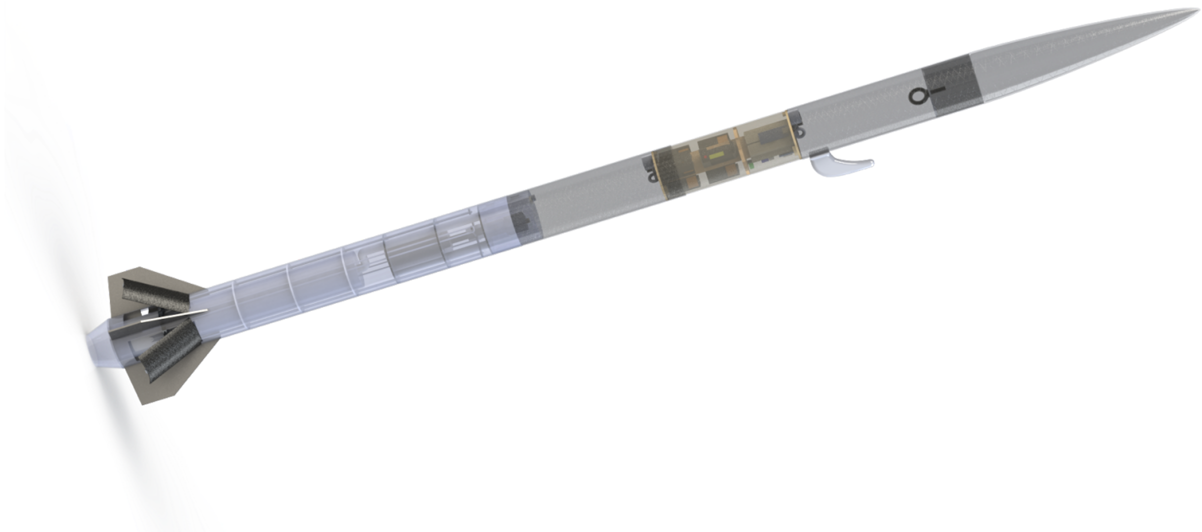

Preliminary Design Review

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 69.48 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. 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 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. A Featherweight Altimeters Raven III 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.

Introduction

The Space Grant Midwest High-Power Rocket Competition provides students with a chance to apply engineering and design skills. The objective of this year's competition is to design an adaptable, high-power rocket that will fly to the same altitude on two different motors (one I-class and one J-class, or one J-class and one K-class). A custom, non-commercial avionics package must be designed to directly measure velocity versus time. Up and down video must also be recorded in order to verify that the drogue and main parachutes are deployed from the primary source instead of by backups. To accomplish these objectives, an aerobrake was designed to slow down the rocket when it is launched with the higher impulse motor. The performance of the aerobrake was estimated using OpenRocket. Custom components were designed in SolidWorks. A pitot tube will be used to measure velocity versus time. Two cameras will be attached to the rocket using 3D-printed pods.

Rocket Mechanical and Electrical Design

Dimensional Specifications

Main Body

The designed rocket has an outer diameter of 3.125 inches and has peripherals that extend to a maximum distance of 5.062 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 (13.54 in), the main parachute bay (11.00 in), the electronics bay (8.25 in), the drogue parachute bay (9.34 in), the pneumatic housing (10.89 in), the aerobrake/fin section (15.00 in), and the boat tail (1.55 in). The nose cone selected is a hollow o-give 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 o-give design allowed the rocket to travel to the highest altitude possible.

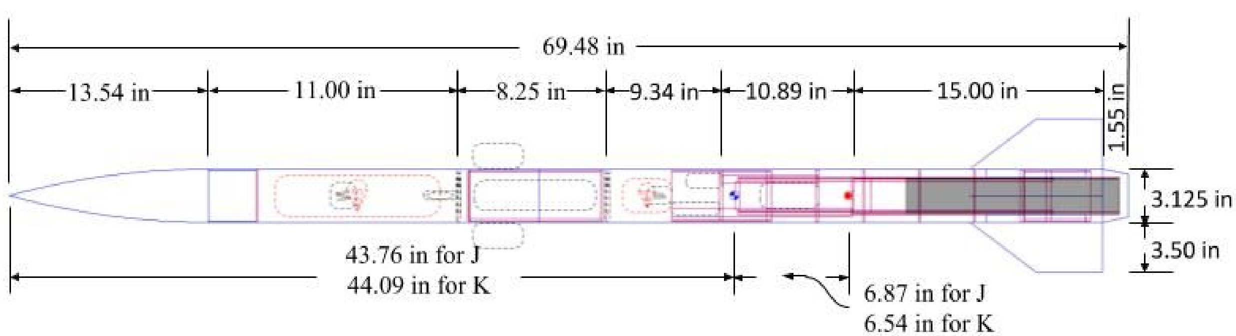

Figure 1 - Dimensions for the design's distinct sections are shown above the wireframe model. Dimensions for CG and CP relative to the nose cone are shown below the wireframe model.

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 will be attached to the bulkheads inside the rocket at two points; one point is near the bottom of the fin while the other attachment point is near the top of the fin. The fins are designed to pass through slots in the airframe and will have internal fillets attaching them to the motor mount tube. They will also be epoxied to the bulkheads and will have aerodynamic fillets on the surface of the fin.

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 wire system and pneumatic linear actuator. Four fiberglass flaps are attached to the rods to provide a drag surface.

This pneumatic system is powered from a small 12 gram CO_2 cartridge that is routed through a regulator to a three-way two-position solenoid control valve. Once the solenoid valve is activated, CO2 travels into the 1 inch stroke pneumatic cylinder which in turn actuates the 3/32 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 CO2 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 CO2 canister, the pressure regulator, the solenoid control valve, and the adjoining air hoses. This is held within a smaller 3 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 Designed for Safe Flight and Recovery section later in this document. The pneumatic accesories bay is shown in Figure 2.

