Preliminary Design Report

2017 NASA's SPACE GRANT MIDWEST HIGH-POWER ROCKET COMPETITION

MILWAUKEE SCHOOL OF ENGINEERING

Raider Rocketeers

TEAM MEMBERS:

Team Mentor: Frank Nobile - maxq3@aol.com
Fauclty Advisor: Dr. Anand Vyas - vyas@msoe.edu
Team Lead: Nicholas Paul - pauln@msoe.edu
Sam Nolan
Eric Rasmussen
Muffi Kaiser
Joshua Furey
Alex Van Dyck

10 March, 2017

TABLE OF CONTENTS:

EXECUTIVE SUMMARY

The team utilized computer programs such as Solidworks, MatLab, and Openrocket to design a rocket that would meet all the objectives of the competition. A four inch diameter body tube was chosen to provide adequate room for electronics and internally housed drag fins. The final rocket length from the tip of the nose cone to the base of the fins is 65 inches and weighs 9.5 pounds. Using Openrocket a projected apogee of 5,200 feet was determined for an Aero-Tech J415W-6 motor, and for an Aero-Tech K540M-2 motor a projected apogee of 6,500 feet without the use of the drag system. Once at apogee a drogue parachute will deploy allowing the rocket to descend at 30 feet per second until 1000 feet where the main parachute will be deployed and the rocket will land at a velocity of 10 feet per second.

The drag system designed utilizes a gear train connected to servo motor to deploy the drag fins after motor burnout and then retract them before apogee. An Arduino Mega will be used to control the deployment of fins. The Mega will then use data from a Raven 3 as well as an accelerometer to predict the future path of the rocket and adjust the fins deployment accordingly. To monitor the deployment of the fins and parachutes two cameras will be mounted to rocket looking both up and down outside the airframe. Once the rocket is launched a transceiver will be used to monitor the status of the rocket realtime as well as sending back the rockets current longitude and latitude for physical tracking and recovery.

PROBLEM STATEMENT

The objective of the 2017 Space Grant Midwest High-Power Rocket Competition is to design and construct an “adaptable” single stage, dual deploy high-power rocket system that will fly to the same highest possible altitude on two motors (one I-class and one J-class, or else one J-class and one K-class) that are as different as possible from one another. The rocket must be recovered safely and in flyable condition. The students must predict the rocket’s flight performance (with each selected motor) and construct a non-commercial on-board data collection package for the rocket that will directly measure velocity versus time, for comparison with data collected by a commercial rocketry altimeter, as well as sense and log airframe separation and parachute extraction from the airframe for both drogue and main parachute deployments, and also collect up and down video from outside the airframe to certify expected (i.e. primary, not backup) drogue and main parachute full deployment [1].

ROCKET AIRFRAME AND ELECTRONICS PAYLOAD

Assumptions

In designing the rocket, several assumptions had to be made. The main assumption came from Barrowman’s theory (Appendix B), which assumes that the rocket is thin in comparison to its length, and that the fins are thin flat plates. The other design assumptions and limitations came from the competition handbook and problem statement.

Airframe Design

Figure 1 below is a CAD drawing of the rocket with some basic dimensions. The caliber of stability for this design was computed to be 2.6.

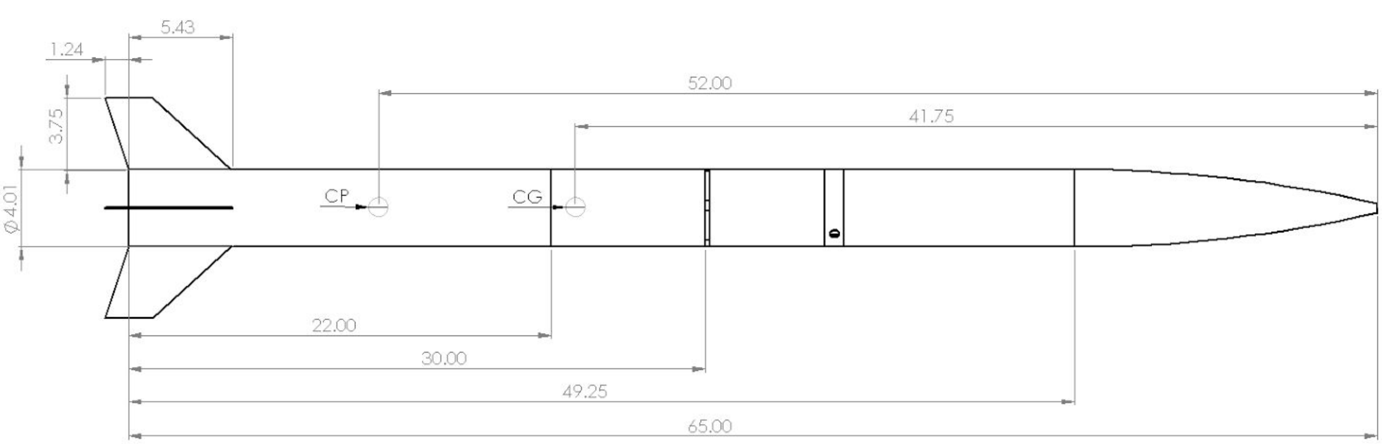


Figure 1: Rocket CAD Drawing

Body Tube

Several material choices were considered for use in the body tube, such as fiberglass, PVC, cardboard LOC, and blue tube. To aid in the selection process, design constraints such as the ease of construction, price, and strength were established. Blue tube was selected based on team members' previous experience with the material in 2016 WSGC Collegiate Rocket Competition, as well as its low price point and high strength.

The dimensions of the body tube were chosen to satisfy a few different factors in the rocket design. The size of the drag flaps needed, as well as the ability to fit a large variety of electronics inside the body weighed heavily on this decision. Another factor was that the rocket needed to fit two parachutes for the dual deployment. Based on these requirements a 4 inch diameter body tube was chosen.

The length of the body tube depended on the size and spacing of the electronics, as well as where the rocket would separate for the drogue and main parachutes to deploy. To help optimize the length of the body tube, the rocket was modeled in a CAD program (Solidworks) to ensure that all the parts would fit. The length was then verified in Openrocket, a rocket simulation and design software. It was determined that the rocket would be separated into three sections: the nose section, the main body, and the lower body. These three sections give the body a length of four feet, and overall rocket length would be 65 inches.

Nose Cone

For the nose cone, the Intelli-Cone from Public Missiles was selected. This nose cone is made from plastic, and and is specially made to house an electronics bay. This was chosen because the direct velocity measurement system that is going to be used will be housed in the nose. The nose cone is ogive shaped, with an exposed length of 16.75" and a 2.1" X 14" payload bay.

