Preliminary Design Report

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The University of Iowa AIAA
Midwest High Power Rocketry Competition
Submitted on: March 18, 2016

Table of Contents:

Executive Summary

Included in this report is all the information regarding the preliminary design of the University of Iowa Team 1's rocket. This report addresses each of the components used in the high-power rocket, as well as explanations regarding why the components were chosen. The aforementioned components include the materials used to construct the body of the rocket, planar fins, grid fins, electronics package, recovery system, and the propulsion system. Each section includes all calculations and diagrams necessary, as well as the specific material or product being used in the rocket. The analysis of the design was performed through use of modeling software, and plots of the rocket's projected performance are included as well. Safety procedures are discussed along with the safety analysis. Finally, the equations used to make calculations, as well and all external sources used to aid in the design of the rocket, are included in the appendices at the end of the report.

Design Features of Rocket

Rocket Fin Specifications

Various fin designs were considered for use in the high-powered rocket. Triangular, rhombic, and trapezoidal fins were all considered. The final choice fell between the rhombic shape, or the trapezoidal one. When addressing the issue, it was brought to the team's attention that rhombic fins were typically used with heavier rockets, and trapezoidal fins were used for lighter ones. While the choice was fairly arbitrary, all members of the group agreed that the rocket was light, and for this reason, the trapezoidal fin shape was chosen. Additionally, through research and modelling, it became apparent that tabbing the fins would generate more stability and result in less fin flutter.

In order to observe the effects various shapes and sizes of fins had on the rocket, modelling and flight simulation software known as OpenRocket was used. It plotted the path of the rocket, and the graph of the various quantities calculated by the software can be found in *Figure 5* of *Appendix C*. OpenRocket also indicated that the use of 3 fins, instead of 4, was far more effective. Thus, the high-power rocket will have 3 trapezoidal fins set equidistant from each other. The placement of the fins can be observed by looking at *Figure 6* in *Appendix C*.

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 other materials. Unlike fiberglass, Blue Tube 2.0 does not need to be sanded down or even made from scratch. 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.

Currently, the rocket has a total length of 84.2 cm, with a 5.4 cm maximum body diameter. Included in this total length is the exposed length of the nosecone (22.23 cm), the body tubes, and all transitional pieces. The total weight of the rocket is projected to be 1,150 g, a value which accounts for the weight of the motor, internal electronic units, and all the materials used for construction. However, a greater weight was accounted for in performing calculations, as the team felt it wiser to leave room for any adjustments that might be made.

Nosecone Specifications

A fiberglass nosecone of diameter 5.4 cm is to be used by the rocket. It is purchased from Apogee Rocket Components, and is 27.94 cm in total length, although only 22.23 cm will be left exposed on the rocket. In total, it weighs approximately 130.7 g, and has a 4:1 Ogive profile.

Propulsion Design Specifications

For our test flight and our competition flight, the Cesaroni H152BS motor will be used, along with the Cesaroni Pro-38 motor casing. To ensure that any necessary changes made to the design will be appropriately transferred to the final rocket, the H152BS will be used on the model rocket as well. The motor casing is constructed from aluminum 6061-T6, and is 17.53 cm in length. Additional details regarding the motor can be found in *Appendix A*, under *Table 1*. This motor was chosen by comparing several different motors and choosing the one which delivered an appropriate impulse, while also taking the rocket up to the desired elevation, given the projected weight of the design. Specifications for the motor were taken from *Source 1* in *Appendix B*.

Recovery System Design Specifications

Although the final mass was found to be approximately 1,150 g, the team thought it best to calculate for the size of the parachute with a slightly larger mass for the rocket of 2,000 g, which correlates to a weight of approximately 5 lb. Calculations were performed with several assumptions, with the most important being that the descent rate be lower than the projected landing velocity of the simulation. The rate used for calculations was 5 m/s.

