Preliminary Design Report

Prepared by:
The University of Iowa AIAA
Midwest High Power Rocketry Competition
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Executive Summary

This report contains all information about the preliminary design of the University of Iowa's rocket. Included are descriptions of components, including the fins, airframe, propulsion system, coupling interface, and payload system. Within each description are details and equations utilized as well as the reasoning behind design decisions. Diagrams of components and the overall design are given. Along with the design descriptions, analysis of the rocket design is included with appropriate figures and plots of resulting simulation data. This analysis was used to provide the predicted performance of the rocket as designed. Safety analysis is also included, and all relevant safety procedures are discussed. Finally, the included appendices give breakdowns of equations used as well as external sources utilized during the design of the rocket.

Design Features of Rocket

Rocket Fin Specifications

During our model rocket competition, different fin designs were tested for performance and efficiency. Members researched various designs to minimize drag, which were then applied to their models. Rockets with a more trapezoidal shape showed good performance, and triangular shaped fins were ruled out. It was also observed that the majority of high-power rockets had trapezoidal fins. These launches also showed that 3 fins work better than 4 fins when aerodynamic efficiency is concerned. Tube fins were also considered briefly, but it was determined that they would require more time than available to produce. The conclusion was to create 3 trapezoidal fins, 120 degrees apart from each other. We also decided to use tab fins, to provide better stability and to optimize use of the materials ordered.

The OpenRocket simulator was used to model the fins for our rocket. To have optimal tab fins, the calculations used by the simulator show that the fin should 2x the diameter out from the rocket, the inner side of the fin should be the same, and the outer side should be half that. The equations for these calculations are listed in *Appendix D*. A 1/16 in (0.1588 cm) thick woven carbon fiber reinforced epoxy matrix was purchased as the material from which the fins would be cut. A water-jet CNC cutter was used to cut out the appropriate geometry for each fin. Models of the rocket fin designs can be found in *Appendix C* as *Figure 5* and *6*.

Rocket Body Specifications

The body of the rocket was designed to be composed of Blue Tube 2.0, a type of vulcanized craft paper for large model rockets, which experiences less deformation during stress tests than materials like carbon fiber and Kevlar. The relatively low cost and easy access to the material through Apogee Rocket Components supported the use of Blue Tube 2.0 as the main material for the construction of our rocket.

The current design of the rocket is 44 in. in length and 3.1 in. in diameter. This includes the nosecone (11.25 in.), electronics package, streamer and parachute bays, and active drag system bay. These dimensions can be seen in *Figure 1* and *Figures 4, 5 and 6* of *Appendix C.* While the weight of the rocket is not entirely known at this time, estimates based on the sum weights of the components place it at around 2.268 kg (5 lbs).

Nosecone Specifications

The nosecone of the rocket was bought through Apogee Rocket Components and is constructed of polypropylene plastic. It has a standard ogive profile and is 28.58 cm in length. It includes a small tab on the inside for the connection of a parachute and shock cord. This may be removed for our rocket in order to create a more durable attachment for the streamer and shock cord.

Propulsion Design Specfications

The motor to be used for both the test flight and competition flight is the Cesaroni I242 motor. This motor will be used for all flights of the rocket in order to ensure consistency. This will also allow for accurate comparisons between the performances of the test flight and the competition flight. The motor will be placed in a Cesaroni Pro-38 case. This motor casing s made out of thin-wall 6061-T6 aluminum tubing with an anodized coating for corrosion protection, with a rear closure. Specific data regarding the motor is given in *Table 1* in *Appendix A*. This table includes information regarding the motor length, motor and propellant weight, the maximum thrust, the total impulse and the burn time. Specifications for the motor were taken from *Source 2* in *Appendix B*.

Recovery System Design Specifications

As the final weight was not available, design specifications were calculated using an estimated recovery weight, based on the sum of the weights of the all of the parts, of about 4 - 5 lb. This recovered weight does not include the weight of the motor, as that was assumed to be nominal after burnout. A descent rate of 16.4 ft/s (5 m/s) was approximated using OpenRocket simulation values.

Streamers were selected for use with a dual deployment system to decrease drift distance. An estimated descent rate of 98.4 ft/s (30 m/s), using OpenRocket was used to calculate the size requirement of the streamers. After calculations were completed, it was decided that one streamer would be used to increase drag. The selected streamer was a 7 inch by 70 inch (17.8 cm by 178 cm) ripstop nylon streamer. The size and number was selected because the surface area will provide enough drag to slow the rocket during descent while still being small enough to easily pack into the rocket body.