Figure 2 - The Pneumatic accesories bay containing the Solenoid control valve (center), the CO2 pressure vessel (right), and the motor eject redirection tube (top right).

Figure 3 - The pneumatic cylinder bay containing the pneumatic cylinder (center), the motor eject redirection tube (right), safety cowl (left), and movement arm/carriage (top).

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 3/32 inch looped wire segments. The pneumatic cylinder bay is shown 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 4. 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.

Figure 4 -The flap linkage connected to the pneumatic system via wire system. Linkage is connected to the flaps by movement arm pinned to both the bottom ring support and the main flap spar. Flaps are attached to main flap spar by screws at either end of the spar.

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. As discussed later in the Analysis of Anticipated Performance section, 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.

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 7” 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 parachutes will each be protected from the ejection charges by an 8” and 10” Nomex flame protector. 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.

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. Additionally, 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 Raven III 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.

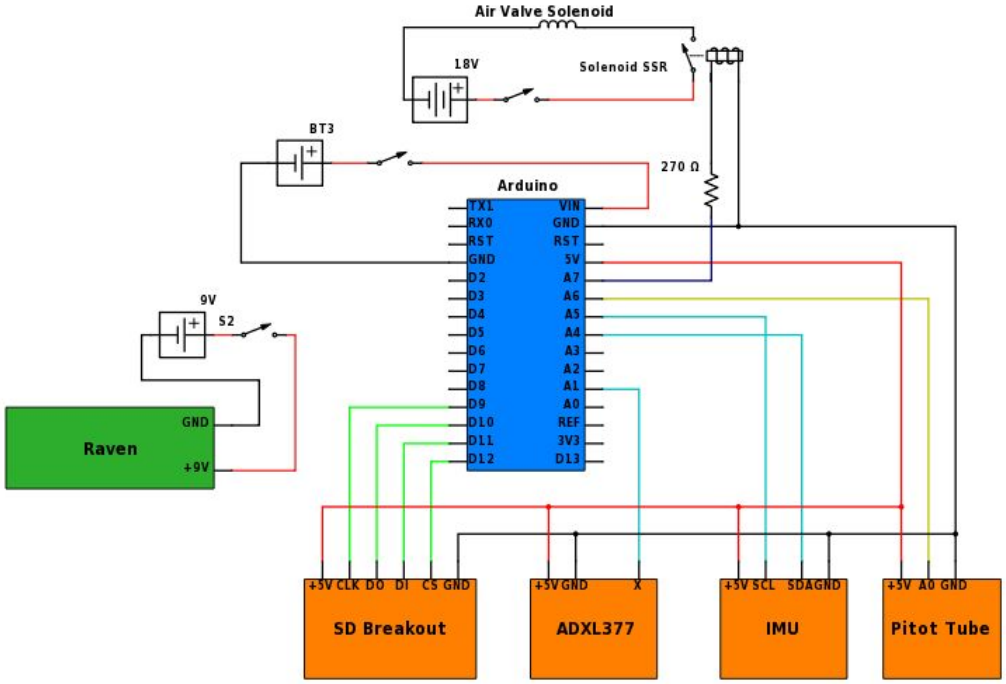

Figure 5 - The wiring diagram for our avionics package. The system uses three sets of 9V batteries to power three separate systems, the Raven III (green), the Arduino (blue) and sensors, and the air valve solenoid which uses two 9V batteries in series for the 18 volts required by the valve.The four orange sensors from left to right are the SD breakout board, the 200g accelerometer, the 10-DOF inertial measurement unit, and the pitot tube. The solenoid valve is at the top of the diagram and is powered through a solid state relay.

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, Raven III, and Altimeter 2 will be placed. Wood was chosen for most components due to its electrical isolation. The endcaps are held together using a threaded rod 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.

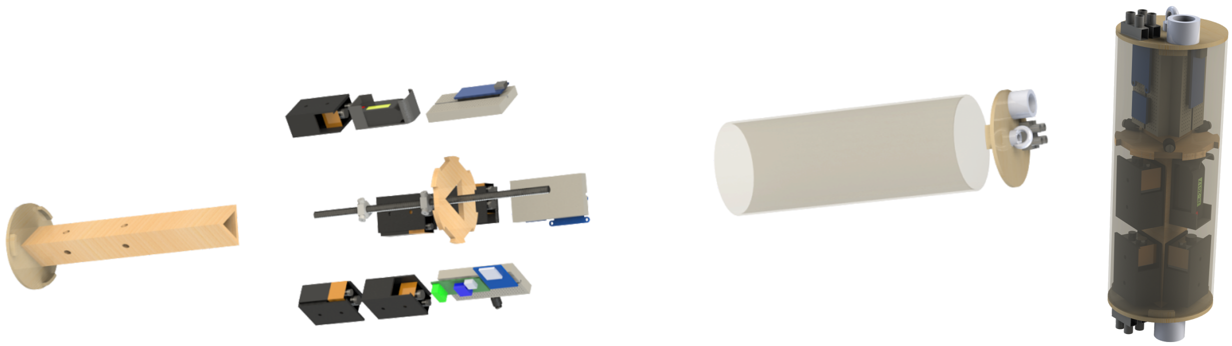

Figure 6 - Avionics bay rendering of the exploded view (left) and assembled view (right). The wooden sled can be seen on the far left, the top endcap and fiberglass tube (set transparent for internal visibility) on the right, and the sensors, batteries, threaded rod, rod braces, and center bulkhead in the middle. The assembled view shows how all components fit together.

Mounting of up/down-looking video

In order to capture video facing both up and down, a camera fastened inside a pod will be used. The camera will be a Mobius Action Camera contained inside a 3D printed pod on the right. They will be attached to the body tube by fasteners and placed just outside the avionics bay. Their placement on the rocket shall be such that the drag created by each pod is offset by the pod on the other side. The video will be stored locally on microSD cards and captured at sixty frames per second at 720p to provide adequate video quality.