In order to determine an appropriately sized parachute for the recovery system, several parameters had to be identified and defined. Similarly, reasonable assumptions had to be made to achieve results. The first issue addressed was the descent rate that was desired for the rocket. Although the current projection is a descent velocity of 11.2 m/s, decreasing it to 5 m/s would likely be far safer for the teams and the rocket. The following calculations were done in English units, so that quantities would be more easily grasped during team discussions. Through simple unit conversion, it is seen that 5 m/s is equivalent to 16.4 ft/s. As mentioned previously, the weight of the rocket is assumed to be, at most, 5 lb. Another constraint defined during these calculations is the density of air, interpolated to a value of 0.00224 slugs/ft^3. The final, and arguably most important, parameter is the drag coefficient of the parachute. A value of 0.75 was found to be best, and most common amongst parachutes. Using these values, along with *Equation 10* from *Appendix D*, the value of the area of the chute was calculated to be 22.13 ft^2. Thus, the chute necessary for a slower descent in the rocket would have a radius of 31.85 in. While such a chute would result in a slow and safe landing, it presents a large problem in the logistics of packing the chute into a relatively small rocket. Thus, a better middle ground will likely be established for the final chute used in the competition rocket.

Active Drag System Design

Having an effective active drag system is an important constraint to this year's competition. To address this, a pair of grid fins will be attached on opposite sides of the rocket. A standard grid fin operates by utilizing a set of aerodynamic structures set and contained within a box. By changing the angle at which the grid fin sits, the total drag on the rocket will change, leading to a change in the velocity and apogee of the rocket. The proposed grid fins are curved overall, allowing them to sit closer to the body of the rocket, and generate less initial drag. *Figure 2, Figure 3,* and *Figure 4* in *Appendix C* all illustrate how the grid fins will look, and various positions they will sit in.

The grid fins mounted on the rocket will be moved, via a pair of servos, once the onboard altimeter indicates a certain height has been reached. The power for the servos will be drawn from a 5-Volt battery, which is part of an accessory circuit to the rocket's primary electronic circuit. In tandem with this, a camera will start recording the deployment of the active drag system shortly before the grid fins are activated. The grid fins will be made of 3D-printed ABS plastic. Unfortunately, the effects of grid fins on the rocket were not able to be determined in the OpenRocket simulation software, as no such option existed. However, calculations can be performed to determine at what elevation the grid fins need to be deployed.

Planned Construction Solutions & Techniques

Standard construction procedures were followed, with the group being split to address the various parts of the rocket. By splitting the large group into two, the focus was evenly split amongst the electronics package within the rocket, and the design and construction of the rocket body. All construction was performed with university-owned equipment, whether it was smaller hand tools, or larger pieces of equipment such as a table saw.

While most of the components of the rocket are available to purchase, creating custom fins allows for a certain level of control in regards to rocket guidance and stability. By creating fins out of balsa wood, a cheap and effective set of fins can be created by the team, allowing for experimentation with various designs. All work with more dangerous tools was performed with professional supervision.

Design Features of Payload System

In order to meet competition requirements, the team decided to create a custom electronics package in order to minimize the weight and size of the components. Several electronic components were chosen to accomplish the tasks of collecting video and flight data. The video collection is accomplished by using a 0.6 Megapixel CMOS Sensor ArduCam which will be interfaced with an arduino pro mini. The camera will be connected via 0.5 mm pitch 6in Flat Flex Cable in order to extend the camera from the rest of the electronics package and video will be saved with a MicroSD card via breakout board. The data collection system consists of an Arduino Pro Mini, an Accelerometer, an Altimeter, and an MicroSD card breakout board.

To implement the video collection device, the source code for the ArduCam was modified to meet our need and work with the other electronic components. The code was modified so that the camera would turn on as soon as the other electronic components start acquiring data and allowed for more control over the camera itself. More code was added for exception handling for situations such as the improper ejection of the MicroSD card. The added code helps in preventing data corruption/errors that can happen due to accidental ejection of the sd card on the descent of the rocket as well as recording errors that can happen mid flight.

