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ROCKETDOGS

FLIGHT READINESS REPORT

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Executive Summary

The Wisconsin Space Grant Consortium is the host of an annual Regional Rocket Design Competition. The RocketDogs Senior Design Team, located at the University of Minnesota Duluth, has designed a high-powered rocket for their first WSGC competition on April 26th-27th of this year. The goal of the competition is to design a rocket to reach an apogee of 3000 ft as accurately as possible using a Cesaroni I540 motor. The rocket itself must be no greater than 72in in length, have a maximum tube diameter of 4 in, and a maximum weight of the rocket of 7.5 lbs, excluding the motor.

The final design of the rocket is a 3 in diameter, 6 lb, and 60 in long body with a one-time deployed air brake. It was constructed using components from reputable rocket dealers and includes a fiberglass wrapped body tube, fiberglass motor mount and fins, and a plastic nose cone. The recovery system includes a 60 in parachute which is deployed using black powder canisters to pressurize the body tube. The black powder canisters are ignited electrically by an on board altimeter. The electronic hardware includes an altimeter, data logger, Arduino microprocessor, and power supply housed in the electronics bay of the rocket.

The air brake was designed in SolidWorks CAD software, simulated in ANSYS/Fluent for computational fluid dynamic (CFD) analysis and finite element analysis (FEA), and fabricated using a selective laser sintering (SLS) process of glass impregnated nylon. The air brake uses fins that protrude out of the body. They are in the form of a teardrop in its initial state to limit its increase in drag during the boost and coast phase. When deployed, solenoids release a spring loaded disc which separates the teardrop into two parts and exposes flat surfaces normal to the rocket's flight path. The drag coefficient of the rocket was found using CFD at discrete velocity points and FEA was used to verify that the brake was structurally capable of handling the expected worst case flight conditions. Deploying the brake increased the rockets overall drag by as much 49.8 percent. The brake was fabricated using the SLS process because of its ability to quickly produce multiple brakes that had the required material properties to allow for testing.

Flight characteristic equations were generated to predict the flight of the rocket. It was determined that with ideal flight conditions and a rocket weighing six pounds, the brake would deploy 5.1 s into flight at an altitude of 2059 ft and at a velocity of 300.3 ft/s. It takes the rocket 12.32 s to reach an apogee of 3000 ft. Variations in flight conditions have been accounted for by running simulations with different flight conditions and creating a data table from this information. The altimeter and Arduino actively compare in- flight data with the data tables in real time; this determines when the brake will be deployed. In this way, real time data is used to accurately achieve an apogee of 3000 ft.

Ground testing of the brake deployment and parachute ejection system were completed to ensure the systems would work. These systems, as well as the electronics, have successfully passed all tests completed on the ground. Assembly of the rocket has gone smoothly. On April 26th, the RocketDogs group will present its design to the WSGC panel of judges. The group will be ready to launch the rocket April 27th at the Bong Recreational Area.

Team Summary

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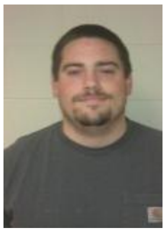


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Design Challenge

Rocket design teams were to design and launch a high powered rocket to an altitude of 3000 ft to successfully compete in the Wisconsin Space Grant Consortium's Regional Rocket Design Competition on April 27, 2013. The following constraints were set by the competition rules:

- Rocket Motor
  - Teams must use a Cesaroni I540 motor
- Geometric Tolerances
  - Maximum body tube diameter: 4 in
  - Maximum overall length in launch configuration: 72 in
  - Max weight in launch configuration (less motor): 7.5 lbs
- Flight Recorder
  - Teams must use a Raven III flight data recorder provided the day of launch
  - Must be powered by a 9V battery
- Safety Inspection
  - Each rocket must pass the Range Safety Officer's inspection the day of the launch before it is allowed to fly
- Successful Launch
  - Attain an altitude of at least 2500 ft but not to exceed 3500 ft at apogee as reported by the WSGC flight recorder
  - Parachute must be electronically deployed
  - All parts of the rocket must be recovered together and in flyable condition

Component Restrictions

In order to meet the provided building constraints, all of the components being used in the assembly of the rocket were purchased from reputable vendors such as Apogee Components and Madcow Rocketry. By using components that have proven themselves in the high-powered hobbyist market, the integrity of individual components does not have to be further evaluated in this report.

RocketDog's design is a combination of manufactured rocket parts, rather than a kit. Public Missiles and Madcow Rocketry are the primary providers for the structural rocket components like the body tube and motor mount. Electronic hardware was purchased from Apogee Components and Sparkfun Electronics. Miscellaneous hardware, such as the ignition canisters and mounting pieces, were purchased from Apogee Components.

Rocket Components and Features

The RocketDog's team design incorporates a one-time deployed air brake actively controlled in flight via the altimeter and Arduino microprocessor. The air brake design utilizes a spring-loaded, rotating disc released by solenoids. The air brake design is discussed in greater detail in the Air Brake Design section.

The launched rocket contains an electronic payload, recovery system, air-brake and motor. The vehicle was built from individually ordered parts rather than attempting to customize a rocket kit. This allowed the necessary customization required to incorporate an air-brake. Table 1 contains the overall specifications for the rocket:

Table 1: Rocket Specifications

Rocket Specifications	
Length	59.075"
Diameter	3"
Nose Cone	Plastic Ogive, 13.25" long
Motor	Cesaroni I540
Total Mass (Less Motor)	6.0 lb.

Figure 1: The Assembled Rocket

Figure 1 above shows the assembled rocket. Final assembly and painting is on schedule to be completed by April 15th, 2013.

The airframe is split into three parts. Two parts are connected via the air-brake near the back of the rocket (see Fig. 2). It is also sectioned at the electronics bay in order to deploy the parachute. The airframe body is fiberglass wrapped phenolic tubing. This material was chosen due to its high strength and relatively low weight.

The nosecone is an ogive-shaped plastic component chosen for its low weight. This nosecone will be epoxied into the forward airframe section that is attached to the electronics bay by plastic rivets. The motor mount is made from fiberglass for its strength and stability, as are the three centering rings holding the motor mount tube into the airframe. The centering rings are spaced on the motor mount tube in order to have them assist with fin stability. The air-brake works as a holding surface at the rear edge of the fins as well.

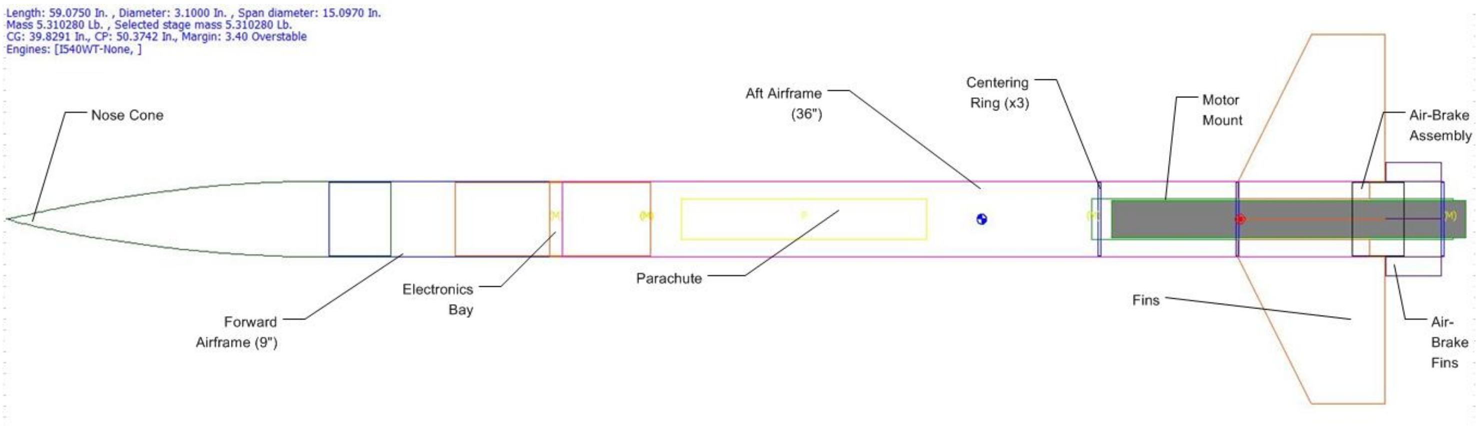

Figure 2: Rocket Components

The fins chosen are made of fiberglass, ensuring a strong and stable fin that can withstand possible impact on descent. The fins are epoxied to both the airframe and motor mount tube. They are also epoxied at the front to a centering ring, as well as the rear to the airbrake, providing secure mounting. The fin shape was chosen to increase stability as well as the drag, helping the rocket reach the desired apogee. To mount the rocket onto the launch rail, standard rail buttons are bolted and epoxied into the airframe.