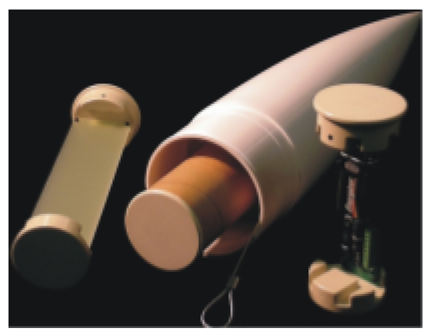


Figure 2: An example of Public Missiles Intelli-Cone

Fins

Barrowman's theory postulates that the fins of the rocket are the main component that determines the center of pressure. Because of this the stability of the rocket is mainly dependant on the fins. Their shape was designed using research, past experience, and an iterative design method in OpenRocket.

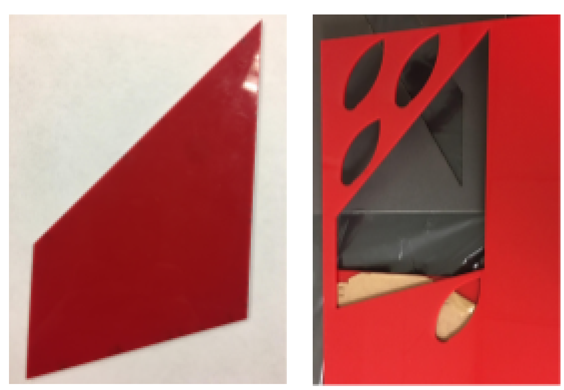


Figure 3: Example fin (left) example sheet after the laser cutting (right)

The material for the fins was chosen to be G10 fiberglass and it is 0.125” thick.. The fins were laser cut using MSOE’s own CO_2 laser cutter. Figure 3 on the right shows the fin and the skeleton the fin was cut from. The optimum design includes a root chord of 5.6 inches, a span of 4 inches, a tip chord of 2.5 inches, and a sweep angle of 42.1°, as shown in figure 4. 4 fins were chosen so the drag system design, which has 4 flaps, can be evenly spaced in between the fins. This is important so that the rocket does not lose stability in flight due inadequate airflow over the stability fins.

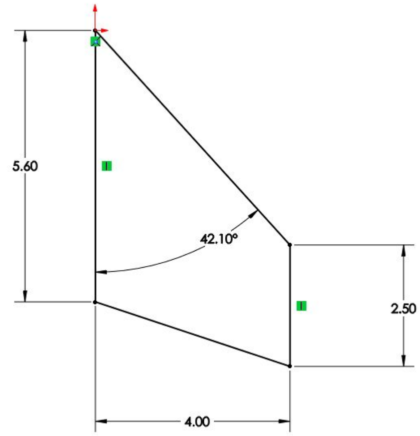


Figure 4: A dimensioned sketch of the stability fin

Pressure Relief

In order to assure accurate altimeter pressure readings, and to prevent the parachute deployment charge from causing structural damage to the airframe, it is imperative that a pressure relief system be in place to maintain equilibrium between the electronics bay environment and the surrounding atmosphere. The relief system is also necessary in order for the parachute to deploy at the correct altitude, since this process is driven by the altimeter’s readings.

This system consists of a hole drilled through the fuselage section of the electronics bay. Determining the correct size for the relief hole depends on the size of the fuselage, the volume of air inside the electronics bay where the altimeter is housed, and the pressure gradient that will develop between the surrounding atmosphere and the electronics bay as the rocket ascends in altitude. As a rule of thumb, the equivalent area of a ¼ inch hole should be used for every 100 cubic inches of electronics bay internal air volume.

Another consideration which can substantially affect altimeter readings is the effect of crosswinds during flight. To minimize this error, three or more holes can be drilled at even angles around the fuselage, so that pressure differences from crosswinds can easily pass through the electronics bay. When crosswinds are not negligible, this will result in more accurate altitude measurements than a single pressure equalization hole would provide.

For this rocket design, two separate electronics bays will need pressure equalization: the main bay housing the altimeter for parachute deployment, and the upper nose cone bay housing the velocity measurement apparatus. For simplicity, the air volume inside the electronics bays will be the volume of an empty cylinder and an empty cone, respectively (this will result in a conservative pressure relief hole size, since some of the air is actually displaced by the payload). The volume equations for the electronics bays are shown below.

Cylindrical Bay:

$$V = 2\pi r^2 l$$

where V is the volume, r is the radius of the cylinder and L is the length of the cylinder.
Nose Cone Bay (modeled as a triangular cone):

$$V = \frac{\pi r^2 l}{3}$$

where r is the radius of the base circle, and L is the length from the tip to the center of the base circle.

Given the above volume equations, the dimensions of the respective electronics bays, and the pressure hole size rule, the size of pressure equalization holes to be used for this design are shown in table 1 below.

Table 1: Pressure Equalization Design Parameters

	Cylindrical Bay	**Nose Cone (Conical) Bay**
Internal Volume (in^3)	188.5	70.2
Single Hole Area (in^2)	0.47	0.176
Triple Hole Area (x3) (in^2)	0.157	0.059

Electronics Bay Structure

The electronics bay will be a Madcow Rocketry electronics bay designed for a four inch body tube. It will be used as a coupler for the top section of the rocket to the middle section of the rocket. The bay uses two metal rods to hold a sled on which the electronics are mounted to. Each side of the sled can hold electronics, and can be accessed by removing the nuts on top of each rod and sliding the sled out. The sled and bulkheads are made from wood, with the upper bulkhead containing a steel eyelet to attach the parachute to. The electronics bay has been used by team members in previous builds and has performed as intended and without issue.

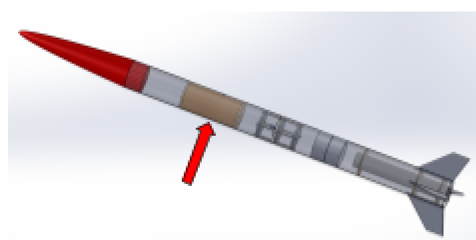


Figure 5: The location of the electronics bay

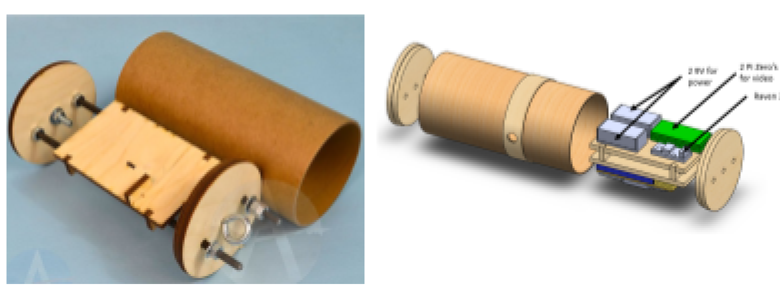


Figure 6: The structure and layout of the electronics bay [10]

Recovery System Design

The competition guidelines state that the rocket must use a dual deployment parachute system, consisting of both a drogue and main parachute. The main parachute is located in the top section of the rocket, between the nose cone and the main body, while the drogue sits in the bottom between the main and motor sections. The drogue parachute is deployed at apogee, and is only intended to partially slow the rocket's descent. This is to ensure the rocket does not drift far during its fall, while allowing enough time for the main parachute to be deployed at a lower altitude. As per the design constraints, this altitude will be 500 feet. An altimeter will be used deploy both the parachutes at the correct times.

