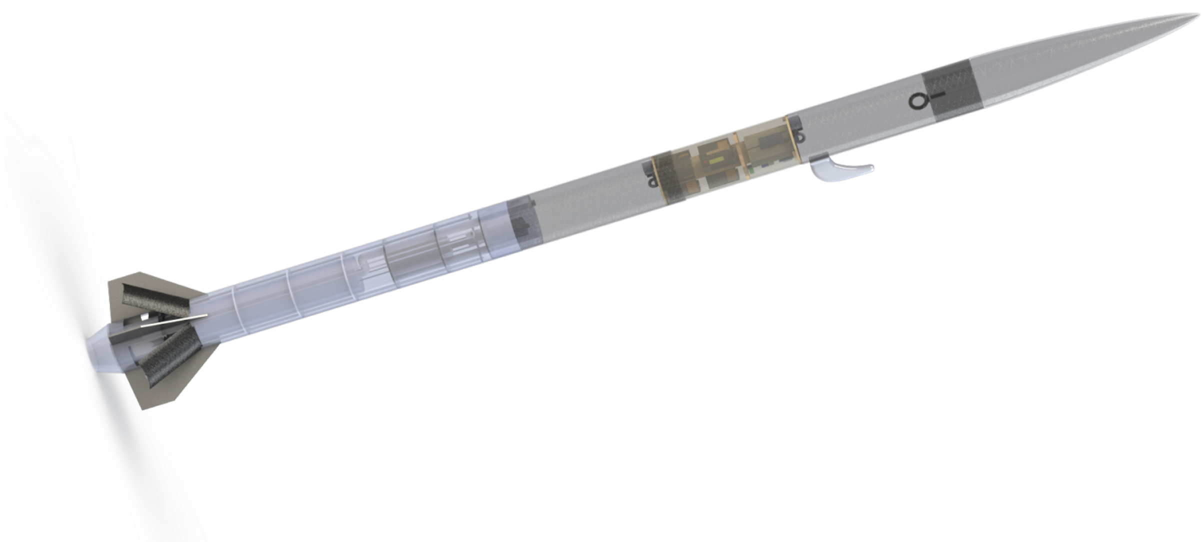

Flight Readiness Report

Icarus Rising, University of Minnesota Twin Cities

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Executive Summary

The 2016-2017 Space Grant Midwest High-Power Rocketry Competition requires teams to design a single stage, dual deploy high-power rocket that will reach the maximum altitude on two different motors (one I-class and one J-class, or one J-class and one K-class). Our team chose to use J-class and K-class motors because they will allow the rocket to reach a higher maximum altitude. Our rocket was designed using simulations in OpenRocket. The rocket has an overall length of 73.55 inches with an outer diameter of 3.125 inches. The outer diameter was chosen to be as small as possible and still be large enough to house the pneumatic aerobrake system. A smaller diameter for the rocket reduces the weight and drag of the rocket allowing it to reach a higher altitude. A test launch was conducted on Saturday April 29. The rocket flew to 2327 feet with the J motor. The altitude was much lower than the expected value because the additional components caused the weight of the rocket to increase. A flight with the K motor was not possible because the motor was not available at the launch. When the pneumatic aerobrake system is activated on the flight with the K motor, a set of flaps will be deployed. These flaps will be deployed after the motor burnout and will increase the drag of the rocket and cause the apogee of the rocket to decrease and match the apogee of the rocket when it was launched with the J motor. The competition requires up and down video to be recorded. To achieve this footage, two cameras will be mounted in 3D-printed pods on opposite sides of the rocket. The two cameras worked as intended during the test flight. The competition also requires a custom avionics package to directly measure velocity versus time. This package consists of an Arduino Nano microcontroller, a 10 degree of freedom inertial measurement unit, a 200 g's accelerometer, and a pitot tube. Along with measuring velocity versus time, this package will also control the deployment of the aerobrake. Because the data from the test flight was not recorded, the avionics layout was redesigned to make it more robust. A Featherweight Altimeters Raven3 altimeter is used to control the deployment of ejection charges used for the drogue and main parachutes. The drogue parachute will be deployed at apogee and the main parachute will be deployed at an altitude of 800 feet. An Aerotech J415W-L motor and an Aerotech K1103X-14A motor will be used to power the rocket. The rocket is expected to reach an apogee of 4200 feet with each motor, with the aerobrake active for the launch with the K motor. The J motor will provide and average thrust of 343 Newtons for 3.5 seconds and has a total impulse of 1201 Newton-seconds. The K motor has an average thrust of 1045 Newtons for 1.688 seconds and a total impulse of 1764 Newton-seconds.

Summary of Design
Design and dimensions
Main Body
The designed rocket has an outer diameter of 3.125 inches and has peripherals that extend to a maximum distance of 4.062 inches from the centerline. This design can be split into several distinct sections going down the rocket. These sections and their corresponding vertical lengths are the nose cone (12.5 in), the main parachute bay (13.00 in), the electronics bay (8.25 in), the drogue parachute bay (6 in), the pneumatic accessories bay (6.25 in), the pneumatic housing (11 in), the aerobrake/fin section (15 in), and the boat tail (1.55 in). The nose cone selected is a hollow ogive profile sold by Madcow Rocketry. This nose cone's shape was selected due to the predicted rocket trajectory and velocities via OpenRocket. These simulations showed that the ogive design allowed the rocket to travel to the highest altitude possible.

Fin Design
For the design of the fins, a clipped delta shape was chosen. This shape of fin was chosen because of its small drag imprint with their swept design while having a large enough surface area to adequately keep the rocket stable. The size of the fins was chosen to keep a static margin within competition specifications while the aerobrake is both deployed and in the stowed configuration. The fins are attached to the main body of the rocket using fillets. Four holes were cut down the length of the body tube the proper width of the fins. The length was slightly shorter, making it necessary to slide the fins into the slots, making a more secure fit. The design of the fins still allows for uninhibited movement of the aerobrake system.

Aerobrake System Specifications
The aerobrake system was designed with simplicity and robustness in mind. A two ring system actuates four deployable radial arms via a looped wire system and pneumatic linear actuator. Four fiberglass flaps are attached to the radial arms to provide a drag surface.

This pneumatic system is powered from a small 16 gram CO_2 cartridge that is routed through a CO_2 release valve, through a pressure regulator, leading to a three-way two-position solenoid control valve. Once the solenoid valve is activated, CO_2 travels into the 1 inch stroke pneumatic cylinder which in turn actuates the 1/16 inch wire system which operates the radial arm flap system. Once the flaps are determined to be closed, the solenoid valve is reactivated allowing all CO_2 within the air cylinder to escape back through the valve and routed to the exterior of the rocket.