Details of the rocket's structural components and their respective properties can be found in Table 2:

Table 2: Rocket Component Details

Component	Manufacturer	Material	Length	Diameter
Airframe	Public Missiles	Fiberglass Wrapped Phenolic Tubing	45"	3"
Nose Cone	Public Missiles	Plastic	13.25"	3"
Centering Rings	Public Missiles	G10 Fiberglass	0.093"	3"
Motor Mount	Madcow Rocketry	G10 Fiberglass	14.75"	38mm
Electronics Bay	Apogee Rockets	Blue Tube	8"	3"
Fins	Public Missiles	G10 Fiberglass	6"	-
Engine Retainer	Apogee Rockets	Aluminum	0.5"	38mm
Parachute	Public Missiles	Rip-stop nylon	-	60"
Shock Cord	Apogee Rockets	1500 lb test Kevlar Cord	18'	.23"
Shock Cord Protector	Madcow Rocketry	Nomex	30"	-
Wadding	Madcow Rocketry	Nomex	12" x 12"	-
Rail Buttons	Apogee Rockets	Delrin Plastic	.381"	.381"

Air-brake Design

The air brake is designed to deploy at an altitude determined by onboard avionics taking real-time data to reach the desired 3000 ft apogee. The rocket airframe is sectioned into two parts at the aft, connected via the air brake assembly and motor mount. The air brake incorporates a rotating disc that takes on an airfoil shape behind the fins when not deployed. When deployed, the rotating disk is spun around the axis of the rocket body 45 degrees in order to create a large amount of surface area normal to the airflow. This creates high pressure in front of the rotational section and low pressure behind the fins that are stationary, thus increasing drag and slowing the rocket. The before and after of this action is shown below in Fig. 3.

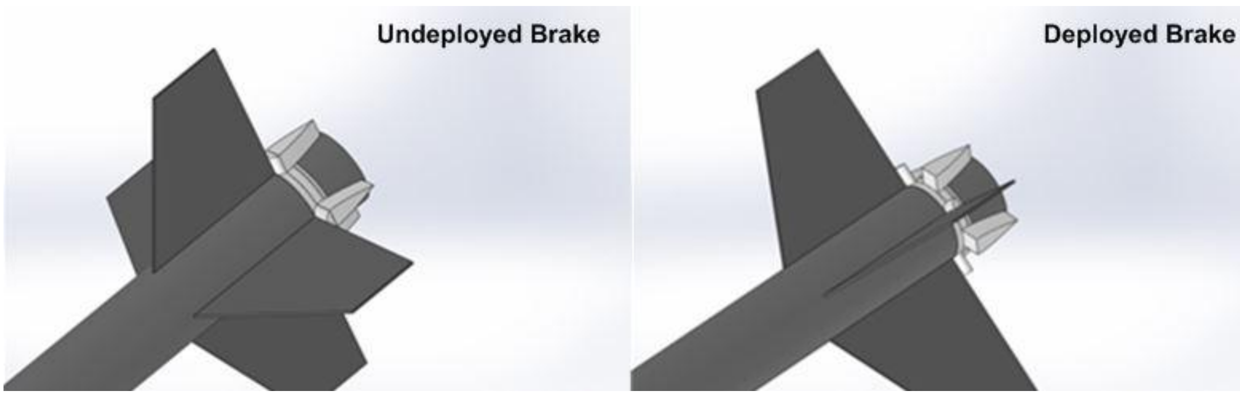

Figure 3: Air Brake Undeployed (Left) and Deployed (Right)

The air brake was manufactured using an additive manufacturing process, specifically selective laser sintering (SLS) 3-D printing using glass impregnated nylon. This process allowed for manufacturing of a complex assembly of accurate components while still obtaining the desired material properties necessary to handle any expected flight condition. The properties of this material allow the air brake assembly to be able to withstand a rapid decent and high temperature near the rocket nozzle.

Figure 4 shows a worse-case scenario stress analysis on the rocket's air brake completed using SolidWorks FEA capabilities. The material used in the stress analysis is Nylon 101, which has yield strength of 60 MPa. The actual glass filled nylon is rated for yield strength of 21 MPa, or 35 percent the yield strength of Nylon 101. It is shown that the maximum stress (~1MPa) is well below the yield stress for glass filled nylon. The forces used in the analysis were determined by ANSYS/Fluent CFD at a velocity of 800 ft/s, well above the expected deployment velocity of 300 ft/s.

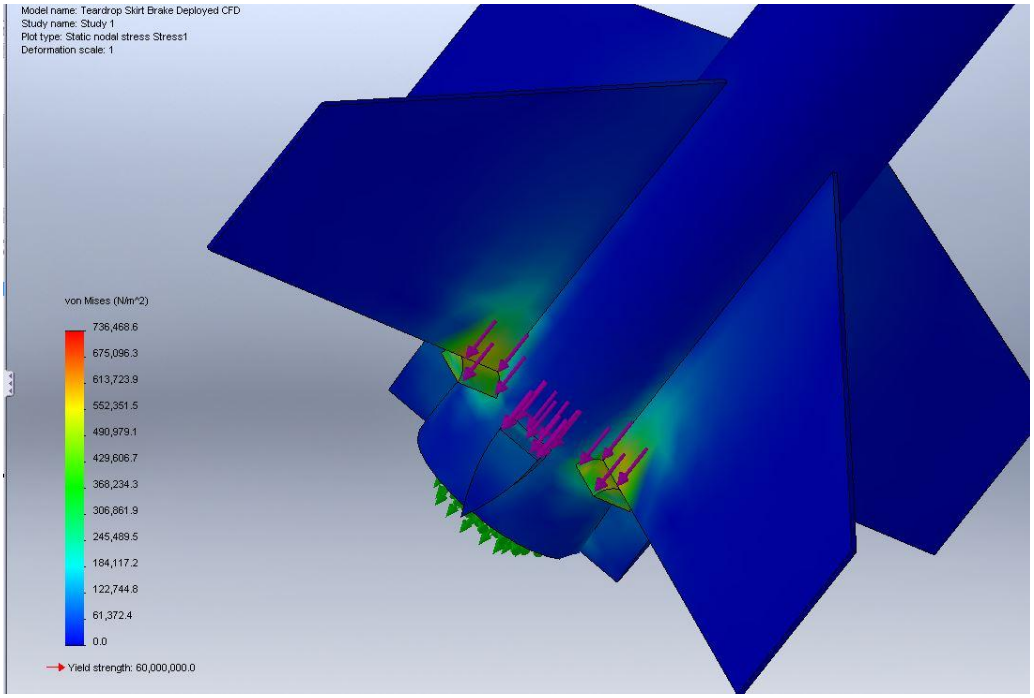

Figure 4: Air brake stress analysis

Shown in Fig. 5 is the actual air brake assembly being test fit. The springs are held in tension when the air brake is in the undeployed state. When the solenoids are electronically activated by the programmed avionics, the solenoid's piston will release the air brake body, allowing the springs to pull the air brake into the deployed state.