To physically track where the rocket is at all times in the flight, a on-board GPS is going to be used. The GPS will calculate the current coordinates and transmit the data back down to the ground through a transmitting XBee wireless transceiver. On the ground, a computer will receive the GPS data through another XBee transceiver and processed using MATLAB.

Drag System Design

When creating drag system, the several different types of drag must be considered. The drag types are: skin-friction drag, pressure drag, form drag, and profile or boundary layer drag. Skin-friction drag is friction between the rocket's body and the flow of air. Pressure drag is the resultant force of normal pressures on the body. These two components of drag share some relation and both have to be accounted for in a rocket's flight. Form drag is due to the shape of the body and the streamlines it creates. A streamline occurs when a fluid is traveling with a tangential velocity to a path of the fluid flow, in other terms: it is the event that occurs when air is traveling over an object at a certain velocity. Boundary layer drag or profile drag is caused by the both the form drag and the resultant boundary layer. A boundary layer is an event that occurs when a body travels through a viscous medium, and its thickness is varied by the speed of the fluid. The fluid closer to the body moves slower than the fluid on the edge of the boundary layer. [5]

All of the proposed designs used one or a combination of the previously stated drag types. To aid in the decision making process, a decision matrix was created. The weights in the matrix were determined their importance to the design. The most important category was the reliability of the system, as it needs to perform across multiple launches and work the same each time. The next highest categories were complexity, deployment time, and drag produced. All of these categories are relevant to the performance of the rocket. The complexity of the system was also weighted high due the short amount of time given for repairs between launches at competition.

Table 2: Drag System Decision Matrix

Decision Matrix (Drag System)								
	Design Criteria [Weighting Scale]							
Design	**Weight [1]**	**Complexity [2]**	**Price [1]**	**Reliability [3]**	**Deployment Time [2]**	**Drag Produced [2]**	**Size [1]**	**Total Points**
1	4	4	4	4	3	2	3	41 / 60
2	2	1	2	2	3	5	2	30 / 60
3	3	3	4	4	3	2	4	39 / 60
4	2	1	2	3	5	4	2	35 / 60
5	2	3	3	3	2	4	2	34 / 60
6	3	3	5	3	4	2	3	38 / 60
7	4	3	3	3	5	4	3	43 / 60

Sketches of all the following designs can be found in Appendix C.

1) The first design was a slider concept. This design used four drag fins that would be extended by linkages connected to a servo motor in the middle. The benefit to this system is that all the fins would extend evenly perpendicular to the rocket instead of at an increasing angle away from the rocket also the weight is centralized. The downside is that the drag fins would not be very large relative to the rockets cross section.

2) The second design used a mechanism similar to what is found in a scissor lift. A motor actuates the linkages to extend the out body panels which causes drag. The benefit of this system is the amount of surface area the body panels create. The downside of this system is the complexity of the linkages and the size of the overall design.

3) The third design is similar to the second design where the body panels are used to create drag. In this design a piston is used to actuate the body panels. The disadvantages to this design included the size and weight of the piston needed to actuate the body panels.

4) The fourth design was a set of drag fins that would be deployed from under the stability fins. The advantage of having this system would be that the drag system would be compact and blend in with the rest of the rocket. The disadvantage is that size and location of the system. To have the system under the stability fins it is competing for space with the motor mount assembly.

5) The fifth design used an inner cylinder that when spun would deploy the drag fins. The advantage to this design is that it leaves room in the middle of the rocket for electronics, making

the rocket more compact and lighter. The disadvantages of this system are the size of the drag fins being too small and the weight of the system not being centralized.

6) The sixth design uses and internal rod with gear teeth on each side and linkages attached to body panels. When the motors are activated the rod will be pushed up or down which extends or retracts the body panels using the linkages. The advantages to this system are that by using body panels instead of internal fins we can obtain a larger surface area to create drage. The downside of this method is the size of the system and its weight.

7) The seventh design uses springs and electromagnets. The magnets are used to open the drag system by repelling each other, when the magnets are turned off the spring will close the system. The benefits are that there are almost no moving parts, the downsides are the power needed and the weight of the system.

8) The eighth design uses a central motor with a belt connecting to all 4 of the fins. When the motor spins the belt will rotate the fins out from the body at an increasing angle. The benefits of this system is that the motion of all four fins is consistent and there is only one part of the system that translates the force to the fins which makes it easy to replace. The downside is that the belt is not as precise as a gear and that the belt is easier to break under tension.

9) The ninth design is the drag system that the team decided on. It uses one central gear attached to a motor, this is then connected four outer gears that are used to rotate the fins out. The benefits of this system are that the gears are very reliable and translate force from the motor more effectively. The drawbacks of this system are that the gears are heavier and and will need to be custom made.