The base guideline for parachute calculations was that 3.5 square feet (3250 square cm) of parachute would be required for every pound of recovered weight. On the Apogee Rockets website, estimated rocket weights are given in the parachute specifications, and based on comparisons between this value and the estimated weight of our rocket, a 36 inch diameter elliptical parachute was chosen. It is made by Fruity Chutes, with a carrying capacity of 4.5 lbs @ 20 fps.

Active Drag System Design

The main goal of this year's rocket competition is to build a rocket containing an active drag system. To accomplish this, we've designed and included a small device that, when rotated, moves small aluminum arms that push movable parts, essentially flaps, of the rocket body outwards and will cause a decrease in vertical speed and acceleration. These flaps are cut out from the rocket body, and so still possess the curvature of the rocket body and fit perfectly to the rocket body when not in use. *Figures 2* and *3* in *Appendix C* demonstrate this.

The device used to move the aluminum arms and open the flaps is made up of two small cylindrical pieces of aluminum, with a hollow 3d printed plastic hollow cylinder in between. This plastic cylinder houses the motor which rotates the end with the aluminum rods. The motor will either be activated remotely via a radio receiver or will activate automatically when the accelerometer measures a certain altitude. Simulation of this cannot be done in OpenRocket since there's no option to do so.

Planned Construction Solutions & Techniques

The majority of construction followed standard rocketry construction procedures, including sizing of airframe tubes, attachment of fins, bulkhead placement, and general component construction. All machining operations were completed using university-supplied hand and power tools, as well as CNC tools such as end-mill, lathe, and water-jet.

As the fins were to be made from a woven carbon fiber composite sheet, typical cutting operations would not have been sufficient to produce quality cuts. Therefore, with the help of trained operators, a water-jet was used to cut the composite sheet into the desired shapes.

Design Features of Payload System

In order to meet competition requirements, it was decided that team members would create a custom avionics system in order to minimize the weight and size of the components. Separate devices were chosen to accomplish the tasks of collecting video and flight data. The video collection device consists of one Mini DVR 808 #16 V3 – Lens D Car Key Chan Micro Camera HD 720P Pocket Camcorder which was modified with a 24 position 0.5 mm pitch 6in Flat Flex Cable in order to extend the camera from the rest of the avionics system. The data collection system consists of an Arduino Micro, an ITG3200/ADXL345 Accelerometer/Gyroscope combo, and an Adafruit MicroSD card breakout board.

To implement the video collection device, the enclosure was removed from the key chain micro camera and the camera was detached from the circuit board. Solder paste was reflowed onto one end of the flat flex cable lead with the use of a hot-air rework station. The camera leads were then placed over the cable leads and the solder was reflowed to join the leads together. This process is less likely to produce shorts between leads or damage cables than the use of a soldering iron. The open end of the flex cable was then attached to the circuit board via a solderless clamp to complete the device.

The data collection system uses the Arduino as the main computer to collect data from the combo board, convert it into useful information, and then save it to the MicroSD card. The Arduino requires a 7-12V power source, so a 9V battery was chosen to power it. Since the combo board and MicroSD card breakout board are designed to interface with the Arduino, no additional circuitry is required (resistors, capacitors, etc.). The code will need to take byte data from the combo board and convert it to usable accelerometer and gyroscope data. This data will need to be run through a filter, which corrects for drift in the gyroscope. The data will then be organized and stored on the SD card using standard read/write functions.

Diagram of Rocket

The center of pressure (CP), which is the balance point of all aerodynamic forces on an object, was calculated both by hand and by computer simulation. The simulation program used to calculate the center of pressure was Open Rocket. Both of these calculations used the Barrowman method, which assumes incompressible flow and no viscous forces. The calculations were done by assigning each component a weighted value, the stability derivative, summing the values multiplied by the distance from a reference line to the center of pressure for the specific component, and then dividing by the total stability derivative. In this case, the reference line was the nose of the rocket. The diagram from Open Rocket of the rocket can be found in Figure 1.