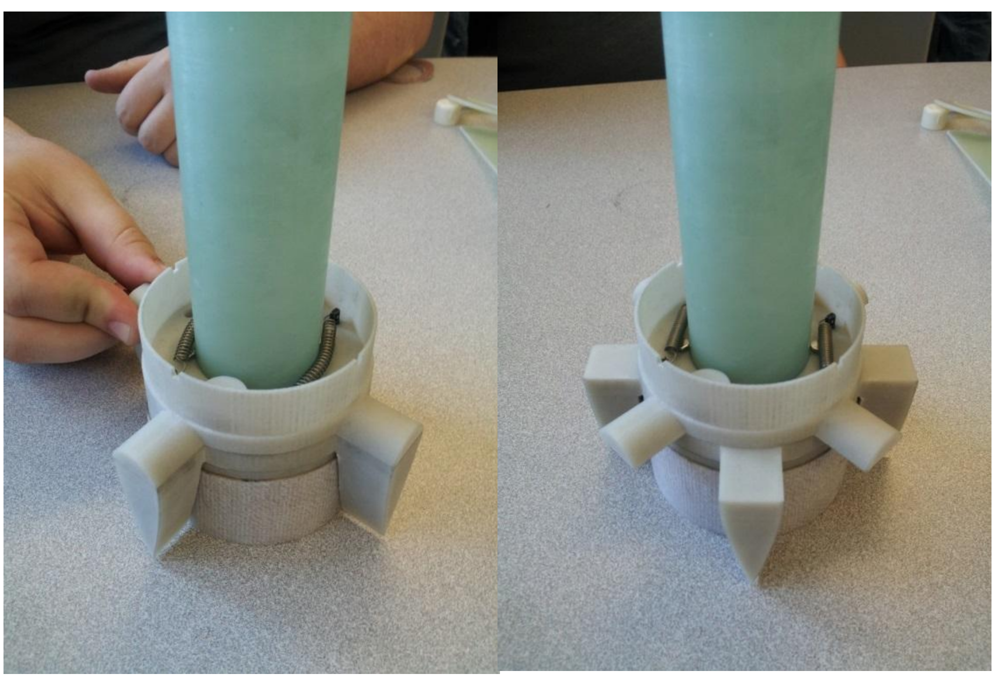

Figure 5: Undeployed and Deployed Air Brake

Motor Choice

The motor was selected by the WSGC as a constraint for the competition. The rocket is propelled by the Cesaroni I540 motor. The motor has the capability to far exceed an apogee of 3000 ft if put in a rocket built for reaching high-altitude. The motor properties are shown below in Table 3. It was assumed that variation in motor performance was negligible.

Table 3: Cesaroni I540 Rocket Motor Specifications

Cesaroni I540 Properties	
Diameter (mm)	38
Length (cm)	36.7
Delay (s)	14
Average Thrust (N)	540
Total Impulse (N*s)	634.6
Burn Time (s)	1.2

Recovery System

The main component of the flight recovery system is a 60" nylon parachute discharged by either the blast cap or the motor ejection charge, providing a level of redundancy. The parachute is deployed at apogee by the blast cap, or after the delay time of the motor ejection charge. The parachute selected is slightly oversized for the rocket, which will help in creating a soft landing for the descent. The decent rate of the parachute is 11.9 ft/s. There is no drogue parachute being deployed from this rocket.

The shock cord being used for the parachute is 1500 lb test strength Kevlar cord purchased from Apogee Components. This cord was selected to provide extreme strength without adding a substantial amount of weight. The shock cord is cut to be just greater than 240" total. A Nomex shock cord protector and reusable wadding is installed in front of both the blast cap and the rocket motor ejection charge, located on top of the motor mount, in order to protect the shock cord and parachute from the heat of ignition. The shock cord is mounted to the forward-most centering ring and to the electronics bay both by swivel-headed steel studs. The parachute is mounted to the electronics bay using a quick link attachment. Figure 6 displays the assembled recovery system. Two nylon shear pins supplied by Apogee are used to hold the airframe to the electronics bay.

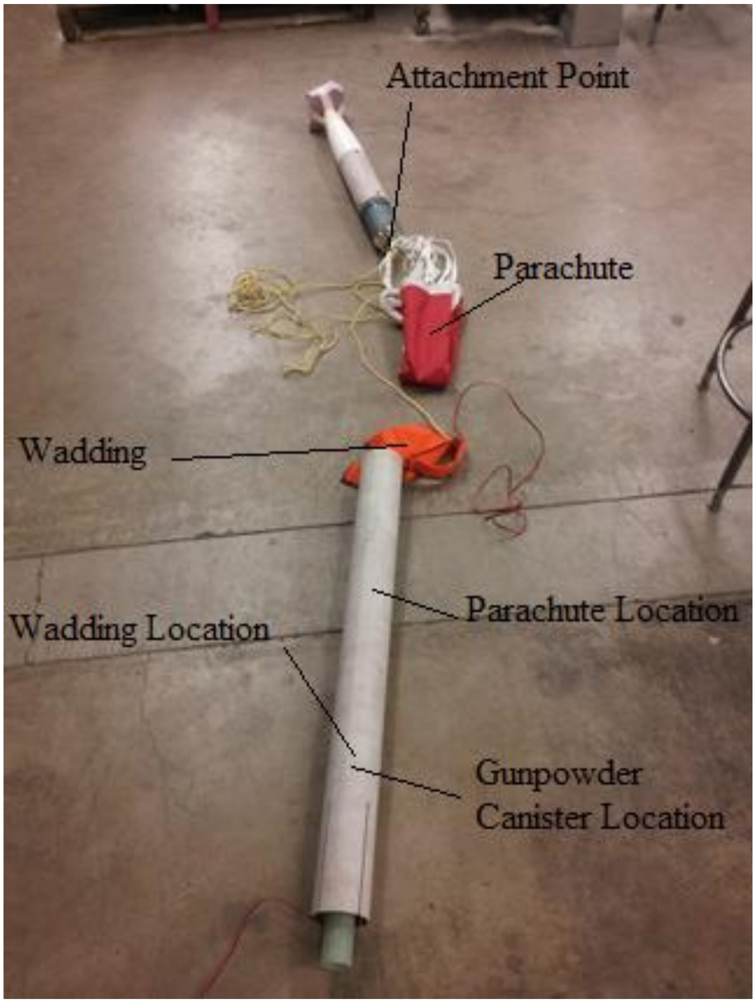

Figure 6: Recovery Assembly

The ejection blast cap was tested multiple times in order to find the proper amount of black powder in order to deploy the parachute. Figure 7 shows time lapse photos of a successful parachute ejection. After testing, the overall amount of black powder needed to successfully shear the pins and eject the chute was 2.5 grams. The location of the blast cap assists in pushing the parachute out of the body tube. Both the blast cap and the motor ejection charge force the parachute and protective wadding out of the body tube. The blast cap located in approximately the same location as the motor ejection charge.

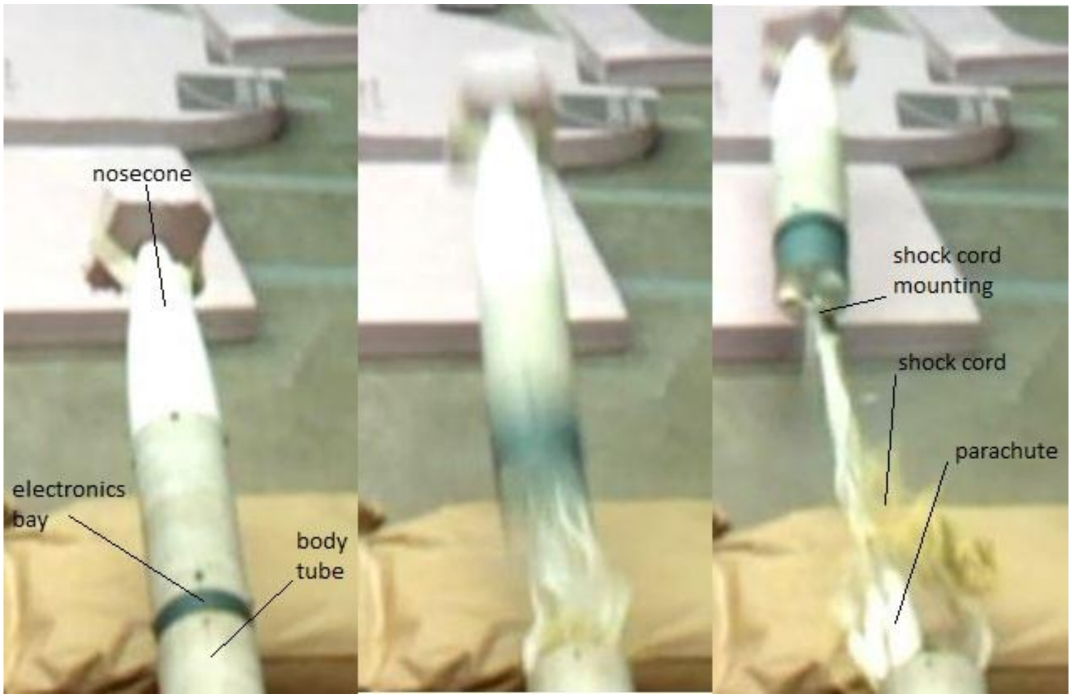

Figure 7: Still Shots from an Ejection Test Video

Avionics and Payload

The primary altimeter being used is the StratoLogger model SL100, made by PerfectFlite (see Figure 8). This altimeter was chosen for its reputation of reliability for capturing flight data and user-friendly support and applications. This altimeter will be used to deploy the ejection charge for the primary parachute, as well as providing telemetry data throughout the flight to a microprocessor controlling an air-brake. The secondary altimeter being used is the Raven III, made by Featherweight Altimeters. This altimeter is provided on launch day by the WSGC to be used specifically for measuring the apogee altitude of the rocket.