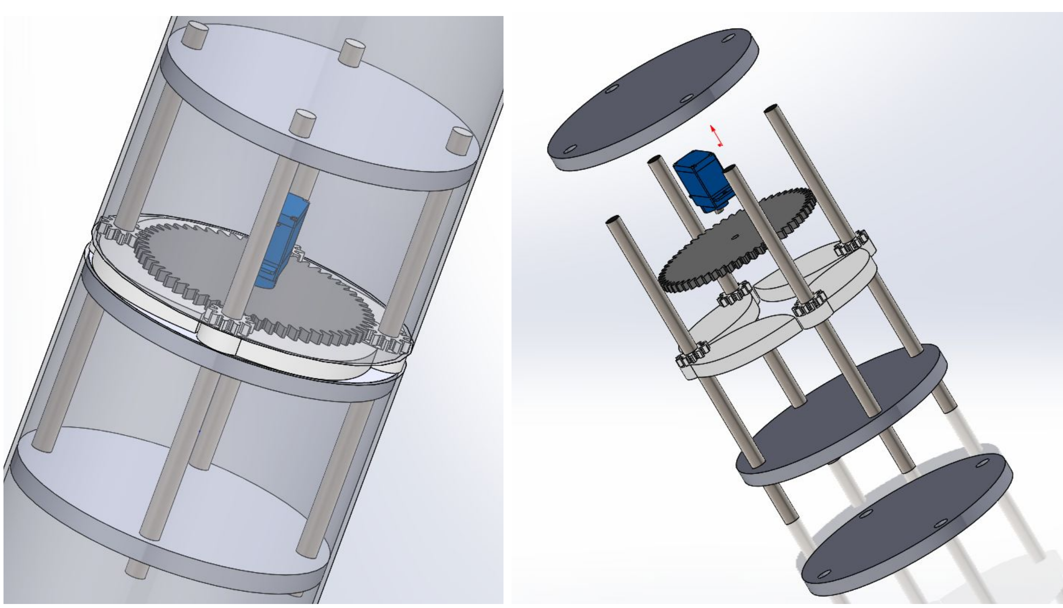


Figure 7: Assembled (left) and exploded (right) views of the drag system

The above figure shows the assembled and exploded views of the drag system. The servo motor is placed in the middle of the main drive gear, keeping the weight balanced and providing maximum torque. The drive gear then contacts the four gears on each of the drag fins, allowing all four fins to rotate at the same time and to the same angle. The rocket body is cut to allow the drag fins to deploy. To ensure the structural stability of the body tube, four threaded rods will be used, and will be attached to the body using bulkheads. These bulkheads will be epoxied to their corresponding body tube segment in a similar fashion to the motor mount. To access the drag system, nuts on top of each rod will be unscrewed to allow separation of the top bulkhead and body tube, thus exposing the motor and gears. This design allows for easy access in case of repairs and provides the maximum surface area for the fins.

Drag Fins

The only scratch built part of the rocket were the drag fins. The drag fins will be 3D printed using a selective laser sintering method and printed in a 30 percent glass filled nylon material.To analyse the integrity of the design, a Solidworks Simulation static analysis was utilized. A pressure of 22psi was calculated as the maximum load a drag fin will need to withstand during flight, and a safety factor of 2 was used in the analysis.

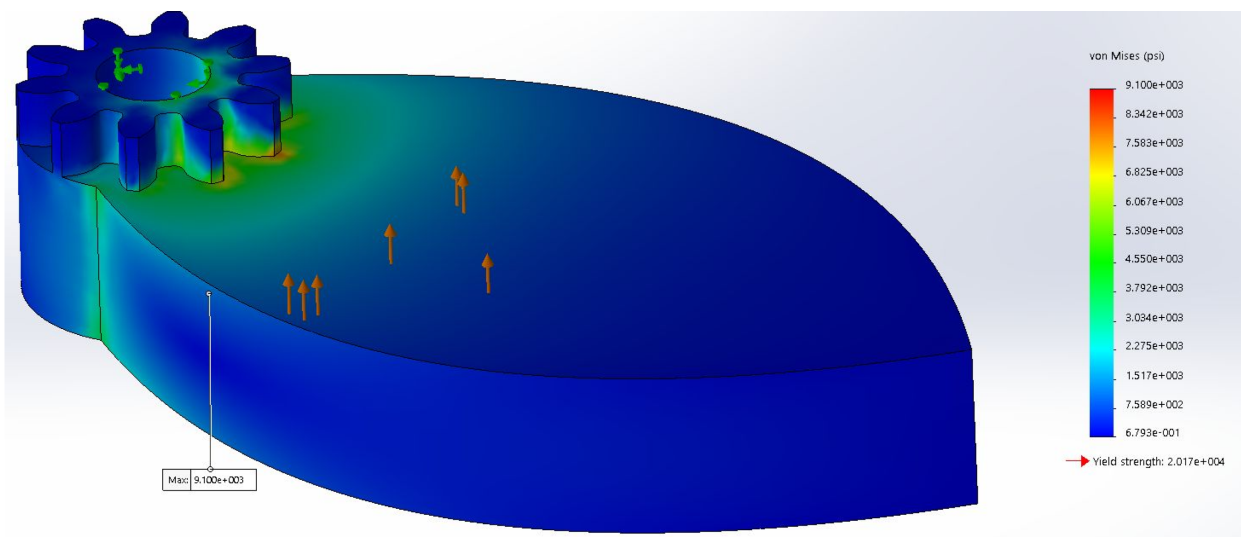


Figure 8: A plot of stress in the drag fin under a 2 factor of safety maximum load

The above figure shows the stress on the drag fin. The highest stress in the drag fins is found at the bottom of the mounting cylinder, but is below the yield strength. This shows the viability of using a 3D printed part. Physical tests on the fins will be performed in order to establish the overall strength and confirm the FEA.

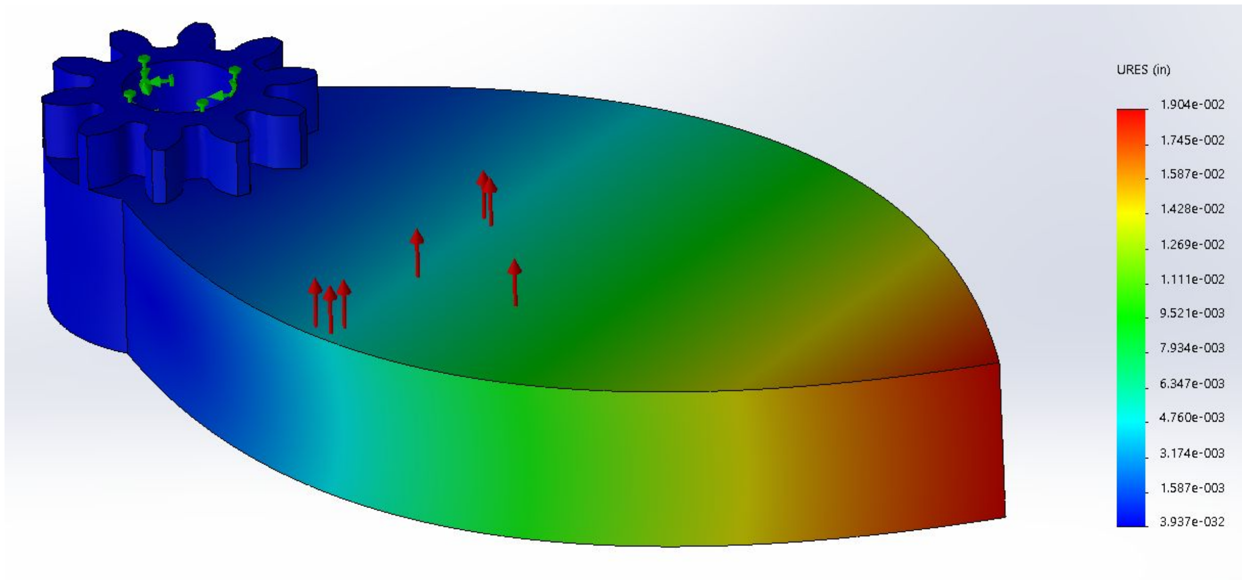


Figure 9: A plot of displacement of the drag fin under a 2 factor of safety maximum load

The displacement plot above shows a maximum displacement of 0.019 inches. This amount of displacement will still allow fins to close quickly without interfering with the body when retracting, which was the main concern.