The aerobrake system can be separated into three main parts going from the top of the rocket down. These include the pneumatic accessories bay, the pneumatic cylinder bay, and the flap linkage.

The pneumatic-accesories bay includes the CO_2 canister, the CO_2 release valve, the air pressure regulator, the solenoid control valve, and the adjoining air hoses. This is held within a smaller 6 inch coupler section for ease of access once the rocket is built, and this bay is supported by a solid bulkhead separating it from the air cylinder movement arm. Within this bay, there are two tubing segments, the motor backup re-routing system and the safety cowl. These segments are to be discussed in the Construction for Safe Flight and Recovery section later in this document. The pneumatic accesories bay is shown in Figure 2.

The pneumatic cylinder bay contains the support system for the pneumatic cylinder alone. The cylinder is held in place by two separate bulkheads and a securing nut. On opposing sides of the cylinder run two tubing sections, one acting as a safety cowl and the other as the motor ejection rerouting pass-through. Attached to the cylinder's movement arm is the movement carriage that connects the pneumatic system to the flap linkage through four 1/16 inch looped wire segments. The pneumatic cylinder bay is shown to the left in Figure 3

The wire segments are passed through all bulkheads until the wire reaches the bottom of the two ring section. The bottom ring moves vertically, moving the radial arms outward through the two piece pin system as shown in Figure 1. Springs will be connected to the bottom ring and a lower motor mount centering ring in order to ensure adequate .closure of the flaps when the system is not in use. This will be aided by the external flow over the flaps while in flight.

Propulsion System Specifications

The propulsion system came to be a J and K motor pairing, as this would give the highest possible altitude and therefore a higher point value for the competition score. certain motors were removed from the selection process for not meeting requirements related to the aerobrake design limitations. All possible motor companies were looked at and, after thorough analysis using OpenRocket, the optimal engine pairing was two Aerotech motors. The J motor is the J415W-L, and the K motor is the K1103X-14A. This engine pairing created the highest possible score due to the large difference in thrust values, due primarily to a slow burn time for the J motor and a quick burn time for the K motor. Both motors are 54mm diameter motors, which makes the assembly around the motor mount tube simpler. The J motor is shorter in length than the K motor, so a spacer will be needed inside the motor casing.

Avionics Systems Specifications

Sensor package

A custom sensor package was developed to provide data logging of flight telemetry. Our package consists of an Arduino Nano microcontroller, a 10 degree of freedom (DOF) inertial measurement unit (IMU) which includes a 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer, a barometer, and a thermometer. An additional 200g accelerometer is used for initial launch acceleration as the 10-DOF sensor is limited to 16g of acceleration. A pitot tube assembly is used for direct measurement of velocity, and a microSD card reader is used for data storage. This avionics package is also responsible for triggering the deployment and retraction of the air brake through a solid state relay. A commercial avionics sensor is included for redundancy and ejection charge deployment. A Featherweight Altimeters Raven3 altimeter is used for this purpose. The package will use three independent power systems to prevent the failure of one causing the others to fail as well as to prevent current drains from one system, notably the ejection charges, causing the other systems to lose power.

Avionics package

The avionics package consists of a fiberglass tube with plywood endcaps. Mounted to the endcaps are PVC ejection charge holders and terminal blocks to allow easy installation of e-matches. The internal structure consists of a three sided wooden sled on which the sensor boards, batteries, a Raven3 altimeter, Altimeter 2, and buzzer are placed. Wood was chosen for most components due to its electrical isolation and lightweight properties. The endcaps are held together using a threaded rod, coupler nuts, and eye bolts. The sled is screwed together with assistance from 3D printed triangular braces that surround the threaded rod. The battery mounts are also 3D printed and attached to the same style braces as the sensor boards. The addition of a bulkhead between the batteries and sensor boards provides lateral stability and wire organization. The avionics bay is capable of holding five 9V batteries; however, only 4 will be used for the three independent systems.

Construction Plan and Techniques

The rocket is separated into sections composed of a nose cone, upper body tube, avionics bay/coupler tube, middle body tube, lower body tube, and fins. The sections will be connected and filled with the internal components according to the following directions:

- Machine fiberglass bulkheads, drag system supports, aluminum bulkheads/centering rings, and custom length NPT fittings.
- Laser cut internal avionics bay sled components.
- Cut fiberglass tubing to correct sizes for upper, middle, and lower body tubes.
- Construct pneumatic cylinder assembly.
    - Epoxy pneumatic cylinder to lower bulkhead.
    - Bolt upper bulkhead to cylinder.
    - Fit safety cowl next to cylinder and epoxy in place.
    - Attach NPT hose to bottom of cylinder and run through cowl.
    - Bolt movement arm to cylinder piston.
    - Attach eyebolts to movement arm through upper bulkhead.
    - Crimp wire to eyebolts (leave extra length).
    - Fit cylinder assembly into lower body tube and epoxy in place.
- Construct motor mount assembly.
    - Cut motor mount tube to correct size.
    - Epoxy endcap to motor mount tube.
    - Epoxy top centering rings to motor mount tube.
    - Epoxy top hinge bracket to motor mount tube.
    - Epoxy redirect tubing to endcap.
    - Pin lower bar to bottom hinge bracket and slide on motor mount tube.
    - Slide assembly into body tube.
    - Run wire through bottom hinge bracket.
    - Epoxy fins through body tube to motor mount.
    - Pin outer drag support to upper hinge bracket and lower bar.
    - Epoxy final centering ring.
    - Epoxy motor retention ring.
- Construct solenoid assembly.
    - Epoxy bulkhead to coupler.
    - Attach right angle valve to solenoid valve.
    - Attach solenoid valve to bulkhead (screwed).
    - Screw eye bolt into bulkhead.
    - Attach NPT tubing.

    - Attach pressure regulator to solenoid valve.
    - Attach pressure regulator to flow control valve.
    - Epoxy pressure regulator to interior of coupler tube.
    - Epoxy and rivet coupler tube to body tube.
- Construct avionics bay in coupler tube.
    - Construct avionics bay sled.
    - Screw electronic components onto sled.
    - Solder components together and wire the rocket.
- Epoxy coupler, bulkhead, and eye bolt onto nose cone.
- Mount camera pods and pitot tube onto body.
- Tie recovery system into rocket.
- Rivet and pin body tube together.

Stability analysis

Stability analysis was performed using OpenRocket, Figure 10 shows the model used for stability calculation. Fin size was varied until a desired stability margin was reached for both motors configurations. Table 3 below provides CG, CP, and stability factor values for the rocket with the J and K motor configurations. The final fin size based on this analysis is an 7.5 inch root chord, 4 inch tip chord, and a 3 inch height with a 46.8 degree sweep angle. All angles follow the as provided in the Fin Design section.

