Delta VT

Virginia Polytechnic Institute and State University

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Summary of Design

The 2015-2016 Midwest High-Power Rocketry Competition is a collegiate rocketry design challenge being hosted in North Branch, MN. As per competition guidelines the rocket will fly to an altitude of 5000 feet and accrue points in the process. A subsequent launch of the same rocket with an electronically activated drag system will bring the rocket to 75% of the initial flight's altitude. To be considered successful, the rocket must also implement ejection charges in a dual-deploy recovery system for the safe retrieval of the rocket after each launch. This is a challenging endeavor and will require the team to design, construct and conduct a multitude of test flights with no external assistance.

The Delta VT team is part of the inVenTs community, a living-learning community at Virginia Tech devoted to improving STEM education by fostering 1st year students and providing them with a community dedicated to success. It is comprised of four integral communities. Galileo and Hypatia cater to students in Engineering, and Curie and DaVinci support students in the Life, Physical and Quantitative Sciences. The communities provide tutoring, assist in professional development, conduct outreach events, host technical skills workshops, encourage social activities, and assist with service learning opportunities for members. For this competition, the team will be working out of Studio 1, an in-dorm workshop, in which members have access to a variety of handheld power tools, as well as 3D printers, laser cutters, CNC routers, soldering stations, and training on how to use all of the equipment.

The 15-member multidisciplinary team is composed of primarily first-year students who will be representative of the communities present within inVenTs. Dr. Kevin Shinpaugh, an Aerospace Engineering professor and avid rocketry enthusiast himself, has agreed to be the faculty sponsor. Although the team is relatively new in the field of high-power rocketry, sub-team leads are working closely with the Virginia Tech Rocketry Club and the New River Valley Rocketry Association, the local Tripoli branch, for assistance in ensuring the safety of the design and construction of the rocket.

The Delta VT team had already designed a 2.200 meter rocket with a 98 mm outer diameter body tube to house all of the required mechanisms for the active drag system **Figure 1,** composed of three sections based on the each function. The upper section containing the two parachutes of the recovery system and nose cone, a midsection that could house the electronics and drag system, and the lower section containing the motor and the fins.

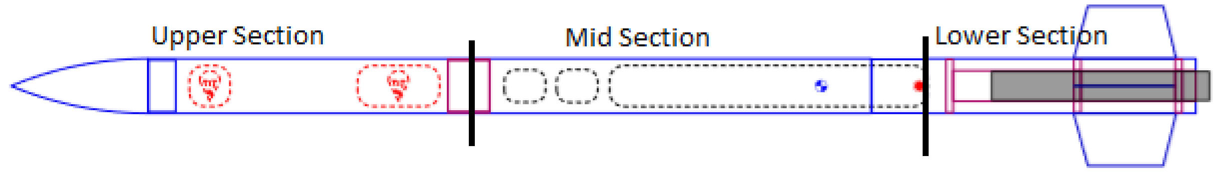

Figure 1: Original diagram of rocket with drag system retracted, black lines indicate section location.

However, after noticing flaws with the original design the team was forced to go back to the drawing board and build a new rocket **Figure 2**. The rocket design is now broken up into three sections and some of the components have been shifted. The airframe itself houses over 6 kg of hardware, with 2.5 kg dedicated to the drag system. The drag system consists of four panels that extend from the body of the rocket to act like an airbrake used in the aircraft industry.

