
| Diameter (mm) | 38 |
| Length (mm) | 367 |
| Maximum Delay (s) | 17 |
| Maximum Thrust (N) | 512.3 |
| Total Impulse (N-s) | 658.0 |
| Burn Time (s) | 1.9 |

## *Dual-Deployment Recovery*

To help ensure body separation when deploying the parachutes, a piston style design was used. Each piston is composed of a 4 inch long section of Blue Tube coupler epoxied to a Balsa wood bulkhead for the piston head. Each piston will be engaged using a black powder filled blast cap. The charges for the blast caps will both be set by the StratoLogger altimeter model SL100, manufactured by PerfectFlite (shown in Figure 2), which is located in the altimeter bay.


**Figure 2: StratoLogger Altimeter**

The first charge will be set at apogee, and will deploy the 30 inch nylon drogue chute. Figure 3 shows the configuration of the drogue chute deployment. The drogue parachute descent rate is estimated to be 38 ft/s, which was found using the descent rate calculator tool on RocketReviews.com.

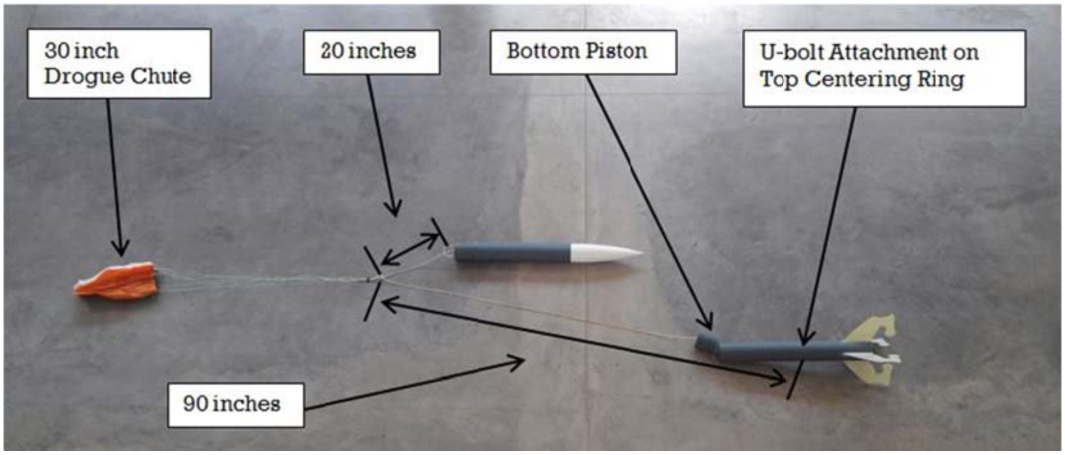


**Figure 3: Drogue Parachute Deployment Configuration**

The second charge will be set at an altitude of 500 feet, at which point the 72 inch main parachute will deploy. Figure 4 shows the configuration of the main parachute deployment. The main chute descent rate is estimated to be 16 ft/s, which was also found using RocketReviews.com's descent rate calculator. The deployment system is attached by 19.5 feet of 1,500 lb test Kevlar shock cord purchased from Apogee components.

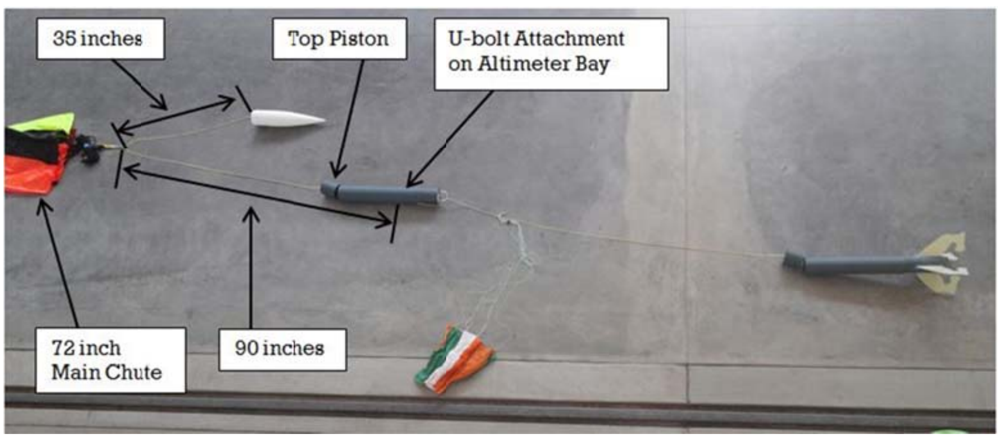


**Figure 4: Main Parachute Deployment Configuration**

The original rocket design contained two aluminum U-bolt fasteners for the shock cord on each piston. In order to reduce the mass of the rocket to fit our desired design mass of 2.8 kg, the fasteners were replaced by a continuous shock cord design. With this design, shock cord will be threaded through the hole in the center of the piston, and a knot will be tied on the top of the piston head, and then sealed and hardened with epoxy.

In order to mitigate risks, ground testing of the recovery system will be done before the test launch. The ground tests will include testing the response of the StratoLogger altimeter with a vacuum and testing the piston system to ensure the proper amount of black powder is used in the blast caps. The testing of the dual-deployment system will occur during the week of April 13th in preparation for a test launch on April 19th.