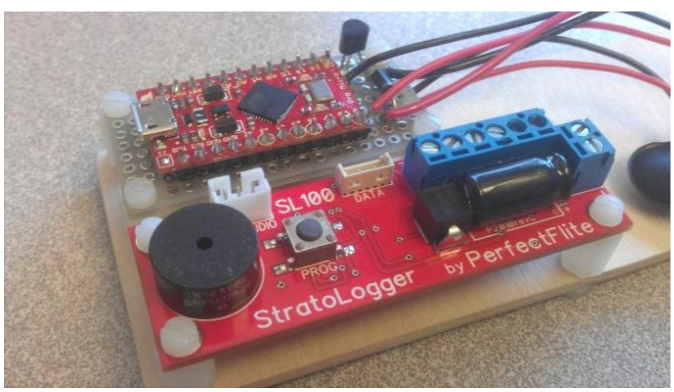

Figure 8: Stratologger and Arduino Controller

The altimeter is exposed to the outside atmospheric pressure by four small vent holes around the perimeter of the electronics bay (see Figure 9). These holes are nominally sized 0.057” each, as specified for the StratoLogger altimeter manufacturer.

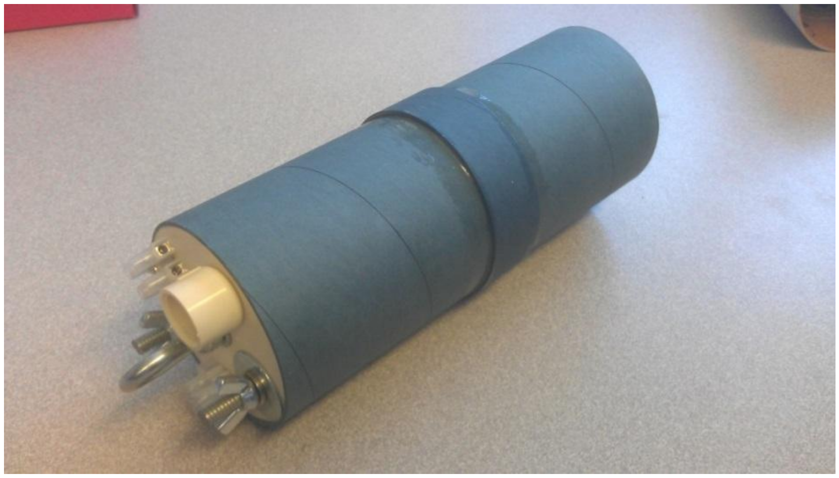

Figure 9: Assembled Electronics Bay

The software involved is largely limited to the Arduino microprocessor. The programming and development software is a package available for free on the Arduino website, and is installed on a laptop so that changes in flight conditions can be made on the day of competition as needed. The StratoLogger does not require any specific software needed for operation; all necessary setup were done on the unit alone. However, for setup and testing purposes, the PerfectFlite DataCap program was used to make precise changes, and was also installed on a laptop if needed at competition. The StratoLogger altimeter provides the apogee altitude of the most recent flight through audible beeping.

The parachute ejection blast canisters are triggered by the StratoLogger altimeter powering a heating element. The rocket motor also has a delayed fuse which will trigger in case the blast cap fails. This provides a redundant system for parachute deployment. The electronic ejection system and altimeter are activated and deactivated by a small button just accessible from outside of the electronics bay, as required. Figure 10 shows the electrical hardware found within the electronics bay, while Fig. 11 details the wiring schematic of the system. The reliability of the control system was tested on the ground by effectively mimicking the stages of flight using a pressure chamber. This control system provides an accurate means of controlling the apogee of the rocket while maintaining a relatively simple rocket design.

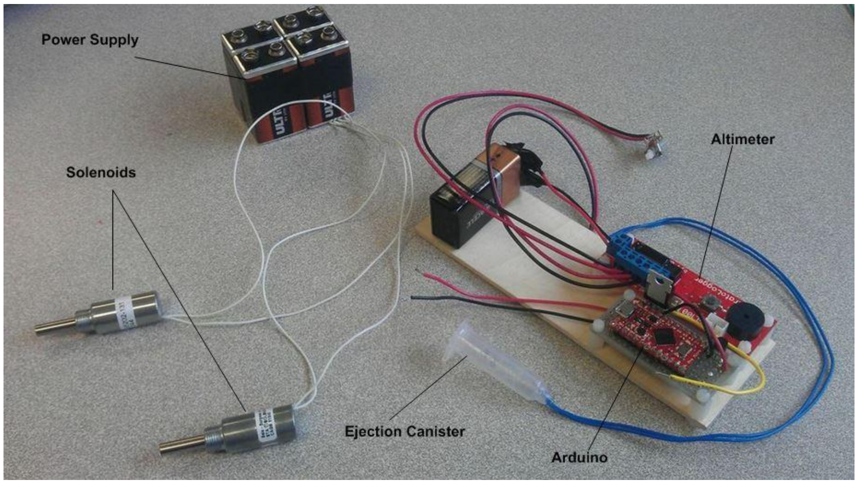

Figure 10: Electrical Hardware

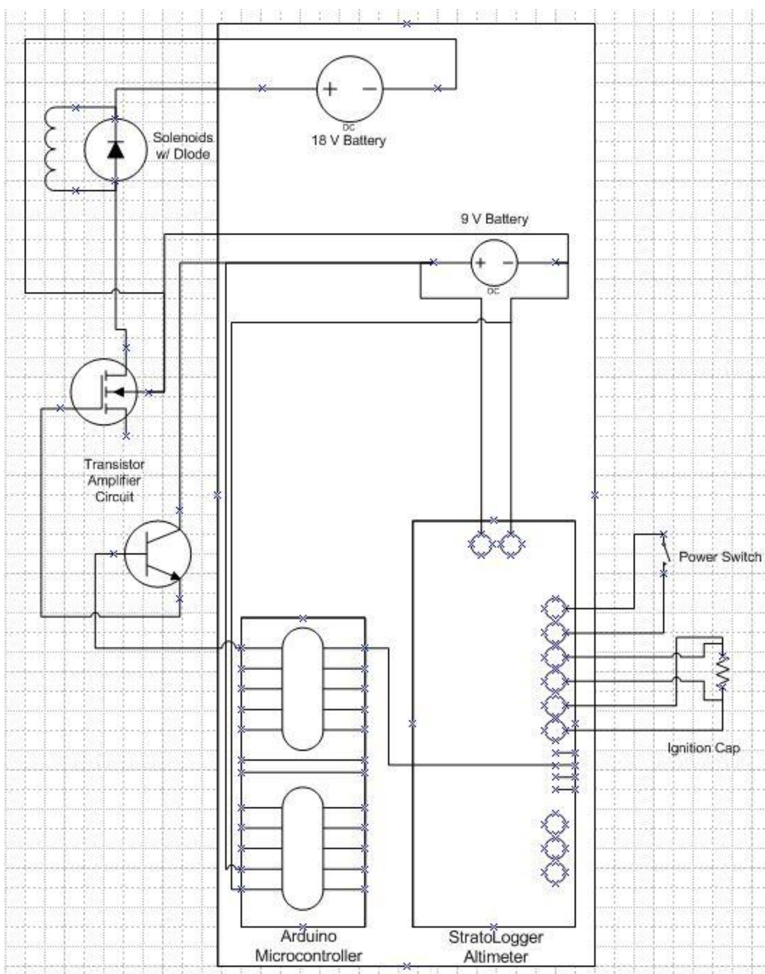

Figure 11: Wiring Diagram

Motor Retention System

The rocket motor is contained in the fiberglass motor mount tube. An aluminum AreoPack engine retainer is used to retain the motor in the motor mount. The retainer ring collar is bonded to the rear of the motor mount tube with J-B Weld, and then the rocket motor can be slid into the tube and retained by screwing the cap onto the retainer. This retainer, shown in Fig. 12, allows easy motor installation and removal and secure mounting. It is also able to handle the impact of the rocket during descent.