OpenRocket Values	J Motor	K Motor
CG (inches from tip of nose cone)	46.58	47.04
CP (inches from tip of nose cone)	55.64	55.64
Stability Margin	2.84	2.7

Table 1 - Center of Gravity (CG), Center of Pressure (CP), and Static Margin (Stability Factor) are given as provided from OpenRocket values. CP values are taken at a Mach number of 0.6.

It is difficult to determine the CP using OpenRocket for when the aerobrake is deployed, which was part of the reason the current fin design was chosen. The design will ensure safe flight during motor burn, but it also has a low enough stability factor to prevent a significant movement in the CP from causing the rocket to go beyond the safe stability margin of 5. Testing the CP location experimentally became difficult due to the size of the rocket, and the limitations of the wind tunnel at the University of Minnesota.

Constructed for safe flight and recovery

The rocket's aerobrake was designed to be a redundant system that ensures safe recovery. This is due to the shared linkage that operates the flaps simultaneously. If any part of the aerobrake is damaged during the flight, no single flap would be activated alone. This prevents a potential catastrophic failure due to uneven pressure distribution along the sides of the rocket. While this could mean failure for a single launch, this allows the design to be recovered, repaired, and relaunched allowing the chance at a successful launch.

Due to the high number of rocket designs failing to open the parachute during flight, the motor backup re-routing system was developed. This system accounts for the possible failure of the avionics system to fire the prepared ejection charges. By doing this, the drogue parachute is deployed to ensure the rocket undergoes a partially controlled descent.

Because of the movement of the pneumatic cylinder, the possibility of the pneumatic hosing becoming pinched during flight would cause potential harm to the entire aerobrake system. In order to prevent this, a safety cowl made of ½ inch PEX is routed past the pneumatic cylinders actuation arm ensuring the successful operation of the pneumatics.

Recovery System Specifications

This design of a rocket employs a dual deploy system that uses a drogue and main parachute. For the drogue parachute, the 15” diameter Fruity Chutes parachute was chosen. This is comprised of an elliptical design 1.1 ripstop nylon, having 8 shroud lines certified to withstand a tension of 330 lbs and a kevlar shock cord certified to withstand a tension of 1500 lbs. A coefficient of drag of 0.8 was used for the force calculations. For the main parachute, a 6’ diameter Pro XP parachute from Rocketman was used with kevlar shroud lines and a shock cord certified to withstand 1500 lbs of tension. A coefficient of drag of 0.8 was also used in the force calculations. The main parachute can be packed into a cylinder of 12” long, assuming a diameter of 3”. The drogue can be packed into a cylinder of 4” long, also assuming a diameter of 3”. The main parachute will be attached to a bulkhead in the nose cone and the top bulkhead of the avionics bay. The drogue will be attached to the lower bulkhead of the avionics bay and a bulkhead separating the parachute bay from the aerobrake system. The drogue chute and main cute will each be protected from the ejection charges by an 8” and 10” Nomex flame protector, respectively. A final predicted descent velocity of 15 ft/s is achieved with this configuration. This relatively slow velocity was chosen to ensure the protruding sections of the pitot tube would not be damaged on landing.

Motor Ejection Backup Specifications

By Space Grant Midwest High-Power Rocket Competition regulations, the designed rocket must use the preinstalled parachute ejection charge that is installed on the rocket motors. However in the designed rocket, the pneumatic system would be preventing the motor ejection charge from being effective. Taking this into consideration the rocket has a backup ejection rerouting system that allows the exiting gas from the motor to bypass the pneumatic system via a ½ inch PEX tubing routed through the interior of the design. It was experimentally determined that the tubing used would be able to withstand the heat and pressure of this flow. Because the time that the gas is within the tubing is negligible and the end is open, the material will work even though it is not rated for air by the manufacturer. The backup system can be seen in Figure 3.

Discussion of changes since PDR

Pneumatics

In the original pneumatics design we determined that the CO_2 release valve was able to act as a pressure regulator as advertised by the product's manufacturer. However when testing the pneumatic system we soon found out that this valve acts simply as a flow rate control mechanism. In order to rectify this, another regulator was purchased and added the pneumatic design between the CO_2 release valve and the solenoid control valve. The addition increased the size of the pneumatic accesories bay by 1.5 inches and requires the CO_2 cylinder's orientation to be flipped. Due to the extra length required, the eyebolt size needed to be increased as well. While specifications for the new pressure regulator stated that it would be able to withstand the high pressure of the CO_2 canisters, it became apparent during testing that it could not handle the full pressure. This led to the necessity of partially draining a CO_2 canister before it was connected to the system and the flow regulator was then used to introduce the pressurized gas into the system.

Airbrake Mechanism

The initial airbrake design featured the airbrake flaps being parallel to the body tube when closed. However due to mechanical issues during the build process, the flaps are partially extended by approximately 15 degrees. This mechanical issue creates much more drag than initially expected for the rocket's flight, which led to a significantly lower apogee than the simulations predicted.

Avionics

The original avionics consisted of an arduino nano microcontroller; however, hardware failures caused the arduinos to fail. For the test launch it was replaced with an arduino uno which had a difficult time fitting into the avionics bay due to its larger size. The system was initialized 20 minutes before the launch and sat running for another 10 minutes after the launch. During that 30 minute timeframe there was either another hardware failure or a software failure that resulted in no data being logged. To resolve these issues, a new circuit board was created with all major components on a single board instead of three surrounding the center sled. The center sled was 3D printed in ABS plastic and has integrated battery holders and internal slots for nuts to prevent stripping of the plastic.

Budget

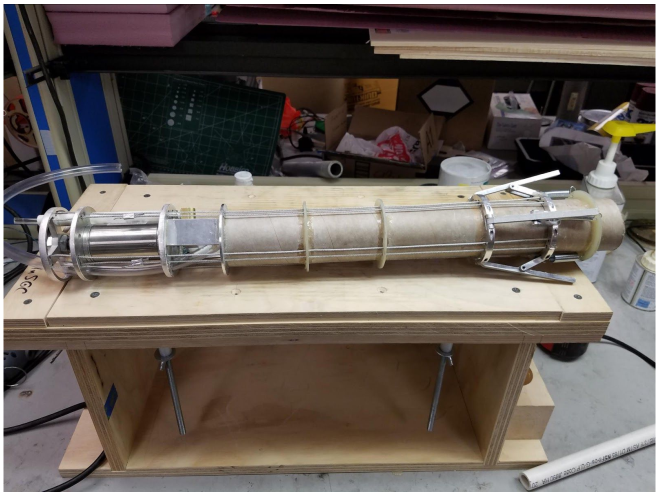
Part	**Vendor**	**Price**	**Quantity**	**Total**
Airframe				
3 inch Fiberglass Nose Cone 4:1 Ogive	Mad Cow	$ 54.95	1	$ 54.95
3 inch Fiberglass Airframe Tube 60 inch	Mad Cow	$ 99.00	1	$ 99.00
Fiberglass sheet for fins/bulkhead	McMaster-Carr	$ 22.32	1	$ 22.32
3 inch Fiberglass Coupler tube (for av bay) 9 inch	Mad Cow	$ 21.00	1	$ 21.00
3 inch Fiberglass Coupler tube (to access CO2 canister) 6 inch	Mad Cow	$ 14.00	1	$ 14.00
DP420 Epoxy	Amazon	$ 18.13	1	$ 18.13
Rail Guides	Off We Go Rocketry	$ 6.00	1	$ 6.00
Eye bolts				