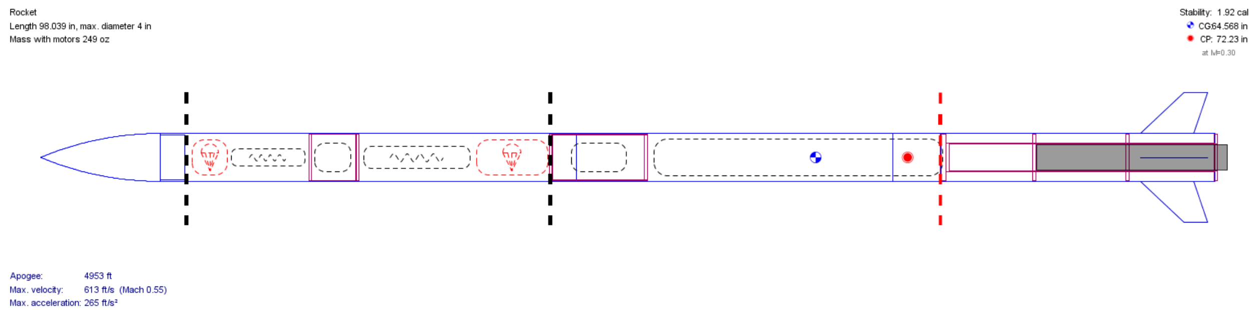

Figure 2: Diagram of new design of worked with drag system retracted, black dotted lines indicate detachable separation sections, red dotted line indicate division of drag system and motor.

Nose Cone

Figure 3: Nose Cone.

The nose cone has been designed with an ogive shape, as this shape resulted in the highest apogee compared with other common designs. The nose cone also has an extra 0.05 m of shoulder that inserts into the body tube to allow for a tight and secure fit. The nose cone has a thickness of 0.002m throughout. Refer to the **Figure 3**.

Upper Section

The upper section of the rocket ecopasses an ebay along with the recovery system. This upper body is made of Blue Tube due to its material properties, including high strength and durability. The overall length of the body tube is 0.889m, with an outer diameter of 0.102 m and a thickness of 0.125 cm. With the nose cone, the complete length of the upper section is 1.143m. Due to the high altitude that will achieve, two parachutes will still be used. The drogue chute will at apogee, followed by the main chute at a lower altitude. Once the main chute has been deployed, it will reduce the speed of the rocket until it is below the requisite 7.315 m/s. Both the drogue chute and the main chute will be made out of ripstop nylon, with a diameter of 0.417 m and 1.914 m respectively.

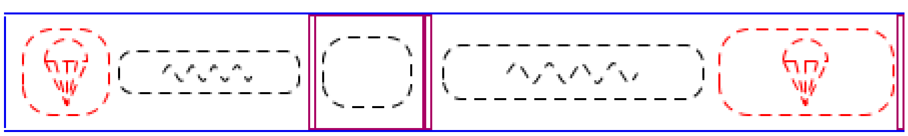

Figure 4: The upper section of the rocket.

Midsection

The midsection, also made out of Blue Tube, measures 0.762m long and contains the electronics necessary to control the rocket and drag system. The midsection was designed to be relatively easy to construct and, if necessary, repair. The electronics and drag system are located on either ends of the section, which are easily accessible locations. During flight, the mid section is connected to the rest of the rocket using nylon shear screws, which contribute negligibly to air resistance. When the rocket is stationary, the screws can easily be removed to allow access to the components.

The dotted rectangle is representative of the electronic equipment. The electronics add a total of 0.350 kg to the rocket. While all of the components of the drag system add approximately 3.150 kg to the rocket strongly changing the center of gravity. The location of the drag system was specifically chosen to be as close to the center of pressure as possible to ensure that the stability remains almost constant when it is deployed.

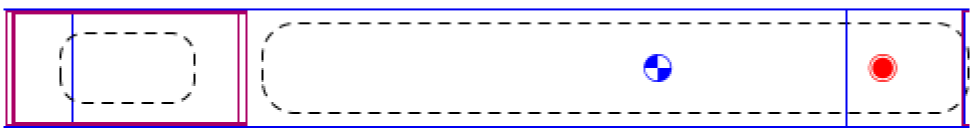

Figure 5: The midsection of rocket with drag system.

Lower Section

The body tube is built with Blue Tube, with a length of 0.584m, and wall thickness of 0.001m. The motor is held in a motor casing 45 cm long, with 2 centering rings holding the casing in place. The centering rings are made of 1.5 cm plywood. A bulkhead is placed at the top of the motor casing to prevent damage to the upper components. The motor protrudes out of the back end of the rocket 2.0 cm to make for ease of removal and reloading.

