inVenTs High-Power Rocketry

Virginia Polytechnic Institute
and State University

Student Team Lead Andrew Farley, afarley0@vt.edu, (540) 588-8473

Faculty Advisor Kevin Shinpaugh, kashin@vt.edu, (540) 231-1246

Team Mentors Wade Foster, John Gilleran, Genevieve Gural, Ziomara Madero-Vargas, Francisco Ramos Mora, Caitlyn Stone

Team Members Payleigh Behan, Aaron Brown, Nicolas Bulzoni Jonathan Dronfield, Meghan Eck, Nicole Gouhin, Jeremy Gross Deep Jain, Justin Metzger, Kyle Sakmyster, Sara Schlemmer Guanang Su

Friday, May 5, 2017

Table of Contents

Executive Summary

The 2016-2017 Space Grant Midwest High-Power Rocketry Competition requires teams to design, construct, and launch a single-stage high-power rocket with the intention of reaching the same apogee with two different motors. Our rocket will be using an active drag system comprised of four horizontal flaps extending from the rocket. The rocket has an overall length of 85”, and a total weight of 13.75 lbs without any motors. The rocket is expected to reach an apogee of 3431 feet with the J motor, and an apogee of 3939 feet with the K motor alone. With the addition of drag flaps used after burnout on the J motor, the true apogee of the rocket is estimated to be within fifty feet of the J motor’s apogee. The rocket has two electrical bays in the rocket: an upper one for the parachute and drogue chute and a lower for data acquisition and deployment of the drag system. The lower drag system is controlled by an Arduino Uno, and has an on-board array of avionic sensors such as an Altimeter and Accelerometer. All data collected through flight will be stored onto an micro-SD card. The upper E-Bay deploys the parachutes by two dual deploy stratologgers. Due to poor weather conditions and other complications, our team was unable to complete a test flight. Our team is still attempting to do so in the coming weeks before competition.

Budget

The 2016-17 budget was calculated using the estimated cost of rocket construction, materials, and launch related cost (**Figs. 2 and 3**). This leads to a total budget of $7,500. The Virginia Space Grant Consortium has granted the team with $4,500 and the rest of the project will be funded with the help of corporate sponsorship.

Estimated Expenses and Spendings

Item	Costs ($)
Test Launch Costs	
Model Rocket Components	$150
4X K-Class Motors	$720
Motor Casings	$250
Electronics	
Arduino	$60
Sensors	$300
Camera	$100
Structure and Payload (Other)	$1,500
Travel(to cover at least half of the team)	
Rental Car(s)	$800
Gas	$450
Tolls	$120
Hotels	$2,150
Food	$500
Registration	$400
Total	**$7,500**

Figure 2: Estimated Expenses

Date	Purchase	Category	Amount
11/25/16	Sub team Rockets	Aero	$56.89
1/23/2017	Registration	Registration	$400
2/3/17	Arduino Supplies	Electronics	$25.61
2/4/17	F30-6JF Motors	Model Rocket Test Launch	$37.98
2/20/17	Female and Male headers, 9V Battery Box Case, Key Lock Switch	Electronics	$36.71
2/22/17	Gear and G10	Mechanical	$270.91
2/24/17	Ultra-Low-Friction Oil-Embedded Thrust Bearing with PTFE, for 1/4" Shaft Diameter Alloy Steel Shoulder Screw 1/4" Diameter x 1-3/4" Long Shoulder, 10-24 Thread Size Nylon Shoulder Screw 1/4" Diameter x 1-3/4" Long Shoulder, 10-24 Thread Size, Black, Packs of 25	Mechanical	$33.21
2/24/17	54mm Motor Mount Tube	Aero	$15.04
2/24/17	E-Elite EFC-721 720p HD Video Camera	Electronics	$46.94
2/24/17	Chutes	Aero	$117.15
3/6/17	Nose Cone	Aero	$32.65
3/6/17	Airframe, Coupler	Aero	$96.85
		Total	$1,169.94

Figure 3: Up to date expenses

Summary of Rocket Design and Dimensions

The rocket is 85” long with a 4” outer diameter. The rocket is split into three sections as seen in Figure 6. The first section is only the nose cone, which is attached to the remainder of the rocket by shock cord, and separates at apogee to deploy the drogue parachute. The second section splits 40” below the nose cone at an altitude of 700 feet to deploy the main parachute. The remainder of the rocket makes up the third section and houses the lower electrical E-Bay along with the mechanical drag system as seen in Figures 4 and 5. The rocket has four trapezoidal fins which have a root chord of 8”, a tip chord of 5”, a height of 3”, and a sweep angle of 40 degrees. The center of pressure is located 61.25” from the top of the rocket. The center of mass with the J800 motor installed is 56” from the top. The center of mass with the K535 motor installed is 56.3” from the top. The rocket weighs 16.25 lbs with the J800 motor installed and 16.5 lbs with the K535 motor installed.

Figure 4 and 5: The drag system retracted (Left), and the drag system deployed (Right).