Paint				
Motors and Casing				
Aerotech K1103X Motor	Off We Go Rocketry	$ 113.00	2	$ 226.00
Aerotech J415W Motor	Off We Go Rocketry	$ 93.00	2	$ 186.00
54/1706K Motor Casing	Peter's friend	$ -	1	$ -
Motor casing adapter	Wildman Rocketry	$ 58.00	1	$ 58.00
54mm Boattail retainer w/ cap	Apogee Rockets	$ 47.08	1	$ 47.08
54mm Motor Mount (with shipping)	Rocketarium	$ 14.40	1	$ 14.40
Competition funds		$ (100.00)	1	$ (100.00)
Recovery				
E-match	Off We Go Rocketry	$ 2.00	10	$ 20.00
68" Main Parachute	Rocketman	$ 68.00	1	$ 68.00
15" Drogue Parachute	Fruity Chutes	$ 53.62	1	$ 53.62
Shock cord	Fruity chutes	$ 9.70	1	$ 9.70
Flame Protectors	Provided by Dr. Flaten		2	$ -
Avionics				
HK Pilot Analog Pitot Tube	Hobby King	$ 21.28	0	$ -
Arduino Nano	Gravitech	$ 9.95	0	$ -
Adafruit 10-DOF IMU Breakout - L3GD20H + LSM303 + BMP180	Adafruit	$ 29.95	0	$ -
MicroSD card breakout board+	Adafruit	$ 7.50	0	$ -
Adafruit ADXL377 200G Accelerometer	Adafruit	$ 14.95	0	$ -
Avionics electrical wiring and connectors	Digikey	$ 61.97	1	$ 61.97
MicroSD Card w/ Adapter	Best Buy	$ 4.99	3	$ 14.97
Camera pods	U of M	$ -	2	$ -
Mobius Action Cam	Amazon	$ 75.00	1	$ 75.00
Raven3 Altimeter	Featherweight	$ 165.00	1	$ 165.00
Aerobrake				
Air Control Valve	Grainger	$ 74.05	1	$ 74.05
7/16" Air Cylinder	Grainger	$ 19.89	1	$ 19.89
CO2 Regulator	Rav X	$ 15.99	1	$ 15.99
3.125" Aluminum Rod	McMaster	$ 36.53	1	$ 36.53
.25x.25x36 aluminum bar	McMaster	$ 11.46	1	$ 11.46
C02 Canisters	Amazon	$ 29.99	1	$ 29.99
Push connect - female	Amazon	$ 2.95	1	$ 2.95
Push connect - male	Amazon	$ 2.95	2	$ 5.90

Push connect - elbow	Amazon	$ 5.20	4	$ 20.80
Pneumatic regulator	Amazon	$ 24.99	1	$ 24.99
Pipe plug	Amazon	$ 1.51	1	$ 1.51
Pneumatic tubing	Amazon	$ 6.74	1	$ 6.74
Steel wire				
Kit Rocket				
HV arcas kit	Apogee Rockets	$ 116.00	1	$ 116.00
H90 motor	Off We Go Rocketry	$ 22.00	1	$ 22.00
Motor casing	Off We Go Rocketry	$ 24.00	1	$ 24.00
Cap for casing	Off We Go Rocketry	$ 18.00	1	$ 18.00
Competition Costs				
Registration		$ 400.00	1	$ 400.00
			Total	$ 1,965.94

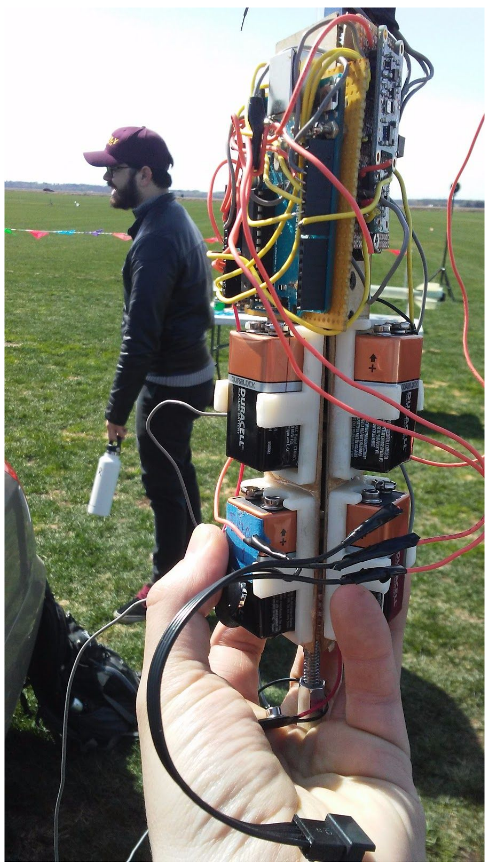
There have been a few changes to the budget since the PDR. This change was caused by the redesign of the aerobrake. The CO2 canisters, push connects, pipe plug, and regulator were added to the budget. This caused our budget to increase by $71.92. Items that were given to us are present in the budget, but the price is set to $0 because we did not need to buy them.

Construction of Rocket



Figures 1 (left) & 2 (right). Assembled motor tube and flaps with pneumatic cylinder (left) and preliminary pneumatic assembly (right).

Figure 3. Lower rocket assembly with completed pneumatics, redirect ejection tube, motor tube, and aerobrake supports.



Figures 4 (left) & 5 (right). Assembled avionics during testing on April 29 with arduino uno backup (left). Assembled lower rocket with aerobrake assembly, fins, and boat tail (right).

Parachute Deployment Monitoring System

In order to capture video of parachute deployment, upward and downward facing Mobius Action Cameras are used. The cameras are contained inside 3D printed pods which are attached to the body tube by epoxy and placed just above the avionics bay. Their placement on the rocket allows the cameras to verify parachute deployment and the lateral drag created by each pod is offset by the pod on the opposite side. The video is stored locally on microSD cards and captured at sixty frames per second at 720p to provide adequate video quality. The upward facing camera is a able to see the main cute deploy when the nose cone comes off and the downward facing camera is able to see the drogue chute deployment from just below the avionics bay. Both camera pods can be seen below in Figure 6 and Figure 7 is a still from video captured during a test launch showing both parachutes fully opened.