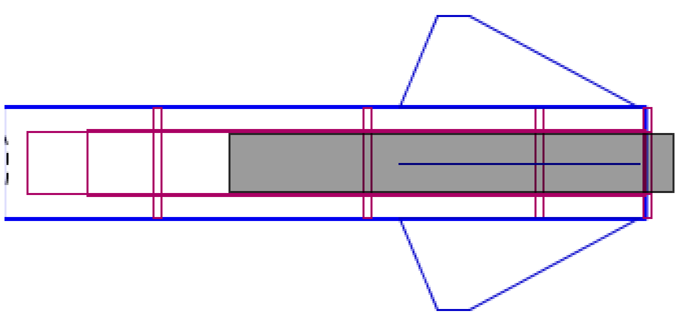

Figure 6: The lower section with fins

Comprehensive Drag System Overview

The drag system has undergone a series of changes since the preliminary design report, aimed to eliminate areas of concern with the previous design. The main concern with the previous design was the way in which the flaps opened. This design had the flaps hinged at the bottom, with the leading edge upwind, as seen in the **Figure 7** below. This configuration was initially favored because it would allow the flaps to be controlled by cables in tension. This would be lighter than the solid members that would be required of a system with hinges at the top of the flaps, that pushes the flaps out to deploy them. This previous design was powered by an electric linear actuator, powered by onboard batteries. When fully extended, the actuator would lower the connection point of the cables, allowing the flaps to deploy. By retracting, the system would likewise withdraw the flaps, pulling them flush with the body tubing.

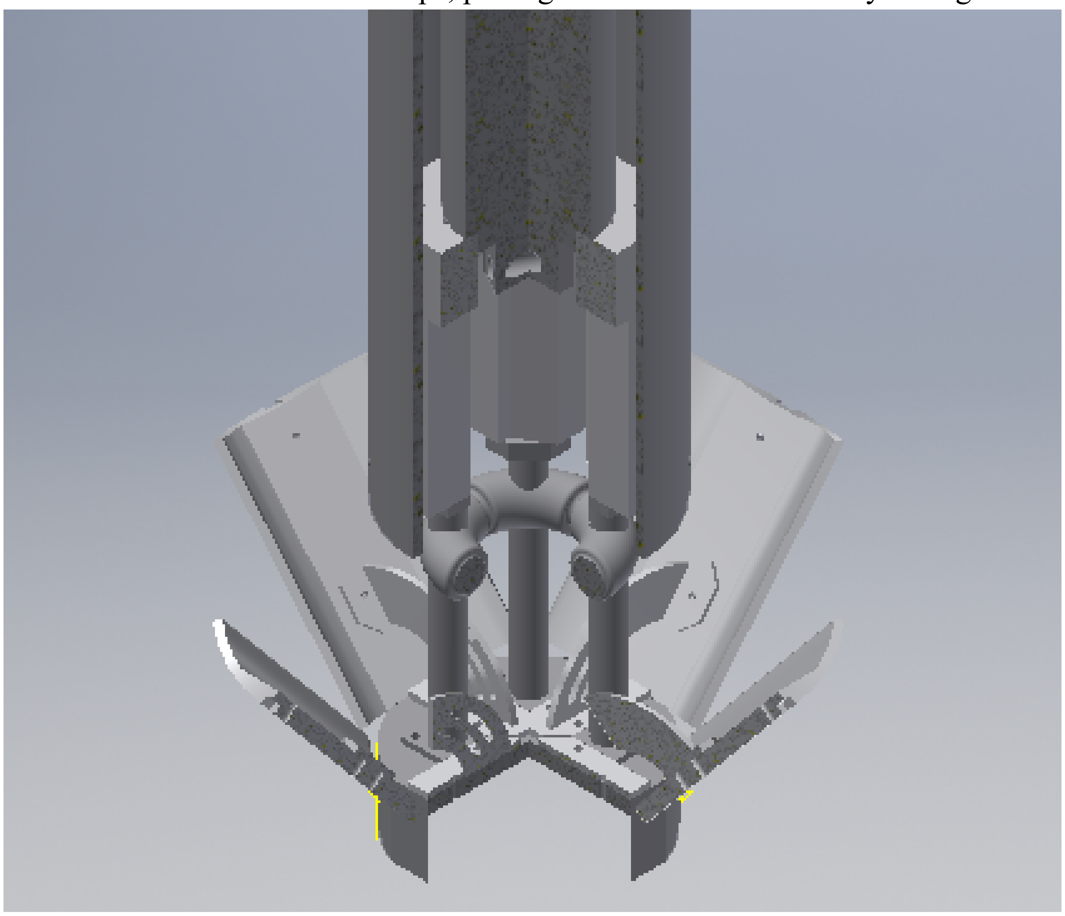

Figure 7: Previous Drag System Design.