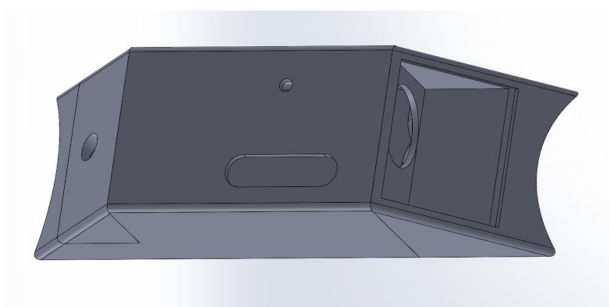

Figure 7 - Camera pod to be attached to exterior of rocket

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 2 and Figure 3.

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, and aluminum bulkheads/centering rings
- 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
    - Epoxy solenoid valve to bulkhead
    - Screw eye bolt into bulkhead
    - Epoxy coupler to body tube
    - Attach NPT tubing
    - Attach regulator to solenoid valve
- 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

Structural analysis of scratch-built parts

SOLIDWORKS structural simulations were performed on the aerobrake system components to determine final component sizes that can successfully withstand the drag forces from deploying the system. The forces on our aerobrake system were calculated to be quite small compared the the structural strength of our chosen materials. The moving components of the aerobrake are machined from 6061-T6 aluminum which offers high strength while being lightweight. The attached flaps which act as the drag surface are made from fiberglass.

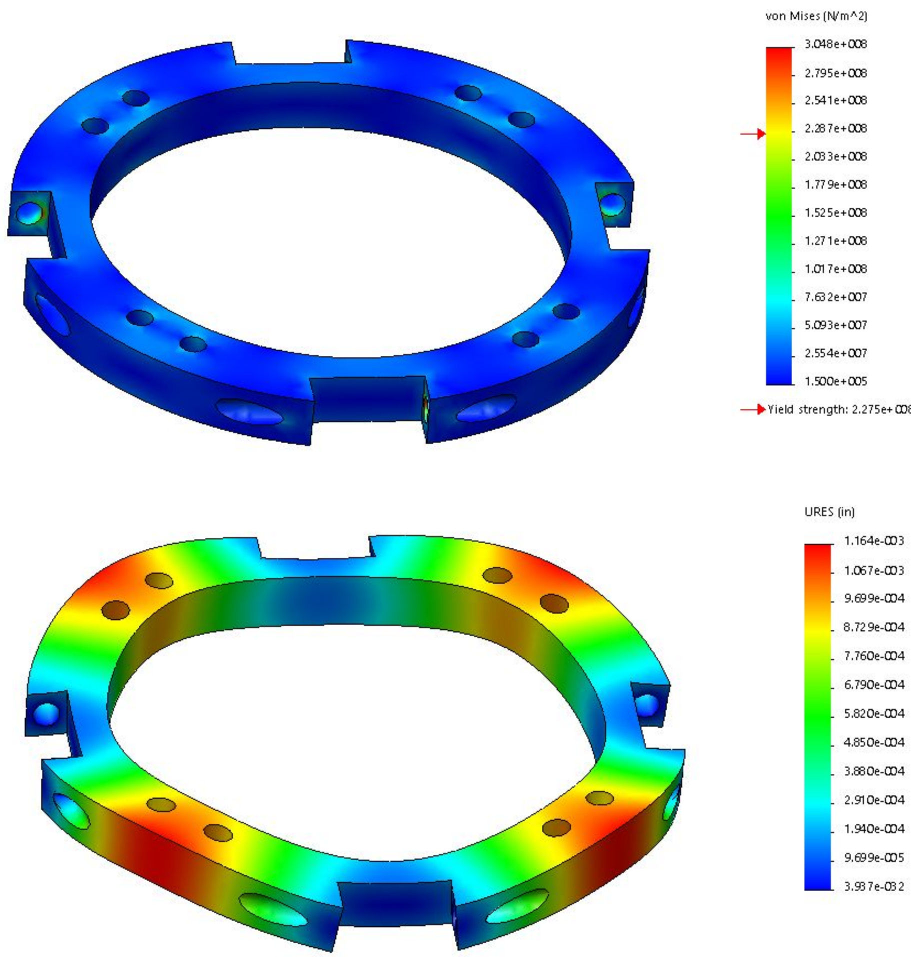

Figure 8 - An example SOLIDWORKS force simulations of the aerobrake bulkheads, using 300 pounds of force applied upwards beneath each of the four sets of holes used to contain the wire to lift the ring. Fixtures were added at the edges of the pin holes. Although, this isn't ideal, it is a close approximation. The top image shows von Mises stress with peak measured stress (factoring out fixtures) to be 76 MPa. The bottom image shows deflection with maximum deflection of 0.002in, it is also exaggerated 100x to give a visual representation of how it would bend. The results are well within a factor of safety of 3.