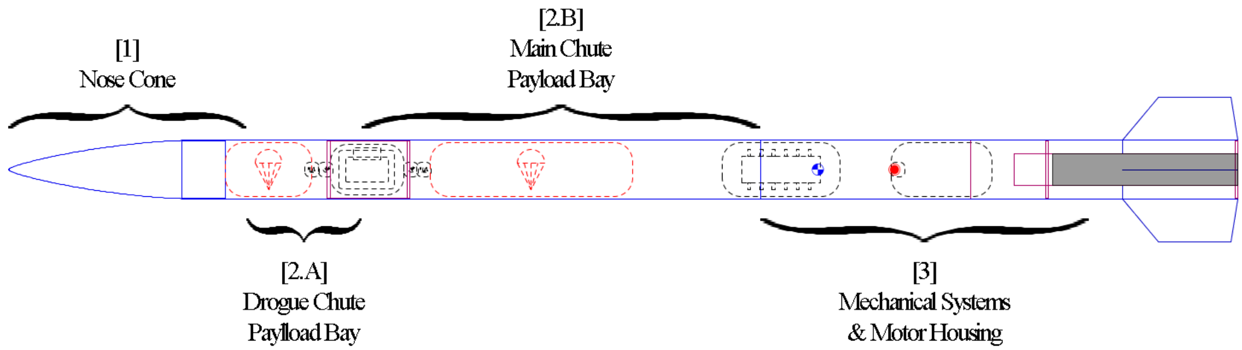

Figure 6: The OpenRocket design schematic.

Stability Analysis

The rocket has a stability of 1.31 cal with the J800 motor installed and a stability of 1.25 cal with the K535 motor installed. The drag flaps are not anticipated to have a significant impact on the location of the center of pressure. Since the flaps open below the center of pressure, any changes in the location of the center of pressure should increase stability.

Summary of Mechanical Design and Dimensions

The drag system consists of three sections. The central section houses the flaps and gears bordered on both the top and bottom by two wooden bulkheads each as seen in Figures 7 and 8. This section is 2" high. The diameter of this central section is the same the the outer diameter of the body tube of the rocket, so that the two are flush. Since the drag system interrupts the continuity of the body tube of the rocket, the drag system had two 6" stabilizing extensions on the top and bottom of the central section to allow for adequate attachment of the drag system to the rocket. The outer diameter of these two sections matches the inner diameter of the main body tube so that the top and the bottom of the rocket can slide over these sections and be screwed into place, allowing for the drag system to be unscrewed and removed if needed.

Each section consists of multiple wooden bulkheads. Most bulkheads are ¼" thick, but the bulkheads in each of the top and bottom sections are made from ½" wood because these bulkheads contain the holes where the attachment screws are located. The system also contains multiple ¼" steel all-thread rods with appropriate washers and nuts that hold the flaps, bulkheads, and sections together.

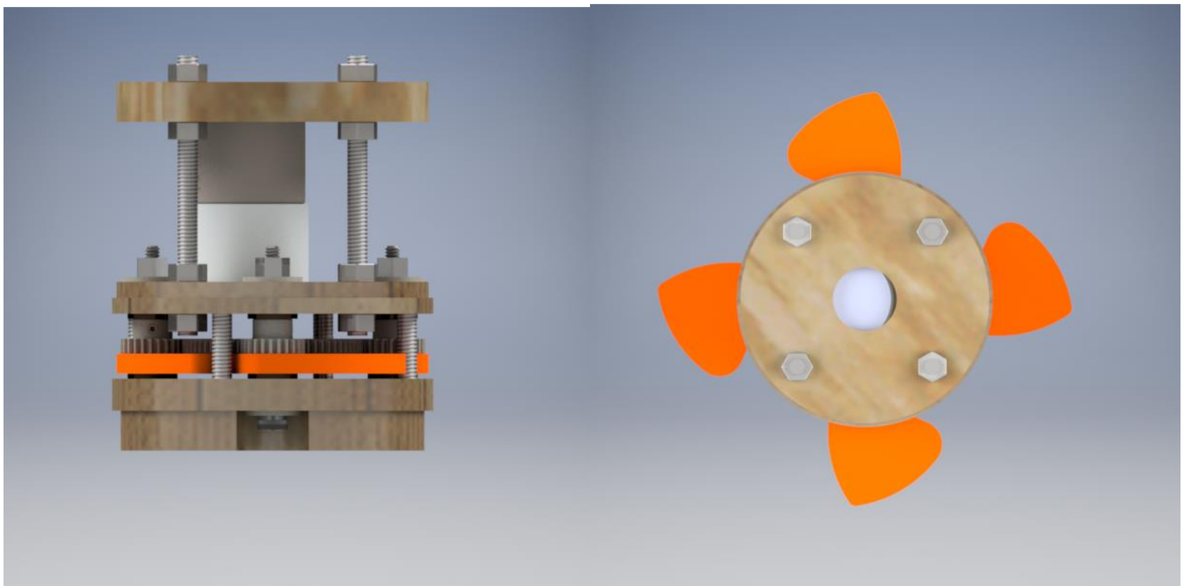

Figure 7 and 8: A side view of the retracted drag system(Left), and top-down drag system deployed (Right).