After receiving a strong recommendation from our faculty advisor Dr. Shinpaugh to have the flaps hinge at the top, to resemble a more traditional airbrake, we began the process of redesigning our drag system from the ground up. Our new design addresses many of the weaknesses present in the previous design.

Figure 8: Current Drag System Overview.

The first major change is that the electric linear actuator has been replaced with a pneumatic air cylinder and an air tank. This change was made in order to increase the speed of deployment, as well as eliminate the design challenges of providing the linear actuator an appropriate power supply from onboard batteries. The dual-stroke air cylinder used in this design has a 2-inch bore, 3 inch stroke and a maximum operating pressure of 250 psi. In practice, we plan to pressurize the cylinder to 100 psi, producing approximately 315 pounds force to deploy the drag flaps. This has a significant safety factor over what we expect the force needed to deploy the flaps will be. The air tank we will be using is a high-pressure paintball tank, with an internal volume of 13 cubic inches and a maximum operating pressure of 3000 psi. With the appropriate regulators to reduce pressure to 100 psi, this tank should be sufficient to power the drag system for at least 10 flights on a single tank of air. To regulate airflow, a solenoid will be used.

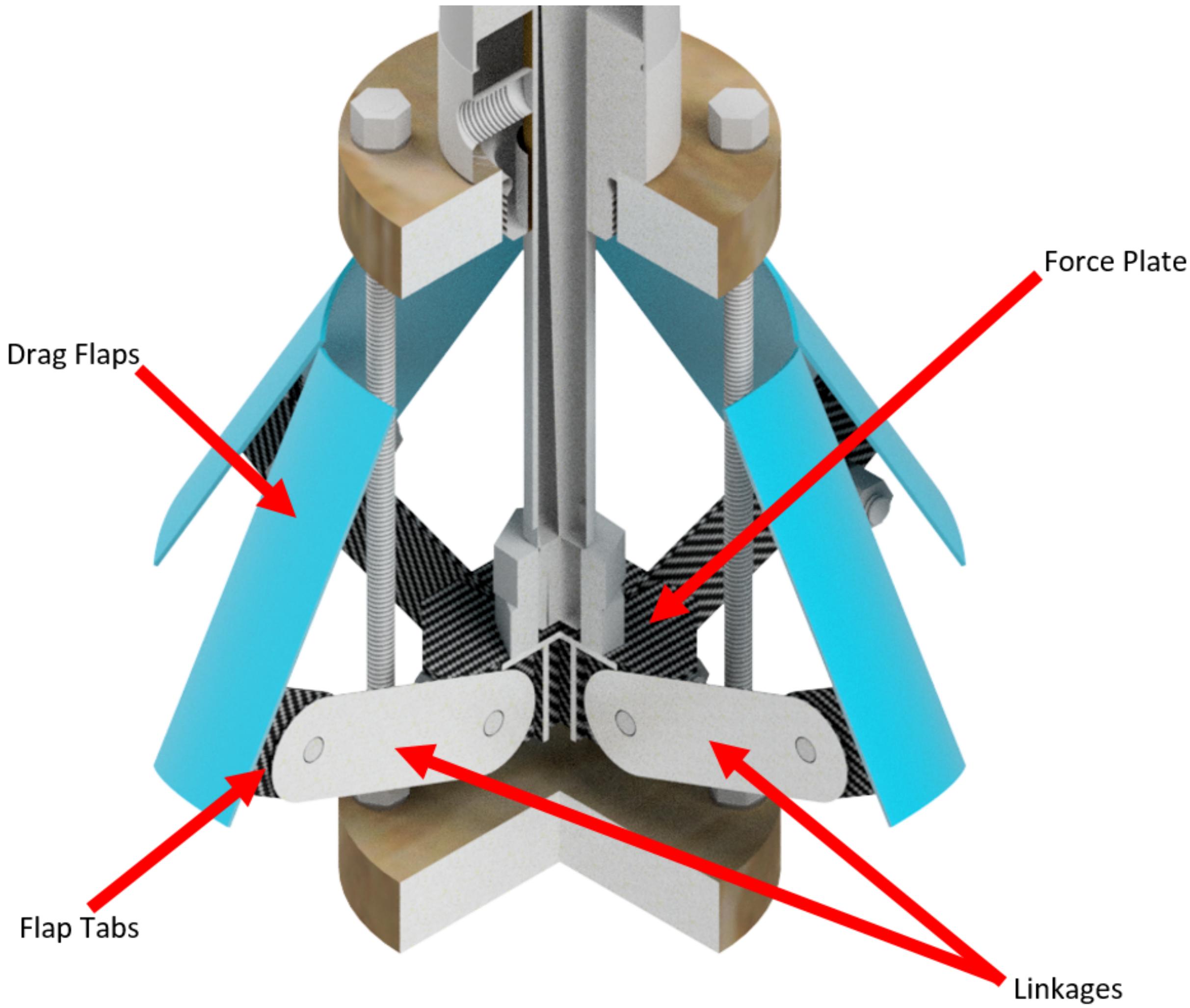

Figure 9: Drag System Section View Diagram.