Figure 6 - Both camera pods are shown, the red and blue pod is the upward facing camera while the solid black camera pod is looking downward. The white object in the middle is the 3D printed holder for pitot tube.

Figure 7 - On board footage from both cameras showing drogue deployed and the main chute in the process of deploying. The cameras easily show both deployments without any complications.

Photos of Completed Rocket and Test Flight

Figure 8 - Rocket components during assembly at the launch site.

Figure 9 - Rocket fully assembled on launch pad shortly before ignition.

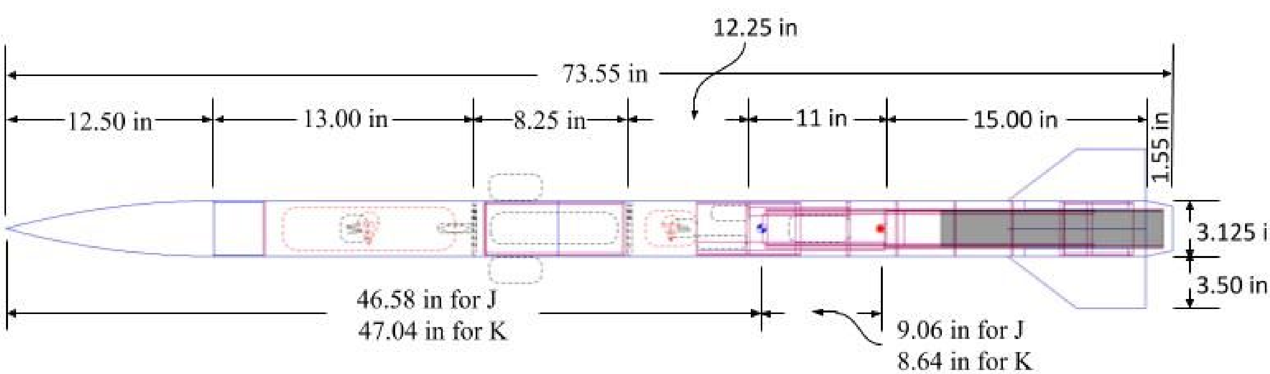


Figure 10 - Dimensions for the design's distinct sections are shown above the wireframe model. Dimensions for CG and CP relative to the nose cone are shown below the wireframe model.

Figure 11 - A single frame from 3 view video just after launch, top left video captured from an onboard camera looking downward, top right from an onboard camera looking upward, and the bottom image captured from ground level. [Link to the Youtube video]

Figure 12 - Recovery of the rocket after the launch. The rocket drifted roughly 400 meters from the launch location.

Test Flight(s) Report

Flight Performance

The rocket was successfully launched on April 29th in North Branch, Minnesota. We were able to recover the rocket with no damage to the structural components. Both up and down video were successfully captured and data was logged via the Raven3 altimeter. Our custom logging system as well as the Altimeter 2 logging system failed to gather information.

Drag System Performance

Drag system performance was not tested during the launch due to a lack of the higher powered motor. A future test launch has been scheduled for 10 May in order to test the drag system in flight and determine how effective the system is and if things can be altered to increase performance of the system or of the rocket as a whole. However, the system actuated extremely reliably on the ground and between expected forces on the flaps and the force output by the system indicate that the system should perform as expected during the launch.

Recovery System Performance

The recovery system worked nearly perfect. All chutes deployed and frame by frame analysis of the on board video footage shows the secondary charges for both the drogue and the main chutes also detonating. The drogue chute separation happened just after apogee as desired and fully deployed. The main chute separation occurred at 800 ft and seemed to fully deploy. However, upon review of the onboard data the descent velocity was determined to be just 29.1 ft/s, which was a significantly higher than expected descent velocity, given the size of the parachute and the weight of the rocket. This led to further analysis of the camera footage and it was determined that at least 2 of the shroud lines on the main chute became tangled upon release from the body tube. This caused the main chute to not fully deploy, but deployed enough to prevent the rocket from being damaged upon impact with the ground.

Variable	J415 Motor	K1103
Mass without motor (lb)	11.4	11.4
Motor mass (lb)	2.64	3.22
Total launch mass (lb)	14.04	14.62
Maximum altitude (ft)	2327	n/a
Maximum velocity (ft/s)	480	n/a
Maximum Acceleration (ft/s^2)	283	n/a
Descent Velocity (ft/s)	29.1	n/a
CG (in from tip of nose cone)	46.58	47.04

CP (in from tip of nose cone)	55.64	55.64
Stability Margin	2.84	2.7

Table 2 - Flight characteristics for the J415 motor and the K1103 motor. Only flight data (altitude, velocity, etc.) are recorded for the J415 motor, as the K1103 motor has not been test launched yet.

Plot of altitude, velocity, acceleration vs. time (actual and estimated) from Raven3, simulations, and own sensors if possible.

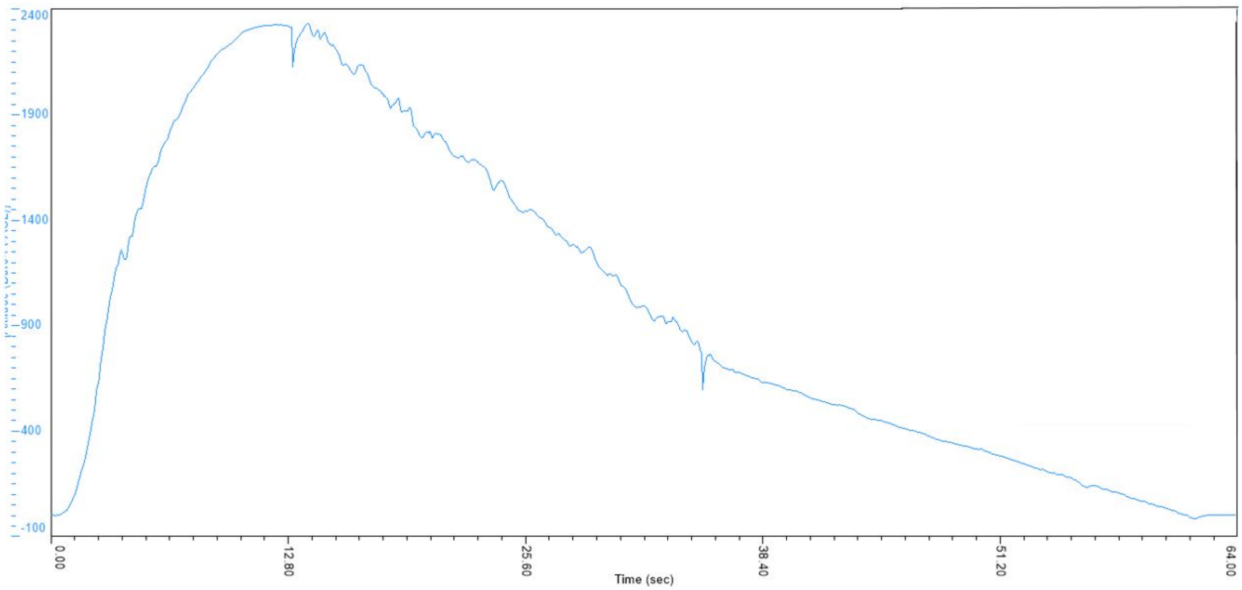


Figure 13 - Actual altitude vs time data gathered from the Raven3. The data gives a maximum altitude of 2327 ft and the entire launch from ignition to landing took just over 60 seconds.