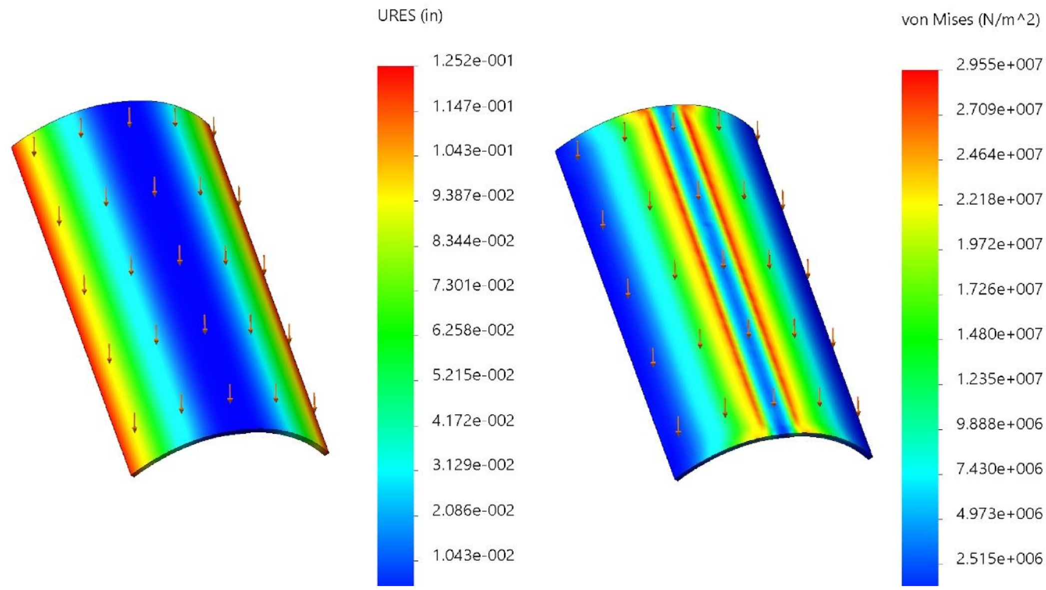

Figure 9 - Fiberglass drag fins with 65 pounds of force and projected onto the surface normal to how the air will be flowing around it. The left image shows deflection in inches and the right shows von Mises stress in Pa. A maximum deflection of 0.13 inches and stress of 29.5 MPa were measured from this simulation.

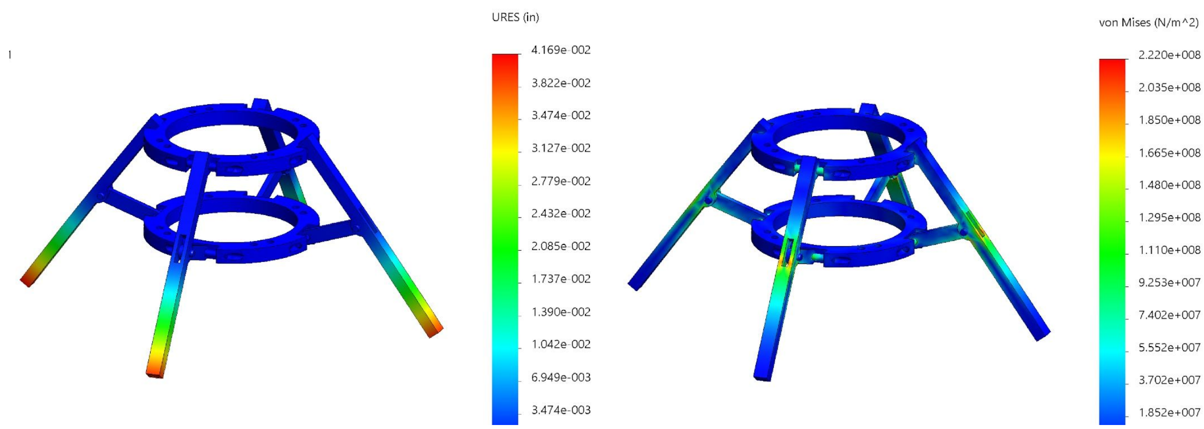

Figure 10 - 6061-T6 aluminum flap linkage assembly with 80 pounds of force projected onto the main support spar normal to the surrounding airflow. The left image shows deflection in inches and the right shows von Mises stress in Pa. A maximum deflection of 0.04 inches and stress of 220 MPa were measured from this simulation.

Overall risk mitigation analysis

Safety of those around the rocket and the rocket itself must be the highest priority. Safe handling of the motors and the pyrotechnics is of great concern. Steps will be taken to train every team member on the risks of high-power rocketry. Great care has been taken to ensure the reliability of parachute deployment, overall stability of the rocket, and functions of the avionics. The avionics code will go through a stringent test procedure to ensure all bugs are worked out of the system before the test flight. To guarantee parachute deployment, a redundant ejection charge system will be put in place. Not only will the Raven be deploying four ejection charges, but the motor also has a delay backup charge that will make sure the chutes will deploy. There will be many bench tests conducted on the drag system and parachutes. These tests will be conducted to simulate the g-forces, stresses, and drag that will be felt on the rocket during launch. Once testing of the rocket systems has been completed, a full-scale test flight of the rocket will be conducted using both motors.

Analysis of the Anticipated Performance

Simulation Assumptions

Simulations were done using OpenRocket, a free open source software for high-powered rocket modeling and simulation. The software uses a Runge-Kutta 4 numerical integration to calculate data used in the simulations. There is no way to deploy a system mid flight in OpenRocket, but there is a need to do this to model the deployment of the flaps of the aerobrake. The solution that was determined was to model deployment of a parachute with variable diameter at a set time post launch. OpenRocket equated the deployed parachute to a simple increase in area which could be related back to projected area of the aerobrake flaps. Variability in the parachute size allowed the determination of minimum altitudes attainable with different K-class motors. Given limitations in the maximum reasonable size of the aerobrake certain motors were ruled out as it would be impossible to slow them down enough to reach the same altitude with both J and K motors. This method does limit the ability to "retract" the parachute, so it simulates the aerobrake deploying just after engine burnout and remaining open until apogee, while the aerobrake will need to retract before the rocket reaches apogee.

Most simulations were done from the North Branch launch location, its respective altitude, an assumed wind of 6.56 ft/s (2 m/s), and a temperature of 75° Fahrenheit. The exception to these external parameters can be found below in the Environmental Conditions Analysis section.

Flight Analysis

Flight analysis was performed on multiple motors until the best two were chosen based on all factors in the figure of merit equation for the competition. Table 1 shows the resulting values of the J motor and K motor with and without the aerobrake deploying.

Estimated Values	J Motor	K Motor With Brake	K Motor No Brake
Apogee (ft)	4198	4200	7285
Peak Velocity (ft/s)	520	870	870
Peak Acceleration (ft/s^2)	248	765	765

Table1 - Apogee, Peak Velocity, and Peak Acceleration values obtained through OpenRocket for the J motor and the K motor with the aerobrake deployed and without it deployed.