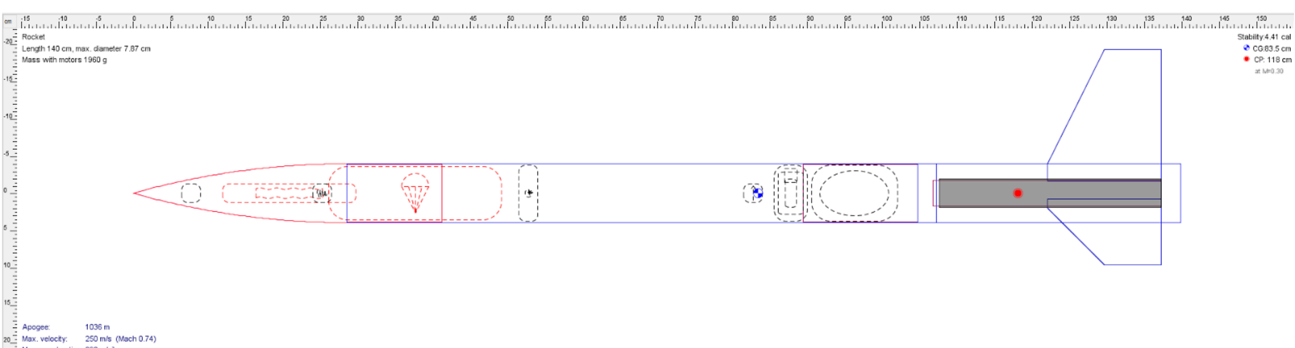

Figure 1: CG (Blue) and CP (Red) of Rocket

The center of pressure equation can be found in *Appendix D, Equation 1*. The stability derivative ($C_{N\alpha}$) value for the nose cone was calculated from *Equations 2* and *3*; the $C_{N\alpha}$ represents the slope of the restoring force as a function of angle of attack for a given component. Values for the fins were calculated from *Equations 4*, *5* and *6*. Using the Barrowman method, $C_{N\alpha}$ of the airframe tube is 0 because the effect of the airframe tube is negligible. An explanation of dimension variables can be found in *Appendix A*, *Table 4*.

Analysis of Anticipated Performance

The flight analysis of the rocket was calculated using Open Rocket software. The software allowed input of the dimensions and weights of the rocket components along with the impulse of the competition motor, and returned a graph with specific flight data. A total of seven variables were calculated to produce the resulting graph including time (s), altitude (m), total velocity (m/s), CP location (cm), CG location (cm) and drag force (N). This graph can be found in *Appendix C* as *Figures 7*.

As shown in *Figure 7*, the rocket motor burns for about 2.3 seconds, getting the rocket to a maximum acceleration of about 400 m/s^2 and a maximum velocity of 250 m/s. At about 12.5 seconds after launch, the rocket will reach maximum altitude, at about 1,040 m (3412 ft). This simulation does not include the actve drag system, as it cannot be simulated using Open Rocket. However, dependent upon the altitude the active drag system is activated, the maximum velocity may be decreased and the maximum altitude will be decreased. The test launch of the rocket will determine at what height the active drag system should be activated and how long it should be open for.

The estimated flight time is about 72 seconds, without the active drag system, which will reduce this time, but only slightly. With average wind speeds of 5 and 10m/s, there is a horizontal distance less than 800m. The calculated velocity at impact for the rocket is 5m/s. This will be slow enough to prevent damage to the fins and electronic components.

The CP is located 34.5 cm below the CG before burnout, as shown in *Figures 1* and *9*.

Innovation

Team members designed the fins for the rocket. The designs were based on calculations described in the *Rocket Fin Specifications* section. This was done in an attempt to maximize stability while decreasing possible drag, so that the active drag system influences drag the most.

Safety

Designed for Safe Flight and Recovery

The rocket contains a dual deployment system to keep it from traveling extensive distances. The dual deployment system typically utilizes a drogue chute and a regular parachute, but a streamer was selected instead of a drogue chute for this rocket. The streamer is more cost-effective while still providing additional drag for the dart during descent.

Materials-Handling Procedures

For the low-powered model rocket flights, a 24-pack of C6-5 motors was purchased. The motors were kept in a metal drawer when not in use. This is where leftover motors will remain until used or discarded.

The construction of the rocket will require the use of various epoxies. When these epoxies are used, gloves and respirators will be worn as safety precautions. When not in use, the epoxy will be stored in a flammable cabinet as a cautionary measure. Safety goggles will be worn at all times when construction all aspects of the rocket.

Planned Assembly Procedures

For both the test flight and the competition flight, two teams will be created to better streamline the assembly of the rocket and ensure that everything is prepared for the flight. The electronics team will construct and prepare the electronics package. This team will be made up of the members who designed the electronics package and wired all of the electronics. During assembly, these members will ensure that all of the electronics are working and that the camera is on and ready to record the flight. The second team will prepare the parachute and streamer for the rocket and ensure that the dual deployment system is ready. Charges will be placed into the dual deployment system at this point. Then, the competition altimeter will be activated and secured in the electronics package. The electronics packaged will then be inserted into the rocket and secured.

Once the rocket has been prepared, it will be placed on the launch stand. The data collection system and dual deployment system will then be activated.