Active Drag System

In order to reach the target apogee for the second launch using the higher class motor, the drag system needs to be properly controlled. An active drag system was the prefered method for controlling the drag, adapting to the current conditions of the rocket. An Arduino Mega will be the processing unit that decides when to deploy the drag fins. The Mega will receive altitude data from the Raven 3, as well as acceleration from an accelerometer. The Mega will then use this data to calculate the forces on the rocket and predict the future path of the rocket. The drag fins would then adjust to correct the flight of the rocket. The main force that will impact the trajectory of the rocket will be the drag force induced by the drag fins. Drag is modeled as:

$$F_{drag} = \frac{1}{2}\rho A c v^2$$

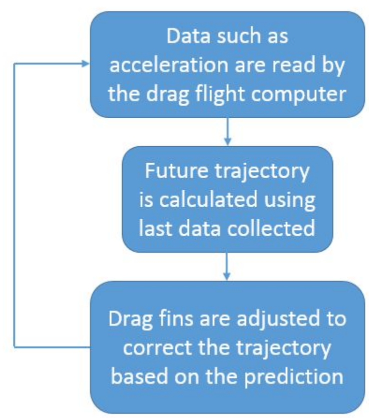


Figure 10: A flowchart explaining the drag system control process

with ρ being the air density, A being the surface area, c representing the drag coefficient, and v representing the velocity of the rocket. Since the program will adapt to the current conditions of the rocket, variables such as the drag coefficient can be solved for and be used to continuously make the program more accurate to reach the target apogee.

Camera System Design
A Raspberry Pi Zero will be used as the camera system in order to capture significant flight events. In order to capture events on the entire rocket, two cameras will be used; one looking up and the other looking down. Both will be positioned facing outwards, and will use a thin plastic film in order to angle the field of view.

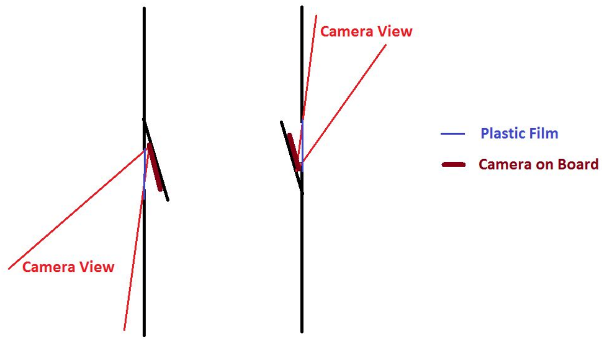


Figure 11: The views of the on board camera system

The video will then be recorded along with a timestamp in order to log significant events, like the drag system and parachute deployments. The data collection system is a Raspberry Pi Zero, and is shown below:

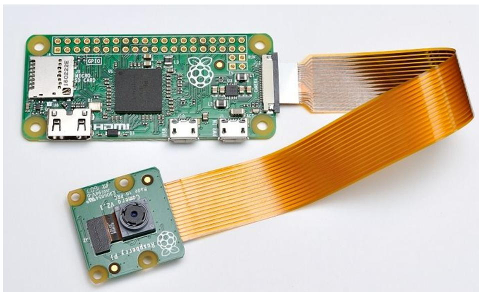


Figure 12: Camera Electronics Package

Electronics Payload

<u>Electronics Bay</u>
The location of the electronics bay is in the middle portion of the rocket, above the drag fins and below the nosecone of the rocket. The outer shell of the electronics bay will be fixed inside of the body tube. To make accessing the electronics easier, a panel will slide out with all of the electronics mounted onto it as illustrated in figure 11. Prior to launch, the electronics panel will be secured for flight. A Raven 3 altimeter was chosen to control the dual deployment of the parachute system.

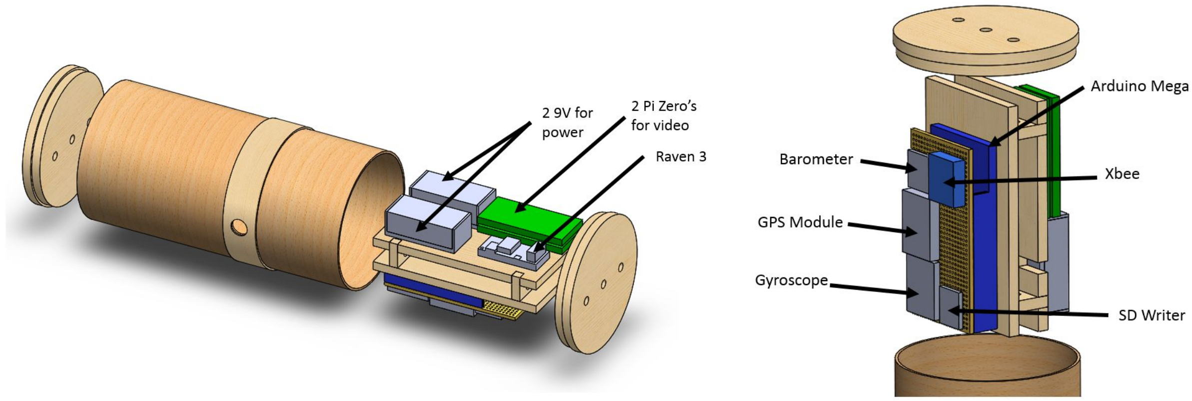


Figure 13: Layout of the electronics bay

Drag System

The electrical payload for this rocket will trigger the air brake system, opening the drag fins when needed and to retracting them before apogee. These calculations will be performed by an Arduino Mega microcontroller. This is connected to the Raven 3 altimeter to find altitude and velocity of the rocket. The Mega controls a high torque 360 degree servo motor to control the fins.

Data Transmission System

There will be a wireless data transmission system so that various aspects of the rocket performance can be monitored in real time on the ground. The rocket will not be controlled through this transmission network and will operate the same without the network connected. The GPS system, however, relies on the transmission network to locate the rocket after landing, so long-range antennas and a generous power supply will ensure the stability of the network. If the rocket flies outside of the transmission range, data will be logged on a microSD card, and the rocket will continuously attempt to reconnect to resume data transmission. A wiring schematic is shown below in figure 12.