Summary of Electrical Design

There are two electrical bays, both of which have an total outer diameter of 4”. The lower E-Bay, which controls the drag system, is 8.5” long and is attached to the outer tube via 4 shear pins towards the top of the E-Bay, and 4 carpenter screws into the outer tube and bulkhead on the lower end of the E-Bay. This E-Bay uses a single key switch to turn on the avionics system. The upper E-Bay is 9.5” long, and is attached with 8 carpenter screws, 4 in each bulkhead. For redundancy, this E-Bay has two key switches to turn on the stratologgers. Both E-Bays have their respective sensors mounted onto acrylic using machine screws and nuts. The upper E-Bay has wires routed through holes in the top and bottom bulkheads that connect to header pins that will ignite the electric matches being used to detonate the black powder charges for the parachutes.

Changes since PDR

Airframe Design Iterations

Due to the mass of the electronic bays and mechanical bay being drastically greater than what was expected in the initial design process, a new K-class motor with higher thrust is required. It was determined that an Aerotech K535W would be the optimal choice. The rocket is now split into 3 sections instead of 4, as described in the summary of the rocket design. The overall length of the rocket increased by 5” to account primarily for changes in the design of the mech bay. The height of each fin was shortened to 3” and the root chord increased to 5” in order to move the center of pressure up the rocket, as the added mass made the initial design over stable.

Mechanical Bay Design Iterations

The original mechanical bay design had the flap deployment mechanism in compression. The shoulder bolts that the flaps are attached to were also used as the primary load-bearing structure for the bay. This resulted in the drag flaps experiencing a strong friction force due to the clamping force of the bolts. To alleviate much of this compression, four threaded steel rods were placed between the bulkheads bordering the drag flaps. With this improved design, the bulkheads could be tightened around the flaps with the same rods used previously, but the new threaded rods would take the majority of the compression forces instead of the flaps. After testing, it was clear that the flaps could open much quicker as a result. The threaded rods alleviated the need for contact switches, as well, as they provide a mechanical stop, preventing the flaps from over-extending. The DC motor would not need to be turned off as the motor stalls after the flaps hit the rods.

Since the outer diameter of the drag system is flush with the outer body tube of the rocket, the drag system must be able to adequately hold the top and bottom of the rocket together. To maintain structural rigidity, the drag system must have a strong connection to the sections of body tube above and below it. The bottom of the mechanical bay is fastened to the body tube through a 5 ½” long section of coupler tube, which contains bulkheads that allow screws to secure it though the body tube of the lower section of the rocket and also allow access if needed. The top of the mechanical bay is secured through a series of bulkheads extending 5 ½” into the body tube of the upper rocket body tube. This space also houses the flap-actuating DC motor, driver, and battery while also providing a structural support for the electrical bay. The voltage of the battery used to power the motor was increased from 9 V to 18 V to ensure that the flaps will deploy under even the most demanding flight profile.

E-Bay Changes

The overall design of the both E-Bays did not change from the preliminary design report; however, some components were changed. The Arduino Mega was replaced with and Uno because the Mega was not compatible with all of the other hardware. The lithium ion battery was replaced with a 9V alkaline, as well, due to concerns that it was not reliable when exposed to large forces. A second key switch and battery was added to the upper E-Bay in case one fails. Foam board was added under the gyroscope and accelerometer to help provide support to the sensors and prevent bending during launch. In addition, LED indicators were added to the lower E-Bay to serve as a debugging readout.

Flight Control Program

Information about the rocket's state is measured from two onboard sensors: the Adafruit BMP085 and LSM303. The BMP085 is a barometric sensor which collects temperature and pressure readings, and calculates altitude from these measurements. The LSM303 measures acceleration in the vehicle's longitudinal direction.

The data acquisition routine takes the altitude and acceleration measurements as the two-dimensional measurement vector, Z, for a Kalman filter which returns a state vector, X, containing the estimated altitude and velocity of the vehicle. These values are filtered because the altitude readings contain absolute positioning, but are low frequency, whereas the acceleration measurements are high frequency but are subject to drift. Combined, they provide a more accurate measurement of altitude and velocity than either one could alone. This is vital to success, since the drag system control algorithm depends on reliable vehicle state information.

The performance of the rocket is modelled by the differential equation seen in Figure 9 ,where v is the velocity of the vehicle. This assumes that only two forces act on the rocket during flight: drag and gravity. Drag is proportional to velocity squared, inversely proportional to mass, and is additionally proportional to many other constants such as reference area, atmospheric density, etc. All of these coefficients are encapsulated into the term k, referred to as the drag characteristic. This relation is valid only after motor burnout, and is used to predict the rocket's trajectory during coasting. From this differential equation, functions which describe altitude and velocity over time can be produced, which provide a way to predict the vehicle's trajectory.

$$\dot{v}(t) + \frac{k}{m} v(t)^2 + g = 0$$

Figure 9: Relationship governing rocket trajectory

Airbrake Control Algorithm

The electrical subteam developed a tool used to predict how changes to the vehicle's drag characteristics will affect its future trajectory - intuitively, the vehicle is expected to go slower, and fly lower, with a higher drag characteristic, k. While the vehicle has relatively constant mass between flights, the reference area of the rocket will change when the air brakes are engaged. Consequently, the onboard controller computes predictions for two models: one for both the passive and deployed drag characteristics. These two predictions are modelled in Figure 10.