## *Fin Design*

The fins are designed to look like bulldog legs, as the Flying Bulldogs team is proud to represent the University of Minnesota Duluth. The design of the custom fin adds a unique element to the rocket, from an engineering aspect as well as an aesthetic standpoint. The design was based on a more traditionally-shaped fin, which can be seen in Figure 5. The fin has low frontal area which will help prevent excessive drag.

**Figure 5: Traditional Fin for Basis of Bulldog Fin**

The outer dimensions of the basic fin shape were used as an envelope to ensure the final fin design did not deviate too much from standard fin design. The paw portion of the fin is slightly pulled away from the airframe in order to prevent any direct contact from the ignition of the motor. A finalized model of the fin can be seen in Figure 6. The fins are made out of 1.58 mm thick G-10 fiberglass because of the material strength and flame resistance. Once the fins were finalized, a DXF file of the fins was created, and a water jet was used to cut the fins. The water jet and DXF file provided the precision needed to ensure uniformity across the four fins. In order to avoid delamination of the material during cutting, a one inch lead-in was planned.

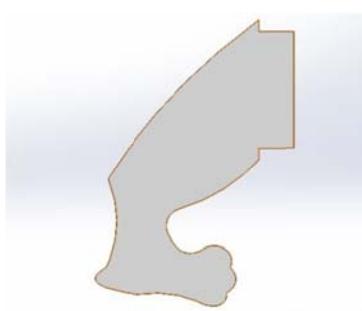

**Figure 6: Bulldog Fin Design**

In order to make sure the fins are stable and firmly attached to the body of the rocket, keyways were added to the centering rings and a tang was included in the design of the fin. When the fins were inserted through the airframe, the top and bottom of the tang of each fin lined up with keyways on the centering rings. The side of each tang also rests along the motor mount. This assembly makes the fins more rigid and makes their placement more precise. Figure 7 shows the centering ring design and Figure 8 shows an assembly view of the fins in the keyways of the centering rings. The small holes in the centering rings will hold threaded rods, which will add structure to the top centering ring, as this will be one of the mounting points for the shock cord (shown in Figure 9).

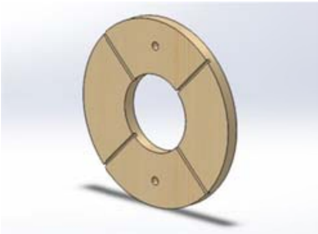

**Figure 7: Centering Ring Keyways**

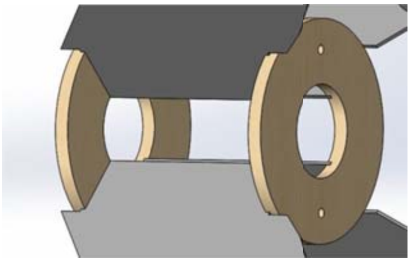

**Figure 8: Fins in Centering Rings**

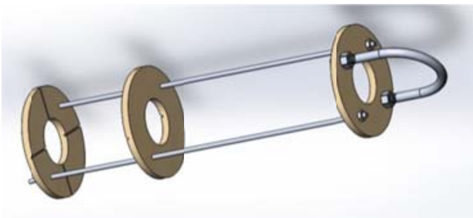

**Figure 9: Threaded Rod Centering Ring Assembly**

A K-epsilon model was used in ANSYS/Fluent to simulate the fluid around the rocket (shown in Figure 17). This accounts for the turbulent kinetic energy of the fluid around the rocket and the dissipation of that energy. The simulation was done at the max estimated velocity, 500 ft/s, to determine the maximum drag force the fins will encounter. The simulation had to account for compressibility effects at high velocities. At 500 ft/s, a pressure inlet boundary was used with variable air density. The air density was calculated using the ideal-gas law. The method used also required taking into account viscous heating of the fluid.

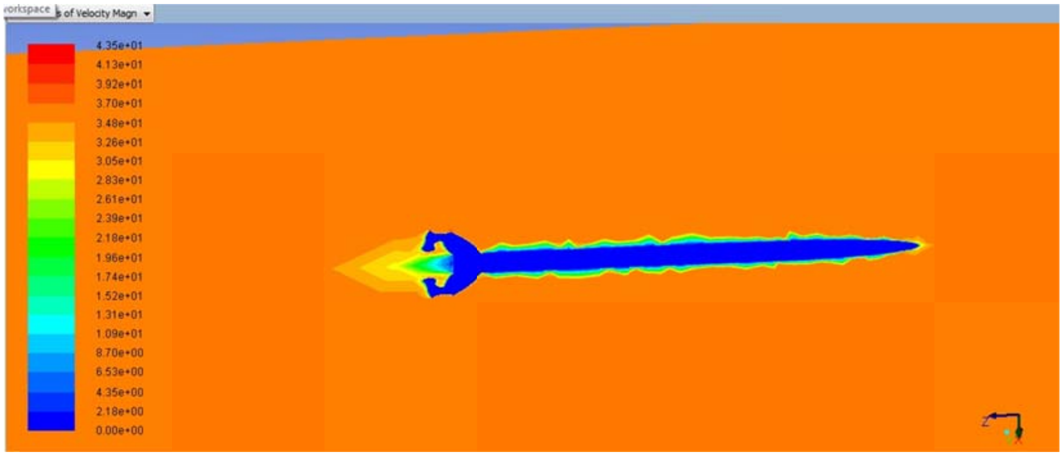


**Figure 10: Rocket ANSYS/Fluent**

Figure 11 shows how the fins affect the velocity of the fluid around it. The velocity between the gap of the paw and the leg is the same as behind the paw. This design will have little effect on the overall drag coefficient.