Planned Pre- and Post- Launch Procedures

Teams will assemble the rocket before launch, as described in the *Planned Assembly Procedures* section. The project supervisor will have a checklist and will coordinate with each team during the assembly process. This will ensure that everything is properly assembled and that nothing has been forgotten. The pre-launch procedure will also be coordinated with the safety officer in order to comply with safety guidelines.

Post-launch, a radio tracker will be used to find the location of the rocket. Once it is determined that all charges have been deployed, the team will recover the rocket. Then, the teams will remove the altimeters from each component to retrieve altitude data. The electronics will then be removed from the rocket so that the flight data and video can be accessed.

Budget

The estimated costs associated with this competition can be found in *Appendix A* under *Table 2* and *3*. The Iowa Space Grant Consortium was kind enough to offer sponsorship of the team. They will be covering the cost of competition registration as well as the cost of hiring a judge. $1500 was granted towards construction costs. The team has also participated in various volunteering events at the University of Iowa in order to raise an additional $300.

Appendix A: Tables

Table 1: Motor Specifics

Diameter	38mm
Length	30.2 cm
Total Mass	549.9 g
Propellant Mass	305.2 g
Maximum Thrust	284.7 N
Total Impulse	548.2 N-s
Burn Time	2.3 s

Table 2: High-Powered Rocket Competition materials list and estimated budget

Item	Minimum	Maximum	Weight
Shock Cord	$5.00	$5.00	.025lb
Parachute	$89.00	$101.00	2 lbs
Accelerometer	$25.00	$25.00	.02lb
Pressure Plug(X2)	$25.00	$25.00	.02lb
Rocket Motors (X2 for testing)	$100.00	$100.00	2.3125lb
Motor (Ceseroni I242)	$45.00	$60.00	1.212lb
Nose Cone	$30.00	$50.00	.33lb
Motors for ADS (Servos)	$10.00	$20.00	.2lb
Nozzle	$50.00	$50.00	.2lb
Blue Tube	$30.00	$30.00	1.6lb
Microcontroller	$3.00	$3.00	.02lb
Power Adapter	$1.00	$1.00	.01lb
SD Card Writer	$15.00	$15.00	.01lb
Altimeter	$15.00	$15.00	.02lb
Streamers	$7.00	$7.00	.2lb
Apoxie	$20.00	$20.00	.2lb
Engine Block	$15.00	$15.00	.5lb
	$485.00	$542.00	

Table 3: High-Powered Rocket Competition Travel Expenses

Project	*Expense*	*Cost*
Rocketry Competition Traveling Expenses		
	3 nights in hotel	$1,700
	3 cars, 2 trips	$300
		$2000

Table 4: Center of Pressure Dimensional Variables and Functions

n	Number of fins
l_s	Fin span length
d_n	Diameter at nose base
l_m	Fin mid chord length
l_r	Fin root chord length
l_t	Fin tip chord length
l_n/X_b	Nose length
d_u	Upstream diameter
d_d	Downstream diameter
d_b	Average diameter
d_f	Diameter at fin root
X_c	Distance to tailcone
X_f	Distance to root of fin
$C_{N\alpha}$ (R)	Total $C_{N\alpha}$ for rocket
$C_{N\alpha}$ (n)	$C_{N\alpha}$ for nose
$C_{N\alpha}$ (c)	$C_{N\alpha}$ for diameter change
$C_{N\alpha}$ (f)	$C_{N\alpha}$ for fin set
K_{fb}	Interference effect coefficient
X_{cp}	Distance to X_{cp} total center of pressure
X_{cp} (n)	Distance to X_{cp} for nosecone
X_{cp} (c)	Distance to X_{cp} for diameter change
X_{cp} (f)	Distance to X_{cp} for fin set

Appendix B: Sources

Source 1: Organized Storage, https://www.google.com/drive/

Source 2: Motor Specifics, https://www.apogeerockets.com/Rocket_Motors/Cesaroni_Propellant_Kits/Cesaroni_Certification_Special/38mm_Certification_Propellants/Cesaroni_P38-4G_White_I242

Source 3: OpenRocket Simulator, http://openrocket.sourceforge.net/

Source 4: Trapezoidal Fin Design, http://www.nakka-rocketry.net/fins.html

Source 5: Motor Casing, http://www.pro38.com/products/pro38/hardware_pro38.php

Appendix C: Figures

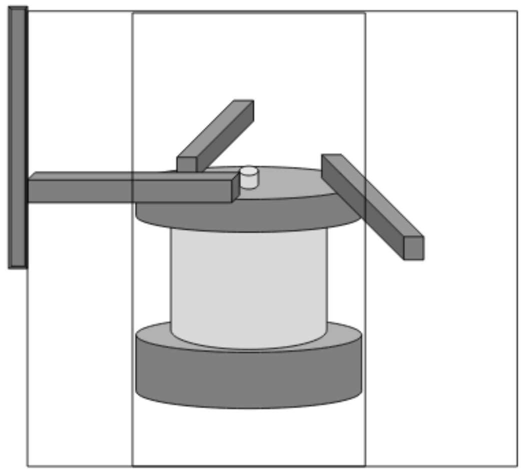

Figure 2: Active drag system when not in operation, showing how the system is enclosed