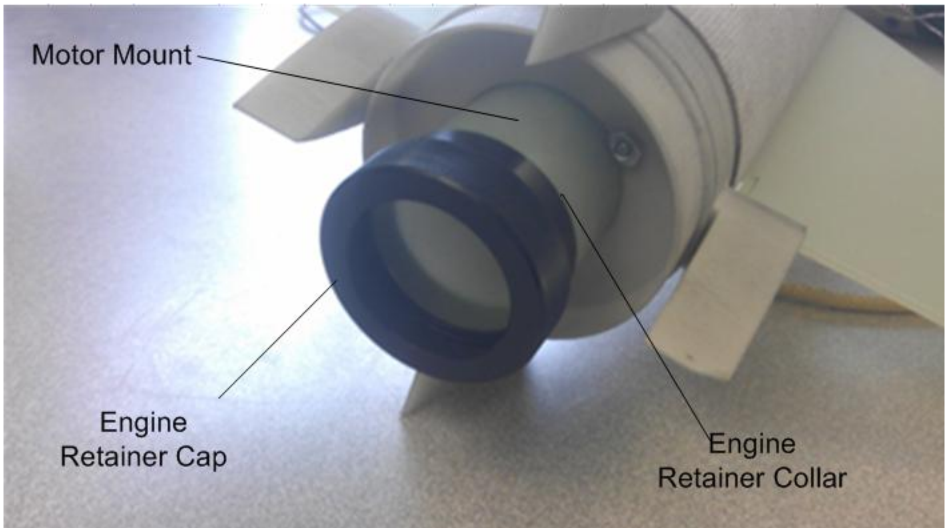

Figure 12: Motor Retainer

Epoxy

Loctite's Epoxy Gel, item number 1405602, was used on all structural joints in the rocket. This product is a two part epoxy gel, rated for 3000 psi. The epoxy is commonly used and has the appropriate physical properties for the application, including the necessary structural strength. The epoxy was mixed one to one as required, and was used to create the fin fillets as well. FIX-IT epoxy clay (PN 29590) provided by Apogee Rockets was used for the final fin fillets, due to its strength and molding ability. In order to attach the motor retainer to the motor mount tube, J-B Weld epoxy was used, as recommended by the manufacturer.

Rocket Finish

The addition of paint and finish reduces the impacts of surface defects and surface abnormalities on the rocket's drag characteristics. Defects and low spots in the surface of the rocket were filled with Elmer's Carpenters' Wood Filler, item number E855. This creates a smooth surface to begin the finishing process. The filled areas, as well as the entire surface of the rocket, are then sanded with 100 grit sandpaper to create a rough surface for the primer to adhere.

The primer used is a Rust-Oleum sandable gray primer, item number 249419. Sandable primer provides a good surface for the color coat to adhere to, while also filling small defects and scratches. Three coats of primer are applied to the rocket body, with sanding in between each coat with 220 grit sandpaper to ensure proper adhesion. Three coats of base color are applied with light wet sanding in between as needed. Rust-Oleum enamel paint is used for the color coats, item number 7768830. This was chosen due to its high strength and high gloss finish. A final clear coat is employed to protect the paint and provide a high gloss finish. Rust-Oleum Crystal Clear Enamel, item number 7701830, is used as the final clear coat. The rocket is on schedule to be completed and painted by the 15th of April.

Simulation and Testing

Wind Tunnel Testing

Three air brakes were designed and compared in order to determine which brake model would be used. Each model, shown in Fig. 13, was manufactured using SLS manufacturing and then assembled.

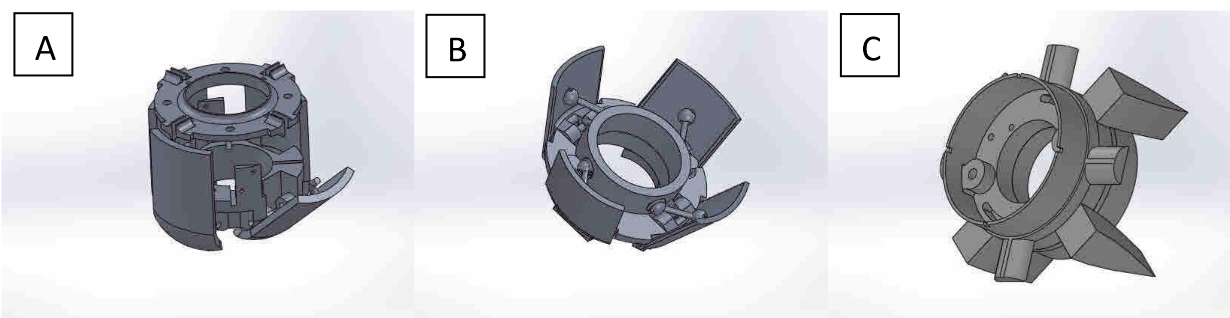

Figure 13: Air Brake Designs

The brakes were then mounted in a wind tunnel and monitored using a load sensor to record the force on the deployed brake from the airflow, and a high speed camera to view how the brakes deployed. This wind tunnel testing provided the ability to see how each brake would operate under the loads involved at high speed flight. The wind tunnel was operated at varying velocities up to 200 mph. Figure 14 shows a wind tunnel test setup.

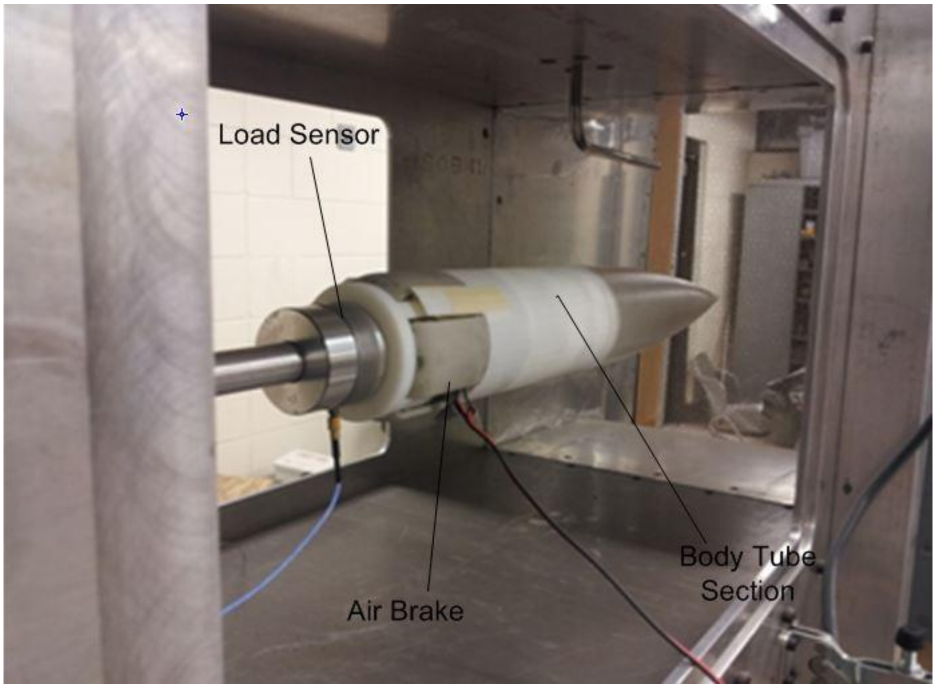

Figure 14: Wind Tunnel Test Setup

From this testing, as well as bench testing of each brake, designs A and B were eliminated. The high speed camera captured inconsistencies in deployment of the two eliminated fin designs, which would cause instability in flight. From this evidence, the rotating skirt style air-brake labeled C in Fig. 13 was chosen as the final brake design.

Computational Analysis

Analysis and testing of the chosen rocket and brake design was completed to quantify its effect on the rockets flight. 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 fin design, tube sizing, overall length, center of pressure, etc. This allowed for the base components to be chosen and the other components chosen around this structure. Rocksim provided the ability to compare the created flight characteristic equations with that of reputable simulation software.

ANSYS/Fluent was used to determine the rockets overall drag coefficient with the air brake deployed and undeployed. A K-epsilon model was used to simulate the fluid around the rocket. This accounts for the turbulent kinetic energy of the fluid around the rocket and the dissipation of that energy. The simulation was completed at discrete velocities and the drag coefficient interpolated between these velocities. The simulation was split into two parts to account for compressibility effects at high velocities (> 300 ft/s). In the sub 300 ft/s simulations, a constant air density velocity inlet was the dominant boundary condition. In the simulations over 300 ft/s, a pressure inlet boundary condition was used with variable air density. The air density was calculated using the ideal-gas law. This method also required taking into account viscous heating of the fluid. The results of the simulation for the deployed and undeployed brake can be seen in Fig. 15. The rocket's overall drag increases up to 50 percent (depending on the velocity) when the brake is deployed.