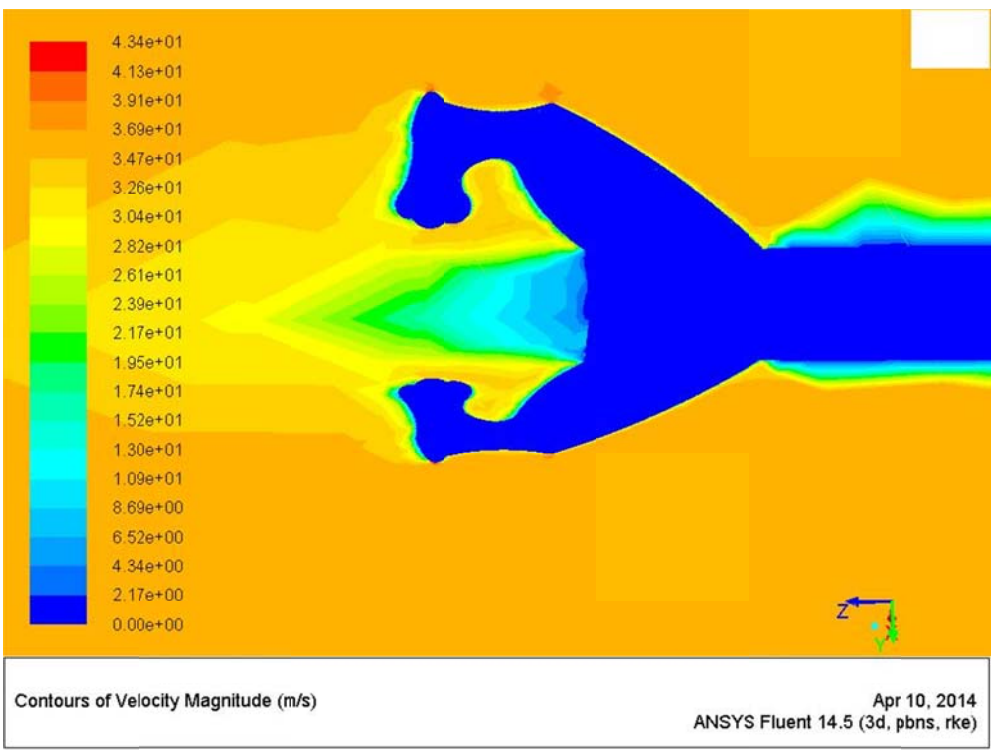


**Figure 11: Fin ANSYS/Fluent**

## Design Features of Payload System

The flight performance will be measured by an altimeter, a Pitot-static tube, a temperature probe, and a G-Force sensor. The competition will also provide an altimeter for verification of performance.

The nose cone of the rocket is a “smart” nose cone and contains all of the instrumentation for the flight performance, with the exception of the competition-provided altimeter and the altimeter used for deployment of the parachute. The nose cone was purchased from Heavenly Hobbies and was modified to accommodate the smart nose cone.

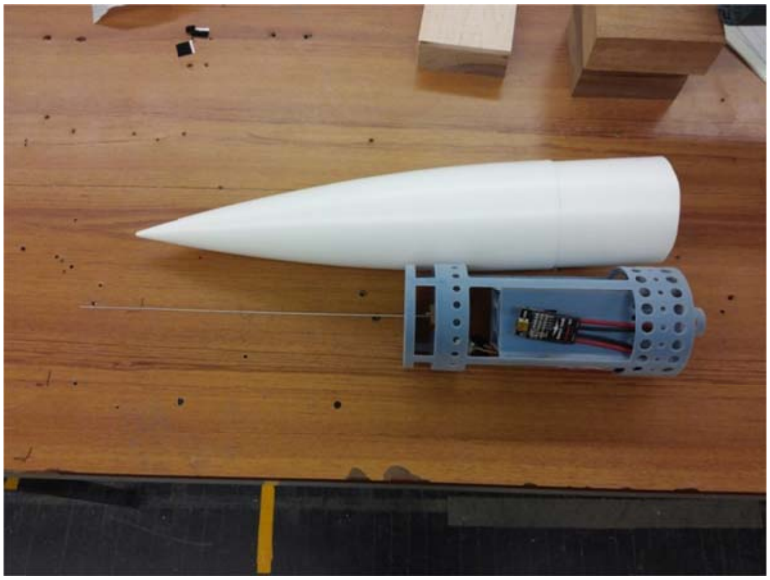

**Figure 12: Nose Cone & Chassis**

A chassis was created to hold the instrumentation and to provide additional stability for the nose cone. The chassis was designed to be lightweight yet provide structural support and to allow easy access to the instrumentation for installation, adjustments, and repair. It is designed to protect the instrumentation after the parachute is deployed. The chassis was created in SolidWorks and rapid prototyped using an Objet30 Scholar 3D printer. It is made out of RGD240, a rigid opaque material, chosen for its strength and stability. The chassis can be seen next to the nose cone in Figure 12.