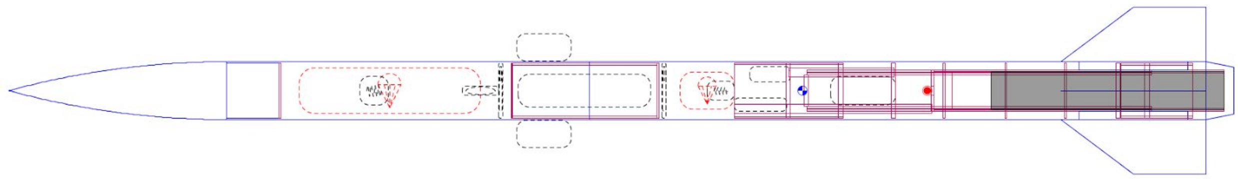

Figure 11 - OpenRocket model with J motor configuration. The red dot is Center of Pressure and the blue dot is Center of Gravity. These locations and respective stability values can be found in the Stability Analysis section below.

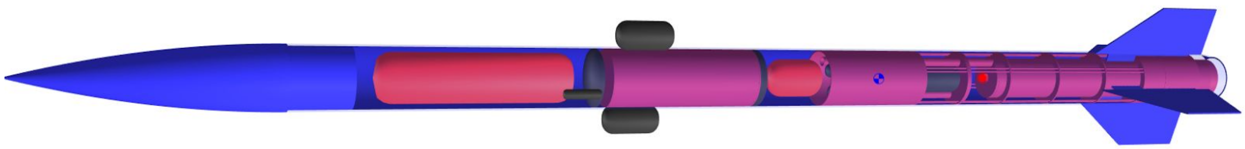

Figure 12 - A 3D rendering of the OpenRocket model in Figure 11.

J Motor

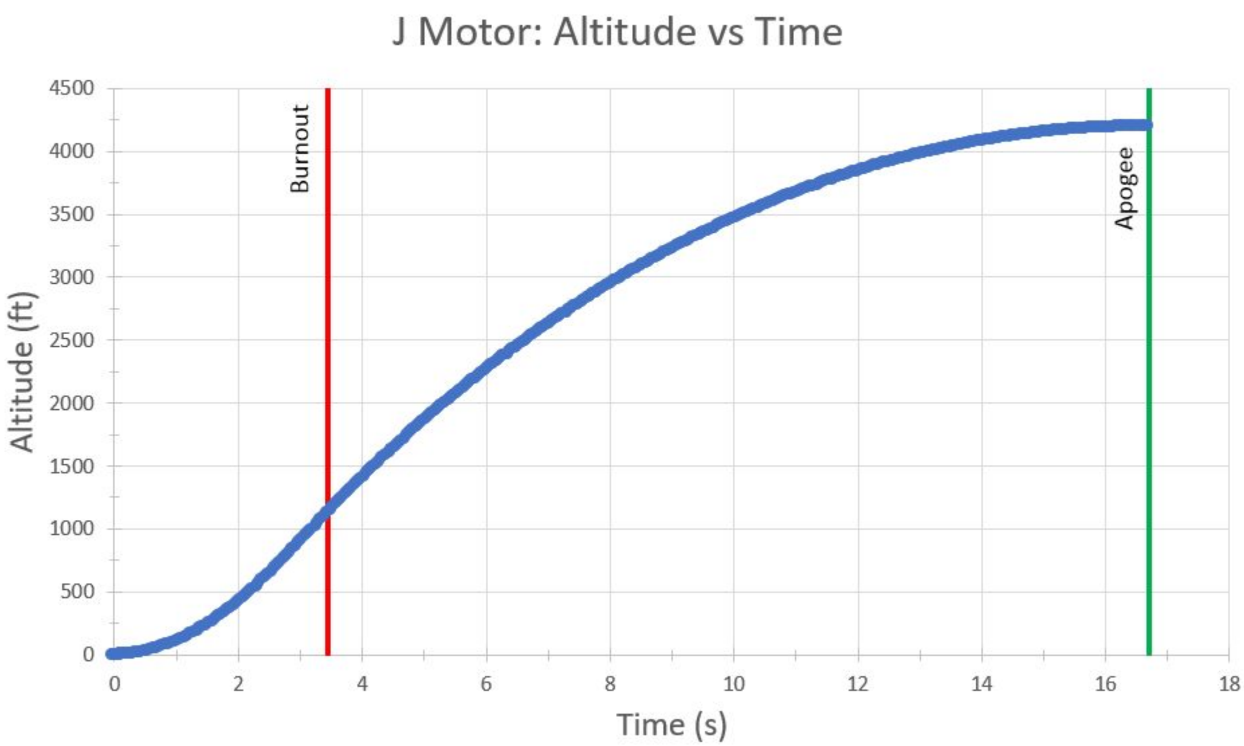

Figure 13 - Altitude vs Time graph for the J motor. Burnout occurs at 3.45 seconds and the rocket peaks at just under 4200 ft.