The mechanics of the drag flaps have also been entirely reworked. As mentioned above, the flaps now hinge at the top and are pushed out by solid members. Force is transferred from the piston rod to the drag system through the force plate, as seen in **Figure 9** above. From here, force is transferred to linkages between the force plate and the flap tabs. These tabs connect to the base of the flaps, and drive their motion. The flaps are attached to the rocket body using Kevlar live hinges, which allow for a wide range of motion while also being extremely lightweight and strong compared to other hinging methods.

Drag Calculations

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421 milliseconds to do this calculation, margin of 2043 milliseconds
vb = 230 m/s                yb = 460 meters            yf = 1750 meters
target = 1312 meters        tmax = 10.1 seconds
ya = 1312 meters            tc = 2.46 seconds
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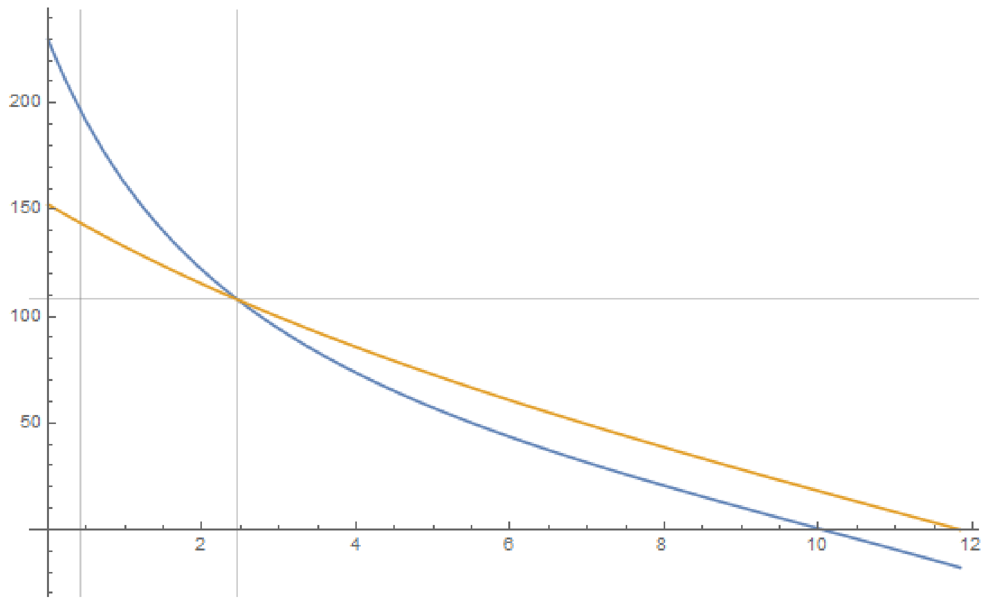

A Mathematica plot of a simulated velocity curve given some expected initial conditions.

Figure 10:

This graph consists of two piecewise functions that model the velocity of the rocket over time. The blue curve represents the velocity over time from flaps deployment to retraction. Finally, the orange curve represents the velocity over time from flap retraction to apogee. The time which the blue curve transitions into the orange is our t_c time. This t_c time is an adjustable time at which the flaps retract.