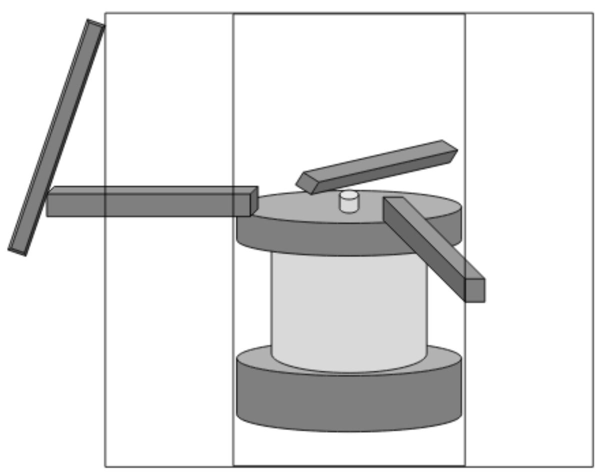

Figure 3: Active drag system when in operation, showing how aluminum rod extends its flap

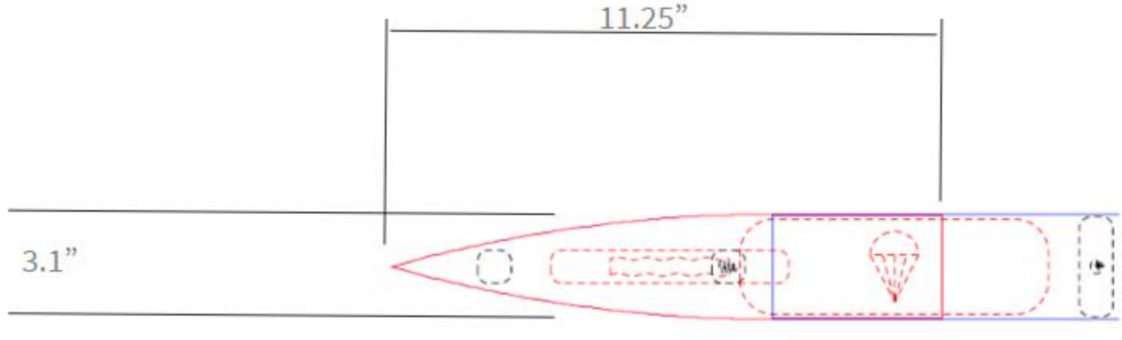

Figure 4: Dimensions of the nose cone

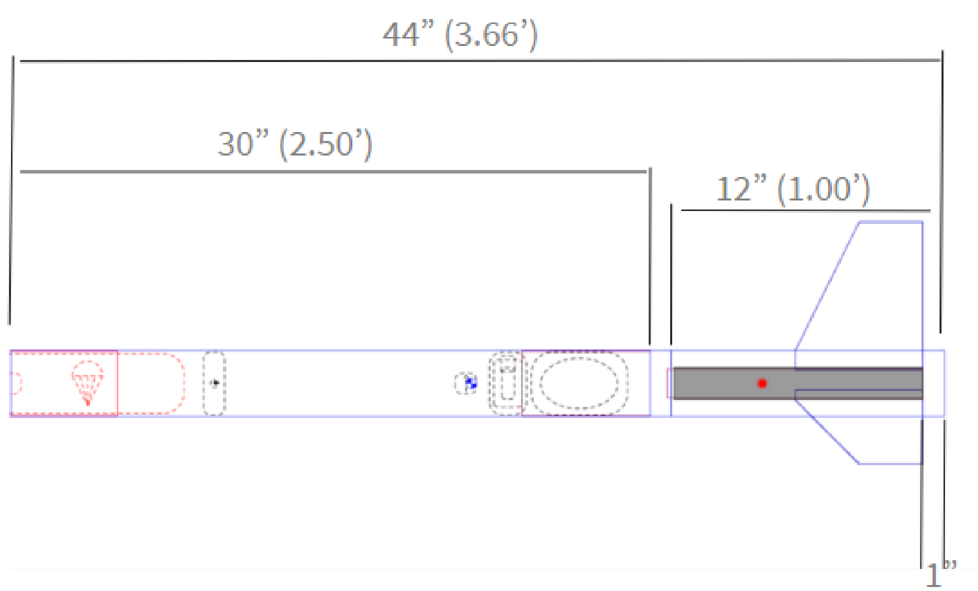

Figure 5: Dimensions of rocket body, differentiating motor section from the rest of the body