The data collection system uses the three Arduino Pro Mini's microcontrollers to control the grid fins, collect data, and save video. from the combo board, convert it into useful information, and then save it to the MicroSD card. The Arduinos require a 5V power source, so three 5V batteries were chosen to power all of the boards. The code will need to record the data from the altimeter and accelerometer and analyze the data to calculate the active drag coefficient. This data will then be organized and stored on the SD card using standard I/O 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 OpenRocket. 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 OpenRocket of the rocket can be found in *Figure 1*.

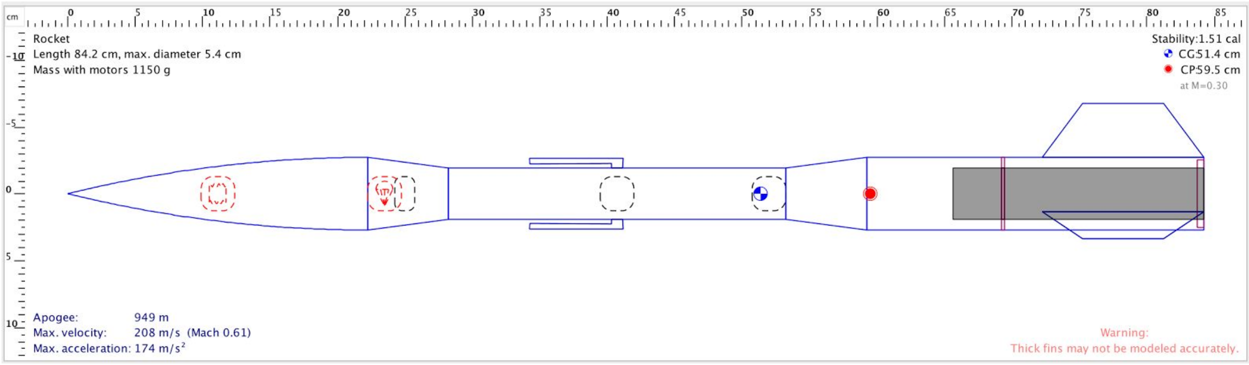

Figure 1: Rocket

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 performance of the current design of the rocket was analyzed using the modelling and simulation software known as OpenRocket. The software allows a 3-dimensional model of the rocket to be created, with included internal components. The dimensions of the materials used in the rocket are used to calculate a mass for each component, which are then summed to determine the total mass of the entire construct. Exact values for each component are available in *Figure 7* of *Appendix C*. Using the specifications of the rocket motor along with the weight of the rocket, and several other related variables, a graph of the altitude, velocity, and acceleration of the rocket over time is plotted. This graph is available in *Appendix C* as *Figure 5*.

The graph indicates that the motor will burn for approximately 1.8 seconds, resulting in a maximum acceleration around 200 m/s^2, and a maximum velocity value of 208 m/s. The rocket reaches an apogee of 949 m (3,114 ft), 9.48 seconds after launch. The model used in the simulation depicts the grid fins as they would sit tucked against the side of the rocket. A simulation with the enabled active drag system, where the grid fins sit opened up, is not available, as the illustration of the grid fins on the model would create a significantly greater drag than the true grid fins would during a real-world launch scenario. The active drag system on the rocket will be deployed once the onboard altimeter reads that a certain altitude has been reached, an altitude which will be determined via the apogee reached by the rocket in previous launches.

Total flight time is estimated to be 93 seconds, with the active drag system in its most low-profile position. Once the active drag system activates, however, this flight time will change, although not too significantly. The simulation was run with minimal wind speeds, and the rocket is projected to hit the ground with a velocity of 11.2 m/s. With adjustments in parachute size, this can be reduced, although the tradeoff then becomes greater weight, and a necessity for far better packing efficiency. The design of the housing for the electronics package will ensure that damage does not occur when the rocket lands.