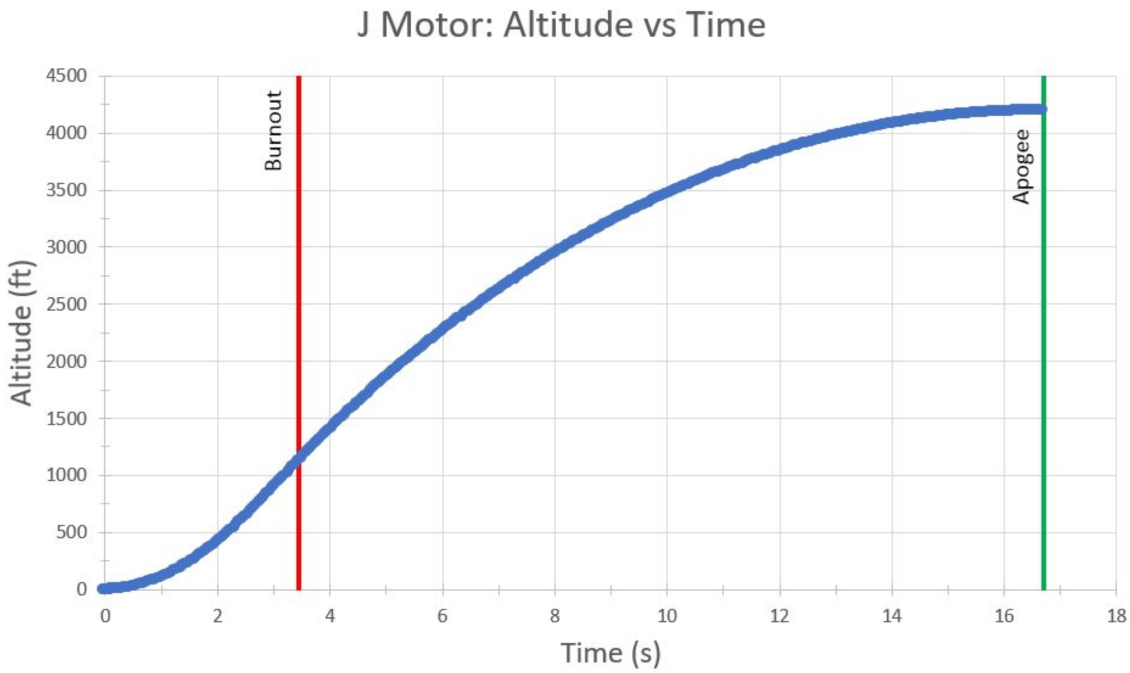


Figure 14 - Expected altitude vs time curve simulated using OpenRocket. Significant differences in apogee altitude between simulation and actual launch are discussed in the following section.

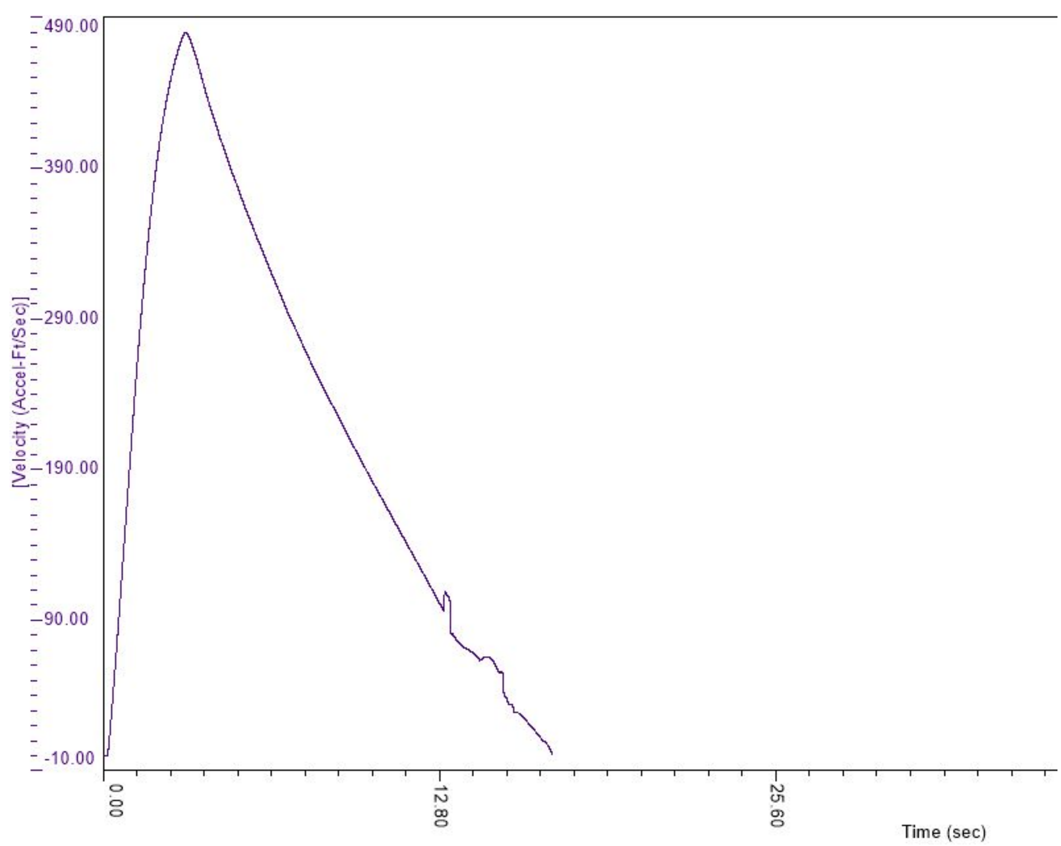


Figure 15 - Actual velocity vs time data gathered from the Raven3. The data gives a maximum velocity of 480 ft/s.