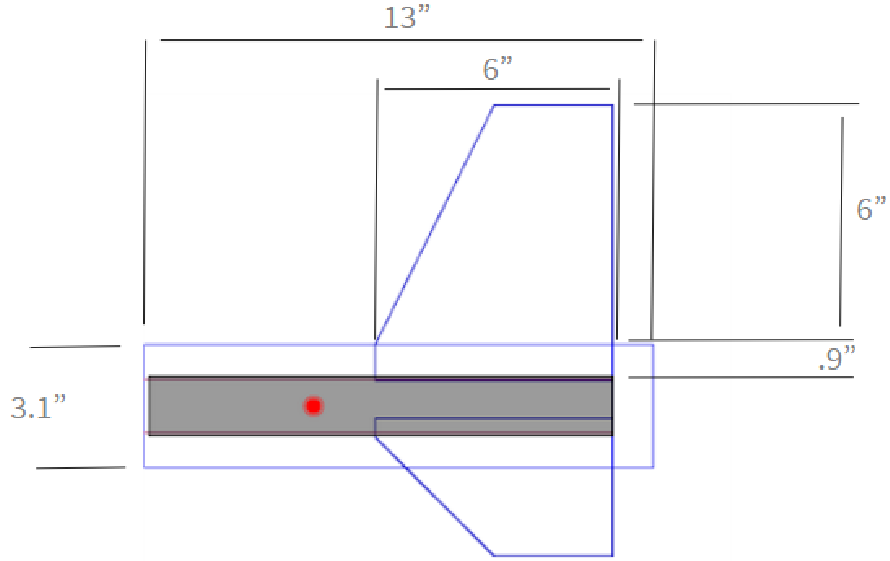

Figure 6: Dimensions of the fins, showing trapezoidal and tabular design

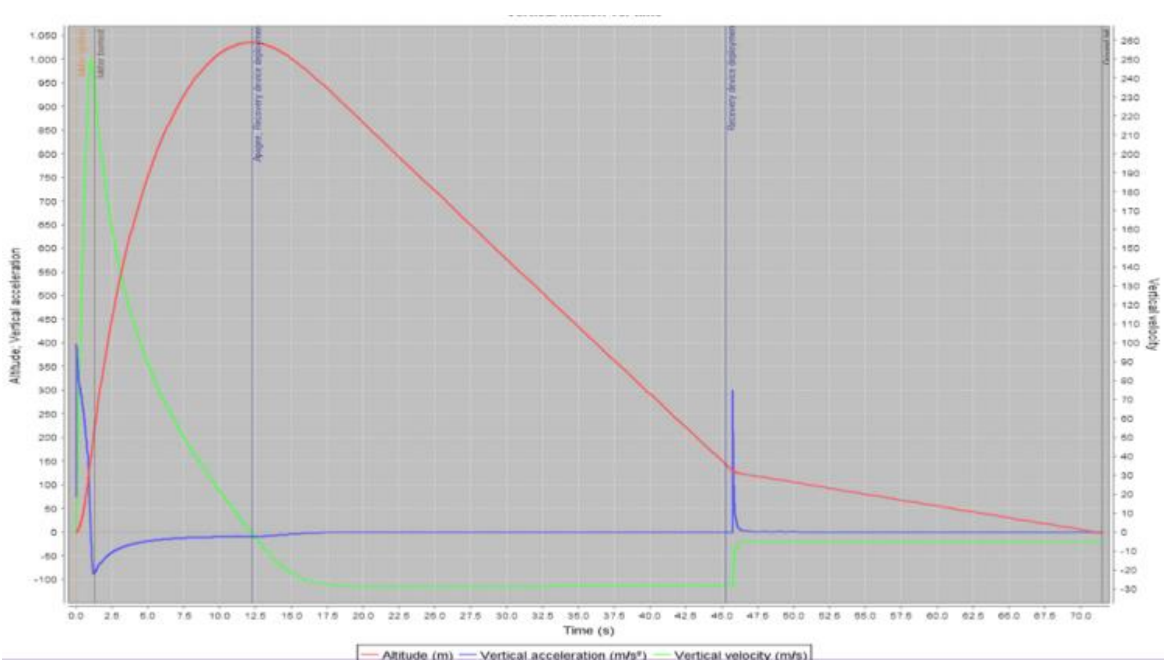

Figure 7: Graph showing the vertical acceleration, vertical velocity and altitude vs time for the rocket