The t_c is a free variable which we have defined to be the upper limit of the integral of the blue curve and the lower limit of the integral of the orange curve. Given initial conditions about the flight of the vehicle at burnout (these initial conditions are burnout height, burnout velocity, and height of the first flight), the vehicle can predict approximately how high it would travel for given t_c values. Unfortunately due to computational constraints, we cannot work backwards: it has proven computationally difficult, maybe impossible, to input a desired apogee and get a specific t_c value. Our solution is to use a binary search routine - the vehicle makes educated guesses as to what t_c value will bring it to the desired height. With each guess, it eliminates half of the possible range of values and guesses closer to the idea value with each subsequent guess.

This allows what would otherwise be a very demanding calculation to be completed in less than a second. The result is that the computer calculates a value t_c which is the time in seconds for which the drag flaps should remain open following burnout. All of these calculations are done immediately following motor burnout and are done as quickly and accurately as possible.

Construction of Rocket

Body Tubing

Photo 1: Cutting the body tubes to size.

The rocket body is made of reinforced cardboard, otherwise known as Blue Tube. Three four foot pieces of four inch diameter tubing were used to cut the different sections. As seen above, a simple jig was used to hold the tubing in place while it was being cut down to size. Both safety glasses and face masks were used due to dust that the tubing emits.

Fins

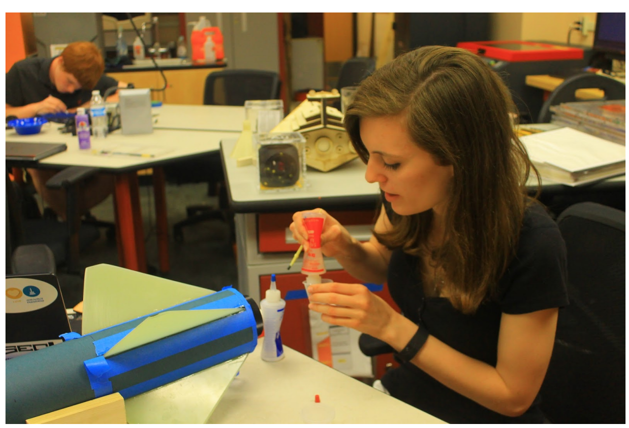

Photo 2: Using epoxy resin to bind the fins to the outer casing.

The initial fin design was a set of four back-swept trapezoidal fins positioned 90° apart from each other. Throughout the build phase of the rocket, as weight estimates were updated to reflect actual values, the fin design shifted to a more forward-swept design. To achieve a the forward-swept design, the fins were optimized in *OpenRocket* to maintain an overall stability between 1.6 and 2.1 calipers with the new design constraints.

The fins are constructed from G-10 fiberglass that was cut to size using the bandsaw located in the studio space the team has worked out of. Once cut to size, the fins were mounted to the inner motor casing of the rocket with 2-ton epoxy resin at the predetermined 90° apart via using a set of laser cut placement jigs. Once the epoxy had set on the inner motor casing, the outer casing was then slid over the fins. The fins were then bonded to the outer casing using 2-ton epoxy resin. Once the resin had set on the outer casing, it was then filleted to create a more aerodynamic structure.

Drag Flaps

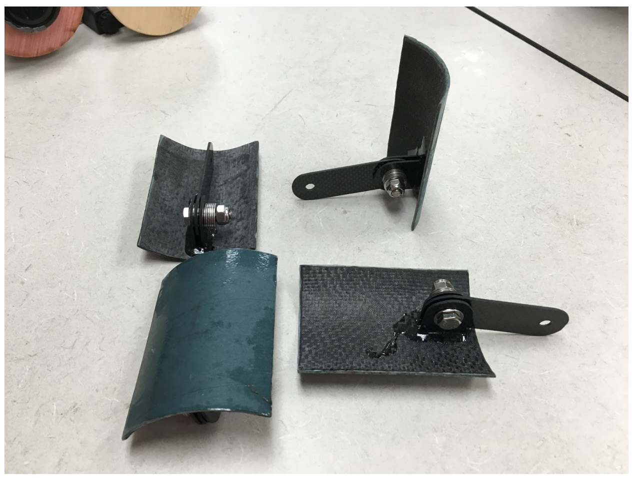

Photo 3: The four flaps that are used to produce drag mid flight.