All electronics in the nose cone are connected to the eLogger V4 Data Logging System, manufactured by Eagle Tree Systems (shown in Figure 13). The eLogger V4 will be connected to a laptop post-flight, and its software will download and analyze the information from the flight. The eLogger is powered by a 9V battery.


**Figure 13: eLogger V4 Data Logging System**

The first method for measuring flight performance will be an altimeter. The altimeter chosen is the Altimeter MicroSensor V4, manufactured by Eagle Tree Systems (shown in Figure 14). It connects directly to the eLogger V4 and its data can be downloaded directly into the analyzing software provided with the eLogger. The Altimeter MicroSensor V4 uses barometric pressure to measure altitude, comes pre-calibrated, and is designed to compensate for temperature. The altimeter can measure altitudes up to 20,000 feet with a tolerance of +/- 1 foot. The altimeter was chosen as the first method of measurement due to its simplicity and its relevance to the goals of the competition. It will also provide verification that the Raven III altimeter, provided by the competition, is accurately gauging flight performance.

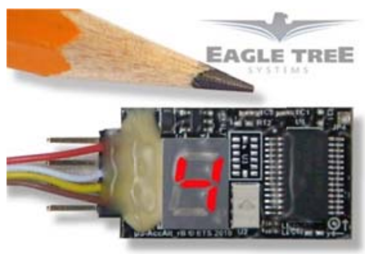


**Figure 14: Altimeter MicroSensor V4**

The second method of performance measurement is a Pitot-static tube. The Pitot-static tube uses Bernoulli's equation to determine fluid velocity by measuring the difference between stagnation pressure (measured through a tube inserted into a hole in the tip of the nose cone) and static pressure (measured through a tube inserted into a hole in the side of the nose cone) of a system. The tubes are connected to the Airspeed MicroSensor V3, manufactured by Eagle Tree Systems. The Airspeed MicroSensor V3 connects directly to the eLogger and its data can be downloaded into the provided software. The Pitot-static tube was chosen as the second method of measurement due to its compatibility with the instrumentation system selected, its relevance to principles covered in mechanical engineering courses, its relevance to aerospace industry, and its compatibility with the design of the rocket.

Additional flight data will be obtained by the 3-Axis 38+G MicroSensor and Micro Temp Sensor (shown in Figure 15), both manufactured by Eagle Tree Systems. These instruments will both connect directly to the eLogger and provide additional data for the software. The Micro Temp Sensor will be mounted directly on the wall of the nose cone near a small hole, in order to have direct contact with the atmosphere. Figure 16 shows a schematic for the connections of the nose cone payload.

**Figure 15: Micro Temp Sensor**

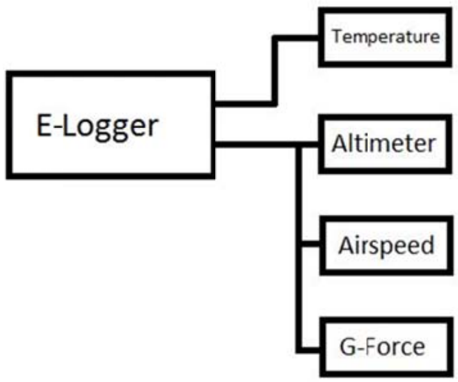


**Figure 16: Payload Connection Schematic**

## Diagram of Rocket

For simulations, pre-selected components were put in the proper place on RockSim9 to get a good estimation of the center of mass for the rocket. However, once epoxy was applied, electronics were installed, and the rocket was assembled, a more accurate center of mass was found by balancing the rocket. The center of pressure was found using RockSim9 simulations. The location of the center of pressure, center of mass with a full motor, and center of mass after motor burnout can all be seen below in Figure 17.

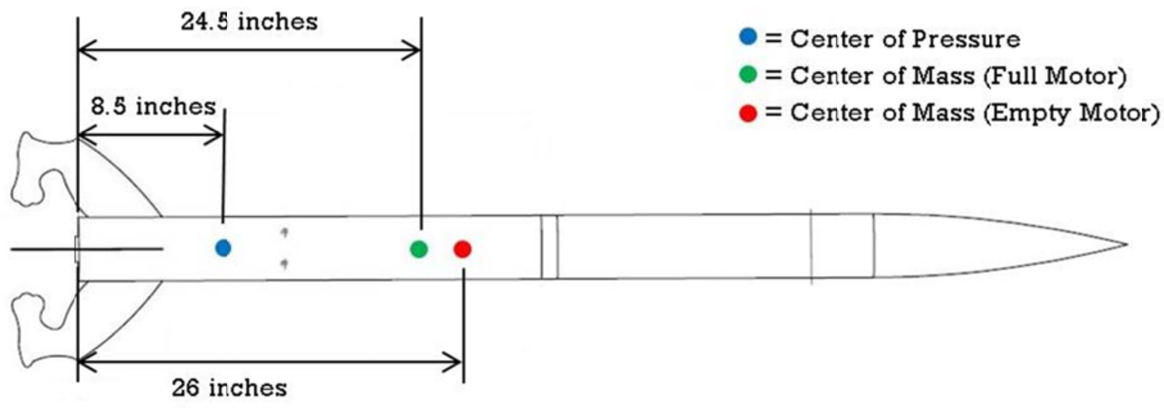


**Figure 17: Center of Pressure and Center of Mass Locations**

The design for the rocket was done using SolidWorks. Shown below in Figure 18 is the finalized 3-D design used to construct the rocket. Note that in the 3-D model one piston is shown transparent as to show the U-bolt location on the top centering ring. The body dimensions in inches can be seen in Figure 19.