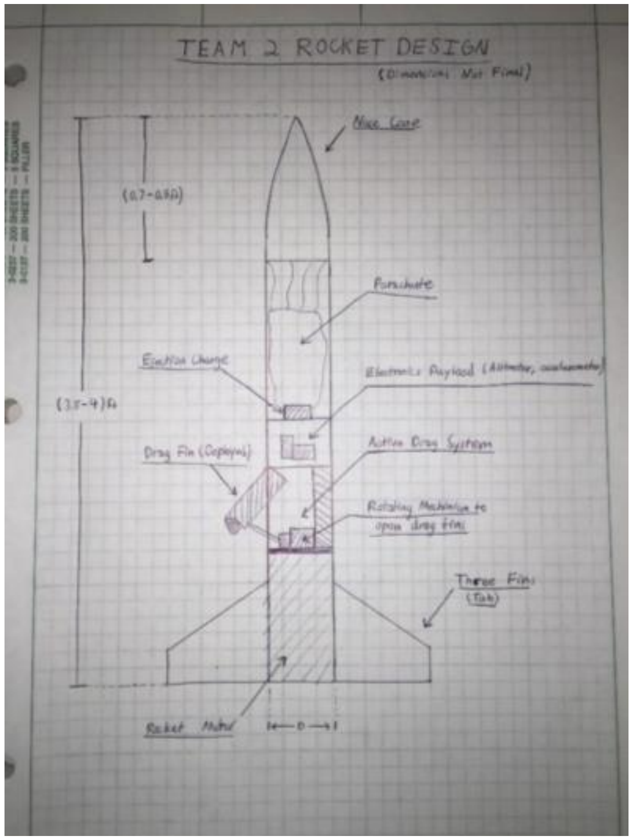

Figure 8: 2-dimensional representation of the rocket, showing early-on dimensions