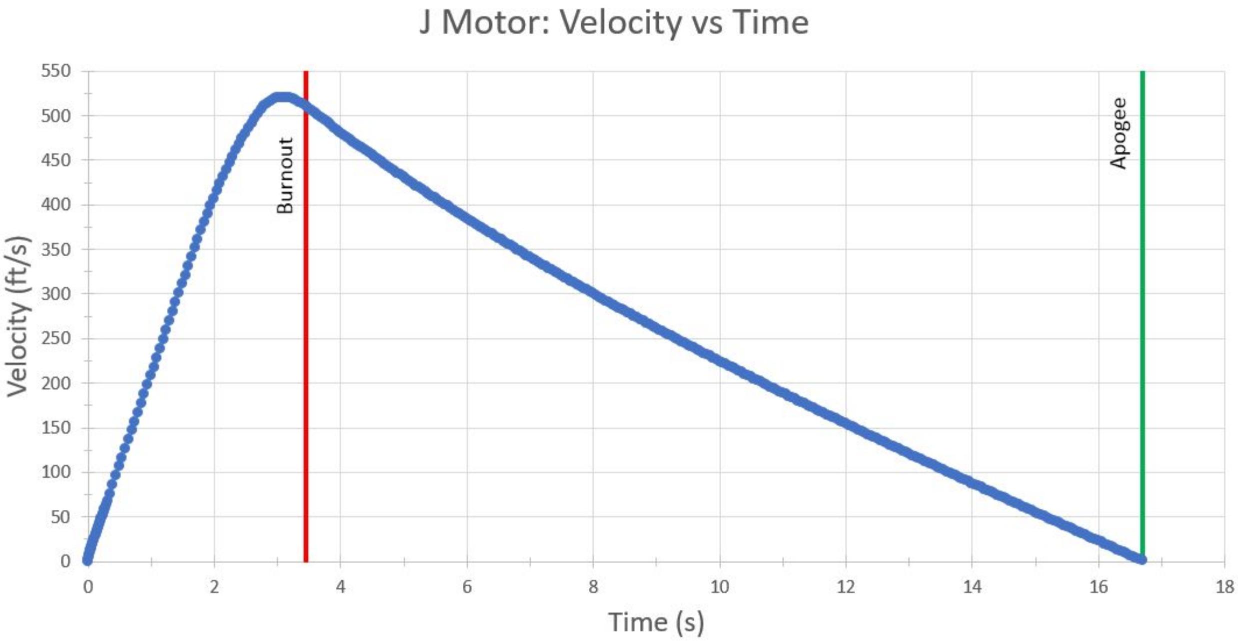

Figure 14 - Velocity vs Time for the J motor. Burnout occurs at 3.45 seconds and the rocket peaks at 520 ft/s during ascent.

K Motor

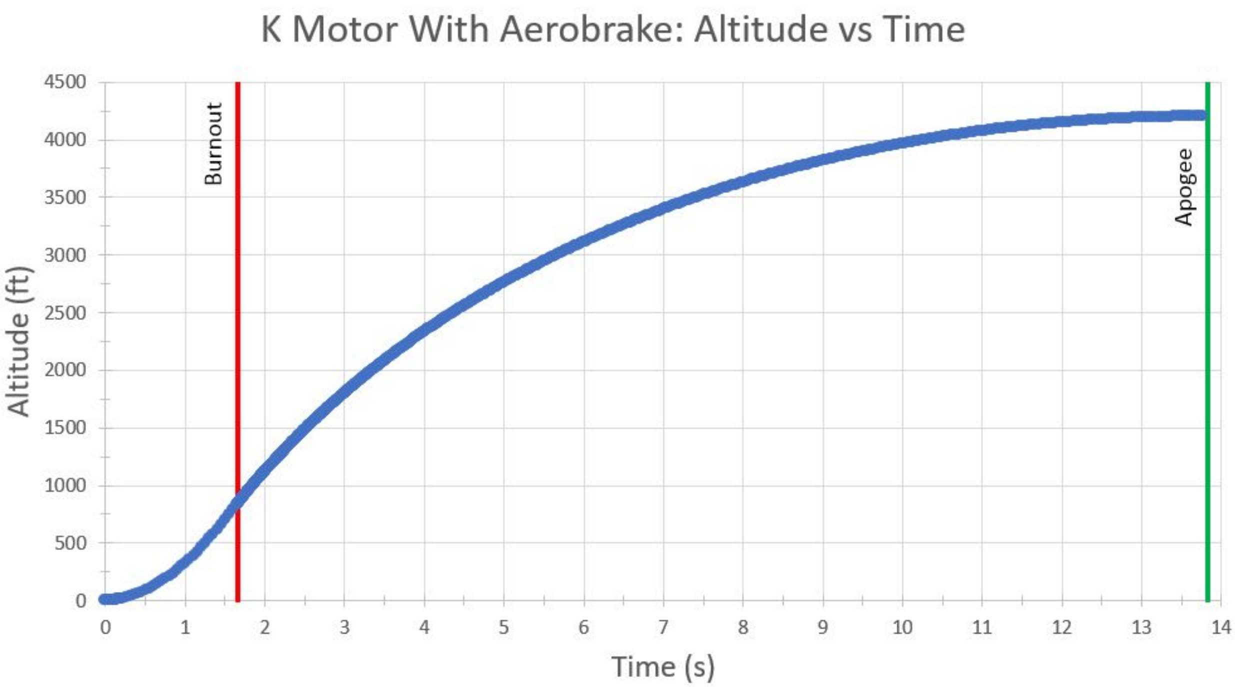

Figure 15 - Altitude vs Time graph for the K motor, with the deployment of the aerobrake. Burnout occurs at 1.65 seconds, the aerobrake remains open between burnout and apogee when the rocket peaks at 4200 ft.