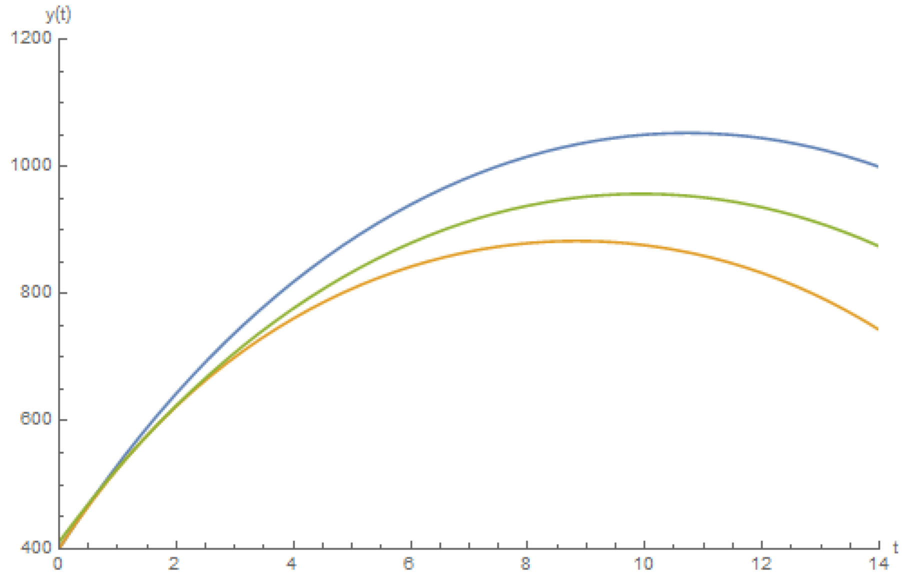

Figure 10: The ideal trajectory model, plotted over time with low (blue) and high (orange) drag characteristic. The green curve represents proper altitude control using the airbrakes.

Every iteration, after new data is acquired and filtered, the microcontroller computes the time to apogee and the apogee altitude given its current velocity and altitude. It also computes possible changes to these values that would be caused if the airbrakes are deployed until the next iteration. If these changes does not cause the apogee to drop below the target altitude, then a flight maneuver is executed by deploying or retracting the flaps. The same calculations are run again next iteration, with new sensor measurements. Iterations occur at a rate of 20 Hz. This attenuating loop continues until an acceptable minimum velocity is detected and apogee is reached.

Construction of Rocket

Airframe

The four fins were constructed from G-10 fiberglass. The outline of the fins were etched in a laser cutter and then cut out using a bandsaw. They were then epoxyed to the rocket body tube and sanded into an airfoil shape using medium grit sandpaper.

The body and couplers of the rocket were made from Blue Tube. Using a handsaw, the tube was cut into the desired lengths and the edges were sanded smooth. A drill was used to create the desired holes. Blue Tube was also used to create the casings for the upper and lower electronics bays, along with the coupler to secure the drag system in place.

The motor mount was constructed from Blue Tube, as well. The tube was cut to the desired length using a bandsaw. Two centering rings were cut using a laser cutter and then epoxied onto the Blue Tube. The upper component of the motor mount closure was epoxied onto the bottom centering ring. For flight, the motor casing is inserted into the Blue Tube and secured against the upper part of the closure. The bottom part of the closure is then screwed on to secure the motor casing.

Once the other sub-systems were completed, they were mounted into the rocket. The mechanical bay was screwed into the blue tube 8.5" above the motor mount in the lower half of the body tube by 14 screws. The main body tube was split at the flaps, and the upper half of the mechanical bay was bolted to middle section of the body tube. The lower E-Bay was attached to the top portion of the lower body tube, with the coupler tube of the E-Bay. The body tube was cut at the lower E-Bay, with the upper section of the E-Bay attached to the upper section of the body tube by shear pins, which break when the ejection charges fire to deploy the main parachute. The upper E-Bay was bolted into the upper body tube 22.5" from the nose cone. Finally the nose cone was placed at the top of the upper body tube.

Figure 11: Fabrication of the motor section of the vehicle.

Drag System Bay

All of the ¼" wooden bulkheads used in the drag system were laser cut. The ½" bulkheads were cut by hand. Prior to assembly, all of the adjacent wooden bulkheads were attached to each other with epoxy. The G-10 flaps were created by etching an outline of the flaps onto the material with a laser cutter and then cutting them out with a vertical band saw and then drilling a hole in each. Gears were attached above the drilled holes with epoxy. All bulkhead units and gears were assembled with rods, bolts, and washers as described below.

The lower stabilizing section of the drag system consists of wooden bulkheads and coupler tube. Four ¼” bulkheads were connected with epoxy and placed inside a 5 ½” section of coupler tube. This entire section was then mounted with epoxy to a ½” bulkhead with a diameter matching the inner diameter of the body tube. On top of this bulkhead are the two bulkheads that the bottom of the central part of the drag system consists of. The top of the two bulkheads had four additional laser cut holes in order to hold the new threaded rod spacers. Both bulkheads have four holes to allow four ¼” bolts to run up to thread through the G-10 flaps to the top bulkheads of the drag system where they are tightened in place with nyloc nut. The two top bulkheads above the central section of the drag system are a mirror image of the bottom bulkheads with the exception of four additional laser cut holes near the outer edge of the bulkheads and a hole in the center.