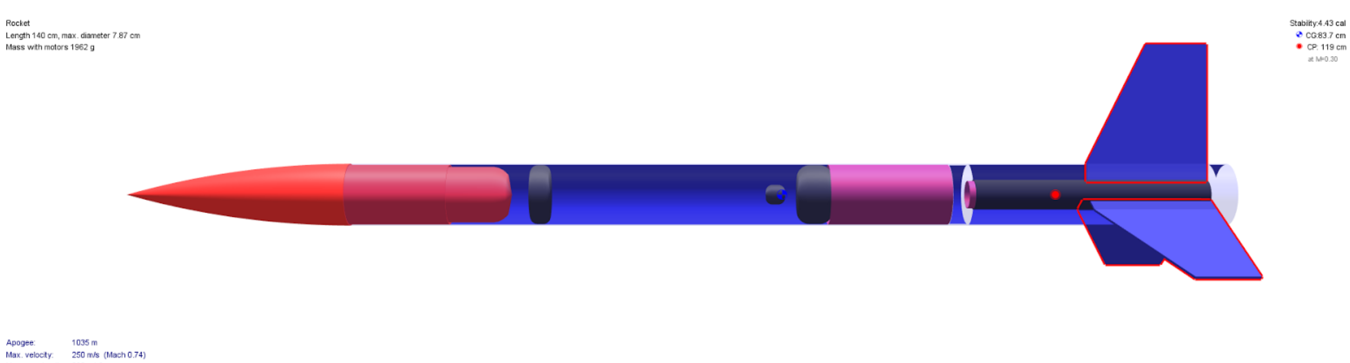

Figure 9: 3-dimensional representation of the rocket, modeled using OpenRocket

Parts Detail

Sustainer

Nose cone	PVC (1.39 g/cm³)	Ogive	Len: 28.6 cm	Mass: 135 g
Parachute	Ripstop nylon (67 g/m²)	Dia$_{out}$ 91.4 cm	Len: 23 cm	Mass: 63.7 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 12	Len: 91.4 cm	
Streamer	Ripstop nylon (67 g/m²)	Length 178 cm Width 17.8 cm	Len: 17.8 cm	Mass: 21.2 g
Shock cord	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)		Len: 40 cm	Mass: 0.72 g
Added mass		Dia$_{out}$ 2.5 cm		Mass: 283 g
Body tube	Kraft phenolic (0.95 g/cm³)	Dia$_{in}$ 7.62 cm Dia$_{out}$ 7.87 cm	Len: 76.2 cm	Mass: 224 g
Tube coupler	Kraft phenolic (0.95 g/cm³)	Dia$_{in}$ 7.62 cm Dia$_{out}$ 7.62 cm	Len: 15.2 cm	Mass: 0 g
Altimeter		Dia$_{out}$ 2.5 cm		Mass: 7.36 g
Active drag system		Dia$_{out}$ 7.5 cm		Mass: 340 g
Deployment charge		Dia$_{out}$ 7.5 cm		Mass: 5.67 g
Electronic Payload		Dia$_{out}$ 7.5 cm		Mass: 70.9 g
Body tube	Kraft phenolic (0.95 g/cm³)	Dia$_{in}$ 7.47 cm Dia$_{out}$ 7.87 cm	Len: 2.54 cm	Mass: 11.6 g
Body tube	Kraft phenolic (0.95 g/cm³)	Dia$_{in}$ 7.62 cm Dia$_{out}$ 7.87 cm	Len: 30 cm	Mass: 88.1 g
Trapezoidal fin set (3)	Kraft phenolic (0.95 g/cm³)	Thick: 0.3 cm		Mass: 179 g
Inner Tube	Cardboard (0.68 g/cm³)	Dia$_{in}$ 3.4 cm Dia$_{out}$ 3.5 cm	Len: 30.5 cm	Mass: 11.2 g
Body tube	Cardboard (0.68 g/cm³)	Dia$_{in}$ 7.62 cm Dia$_{out}$ 7.87 cm	Len: 2.54 cm	Mass: 5.34 g

Figure 10: A list of all parts used to construct the rocket, representing the electronics as one object and not including adhesive materials

Appendix D: Equations

Note: All parameter definitions can be found in *Table 5* of *Appendix A*.

Equation 1:

$$C_{N\alpha(R)} = \sum_{P \in R} C_{N\alpha(P)}$$

Equation 2:

$$C_{N\alpha(n)} = 2$$

Equation 3:

$$C_{N\alpha(c)} = 2\left[\left(\frac{d_d}{d_n}\right)^2 - \left(\frac{d_u}{d_n}\right)^2\right]$$

Equation 4:

$$C_{N\alpha(f)} = K_{fb}\frac{4n\left(\frac{l_s}{d_n}\right)^2}{1+\sqrt{1+\left(\frac{2l_m}{l_r+l_t}\right)^2}}$$

Equation 5:

$$K_{fb} = 1 + \frac{\frac{d_f}{2}}{(l_s + \frac{d_f}{2})}$$

Equation 6:

$$X_{cp(R)} = \frac{\sum_{P \in R} C_{N\alpha(P)} X_{cp(P)}}{C_{N\alpha(R)}}$$

Equation 7:

Ogive: $X_{cp(n)} = 0.466 l_n$

Equation 8:

$$X_{cp(c)} = X_c + \frac{l_c}{3}\left[1 + \frac{1 - \frac{d_u}{d_d}}{1 - \left(\frac{d_u}{d_d}\right)^2}\right]$$

Equation 9:

$$X_{cp} = X_f + \frac{l_m(l_r + 2l_t)}{3(l_r + l_t)} + \frac{1}{6}\left[l_r + l_t - \frac{l_r l_t}{l_r + l_t}\right]$$

Appendix E: Team Members

Anthony McMahon	Mechanical Engineering	manufacturing lead
Austin Jackson	Chemical Engineering	manufacturing support
Brandon McKaig	Mechanical Engineering	manufacturing support
Chris Sosnowski	Mechanical Engineering	project lead
Christian Torres	Mechanical Engineering	manufacturing support
Jace Connor Krstic	Mechanical Engineering	manufacturing support
Jake Keil	Chemical Engineering	presentation lead
Nate Weger	Mechanical Engineering	budget support
Nick Hsiao	Mechanical Engineering	safety
Roman Doyle	Mechanical Engineering	safety
Thomas Niemeyer	Mechanical Engineering	budget
Seema Suthar	Biomedical Engineering	educational outreach
Zachary Luppen	Astronomy & Physics	technical reports

Model Rocket Demonstration Flight – FALL 2015

Shown here is our model rocket competition from Fall 2015. The best launch was of the rocket, 'El Capitan.' Teams consisted of two or three members of the University of Iowa AIAA in order to have as many rockets as possible, and to provide broader experience to everyone.

The first image shows the rocket before launch.

This second image shows the rocket on takeoff, which was a bit horizontal due to the launch stand moving.

This third image shows the rocket high in the sky, now mostly vertical.

This fourth image shows the recovered rocket, held by team member Nicholas Hsiao.

This fifth image shows all members who participated in the rocket competition, after all rockets had been launched. The rocket ‘El Capitan,’ shown above, is held by members Nicholas Hsiao and Anthony McMahon, and is second from the right.