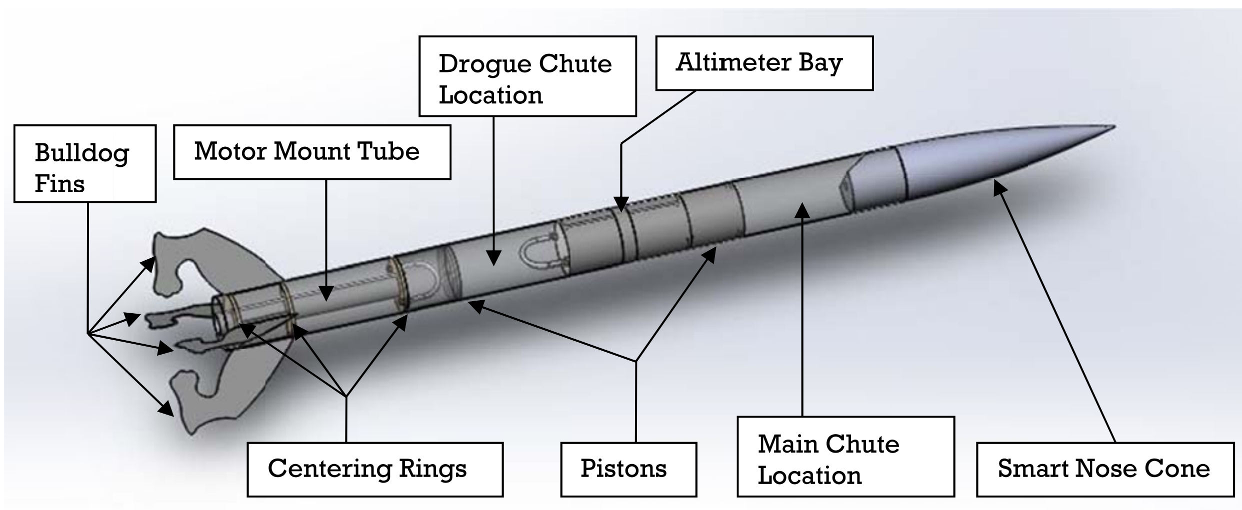


**Figure 18: General Arrangement**

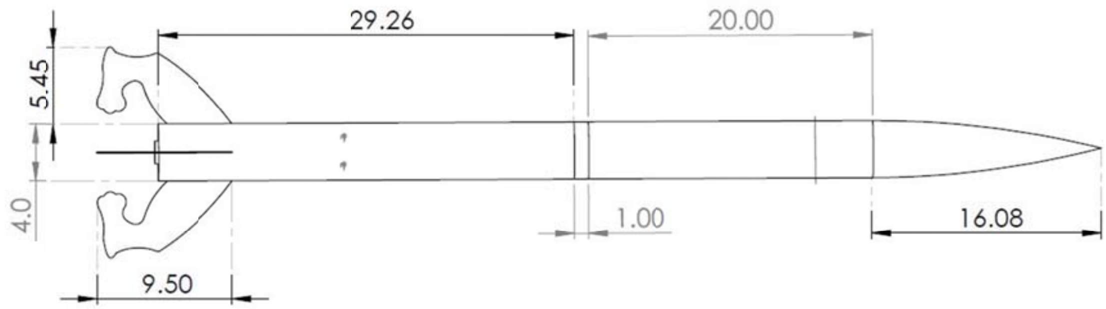


**Figure 19: Body Dimensions (Inches)**

## Analysis of Expected Performance

Analysis of the rocket was completed to find the ideal mass for the rocket. The primary simulation software packages used to analyze the rocket was RockSim9 and ANSYS/Fluent. RockSim9 was used to determine the dominant features of the rocket such as mass, length, center of pressure, etc. The motor that was chosen was placed in the model of the rocket and was launched. The weight of the rocket that had the rocket apogee closest to 3,000 feet was chosen as a target weight.

The flight simulation program Rocksim9 was used to predict the maximum altitude, peak acceleration, and peak velocity. In Rocksim9, the correct motor was selected and attached to a simulation of the rocket. In Figures 20, 21, and 22, below, the maximum altitude, velocity, and acceleration is shown when the rocket was at a mass of 2.8 kg without the motor.