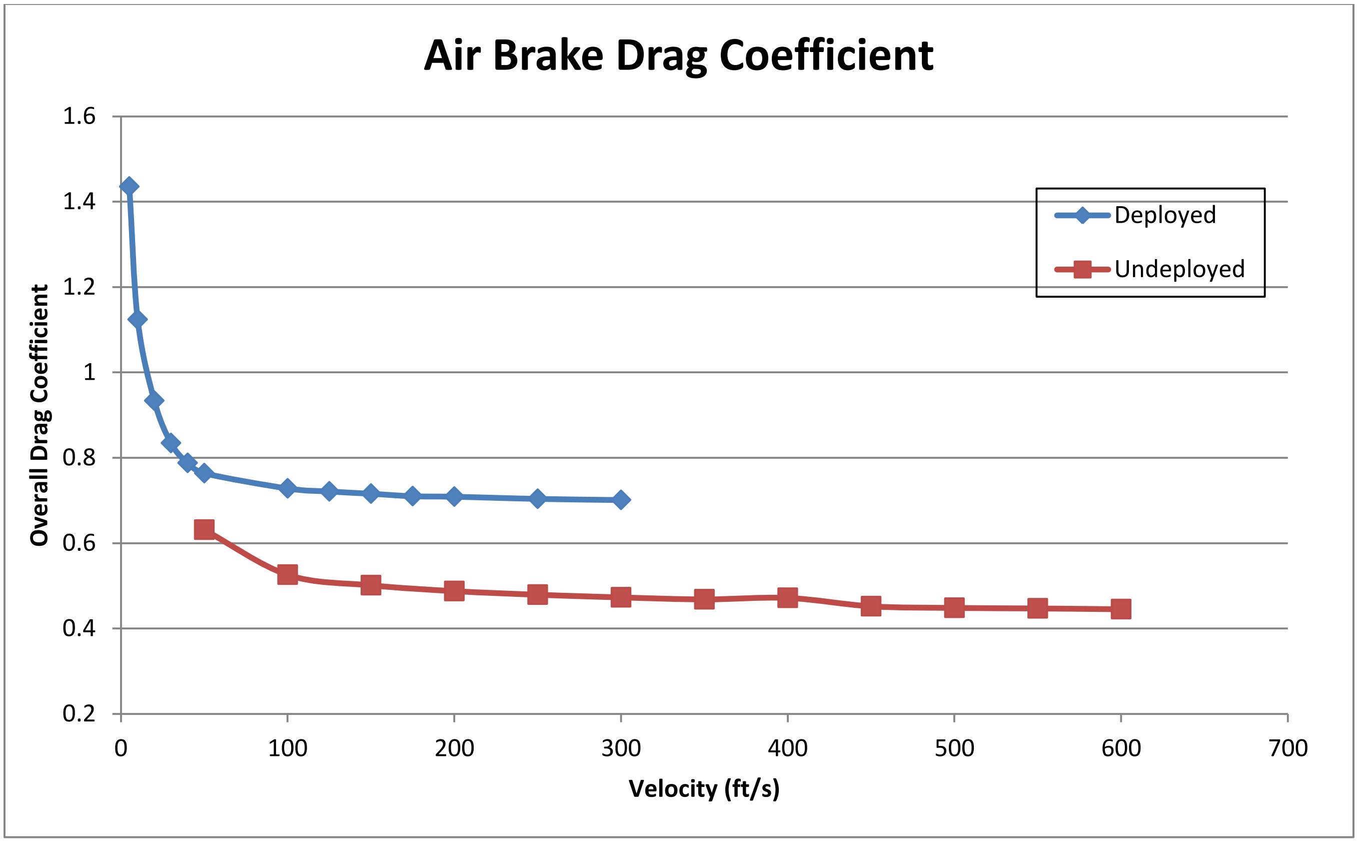

Figure 15: Air Drag Coefficient

These drag curves were integrated into the flight characteristic equations used to calculate when the brake would deploy. The velocity of the airflow at 150 ft/s around the rocket with the air brake undeployed and deployed can be seen in Fig. 16 and Fig. 17 respectively. There is much more disturbance in the airflow with the brake deployed than undeployed. This is evidenced by the larger velocity gradients in the deployed figure compared to the undeployed figure. This shows the effect of the brake increasing the pressure drag and thus the overall drag coefficient.

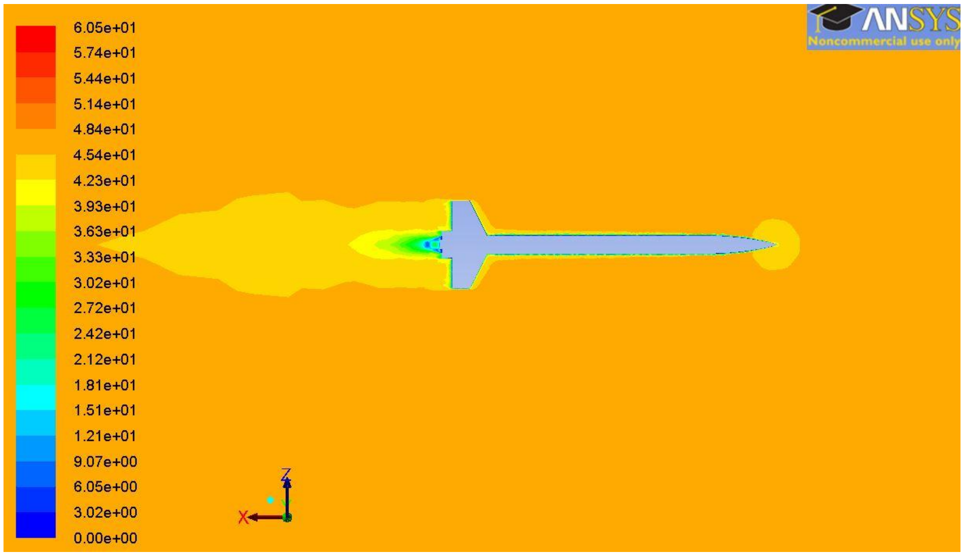

Figure 16: Air Velocity Plot with Brake Undeployed

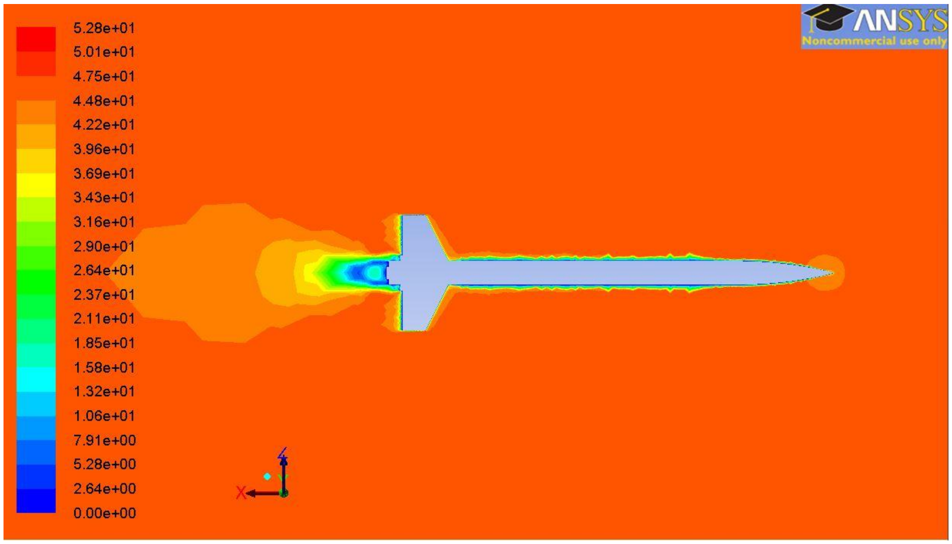

Figure 17: Air Velocity Plot with Brake Deployed

Flight Characteristics

Due to the inclusion of an air brake, RockSim9 was not capable of simulating the flight of the rocket. In order to accommodate the air brake and a variable drag coefficient, the velocity and altitude of the rocket had to be determined mathematically. This was done by solving ordinary differential equations using Mathcad.

There are three governing equations for each of the three phases: boost, coast and brake phase. The form of these three equations is shown in Equation 1.

$$m * a = -m * g - \left(\frac{1}{2}\right) \rho * A * c_d \qquad \textit{(Eq'n 1)}$$

Variable mass due to propellant usage is incorporated, as well as variable drag coefficients for each phase. Of course, the boost phase has an added thrust force.