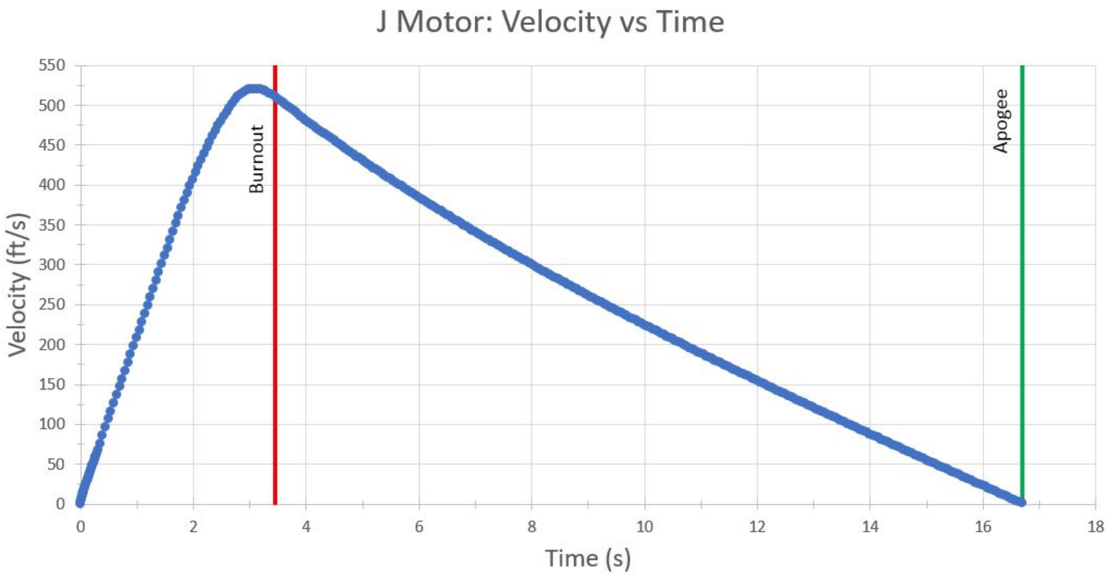


Figure 16 - Expected velocity vs time curve simulated using OpenRocket. Significant differences in maximum velocity between simulation and actual launch are discussed in the following section.

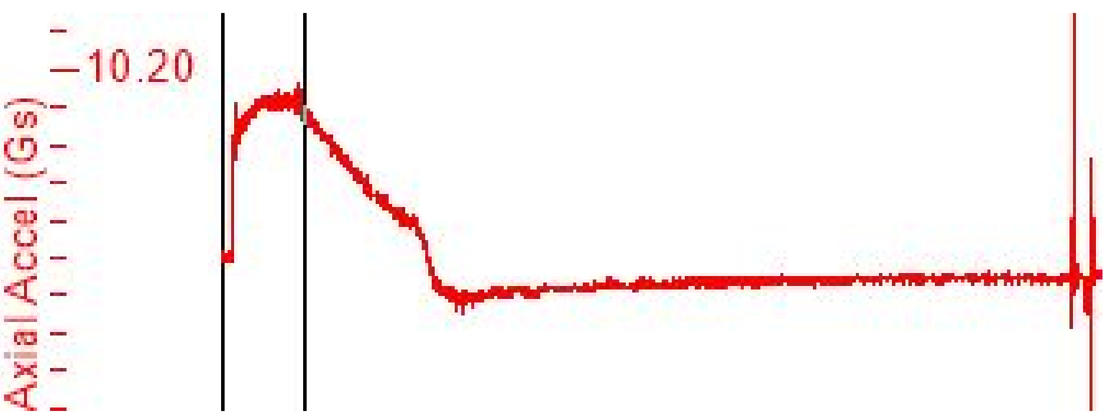


Figure 17 - Actual acceleration vs time data gathered from the Raven3. The data gives a maximum acceleration of 8.8 g (283 ft/s^2).

Discussion of Results

Overall our first test launch was successful but the results were cause for concern. First was our apogee height. Our predicted apogee in OpenRocket was 3646 feet while our actual 2327 feet. This is mostly caused by excess drag on the rocket. During the test flight, the flaps were not able to fully close which caused a significant amount of drag. What also did not go as planned was the data logging of our avionics. The arduino uno started to log data while it was on the launch pad, but sometime just before launch, the data logging errored out and didn't record any data from our test launch. It is unclear at this time what was caused the arduino to error out but there have been many successful bench tests of the arduino logging system.

Using OpenRocket for our simulations, this led to a max simulated velocity of 525 ft/sec while our actual max velocity as measured from the Raven3 came to be 490 ft/s. This lead to a small difference in velocity of 22 mph. Unfortunately because our custom avionics errored out while on the launch pad we are unable to compare the velocity to the Raven3.

Findings and Future Work

Key Findings

During the construction of the rocket, there were many things that ended up working well. What went well was constructing the airbrake assembly outside of the rocket and testing before inserting inside of the body tube. This allowed us to check the fitting and tolerance of all the parts and string the cables down around the motor mount easily and quickly. Having the airbrake assembly outside of the body tube allowed us to perform multiple tests easily and check to make sure that everything went well before everything was assembled into the body tube. Using the waterjet available to us allowed for quicker manufacturing of the aluminum bulkheads and aerobrake components.The waterjet was able to cut the aluminum flap mechanisms, aluminum bulkheads, fiberglass bulkheads, and fiberglass fins. This was a major time saver for manufacturing.

The avionics had an unexpected hardware failure of the arduino nanos. This caused us to have to rely on a full sized arduino nano which made the avionics a tighter fit in the tube than expected. The wiring did not change but the size constraints did. Also, it was quite a challenge to make battery holders that were able to fit within the avionics bay. We went through several iterations of battery holders until one was created that fit our tight size constraints. Overall, the construction of the rocket had its issues, but nothing that we couldn't overcome.

Some future work could include a redesign of the avionics bay to allow for better wiring and space management. Another redesign could include the lower flap mechanism to allow for easier closing of the flaps without the need for springs to pull them down toward the body tube.

Data from the J motor launch was used to modify the OpenRocket simulation in order to fit the simulation results to what was experimentally determined. This was done by increasing the Drag Coefficient of the rocket until the data from the J motor was similar to the test launch data with the same J motor. These parameters were then used to simulated K motor response, both with and without airbrake usage. Without the airbrake deploying the simulation showed that the K motor getting less than 4000 ft, which is shows that the aerobrakes will likely not have to slow the rocket down more than originally anticipated. The required aerobrake size to reach the J motor's altitude with the K motor did not increase, and the resulting simulation's altitude vs time data can be seen in Figure 18 below.