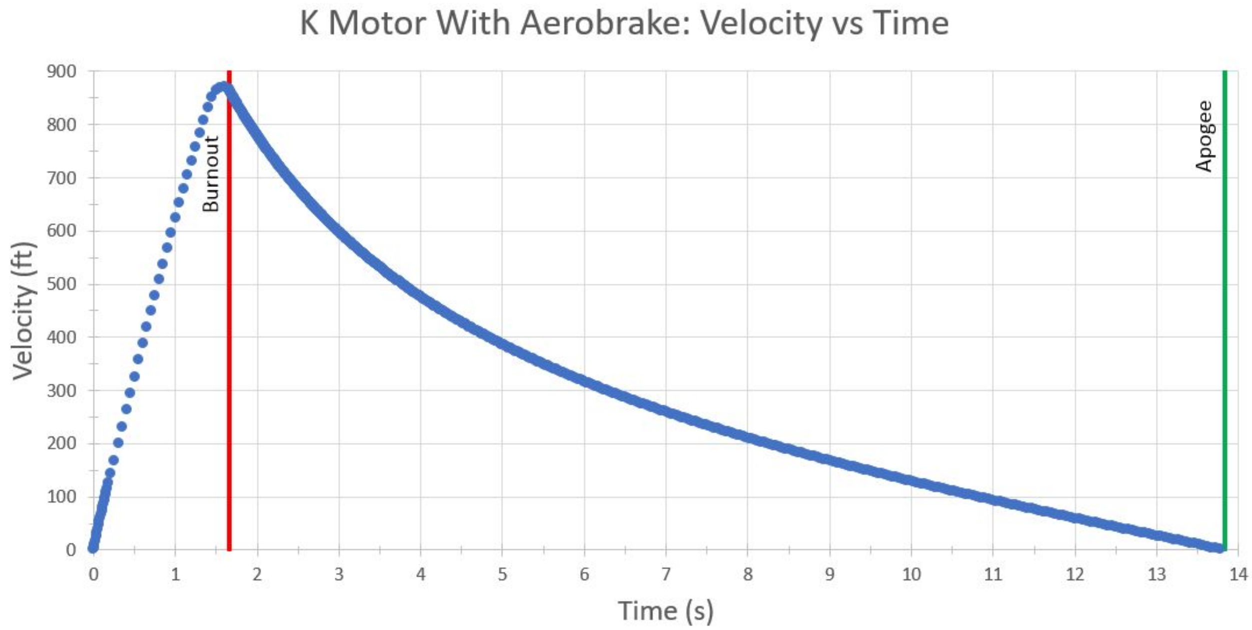

Figure 16 - Velocity vs Time for the K motor with the aerobrake deployed. The rocket peaks at 870 ft/s during ascent, burnout occurs at 1.65 seconds and the aerobrake remains open from burnout to apogee.

Figures 13 through 16, as well as Table 1, were created using data obtained from the OpenRocket model found in Figures 11 and 12, using methods described in the Simulations Assumptions section.

Recovery Analysis

The drogue ejection charge is set to deploy at apogee, and the main is set to deploy at 800 ft above ground. The rocket will be carried by both the drogue and main chute for a calculated total time of 95 seconds. Using force equations based on a parachute of diameter 15", the rocket is calculated to descend at 75 ft/s while being under the influence of the drogue parachute and using a parachute of diameter 6', the rocket is calculated to descend at 15 ft/s during the main parachute deployment. A table for the drift values during descent for varying wind speeds and drogue velocities were is seen below. As the table demonstrates, for a drogue descent velocity of 75 ft/s, the drift for any allowable crosswind value is within an acceptable range.

Drift values for varying drogue and wind velocities					
Drogue Descent Velocity	V_x = 0 ft/s	V_x = 5 ft/s	V_x = 10 ft/s	V_x = 15 ft/s	V_x = 20 ft/s
@ V_i = 65 ft/s	D = 0 ft	D = 513 ft	D = 1026 ft	D = 1539 ft	D = 2052 ft
@ V_i = 75 ft/s	D = 0 ft	D = 467 ft	D = 933 ft	D = 1400 ft	D = 1867 ft
@ V_i = 85 ft/s	D = 0 ft	D = 431 ft	D = 863 ft	D = 1294 ft	D = 1725 ft

Table 2 - Possible drift distances of rocket caused by different descent velocities and wind speeds. V_i is the rocket descent rate. V_x is the horizontal wind speed. D is the drift distance.

Stability Analysis

Stability analysis was performed using OpenRocket, Figure 11 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 8 inch root chord, 4 inch tip chord, and a 3.5 inch height with a 37.14 degree sweep angle. All angles follow the as provided in the Fin Design section.

OpenRocket Values	J Motor	K Motor
CG (in from tip of nose cone)	43.76	44.09
CP (in from tip of nose cone)	50.63	50.63
Stability Margin	2.16	2.05

Table 3 - Center of Gravity (CG), Center of Pressure (CP), and Static Margin (Stability Factor) are given as provided from OpenRocket values.

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 take a significant movement in the CP to cause it to go beyond the safe margin of 5. Once the rocket is built, the location of CP will be verified through experimental tests in the University of Minnesota wind tunnel.

Environmental Conditions Analysis

Environmental conditions can play a significant factor in general rocket performance, but things such as windcocking can also lead to increased time to track down a rocket or likelihood of losing a rocket. In order to understand these effects, OpenRocket was used to run simulations with increased variability in the environmental factors, particularly the wind speed and air temperature. Because the launch takes place in Minnesota, where the weather is extremely variable, temperatures of 65, 75, 85, and 95 degrees Fahrenheit were tested with wind speeds of 6.56, 10, 15, and 20 feet per second for each temperature and each motor. Tables 4 and 5 show that wind speed should have negligible effect on the rocket's peak altitude. However, it will affect peak altitude by relatively small amounts since a 15 ft/s increase in wind speed will result in a reduction in peak altitude by about 0.375% of the peak value, for both J and K motors. The variances in temperature has similar effects on the peak altitude, but has a more substantial effect on the K motor (still less than half a percent for a 10 degree temperature change). When performing the rocket's test flights in April, the temperature change relative to the official competition launch in late May will be factored in, but the probable increase in temperature will only help increase peak altitude and improve the rocket's performance.

J Motor			
Temperature (°F)	Wind Speed (ft/s)	Altitude (ft)	Velocity (ft/s)
65	6.56	4177	520
65	10	4170	520
65	15	4169	520
65	20	4136	519
75	6.56	4198	520
75	10	4189	520
75	15	4178	520
75	20	4160	519
85	6.56	4216	521
85	10	4208	521
85	15	4199	521
85	20	4180	520
95	6.56	4235	522
95	10	4228	521
95	15	4215	521
95	20	4194	520

Table 4 - J motor altitudes and velocities obtained given different temperatures and wind speeds. The data shows that velocity is relatively unaffected by both wind and temperature. However, altitude is uniformly affected by wind speed regardless of temperature, and a 20 degree decrease in temperature causes about the same as a 15 ft/s wind speed increase (a 40 ft decrease in peak altitude).