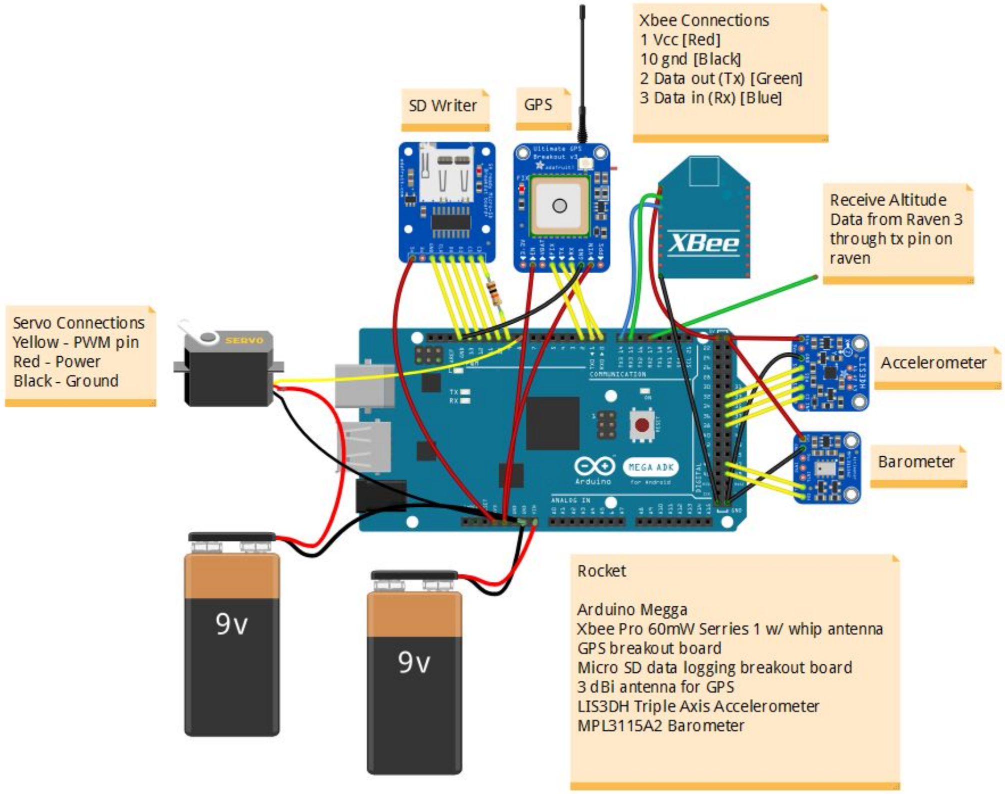


Figure 14: The wiring diagram of the electronics system

Due to the location of the velocity measuring device in the nosecone of the rocket, an additional datalogger is required. To accomplish this task, an Arduino Nano along with an microSD writer will record the analog reading of the sensor as illustrated in figure 15.

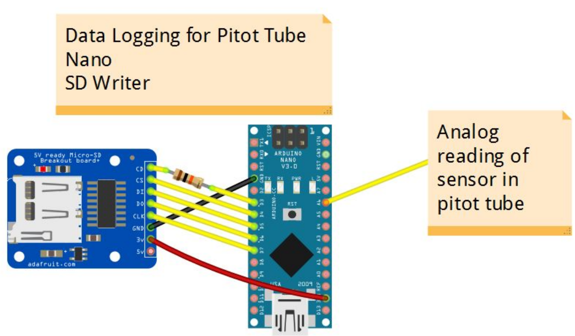


Figure 15: The wiring diagram of the pitot data logging system.

The receiving end of the XBee network consists of one XBee transceiver mounted on a breakout board that will allow it to be connected directly to a computer via USB. To boost transmission distance, a 10 decibel isotropic (dBi) antenna is going to be added to the receiving transceiver through a RP-SMA connection as illustrated in figure 16.

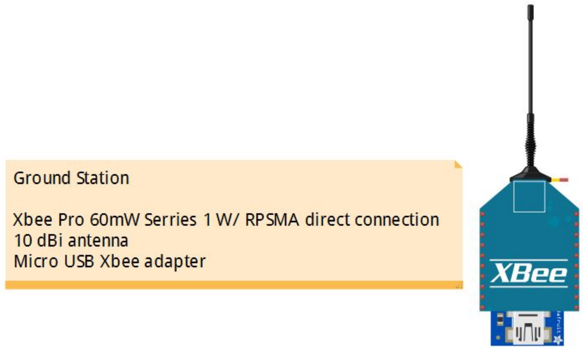


Figure 16: A diagram of the receiving XBee.

Altimeter

The following figure shows the connections for the Raven 3 altimeter [7]. The connections are fairly simple. The Raven 3 can be powered by a 9 volt battery which is what will be powering the other electronics so an additional battery is not needed. The two charges for the dual-deployment are connected to the proper place on the Raven 3. Since the rocket is only a dual-deployment, the additional deployment connections will be left not connected. Another connection will be linking the Arduino Mega to the Raven through the tx pin on the Raven 3.

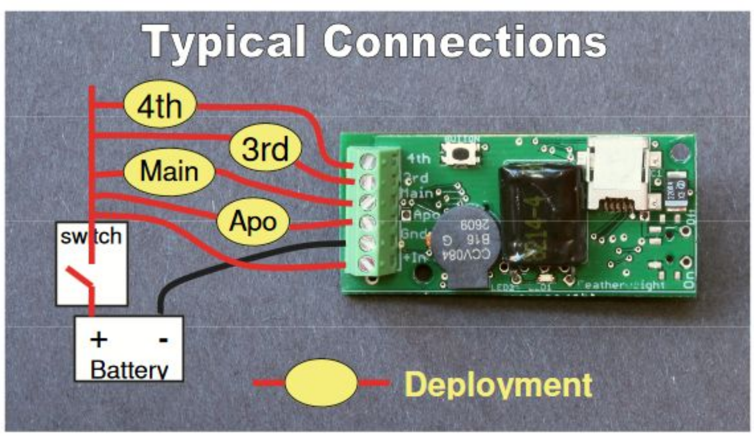


Figure 17: A wire diagram of the Raven 3 altimeter.

Regulations

There are regulations that limit the total transmission for each transmitting unit to 36 Effective Isotropic Radiated Power (EIRP) for each radio [8]. The EIRP is the sum of the radio power and antenna gain. The maximum transmitter power is also limited to 1 watt. The transceiver chosen uses 60mW of power, which correlates to 18 dbm. For the antenna, a small wire antenna with a gain of 3 dbi is going to be added to the sending transceiver on the rocket, boosting the transmitting distance while not limiting the transmit pattern. On the ground, a larger 10 dbi antenna is going to be used to receive the data from the transceiver. Together, these components have an EIRP of less than 36, meeting all regulations.

Velocity Measurement

In order to measure the air speed of the rocket, a system has been devised that measures the temperature of the air and determines velocity. In this setup, there will be a small inlet in the tip of the nose cone, where air will come to a stagnation point. At this point, a thermocouple will measure the temperature. A second thermocouple will measure the temperature of the air passing over the outside of the rocket. The mach number M is then calculated [9]:

$$M = \left(\frac{T}{T_t} - 1\right)\frac{\gamma}{\gamma - 1}$$

Where T is the free stream temperature, T_t is the stagnation temperature, and γ is the ratio of specific heats for air. After finding the mach number, the velocity of the rocket can then be calculated. In order to use this equation, it is assumed that the air used for the stagnation temperature was compressed adiabatically. In order to correct for real-life performance, testing will have to be done and a correction factor will have to be determined.