The outer holes allow a long threaded rod that supports the upper section of the drag system to be bolted to the drag system. The inner hole allows a space for the motor to sit in place and attach to the central gear that was placed between the drag flaps. The motor is held in place by a single ¼” wooden bulkhead about an inch above the previous two bulkheads, bolted to the same four threaded rods. Five inches above this, a group of five threaded bulkheads attached with epoxy are bolted to the top of the four threaded rods, capping the drag system. The batteries and the motor driver are housed in the space between the top bulkheads and the bulkheads above the gears. All of the bulkheads above the two bulkheads that border the top of the flaps and gears have a diameter that matches the inner diameter of the body tube of the rocket. The top of the drag system slides into the body of the rocket and four screws into the top five bulkheads.

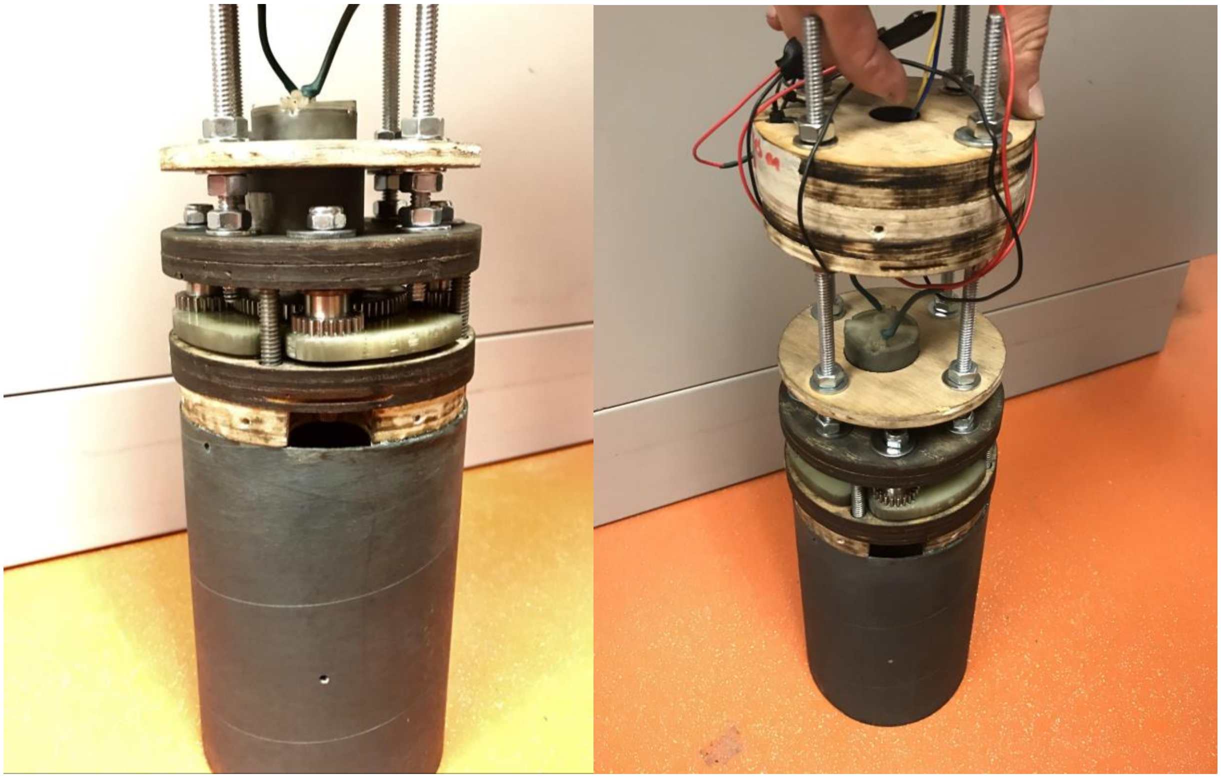

Figure 12: The drag system assembly.

Electronics Bays

Both lower and upper electronics bays are built from similar structures, to reduce the number of unique components needed. Coupler tube was cut to 8" for the lower E-Bay, and 9" for the upper E-Bay to house the electronics in the rocket itself. A coupler bulkhead and body tube bulkhead were combined to tightly seal the E-Bay's top and bottom. ¼" thick steel all thread were driven through both bulkheads to provide structural support and to provide a place for the acrylic boards to be attached. Acrylic sheets were laser cut to rectangular plates to hold electronics. The upper and lower E-Bays' acrylic were cut to 5.75" and 7.5" respectively, and are used to mount all electronic components. There are a total of three key switches which control three independent circuits. The first keyswitch is used to control the data logging and drag system deployment. The other two key switches are used in the recovery ebay, which contains two fully redundant and independent systems to deploy the drogue and main parachutes. In order to easily remove the bulkhead, the key switches assembly was glued to the bulkhead and wires were connected through the switches via crimped connectors. The upper recovery E-Bay has both StratoLoggers attached to the acrylic with machine screws, and the acrylic is mounted with multiple tightly bound zip ties connecting to the all thread.

The lower E-Bay contains an Arduino Uno, a GPS shield, a set of sensors, a tracking beacon, and a 9V battery. The E-Bay is activated by a key switch flush with outer body and held in place with a wooden stopper glued to the bulkhead. The key switch connects a 9V battery attached to the acrylic and mounted upside down so not to come loose during launch. The Arduino and shield are mounted to the acrylic via machine screws. The bottom of the Arduino is padded with a layer of foam board so as to not damage the soldering. Wires are routed through a hole in the acrylic to the protoboard located on the opposite side. The protoboard is attached via machine screws and nuts to the acrylic, as well. An accelerometer, barometer, and gyroscope are attached to female header pins that are soldered directly to the protoboard. Foam board is attached to the bottom of the protoboard, as well, to prevent damage to the solder. A set of LEDs is located near a static whole to indicate that they system is operational.