The drag flaps that we used were constructed out of the blue tube material. As seen in the photo above, they have also been reinforced with four layers of carbon fiber to improve rigidity and to reduce flutter mid flight. The carbon fiber layup process required the use of the following materials: epoxy resin, breather cloth, release cloth, a vacuum bag, four square feet of hexagonal mesh carbon fiber, and a jig.

All of this was used not to replace flaps, but to create a stiffer version of the materials we already had. The setup process took an hour which included cutting down all of the consumable material. According to qualitative testing, the original flaps had over 2 cm of compliance. Post layup, the carbon fiber reinforced panels have less than .25 cm of compliance with a larger force applied.

There are tabs that are placed on the panels perpendicular to the inside face, which are used to interface with the air piston on the inside of the rocket. Carbon fiber was also used to help save weight of the design, while still being able to use larger pieces large enough pieces to ensure the yield strength of the materials is higher than the applied forces during the flight. These were also attached with a custom jig, placing both tabs orthogonal to the very center on the bottom of the panel.

Testing

Testing of the design has consisted of computer (CAD) models as well as incremental testing of the individual pieces. The electronics including the dual deployment altimeter and arduino that actuates the drag system have been put under experimental loads to test their actuation. Unfortunately, due to material limitations and time restrictions of the studio that our team works in, we were unable to make the April 23 deadline for testing the rocket. This April 23 deadline was a result of our launch site in the immediate vicinity.