PREDICTED PERFORMANCE

Performance Predictions

The majority of the flight modeling thus far has been done using OpenRocket software. Using this software, a variety of apogee predictions for the J class motor have been made based on varying weather conditions. These predictions are outlined in table 3 below.

Table 3: Apogee Predictions in Feet

Atm. Pressure (in-Hg) Wind Speed (mph)	29.6	29.8	30.0	30.2
0	5261	5244	5228	5211
5	5251	5233	5218	5201
10	5233	5222	5226	5222
15	5214	5186	8192	5187
20	5162	5199	5174	5162

Table 4 below shows the maximum accelerations and velocities expected from both the J class and K class motors.

Table 4: Predicted Ideal Flight Characteristics

	Max Velocity (ft/s)	Max Acceleration (ft/s^2)
J Class (J415W-6)	712	362
K Class (K540M-2)	946	580

Figure 18 below shows the predicted velocity vs time during the flight under no wind conditions.

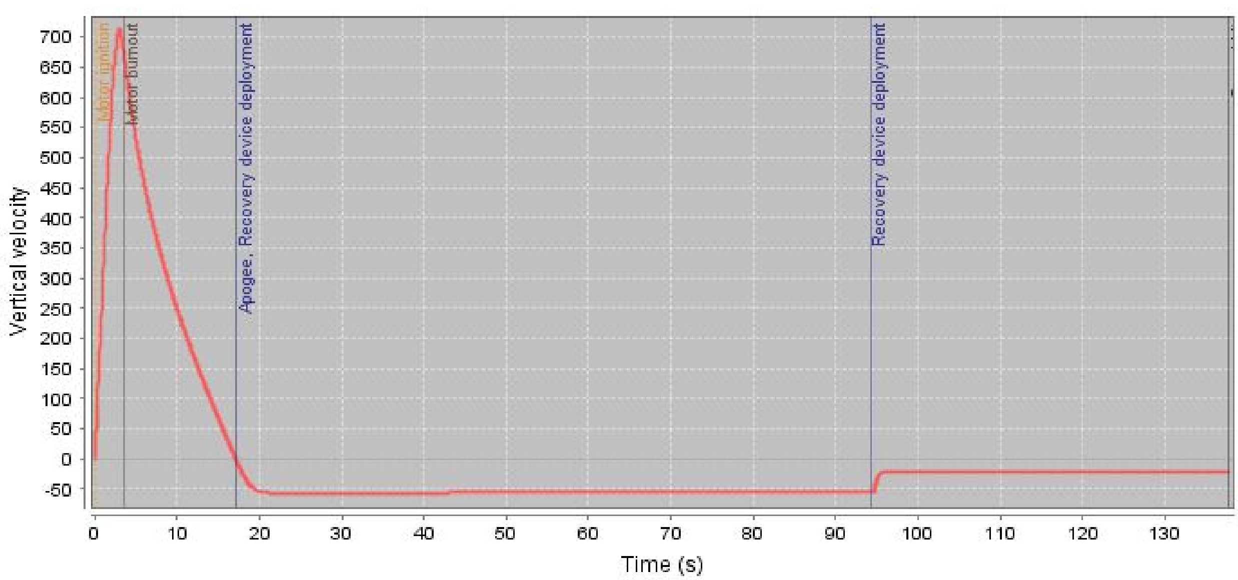


Figure 18: Velocity vs Time

APPENDIX A: BUDGET

	Projected Materials List				
Section	**Product**	**Source**	**Units**	**Price**	**Cost**
	4" Fiberglass 4:1 Ogive Nose Cone	Apogee	1	$41.00	$41.00
	1500# Kevlar Shock Cord (Main)	Apogee	20	$1.00	$20.00
	1500# Kevlar Shock Cord (Drogue)	Apogee	20	$1.00	$20.00
	Parachute & Drogue Chute	Apogee	2	$33.00	$66.00
Recovery System	98mm Blue Ebay	Apogee	1	$42.95	$42.95
	29mmx4" Motor Mount	Apogee	1	$9.55	$9.55
	4x44" Blue Tube	Apogee	1	$38.95	$38.95
	Test Launch Motor(s)	Wildman Rocketry	2	$150.00	$300.00
Rocket Hardware	Adhesives & Hardware	Menard/HomeDepot	1	$150.00	$150.00
	Servo	Amazon	1	$9.60	$9.60
	Data Logging Breakout Board	Adafruit	2	$7.50	$15.00
	GPS module	Adafruit	1	$40.00	$40.00
	LIS3DH Triple-Axis Accelerometer	Adafruit	1	$5.00	$5.00
	MPL3115A2 Barometer	Adafruit	1	$10.00	$10.00
	10 dbi antenna	Amazon	1	$6.00	$6.00
	XBee USB adapter	Adafruit	1	$30.00	$30.00
	XBee Pro 60mW RP-SMA Connection - Serie	Digi Key	1	$34.00	$34.00
	Xbee Pro 60mW Whip Antenna Serries 1	Adafruit	1	$38.00	$38.00
	Arduino Mega	Adafruit	1	$46.00	$46.00
	Arduino Nano	Amazon	1	$8.00	$8.00
	Raspberry Pi Camera System	Amazon	1	$82.00	$82.00
Electronics	Raven Mk III	Several Vendors	1	$165.00	$165.00
Competition	Taxes & Shipping		1	$100.00	$100.00
	Hotel	2 rooms 2 nights	4	$70.00	$280.00
	Travel	Gas (2 cars)	2	$100.00	$200.00
Travel	Meals		6	$15.00	$90.00
				Total	$1,847.05

APPENDIX B: Barrowman's Theory

The Barrowman equations permit you to determine the stability of a rocket by finding the location of the center of pressure (CP). The value computed is the distance from the tip of the rocket's nose to the CP. In order for a rocket to be stable, you would like the CP to be aft of the center of gravity (CG).

The computation of CP isn't as hard as it looks at first. Check out the spreadsheet example at the bottom of this page.

One can find the CG of a rocket by simply finding the balance point after loading recovery system and motor. One can then measure from the tip of the rocket's nose to the CG. The calculated CP distance should be greater than the measured CG distance by one rocket diameter. This is called "one caliber stability".