The flight profile was created by integrating the differential equations—once for velocity and again for altitude. Figure 18 shows the overall velocity and altitude of the rocket at 6 lbs.

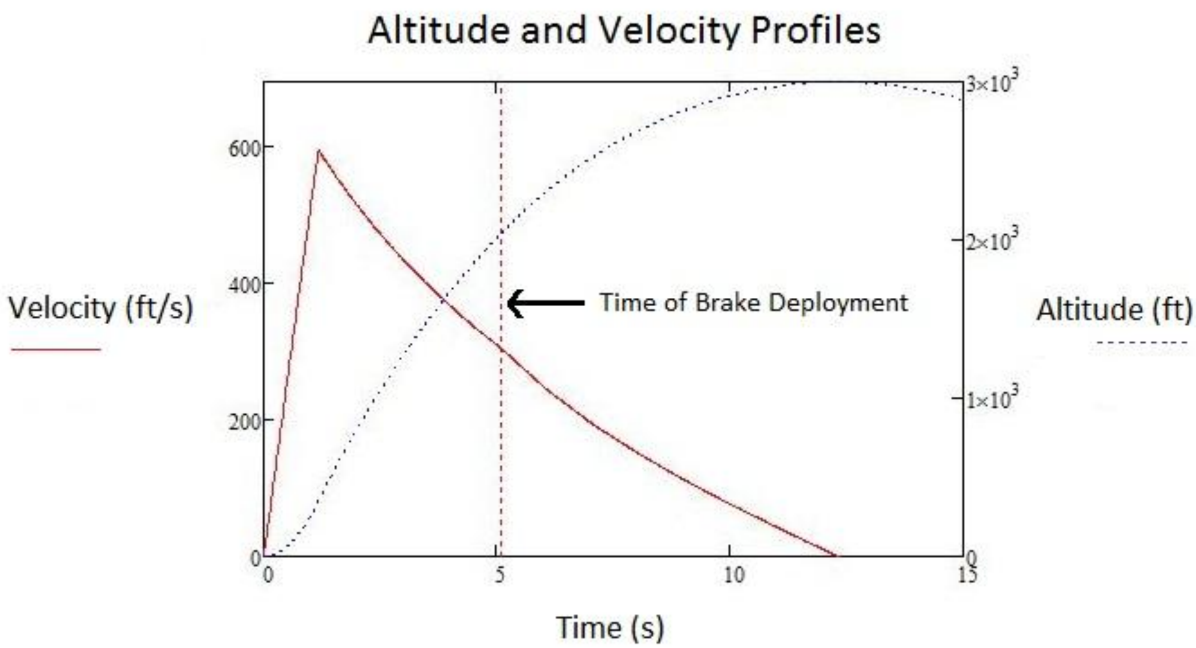

Figure 18: Velocity and altitude profile of the rocket with respect to time.

In Fig. 18, the physical characteristics of the flight can be seen. The spike in the velocity represents the boost phase. At brake deployment, the velocity decreases at a faster rate; this is expected with an increase in the drag coefficient. The altitude also increases less quickly, but is not as noticeable. Apogee is reached when velocity equals zero, and where the altitude curve turns negative.

These equations determine the time when the air brake needs to deploy in order to reach the desired apogee. This is done by taking velocity and altitude data during flight using the Arduino controller and Stratolloger. The controller is programmed to compare a data table consisting of the altitude/velocity ratio of the ideal flight with alternate solutions. By using a ratio of the velocity with altitude, the necessity of a specific time variable is removed; the Arduino will trigger deployment based on the velocity at a certain height, rather than at a certain time. This removes the possibility of error due to the altimeter misinterpreting 'time zero'. The alternate solutions are essentially the ideal velocity and altitude with varying error, which will be calculated and programmed before launch based on conditions of that day. The Arduino will compare the *actual* velocity and altitude (using the altimeter) to the *ideal* velocity and altitude during flight, and determine the alternate solution based on the difference between the two (the error). The full Mathcad worksheet may be viewed in the Appendix.

Table 4 shows the calculated values for the different characteristics of the anticipated flight.

Table 4: Flight Characteristics

Flight Characteristics	
Deployment Time	5.157 s
Time to Apogee	12.325 s
Max Velocity	593.1 ft/s
Velocity at Brake Deployment	300.3 ft/s
Altitude at Brake Deployment	2059.4 ft
Percentage of Flight Time Remaining After Deployment	58.16 %
Altitude Remaining After Deployment	940.6 ft

Safety Plan

The rocket and its components were tested on the ground and before installation to test for function and to prevent catastrophic failure of the rocket during flight. This included wind tunnel testing of the brake and testing the electronic parachute deployment. The epoxy used in the fabrication of the rocket is a two-part epoxy, which provides enough strength to protect against rocket failure.

To ensure safe launch of our rocket, a launch check-off list will be followed. All safety precautions associated with the launch site will be followed. A pre-flight inspection by the range safety officer will also guard against failure of the rocket which could result in unsafe situations.

A list of the most likely failure modes of the rocket was created to help determine the weakest points on the rocket in terms of performance and safety. Each failure mode was examined to find what was likely to cause failure and what could be done to prevent failure. The results of that analysis can be seen in Table 5.

Table 5: Failure Modes

Failure Mode	Effects	Possible Cause	Mitigation
Brake Deployment Failure	Target apogee is overshot	Weak Solenoid; not enough power to switch solenoid; altimeter doesn't signal	Use new lithium batteries on launch day; test deployment system pre-launch; successful completion of hundreds of ground tests
Failure of high stress components	Flight failure/Rocket crashes	Large stresses resulting from rapid acceleration; impact on descent	Use of high strength materials in high stress components; use of high strength epoxy
Parachute is prematurely deployed	Flight is shortened/ apogee not reached	Air pressure differences between the external airflow and internal body tube	Two shear pins used to keep rocket together
Parachute lines tangle	Rocket crashes	Improperly packed parachute; lines snag on airframe; wind twists line	Follow packing procedure; inspect the way parachute is packed
Rocket fails to separate	Parachute does not deploy	Not enough gunpowder used; wiring prematurely disconnects	Two ejection canister used with proper wadding; tight connectors used in the wiring; ground testing
Parachute detaches from rocket	Rocket crashes	Harness improperly attached; mounting points not strong enough to withstand loads	Inspect mounting before flight; test mounting points to ensure strength
Charges fail to ignite	Parachute does not deploy	Damp black powder; electronics fail	Store black powder in a dry container; Use well-tested altimeter
Burned parachute	Rocket crashes	Parachute not properly insulated	Insulate the parachute from the charges with wadding

Test Flight

A test flight for the rocket is expected to be done the week of April 15th. The data collected will be used to verify the accuracy of the flight characteristic equations. The test flight will also prove if the rocket is stable and none of the components fail. Ground testing of the components has been successful and the results encouraging. Components will continue to be tested to ensure their reliability.

Launch Check-off List

A launch check-off list will be made which will consist of the following items:

- enter launch conditions into program,
- inspect hardware and parachute components,
- pack flame resistant wadding and parachute,
- ensure brake is in undeployed position,
- install blast cap,
- install payload section,
- install motor and retention ring,
- install igniter,
- place rocket on the launch rail,
- perform visual inspection,
- launch

A formal checklist with the person responsible for performing those tasks will be made once the rocket is assembled.

Schedule

At this point, the final assembly of the rocket needs to be completed, as well as the testing. Lastly, the finishing and painting of the rocket body must be done. Figure 19 contains the planned schedule from April 12th to the competition.

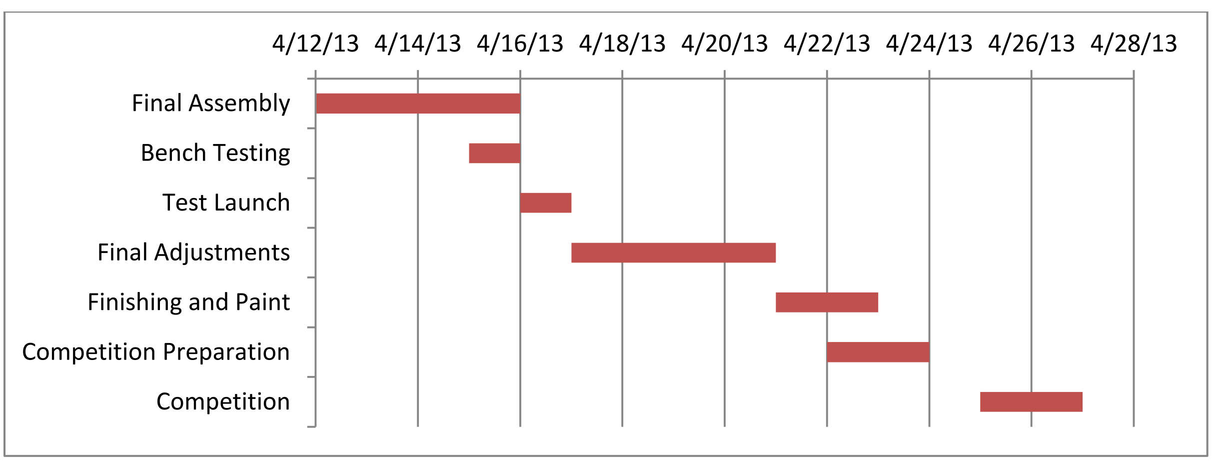

Figure 19: Project Schedule

Budget

Table 6 shows the budget shows the design teams budget for the competition.