The upper E-Bay was constructed the same way as the lower E-Bay but contains 8 carpenter screws instead of 4 and is slightly smaller. The bay contains two fully redundant systems to deploy the parachutes. Each system contains their own key switch, StratoLogger, 9V battery, and two charges located on the top and bottom of the E-Bay for the drogue and main parachute respectively. The two StratoLoggers are mounted to the acrylic with machine screws and nuts. The loggers are slightly elevated with washers instead of foam board because there are no clearance problems around the screw holes. The batteries are mounted above. Holes were drilled in both bulkheads to allow wires to the black powder charges. The charges itself are PVC caps epoxyed to the bulkhead.

Parachute Deployment System

The parachutes are deployed via dual deploy system controlled with a set of StratoLoggers that are mounted in the recovery E-Bay. The system deploys the 24”, six shroud line drogue chute at flight apogee when the onboard accelerometer detects a zero or negative acceleration. To eject the drogue chute from its housing, a 3.5 gram of FFFFg black powder charge is ignited in a housing on the upper end of the recovery E-Bay with an electric match to dislodge the nose cone and deploy the drogue chute. The 84” main chute is deployed in a very similar fashion as the drogue chute. Using altimeters that are incorporated with the StratoLoggers, the main chute is deployed at approximately 700 feet above ground level though the ignition of 4.0 grams of FFFFg black powder, housed on the lower end of the recovery E-Bay, via an electric match.

To assist in the correct deployment of the parachutes, both the main chute and drogue chute are folded according to the “Parachute Folding Procedure” located in the *Pre-*

Flight Checklist. This is done to ensure that the shroud lines assist in correctly deploying the parachutes and also to ensure that they do not become tangled upon deployment.

Test Flight Report

Due to uncontrollable weather conditions, the rocket test launches scheduled for April 1, 2017, and later April 29, 2017, were scrubbed. Increased wind speeds on both of those days would have resulted in possible loss of the rocket to the surrounding environment as the launch site is adjacent to a forest, a river, a set railroad tracks, and an army munitions plant. Currently, a third attempt at a test launch, weather pending, is slated for May 7, 2017 at the Kentland Farms launch site under the supervision of New River Valley Rocketry. As a result of the delayed test launch, only simulated performance data is presented below.

Figure 13: The team preparing to perform a ground test. Courtesy, Thomas Weeks of NRVR

Environmental Conditions

Simulations were conducted assuming nominal launch conditions at the launch site in North Branch, MN. Average environmental conditions for North Branch, as indicated in weather almanac accessed via The Weather Channel's website, on May 21 and May 22 are a high of approximately 70 degrees Fahrenheit and a low of approximately 45 degrees Fahrenheit. and a 3% chance of precipitation. All simulations were run assuming International Standard Atmosphere conditions that were pre-set in OpenRocket, using an average wind velocity of 6.56 ft/s with a standard deviation of 0.656 ft/s. It should be noted that this standard deviation of average wind velocity does have a minor effect on simulated launch results from one iteration to the next.

Launch

Overall launch behavior of the rocket is ultimately dependent on which motor is used. For the J800T-P flight the rocket has a simulated stability of 1.32 calibers (cal) at ignition, reaching a maximum velocity of 517 ft/s. For the K535W, the rocket has a simulated stability of 1.25 cal at ignition, reaching a maximum velocity of 532 ft/s.

Flight

Flight behavior is dependent on which motor is used. For the J800T-P flight, burnout is simulated to occur 1.6362 seconds into flight and apogee 14.436 seconds into flight, reaching a simulated altitude of 3,432 ft. Maximum simulated velocity is 517 ft/s, and maximum simulated acceleration achieved is 15.78 G. For the K535W flight, burnout is simulated to occur 2.8 seconds into flight and apogee 15.939 seconds into flight, reaching a simulated altitude of 3,939 ft. Maximum simulated velocity is 533 ft/s, and maximum simulated acceleration is 7.67 G.

Recovery

The drogue chute deployment for both motors occurs at flight apogee and main parachute deployment occurs at 700 ft above ground level. On the J800 flight, the main parachute deploys 53.387 seconds into flight at a descent velocity of 71.44 ft/s and slows the rocket to 19.4 ft/s before landing a simulated 87.58 seconds after motor ignition. On the K535W flight, the main parachute deploys 61.84 seconds into flight at a descent velocity of 71.329 ft/s and slows the rocket to 19.4 ft/s before landing a simulated 95.621 seconds after motor ignition.

Figures 14 through 18 are graphs and tables detailing simulated flight characteristics for altitude, velocity, and acceleration over the course of the flight.