Terms in the equations are defined below (and in the diagram):

LN = length of nose

d = diameter at base of nose

dF = diameter at front of transition

dR = diameter at rear of transition

LT = length of transition

XP = distance from tip of nose to front of transition

CR = fin root chord

CT = fin tip chord

S = fin semispan

LF = length of fin mid-chord line

R = radius of body at aft end

XR = distance between fin root leading edge and fin tip leading edge parallel to body

XB = distance from nose tip to fin root chord leading edge

N = number of fins

Nose Cone Terms:

For Cone: XN = 0.666LN

For Ogive: XN = 0.466LN

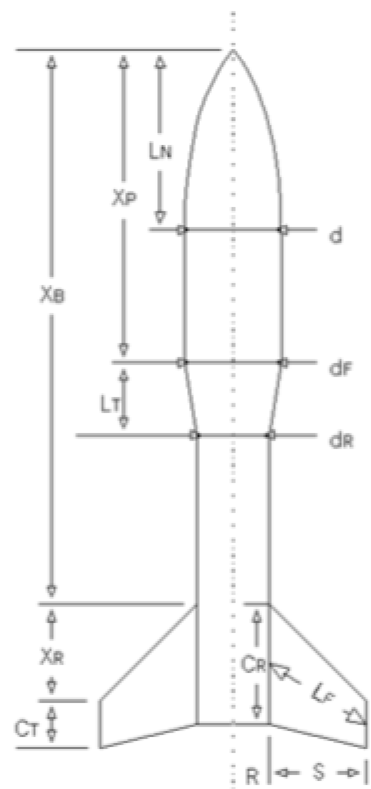


Figure 16: Barrowman's Theory Diagram

Conical Transition Terms

$$\left(C_N\right)_T = 2\left[\left(\frac{d_r}{d}\right)^2 - \left(\frac{d_f}{d}\right)^2\right]$$

$$X_T = X_P + \frac{L_T}{3}\left[1 + \frac{1 - \frac{d_F}{d_R}}{1 - \left(\frac{d_F}{d_R}\right)^2}\right]$$

Fin Terms

$$\left(C_N\right)_F = \left[1 + \frac{R}{S+R}\right]\left[\frac{4N\left(\pi\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_f}{C_R + C_T}\right)^2}}\right]$$

$$X_F = X_B + \frac{X_R}{3}\frac{\left(C_R + 2C_T\right)}{\left(C_R + C_T\right)} + \frac{1}{6}\left[\left(C_R + C_T\right) - \frac{C_R C_T}{\left(C_R + C_T\right)}\right]$$

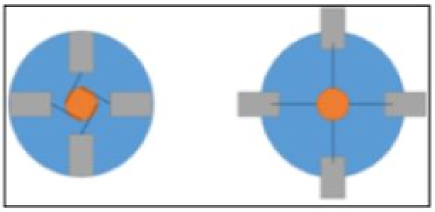
Finding the Center of Pressure:

Sum up coefficients: $\left(C_N\right)_R = \left(C_N\right)_N + \left(C_N\right)_T + \left(C_N\right)_F$ $(C_N)_R = (C_N)_N + (C_N)_T + (C_N)_F$

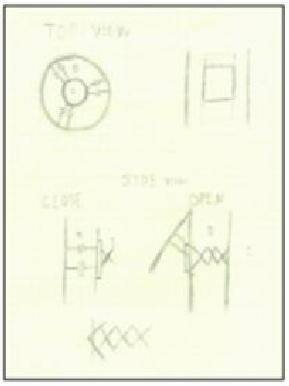
Find CP Distance from Nose Tip:

$$\bar{X} = \frac{\left(C_N\right)_N X_N + \left(C_N\right)_T X_T + \left(C_N\right)_F X_F}{\left(C_N\right)_R}$$

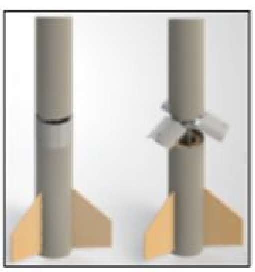
APPENDIX C: PICTURES OF DRAG SYSTEM CONCEPTS



Drag System 1

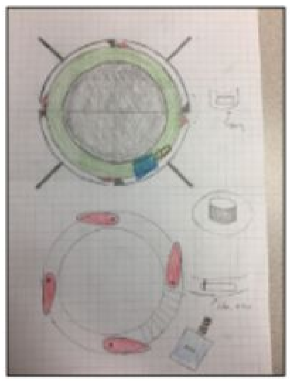


Drag System 2

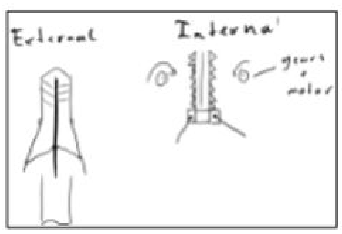


Drag System 3

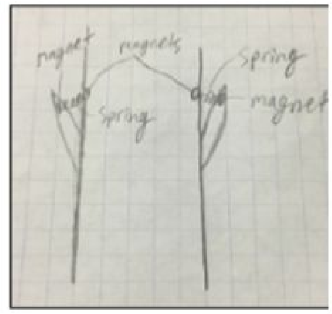
Drag System 4



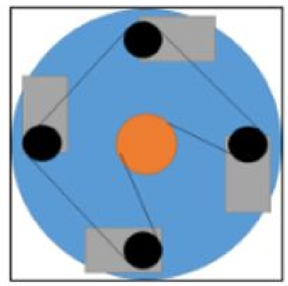
Drag System 5



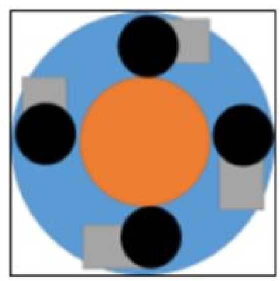
Drag System 6



Drag System 7



Drag System 8



Drag System 9

APPENDIX D: RESOURCES AND ACKNOWLEDGMENTS

[1] "NASA's Space Grant Midwest High-Power Rocket Competition Handbook" Minnesota Space Grant Consortium, 20 Aug. 2016. Web. 11 Jan. 2017

[2] Knowles, Vern. "Altimeter Port Sizing." Altimeter Port sizing. Altimeter Port Sizing, 2002-2007. Web. 17 Apr. 2015.

[3] "RRC2X User Manual." Missile Works Corporation, n.d. Web. 17 Apr. 2015.

[4] Hiller, Jordan "Model Rocket Parachute Descent Rate Calculator." Web

[5] Duncan, W.J., Thom, A. S., and Young, A.D. "Mechanics of Fluids," American Elsevier Publishing Company, Print.

[6] Barrowman, James. "Barrowman Equations." Barrowman Equations. NASA, 25 Feb. 2000. Web. 24 Feb. 2017.

[7] *Raven User's Manual* [PDF]. (n.d.). Featherweight Altimeters.

[8] FCC Rules for Wireless Equipment operating in the ISM bands -www.afar.net. (n.d.). Retrieved March 10, 2017, from http://www.afar.net/tutorials/fcc-rules

[9] "Equations, Tables, and Charts for Compressible Flow." NACA, 1953.

[10] "Photo of Madow Ebay", Apogee, Retrieved. 09 March 2017, https://www.apogeerockets.com/Electronics_Payloads/Electronic_Bays/4-0_Madcow_Ebay

Acknowledgments

Wisconsin Space Grant Consortium

Minnesota Space Grant Consortium

MSOE AIAA Chapter