Table 6: Rocket Design Expenditures

Rocket Design Budget			
Item	Quantity	Cost/Quant.	Cost
Motor	4	$36.25	$145.00
Body Tube (Fiberglass)	3	$97.95	$293.85
Nose Cone (Polypropylene)	1	$19.95	$19.95
Centering Ring	5	$6.39	$31.95
Motor Mount Tube (Fiberglass)	1	$28.00	$28.00
Fins	4	$19.15	$76.60
Electronics Bay	1	$37.95	$37.95
Parachute	1	$73.95	$73.95
Miscellaneous Hardware	1	$217.67	$217.67
Brake Assembly	1	$1,589.00	$1,589.00
Registration Fee	1	$375.00	$375.00
Car Rental for Competition	1	$72.00	$72.00
Travel Mileage (est.)	900	$0.30	$270.00
Hotel (2 nights)	4	$101.00	$404.00
Altimeter	1	$90.00	$90.00
Miscellaneous Electronics	1	$127.52	$127.52
Epoxy	6	$5.00	$30.00
Micro-controller	1	$40.00	$40.00
Linear Actuator	1	$80.00	$80.00
RockSim (software)	1	$149.35	$149.35
		Total	$4,151.79

Conclusion

The 2013 RocketDogs team has finished the rocket design and is scheduled to complete remaining tasks to perform at competition on April 27th. A one-time air brake deployment system is used to control the rocket's apogee in flight. The programming, along with in-flight data, will provide an accurate deployment time to reach the target apogee. Rigorous testing and analysis has been performed to ensure structural integrity and compliance with safety regulations. The team is confident in its design to successfully compete in the WSGC 2013 Regional Rocket Design Competition.

Appendix I: Air Brake Deployment Calculations

Parameters:

$m_R := 6.0\,lbm$	Rocket mass (less motor)
$A_{cr} := .00761043\,m^2$	Surface Area
$A_{crb} := .00909157\,m^2$	Reference area with brake deployed
$Thrust := 540\,N$	Average Thrust
$I := 634.6\,N \cdot s$	Motor Impulse
$t_1 := \frac{I}{Thrust} = 1.175\,s$	Motor Burn Time
$m_E := 598.2\,gm$	Engine Mass
$m_P := 328.8\,gm = 0.329\,kg$	Propellant Mass
$m_B(t) := m_R + m_E - \frac{m_P}{t_1} \cdot t$	Boost Mass
$m_C := m_R + m_E - m_P$	Coast Mass
$g := 9.80665\frac{m}{s^2}$	Gravity
$Dia := 3.1\,in$	Rocket Diameter
$\rho := 1.225\frac{kg}{m^3}$	Density of Air

Dimensionless Parameters (for ODE solvers)

$Thrust2 := \frac{Thrust}{lbf}$ $\quad A_{cr2} := \frac{A_{cr}}{ft^2}$ $\quad A_{crb2} := \frac{A_{crb}}{ft^2} = 0.098$ $\quad \rho 2 := \frac{\rho}{\frac{slug}{ft^3}}$

$t_{12} := \frac{t_1}{s} = 1.175$ $\quad m_{B2}(t) := \frac{m_B(t \cdot s)}{slug}$ $\quad m_{C2} := \frac{m_C}{slug}$

Differential Equations, RHS

$$Dpa(t, VPA) := -32.174 - \frac{\left[VPA \cdot .424 \cdot \left(1 + 12.874 \cdot VPA^{.15} + VPA\right)\right] \cdot 0.5 \cdot \rho 2 \cdot A_{cr2}}{m_{B2}(t)} + \frac{Thrust2}{m_{B2}(t)}$$

$$Dca(t, VCA) := -32.174 - \frac{\left[VCA \cdot .424 \cdot \left(1 + 12.874 \cdot VCA^{.15} + VCA\right)\right] \cdot 0.5 \cdot \rho 2 \cdot A_{cr2}}{m_{C2}}$$

$$Dba(t, VBA) := -32.174 - \mathrm{sign}(VBA) \cdot \frac{\left[0.666 \cdot \left[(|VBA|)^2 + 4.373 \cdot (|VBA|)^{1.18}\right]\right] \cdot 0.5 \cdot \rho 2 \cdot A_{crb2}}{m_{C2}}$$

Solving ODE's

getVtot(tend, tb) :=

```
N ← 1000
Spa ← AdamsBDF(0.001, 0, t_12, N, Dpa)
Tpa ← Spa^<0>
Ypa ← Spa^<1>
Vinit ← Ypa_N
tstart ← Tpa_N
Sca ← AdamsBDF(Vinit, tstart, tb, N, Dca)
Tca ← Sca^<0>
Yca ← Sca^<1>
for i ∈ 0 .. N − 1
    Tca2_i ← Tca_i+1
    Yca2_i ← Yca_i+1
Ttot ← stack(Tpa, Tca2)
Ytot ← stack(Ypa, Yca2)
Vbrake ← Yca2_N−1
Sba ← AdamsBDF(Vbrake, tb, tend, N, Dba)
Tba ← Sba^<0>
Yba ← Sba^<1>
for i ∈ 0 .. N − 1
    Tba2_i ← Tba_i+1
    Yba2_i ← Yba_i+1
Ttotal ← stack(Ttot, Tba2)
Ytotal ← stack(Ytot, Yba2)
augment(Ttotal, Ytotal)
```

Organizing Columns of Results

$Stot(tend, tb) := getVtot(tend, tb)$

$Ttot(tend, tb) := Stot(tend, tb)^{\langle 0 \rangle}$

$Ytot(tend, tb) := Stot(tend, tb)^{\langle 1 \rangle}$

Velocity

$V_{total}(t, tend, tb) := (linterp(Ttot(tend, tb), Ytot(tend, tb), t))$

Altitude

$$A_{total}(tc, tend, tb) := \int_0^{tc} V_{total}(t, tend, tb)\, dt$$

Solve Block

Guesses: $tend := 15$

$tb := 5$

$tc := 12$

Given

$A_{total}(tc, tend, tb) = 3000$

$V_{total}(tc, tend, tb) = 0$

$$\begin{pmatrix} tb \\ tc \end{pmatrix} := Find(tb, tc)$$

$tb = 5.157$ Time of brake deployment

$tc = 12.325$ Time to apogee

Results

$$tb \cdot s = 5.157\,s$$

Deployment time

$$tc \cdot s = 12.325\,s$$

Time to apogee

$$1 - \frac{tb}{tc} = 58.158 \cdot \%$$

% flight to apogee remaining after deployment

$$1 - \frac{A_{total}(tb, tend, tb)}{3000} = 31.354 \cdot \%$$

% altitude remaining after deployment

$$V_{total}(tb, tend, tb) \cdot \frac{ft}{s} = 300.3 \cdot \frac{ft}{s}$$

Velocity at brake deployment

$$A_{total}(tb, tend, tb) \cdot ft = 2059.4 \cdot ft$$

Altitude at brake deployment

$$\left(3000 - A_{total}(tb, tend, tb)\right) \cdot ft = 940.6 \cdot ft$$

Altitude remaining to apogee

$$V_{total}\left(t_{12}, tend, tb\right) \cdot \frac{ft}{s} = 593.1 \cdot \frac{ft}{s}$$

Max Velocity

$$\frac{V_{total}\left(t_{12}, tend, tb\right) \cdot ft}{343m} = 0.527$$

Max Mach number

$$\frac{V_{total}(tb, tend, tb) \cdot ft}{343 \cdot m} = 0.267$$

Mach number at deployment