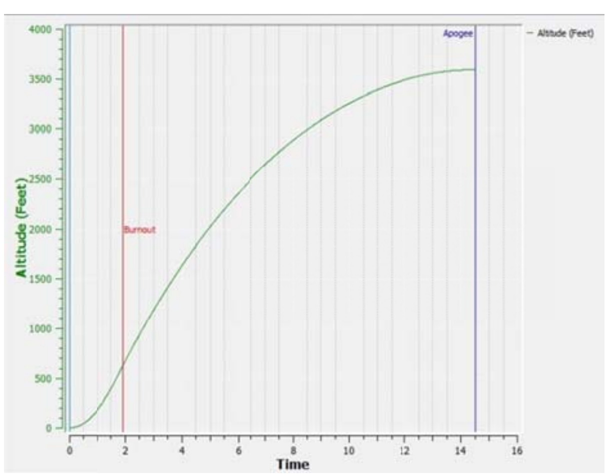


**Figure 20: Altitude vs. Time**

The rocket simulations where done at the specified mass of 2.8 kg and the max attitude, shown in Figure 20, reached in the simulations was 3,590 feet. At this height, the team can fine tune the rocket's mass on the day of launch to accurately have an apogee at 3,000 feet.

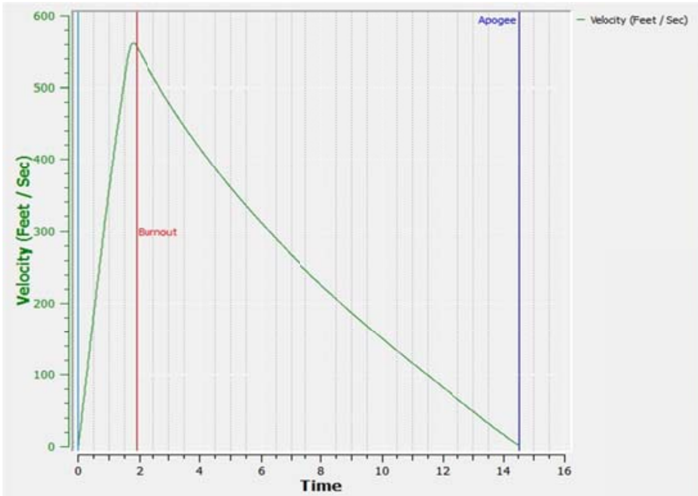


**Figure 21: Velocity vs. Time**

The simulations showed the maximum velocity of the rocket to reach 560 ft/s (see Figure 21). This velocity is just over 0.5 mach. The plan of changing the mass at launch to accurately reach 3,000 feet will also change the velocity the rocket will reach. The simulations stated that the maximum velocity at that weight was about 500 ft/s. The maximum acceleration of 360 ft/s$^2$ (shown in Figure 22) was also found with the simulations. The acceleration will also be lessened by the addition of weight.

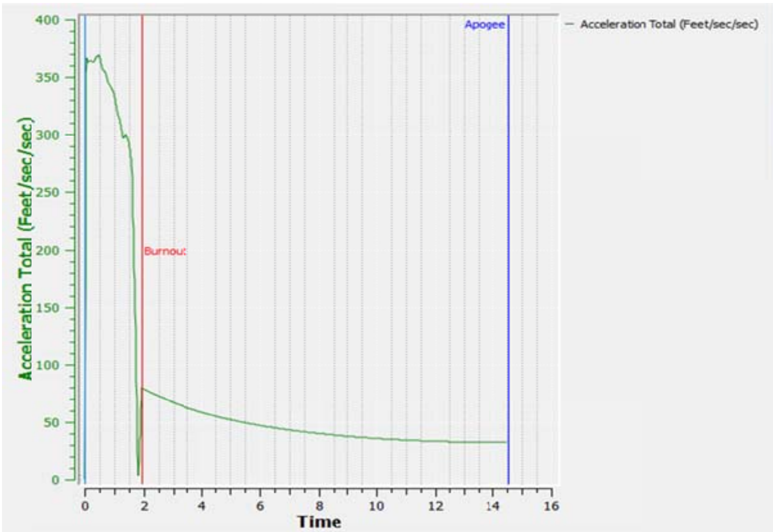


**Figure 22: Acceleration vs. Time**

The center of pressure for the rocket design was also found using the Rocksim9 program. The design of the rocket was created in the program and the center of pressure was calculated by Rocksim9. The center of pressure was located 8.5 inches above the bottom of the body tube.

## Construction of Rocket

There were five different epoxies used in construction of the rocket. To increase the structural support of our shock cord mount on the top centering ring, two aluminum threaded rods were used to support the load throughout all three centering rings. Since it is hard to work with fasteners inside the body tube, the threaded rods needed to be inserted before mounting the centering rings in the body tube. In order to mount the centering rings with threaded rods through them, Loctite Epoxy Extra Time was used, with a setting time of 60 minutes. There were also several devices made from wooden dowels and small brushes to ensure epoxy was applied evenly on all critical areas on all three centering rings. The motor mount tube was then fixed into place with the same epoxy. Epoxy application can be seen in Figure 23 and 24. For a detailed