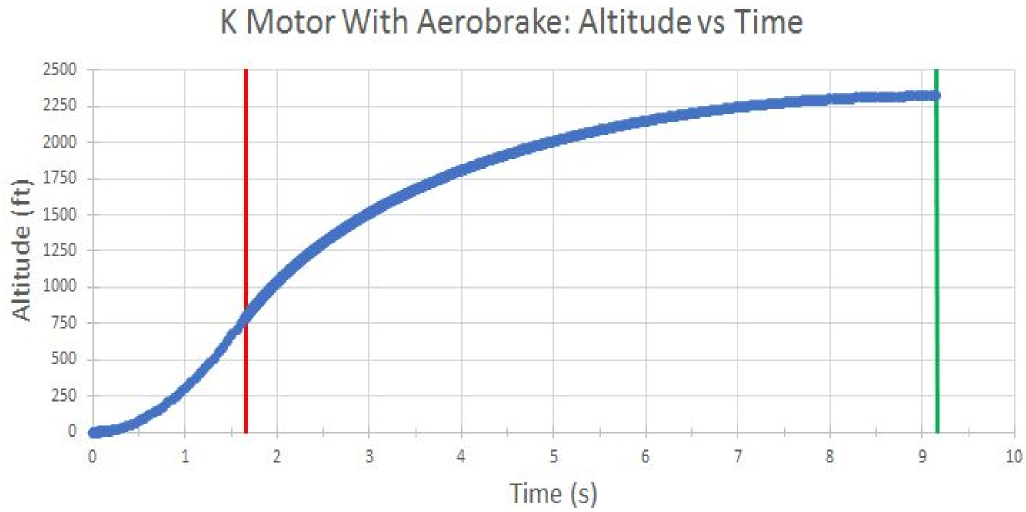


Figure 18 - Altitude vs time for the K1103 motor where the aerobrake was simulated to reach the 2327 ft altitude the J415 motor achieved.

Planned changes/improvements prior to competition flights

- Final descent rate
    - There was an issue with the descent rate on the main chute. The descent rate as measured by the Raven3 during our test flight came to be 29.1ft/s which is 5 ft/s faster than the competition requires. The likely cause of this is because when reviewing the video, it appeared that two of the shroud lines became tangled shortly after ejection. The shroud lines were tangled immediately after ejection from the body tube and never became untangled.
    - Some solutions to this include practicing different parachute packing techniques with testing on each technique. Also, orientating the parachute differently within the body tube would cause it to deploy differently. There was no problems getting the chute out of the body tube with ejection charges.Also, it could be that the winds at higher altitude that day caused a once in a lifetime failure. But this is unlikely, and a second test launch will shed light on the subject.
    - Another solution to the problem is simply to get a larger parachute. The rocket is heavier than the initial calculations, but when we estimated the weight of the rocket, we set in a factory of safety with regards to the descent velocity because we thought it might end up being heavier. Also, the equations of motion that were used to derive the diameter were linearized equation estimating no wind shear, which on the day of launch there was significant wind shear.
- Altitude Problem
    - There is the potential to change J motors to a higher impulse motor in an attempt to get a higher altitude, however this is dependant on availability of the new replacement motor and given the short amount of time between requesting the new motor and launch it seems unlikely that the new motor will be obtained. However, the new motor, an Aerotech J800, is shown to reach significantly higher than the current J-415 motor. The new motor should allow the rocket to get high

enough that points are not lost from dropping below the 3000 ft altitude.

    - Other solutions are being considered including cutting a hole in the body tube where the 1/16 inch wire can can be accesses and possibly manipulated to allow the flaps to sit flush with the body tube, thereby greatly reducing their drag during flight. Another possible option is trimming the flaps down in size, however, this will depend on the degree to which they affect the performance of the K motor, so this option will remain in limbo until the test launch on 10 May.

- Drag
    - The rocket in its current state has many areas of drag, also contributing largely to the lack of altitude that the rocket was able to achieve. The fact that the flaps did not close all the way and just overall having a bulky exterior contributed to the rocket not achieving the same altitude as predicted.
    - Some areas of improvement could be including fly-away rail guides leading to a more streamlined body tube. Also, we will be working to make the flaps sit flush with the body tube reducing a great amount of drag. We have also been thinking about moving the camera pods inside the body tube. But this is unlikely because the quality of video would be greatly reduced.

Appendix

Pre-Flight Procedures

Name: ______________________ Date: ____________ Time: ___________ Launch #: ____

❏ 1. Test all battery voltages.
❏ 2. Inspect all wiring connections in altimeter bay.
❏ 3. Connect batteries to the internal controls.
❏ 4 .Inspect all shock cord connection points.
❏ 5. Inspect the Pitot tube.
❏ 6. Inspect static pressure ports in altimeter bay.
❏ 7. Make sure camera pods are properly mounted.
❏ 8. Insert cameras into pods and secure covers.
❏ 9. Screw caps on avionics bay.
❏ 10. Install ejection charges on altimeter bay topped off with a small amount of wadding and a strip of tape over the top.
❏ 11. Insert altimeter bay into upper section of body tube and secure with rivets.
❏ 12. Inspect and fold main parachute into upper body tube.
❏ 13. Insert nose cone into upper body tube and attach with shear pins.
❏ 14. Make sure all special components are secured.
❏ 15. Mate aerobrake fin section to lower body tube with shear pins.
❏ 16. Fold drogue parachute into the lower body tube.
❏ 17. Mate lower body tube to avionics bay with shear pins.
❏ 18. Make sure the top rail guide is aligned with the bottom rail guide.
❏ 19. Record motor class and full mass.
    ❏ Motor class:________
    ❏ Mass:________g
❏ 20. Install motor.
❏ 21. Place rocket on launch rail.
❏ 22. Turn cameras on.
❏ 23. Arm custom avionics.
❏ 24.Wait for custom avionics initialization beeps.
❏ 25. Arm Raven3 altimeter.
❏ 26. Listen for Raven3 beep sequence.
❏ 27. Visual inspection of rocket exterior.
❏ 28. Photograph of rocket on pad with team.
❏ 29. Launch.
❏ 30. Maintain visual of rocket during airtime.

Post-Flight Procedures

Name: ______________________ Date: ____________ Time: ___________ Launch #: ____

❏ 1. Locate rocket through visual means or radio beacon.
❏ 2. Take a picture of the rocket.
❏ 3. Inspect rocket for any external damage.
❏ 4. Disarm altimeters.
❏ 3. Turn off cameras.
❏ 5. Return rocket to launch site.
❏ 6. Inspect avionics and pitot tube for damage.
❏ 7. Remove cameras from pods.
❏ 8. Remove avionics bay.
❏ 9. Disconnect battery from electronics.
❏ 10. Retrieve all flight data from Raven3, custom logger, and Altimeter 2.
❏ 11. Record empty motor mass.