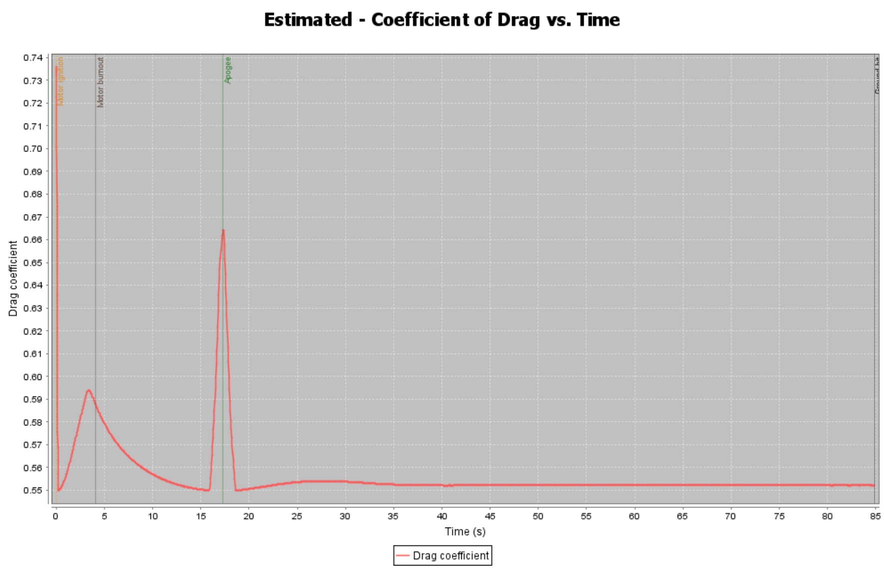

Figure 11: Estimated coefficient of drag vs. time with drag system disabled

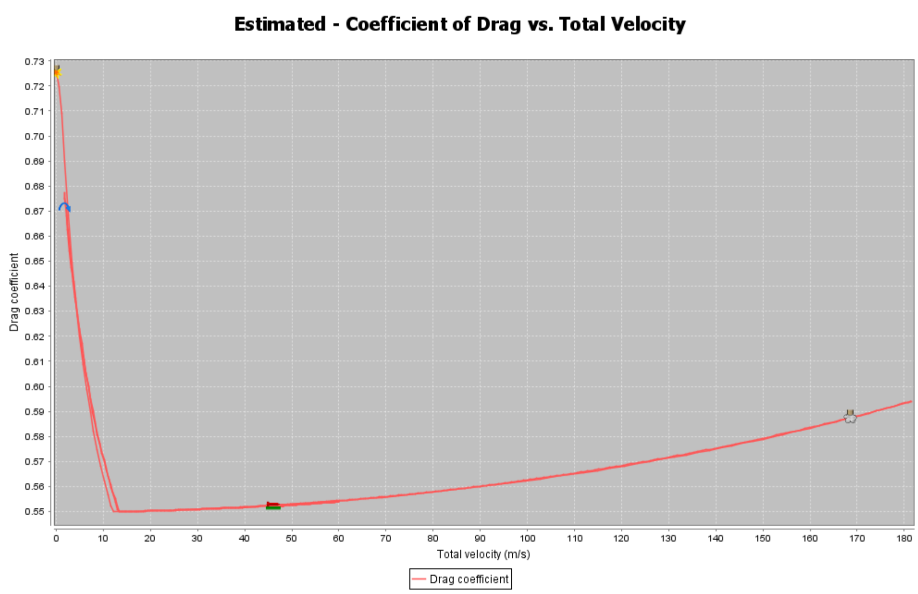

Figure 12: Estimated coefficient of drag vs. total velocity with drag system disabled

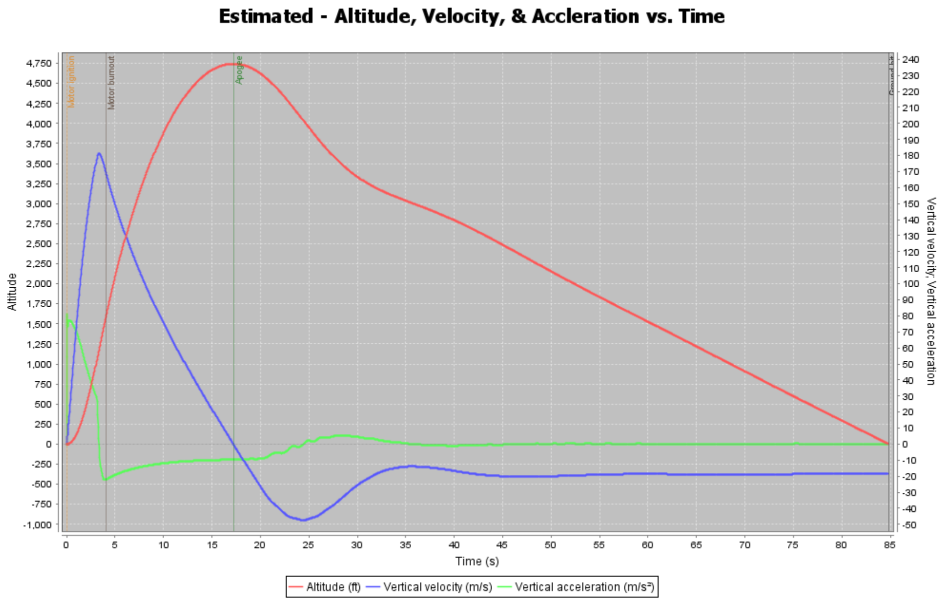

Figure 13: Estimated altitude, velocity, & acceleration vs. time with drag system disabled

Budget

Revised budget with projected spendings with a total budget of $6,850 USD

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Description	**Coments**	**Category**	**Amount ($) USD**
Materials		Construction	$2,150
Cars /Gas	Assuming 3 cars	Travel	$822
Tolls	3 cars, estimated at $40	Travel	$120
Food	10 people, 5 meals about $10 per meal	Travel	$500
Hotels	From May 13th-18th	Travel	$1200
Hotels	Return Trip	Travel	$605
Extra Motor	Test Motors/ Extra Motors if needed	Construction	$150
Competition	Registration Fees	Competition Cost	$400
Total	Total cost of competing		$5947

Table 1: Working budget for 2015-2016 team.

The Virginia Space Grant Consortium has provided the funding for our team to compete. The projected spending has been very close to the actual spending, with minor changes in the budget distribution. One of the major ways we saved money was with the reduction of one car that needs to travel to competition. With an estimated $400 for gas for each car, that was a lot of money saved. In total, we have spent $5947 so far leaving $903 for unforeseen expenses on the road and also leaving funding for the start up of next year's team.