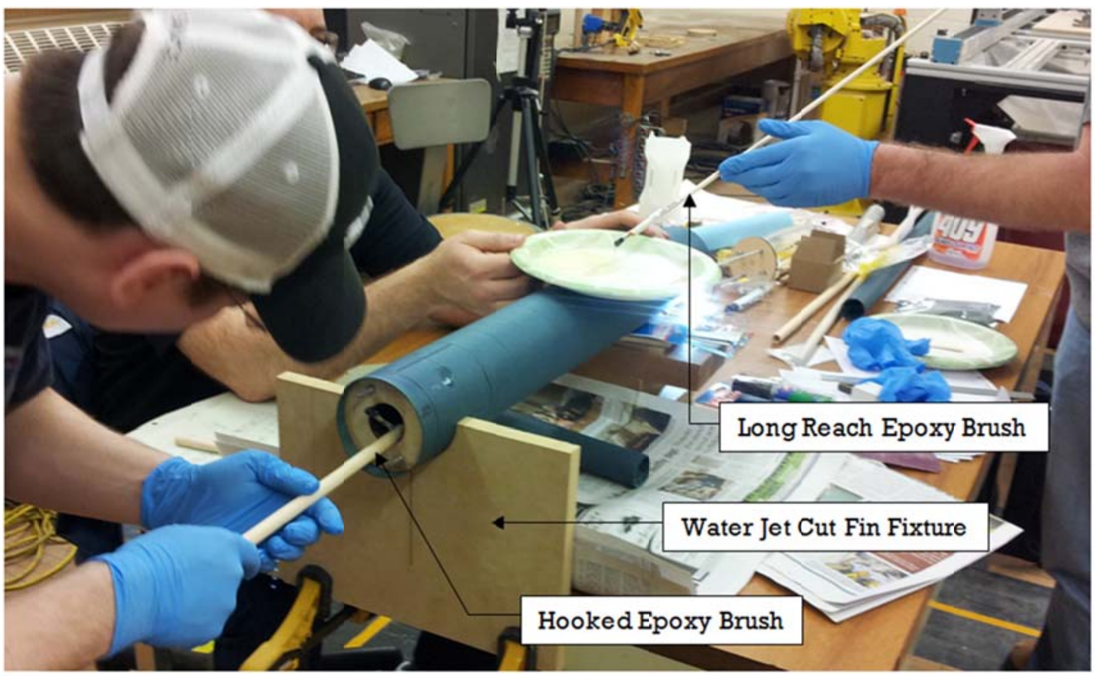


**Figure 23: Applying Epoxy for Centering Rings**

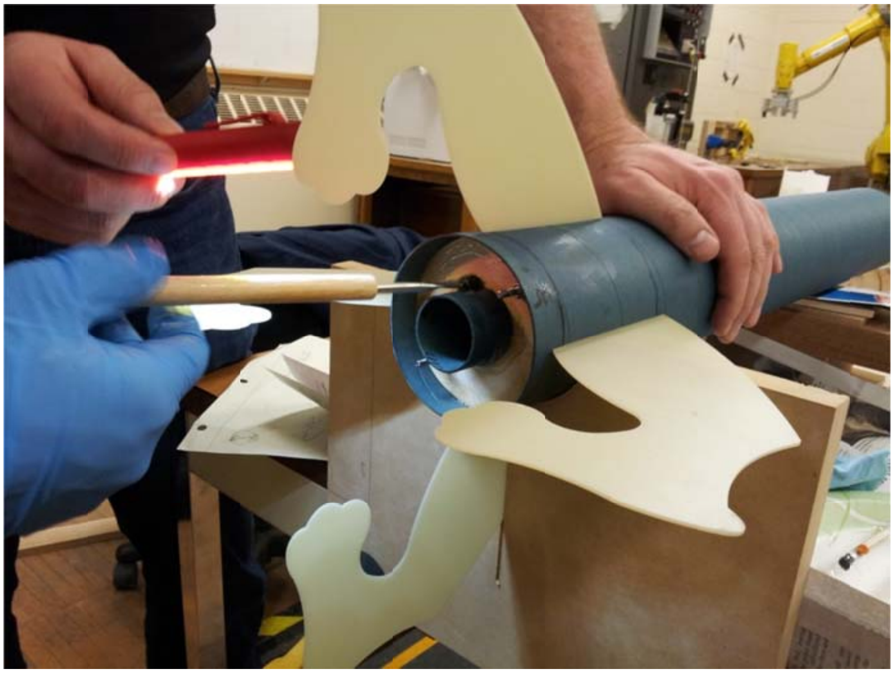

Figure 24: Applying Epoxy for Motor Mount Tube

For the pistons, Devcon 5 Minute Epoxy Gel was used because of its high strength and quick setting time. This same epoxy was used to mount the fins through the body tube slots, through centering ring slots, and against the motor mount tube. A special fixture was designed and cut from wood using the water jet cutter in order to hold the fin securely while the epoxy was setting. The fin fillets required an epoxy that could be easily sanded, therefore, Loctite Underwater Repair Epoxy was used. Devcon 5 Minute Epoxy was then used to fix the mid-electronics bay coupler tube to the fixed bulkhead, as the other bulkhead was fixed on threaded rods with wing nuts. Because of its thermal properties and high strength, JB Weld Epoxy was used to fix the motor mount ring onto the motor mount tube.

## Photograph of Completed Rocket

**Figure 25: Assembled Rocket**

Shown above in Figure 25 is the up to date version of the Flying Bulldogs' rocket. Once testing is complete, the rocket will be painted with three primer coats to protect the body tubes from damage. In preparation of the actual competition, the rocket will be sanded and re-primed, with a design to best resemble a bulldog painted on top, and sealed with a clear coat.