Event	Expected time on J800 flight (s)	Expected on K535 flight (s)
Motor ignition	T+00.00	T+00.00
Liftoff	T+00.02	T+00.04
Maximum acceleration	T+00.01	T+00.07
Maximum velocity	T+01.4362	T+02.6394
Motor burnout	T+01.6362	T+02.8
Drag system deployment	N/A	T+02.9894
Apogee	T+14.436	T+15.939
Drogue parachute deployment	T+14.437	T+16.989
Main parachute deployment	T+53.387	T+61.84
Touchdown	T+87.58	T+95.621

Figure 14: The predicted flight log.

Plots

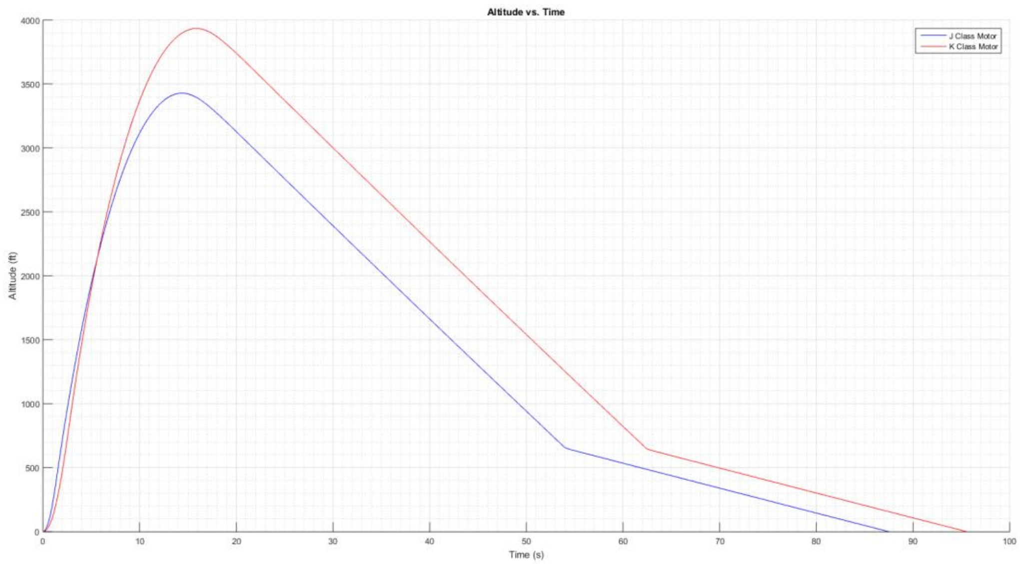

Figure 15: Predicted altitude over time for J and K class motors.

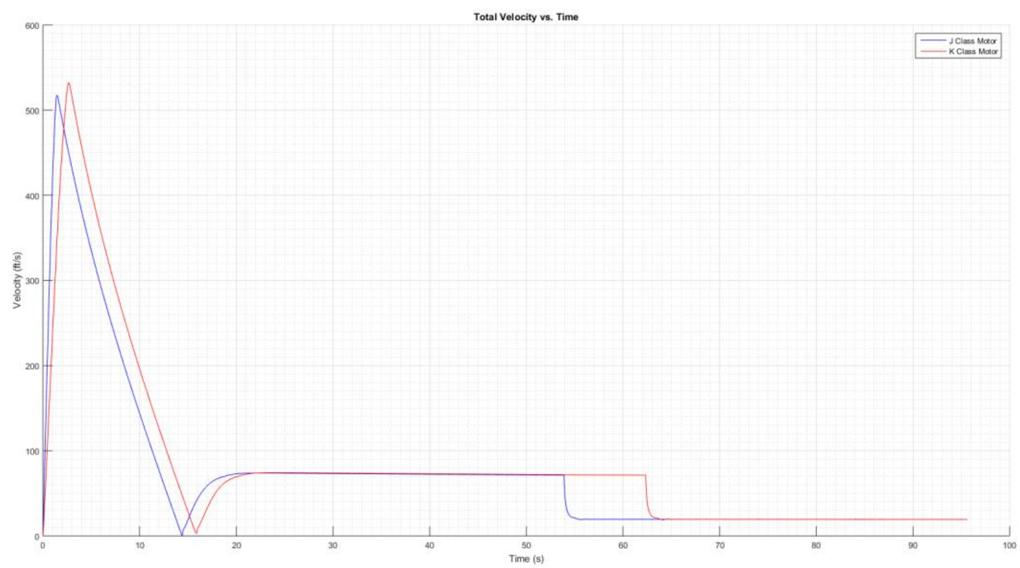

Figure 16: Predicted velocity over time for J and K class motors.