K Motor			
Temperature (°F)	Wind Speed (ft/s)	Altitude (ft)	Velocity (ft/s)
65	6.56	4164	869
65	10	4161	869
65	15	4157	868
65	20	4149	869
75	6.56	4200	870
75	10	4198	870
75	15	4195	870
75	20	4188	869
85	6.56	4237	871
85	10	4234	870
85	15	4232	870
85	20	4227	870
95	6.56	4272	871
95	10	4270	871
95	15	4264	871
95	20	4260	871

Table 5 - K motor altitudes and velocities obtained given different temperatures and wind speeds. The data shows that velocity is relatively unaffected by both wind and temperature. However, altitude is uniformly affected by wind speed regardless of temperature, and a 10 degree decrease in temperature causes the altitude to change by almost 3 times as much as a 15 ft/s wind speed increase (a 35 ft decrease in peak altitude).

Innovation

For this rocket, a unique pneumatic drag system was developed. This system utilizes compressed $C0_2$ to deploy flaps to slow down the rocket. Because of the pneumatic nature of the system, some clever regulation systems were developed to ensure the correct pressure needed to deploy the flap system. A unique cable and bulkhead system was developed to bring tension from the pneumatic cylinder to the actual drag system at the tail end of the rocket. Aerodynamic camera pods were developed to take up and down video simultaneously while adding a small drag footprint. A custom avionics package was created to measure velocity using a pitot tube.

Safety

Designed 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.

Due to 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.

Material Handling Procedures

During construction and launch of the rocket, all hazardous material will be handled and stored with care. As with the nature of high-power rocketry, there are many hazardous materials that will be used. The team plans to read all MSDS and become aware of all hazards that may come about while working on the rocket. As a team, we will follow every rule outlined by the NFPA, TRA, and NAR to provide a safe and incident free launch and construction. The rocket motor will be assembled and handled with the supervision of a trained and experienced faculty member. Their insertion of the rocket motor into the rocket will be done while under the supervision of a high-power certified faculty member. The ejection charges will also be handled in the same careful manner. They will be inserted into the rocket while not connected to any power source.

Pre- & Post- Launch Procedures

Pre-Flight Checklist

❏ 1. Test battery voltages of new Duracell batteries.

❏ 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. Install main chute ejection charge on top of altimeter bay with a full cap of pyrodex topped off with a small amount of wadding and a strip of tape over the top.

❏ 10. Insert altimeter bay into upper section of body tube and secure with rivets.

❏ 11. Inspect and fold main parachute into upper body tube.

❏ 12. Turn on radio beeper and insert in nose cone. Check connection with ground unit.

❏ 13. Insert nose cone into upper body tube and attach with shear pins.

❏ 14. Make sure all special components are secured surely.

❏ 15. Mate aerobrake fin section to lower body tube with shear pins.
❏ 16. Fold drogue parachute into the lower body tube.
❏ 17. Install drogue ejection charge.
❏ 18. Mate lower body tube to avionics bay with shear pins.
❏ 19. Make sure the top rail guide is aligned with the bottom rail guide.
❏ 20. Record motor class and full mass.
  ❏ Motor class:________
  ❏ Mass:________g
❏ 21. Conduct RSO safety checks.
❏ 22. Get pad assignment from LCO.
❏ 23. Install motor.
❏ 24. Place rocket on launch rail.
❏ 25. Turn on camera.
❏ 26. Arm custom avionics. Listen for beeps.
❏ 27. Arm Raven3 altimeter.
❏ 28. Listen for correct beep sequence.
❏ 29. Visual inspection of rocket exterior.
❏ 30. Photograph of rocket on pad with team.
❏ 31. Launch
❏ 31. Maintain visual of rocket during airtime.

Post-Flight Checklist

❏ 1. Locate rocket
❏ 2. Take a picture of the rocket
❏ 3. Inspect rocket for any damage external damage
❏ 4. Disarm altimeters
❏ 5. Inspect avionics and pitot tube for damage
❏ 6. Remove cameras from pods
❏ 7. Turn off cameras
❏ 8. Disconnect battery from electronics
❏ 9. Retrieve all flight Data
❏ 10. Record empty motor mass
❏ 11. Proceed to next flight

Budget

Part	Vendor	Price	Quantity	Total
Airframe				
3 inch Fiberglass Nose Cone 4:1 O-give	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	$ 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
Paint/primer	Home Depot	$ 4.00	2	$ 8.00
Eyebolts	Home Depot	$ 1.50	4	$ 6.00
Linear Launch Rail Lugs (1” 80/20 rail)	Off We Go Rocketry	$ 6.00	1	$ 6.00
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	Borrowed from a 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	8	$ 16.00
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 Air Speed Sensor And Pitot Tube Set	Hobby King	$ 21.28	1	$ -
Arduino Pro Mini 328 - 5V/16MHz	Spark fun	$ 9.95	1	$ -
Adafruit 10-DOF IMU Breakout -	adafruit	$ 29.95	1	$ -

L3GD20H + LSM303 + BMP180				
MicroSD card breakout board+	adafruit	$ 7.50	1	$ -
SparkFun FTDI Basic Breakout - 5V	Spark fun	$ 14.95	1	$ -
Subtotal (above components with shipping)				$ 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
0.125" Steel wire	McMaster	$ 10.96	1	$ 10.96
.25x.25x36 aluminum bar	McMaster	$ 11.46	1	$ 11.46
Ejection charge redirect tube	Home Depot			
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	$ 1,894.02