# Budget

**Table 3: Budget**

| Part | Cost/Unit | Quantity | Total Cost |
|---|---|---|---|
| 98 mm Blue Tube body tube | $0.81 | 48 | $38.88 |
| 98 mm Blue tube coupler | $0.83 | 17 | $14.11 |
| 38 mm Blue tube body tube | $0.35 | 14 | $4.90 |
| 98 mm/38 mm centering ring | $4.05 | 3 | $12.15 |
| 98 mm/58 mm centering ring | $4.05 | 1 | $4.05 |
| 98 mm coupler bulkhead | $4.05 | 4 | $16.20 |
| 98 mm nose cone | $19.99 | 1 | $19.99 |
| 38 mm motor retainer | $31.03 | 1 | $31.03 |
| 1.58 mm G10/FR4 fin material | $0.05 | 120 | $6.00 |
| Devcon 5 Minute Epoxy Gel | $8.15 | 2 | $16.30 |
| Devcon 5 Minute Epoxy | $6.72 | 1 | $6.72 |
| Loctite Epoxy Extra Time | $4.57 | 2 | $9.14 |
| Loctite Underwater Repair Epoxy | $12.48 | 1 | $12.48 |
| JB Weld Epoxy | $6.21 | 1 | $6.21 |
| Threaded rod 8-32 | $0.05 | 46 | $2.30 |
| 2 in. U-bolt with nuts and lock nuts | $3.22 | 3 | $9.66 |
| 72 in. Fruity chute | $181.90 | 1 | $181.90 |
| 30 in CATO chute | $34.99 | 1 | $34.99 |
| 1500 lb Kevlar cord | $0.08 | 236 | $18.88 |
| Cord protector | $0.23 | 58 | $13.34 |
| Small quick-link | $3.25 | 2 | $6.50 |
| Altimeter chassis | $2.00 | 1 | $2.00 |
| Nose cone chassis | $0.00 | 1 | $0.00 |
| Raven III altimeter | $0.00 | 1 | $0.00 |
| Stratologger altimeter | $79.95 | 1 | $79.95 |
| eLogger data logger | $69.99 | 1 | $69.99 |
| Altitude sensor | $37.99 | 1 | $37.99 |
| 38G sensor | $63.99 | 1 | $63.99 |
| Mini-temp sensor | $9.99 | 1 | $9.99 |
| Airspeed sensor | $39.99 | 1 | $39.99 |
| Airspeed tubing | $3.00 | 1 | $3.00 |
| Pitot tube | $0.80 | 12 | $9.60 |
| Pitot tube comp. fitting | $25.00 | 1 | $25.00 |
| Pitot tube lock nut | $1.32 | 1 | $1.32 |
| 9 V battery | $10.30 | 3 | $30.90 |
| Battery connector | $0.61 | 2 | $1.22 |
| Terminals | $0.77 | 2 | $1.54 |
| Ejection canisters | $2.50 | 2 | $5.00 |
| Arming switch | $3.81 | 3 | $11.43 |
| Estes Alpha Model Rocket Kit | $14.99 | 1 | $14.99 |
| Model rocket engine | $2.83 | 1 | $2.83 |
| RGD240 3-D Printing Material | $12.00 | 70.5 | $846.00 |
| Entrance Fee | $400.00 | 1 | $400.00 |
| Gas | $0.30 | 315 | $94.50 |
| **Total cost** | | | **$2,216.96** |

# Test Launch Preparation

### *Test Flight Tools & Supplies*

- Blast Caps
- Wrenches
- Screwdriver
- Wire
- Fast Setting Epoxy
- Spare Pitot-static Tube
- Zip-ties

### *Preflight Checklist*

The following is a list of items included in our preflight checklist. A formal and sequential checklist will be provided to the range safety officer the day of the launch.

- Record Launch Conditions
- Inspect Hardware and Parachute Components
- Install Bottom Blast Cap
- Pack Drogue Parachute
- Install Top Blast Cap
- Test & Install Altimeter Bay
- Pack Main Parachute
- Test & Install Smart Nose Cone
- Install Motor and Retention Ring
- Install Igniter
- Place Rocket on Launch Rail
- Perform Visual Inspection
- Arm Altimeter
- Launch

# Conclusion

The Flying Bulldogs' rocket meets or exceeds the criteria outlined by the WSGC for the competition, in innovative and unique fashion. The rocket's fin design provides stability while demonstrating school pride. The payload system, modified from instrumentation designed for model aircraft, uses four different instruments to gather data for flight performance calculations: an altimeter, a Pitot-static tube, a temperature probe, and a G-Force sensor. The piston deployment of the recovery system ensures more reliable and complete detachment of rocket sections and to protect the parachutes during detonation. The rocket provided ample opportunity for applied learning; team members were able to apply computational fluid dynamics, fluid mechanics, kinematics, computer aided drawing, project management, and other concepts studied in the classroom during the preparation for the competition. The rigorous testing and analysis completed or planned will ensure the Flying Bulldogs will be fierce competitors in the WSGC 2014 Regional Rocket Design Competition.