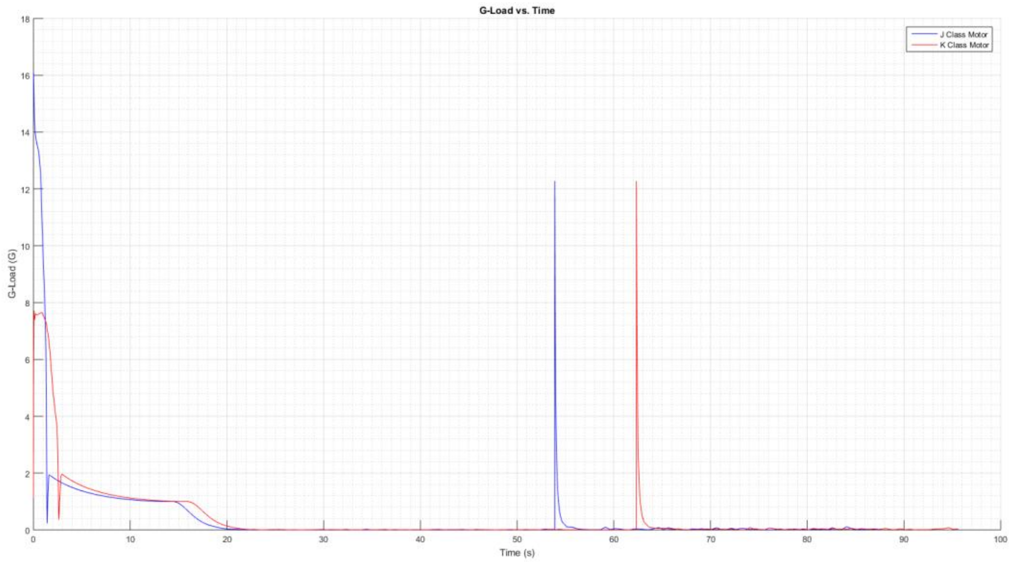

Figure 17: Predicted acceleration over time for J and K class motors.

	No Motor	J Class	K Class
Weight (lbs)	13.7	16.2	16.5
Max Accel. (Gs)	N/A	16.09	7.72
Max Velocity (ft/s)	N/A	517	532
Apogee (ft)	N/A	3,425	3,931
Stability (cal)	2.35	1.32	1.25

Figure 18: Vehicle and flight characteristics.

Pre- & Post-Launch Procedure Assessment

As additional work was performed on the rocket, the *Pre-* and *Post-Launch* procedures evolved to reflect changes that were made and also incorporate any checks that need to be completed prior to launch. Both procedures remain relatively unchanged to how they were previously established, but a few items have been added or expanded upon as they were deemed necessary.

Pre-Launch Procedure

1. Pack and secure parachute and drogue chute as follows:
   Parachute Packing Procedure
   a. Unhook parachutes from shock cord (if applicable)
   b. Untangle shroud lines
   c. Sling/Run with parachutes to evenly open the chute before folding
   d. On a flat surface, with one person holding the shroud lines firmly, a second person extends the upper part of the parachute by gently tugging on the outside center of the parachute, extending the parachute to a semicircle as flat and spread out as possible. Overall length of the folded parachute will be determined by the widest portion of the semicircle.
   e. Once the chute panels have been aligned, apply baby powder to aid in the prevention of the fabric sticking together from moisture.
   f. Starting from the base of the parachute, roll in part of the shock cord into the parachute
      i. This is to help in chute deployment
   g. Tightly roll the parachute, applying additional baby powder as needed, to achieve the desired thickness of the chute roll to ensure fit into the rocket airframe
2. Ensure the electronics are activated and are secure in the rocket
   a. Turn on and test tracking beacon
   b. Set delay
   c. Turn on and secure both competition altimeters
   d. Turn on and secure camera
   e. Download the flight program to the microcontroller, ensuring everything is connected and working properly
   f. Secure the microcontroller system
3. Ensure mechanical’s motor bearings need to be tightened
   a. Do not overtighten; ensure flaps open and close quickly
4. Test mechanical system for functionality
5. Test security of the motor in the rocket
6. Verify that the correct amount of FFFFg powder is in the ejection canisters
   a. 3.5 g for upper section
   b. 4.0 g for lower section
7. Verify mechanical fin system is functional
8. Place flame resistant wadding (dog barf) to separate the ejection charge devices from the payload components in the rocket subsections
9. Inspect fin connections for damage.
   a. Repair if needed with JB Kwik Weld
10. Verify that nose cone is secured to top of rocket, using shear pins if needed

11. Verify that all sections of the rocket are properly connected, aligned and secured
12. Verify correct motor has been installed properly into the rocket
13. Have the Range Safety Officer (RSO), inspect and approve the rocket for flight
14. Mount rocket on launchpad
15. Activate microcontroller
16. Ensure transmitter is activated
17. Arm the recovery devices
18. Toggle electrical systems on with key switches for ignition
19. Launch

Post-Launch Procedure

1. Wait for RSO to declare the area clear
2. Recover rocket using tracking beacon, if needed
3. Ensure all components were recovered
4. Take photo and video of the landing site
5. Examine the rocket for possible damage
   a. Determine if Repair is viable
      i. If Yes, proceed with repairs
      ii. If No, attempt to repair for next launch
6. Download video from camera
7. Download flight data from microcontroller
8. Deactivate camera, microcontroller, and beacon
9. If rocket is in flyable condition, prepare for next flight
   a. Repeat *Pre-Launch Procedure* for subsequent flight

Planned Improvements

Despite overall success, the mechanical subteam has encountered structural issues with the drag system assembly. Ideally, the gears, bolts, and rods should all be attached tightly enough as to not have to worry about movement during launch; however, currently the center gear becomes slightly loose from the motor preventing the rapid deployment of the flaps. The steel rods causing tension between the two plates also has a tendency to fall too deep in the hole causing there to not be enough tension. The threaded rods surrounding the motor have a tendency to come loose as well. It was decided that the best way to fix these issues was to glue the motor into the center gear as well as glue around the bolts supporting the threaded rods to prevent movement. In addition, small circles of paper were added beneath the rods to create more tension.