The Center of Pressure on the rocket is located 8.1 cm underneath the Center of Gravity on the rocket. Stability is not an issue for the design, with a firm value of 1.51 cal.

Innovation

The simulation software package, OpenRocket, was utilized in the design of both the planar fins, as well as the grid fins. By adjusting the dimensions of the fins, a more optimized design was able to be developed by team members. Additionally, the design created can be cut from balsa wood by team members, saving on time and cost. The grid fins are based off an open source design, and are scaled and altered to fit more appropriately onto the competition rocket. Grids fins allow for a better and more controlled active drag system, and allow self adjustment of the rocket through manipulation of the deployment angle.

Additionally, the entire electronics package was built solely by the electronics design team. Specifically, the camera was flashed with custom firmware to allow the capture of video in 720p resolution, at 27 frames per second. The code for the camera was modified to allow for better exception/error handling for situations such as the accidental ejection of the MicroSD card on the descent of the rocket. The modification in programming greatly minimizes the chance for corruption of the data written to the MicroSD card. All decisions regarding in-flight control of the camera was made as a group.

Safety

Designed for Safe Flight and Recovery

The rocket contains a single deployment system to keep it from traveling extensive distances. The deployment system utilizes a streamer and a regular parachute. The streamer is more cost-effective while still providing additional drag for the rocket, in addition to the parachute that is deployed 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, three 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, prepare, and program the electronics package to meet the requirements of the competition. This team will be made up of people who are comfortable with soldering and programming of microcontrollers. During assembly, these members will ensure that all of the electronics are working and that the camera is on and ready to record on launch. The DADS (deployment and active drag system) team will prepare the parachute and streamer for the rocket and ensure that the deployment system as well as the active drag system is ready. The construction team will consist of members from both of the other teams and will ensure that the rocket is assembled correctly. This team will ensure that both of the other systems are compatible with each other when assembling the rocket.

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 via pull-pin switches.

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 GPS 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 both Minnesota teams. 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	18.6 cm
Total Mass	298.0 g
Propellant Mass	138.0 g
Maximum Thrust	212.4 N
Total Impulse	276.0 N-s
Burn Time	1.8 s

Table 2: High-Powered Rocket Competition Materials List and Estimated Budget

Item	Unit Cost	Weight (grams)
Microcontroller (Arduino Pro Mini)	$30.00	6 g
MicroSD card Breakout Board	$20.00	8.505 g
GPS	$42.09	8.505 g
Altimeter	$15.00	4 g
Accelerometer	$10.00	2 g
Camera	$30.00	51.0291 g
SparkFun FT231X Breakout (USB adapter for laptop)	$14.95	N/A
Shock Cord	$5.00	11.34 g
Parachute	$16.99	15.0g
Pressure Plug(X2)	$25.00	9.07 g
Motor (Ceseroni H152BS)	$35.00	298 g
Nose Cone	$36.73	149.69 g
Motors for ADS (Servos)	$20.00	181.44 g
Nozzle	$50.00	90.72 g
Blue Tube	$30.00	498.95 g
Streamers	$7.00	90.72 g
Epoxy	$20.00	45.36 g
Engine Block	$15.00	226.8 g
Fins (3D Printed)	$100.00	15.0 g
Fins	$30.00	22.0 g
Estimated Totals	$552.76	1,734.1291 g

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
S	Parachute Surface Area
W	Total Weight of Rocket
ρ	Air Density
μ(air)	Drag Coefficient
v	Descent Velocity

Appendix B: Sources

Source 1 - High Powered Rocket Motor: https://www.apogeerockets.com/Rocket_Motors/Cesaroni_Propellant_Kits/38mm_Motors/2-Grain_Motors/Cesaroni_P38-2G_Blue_Streak_H152

Source 2 - Motor Casing: https://www.apogeerockets.com/Rocket_Motors/Cesaroni_Casings/38mm_Casings/Cesaroni_38mm_2-Grain_Case

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

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

Source 5 - Grid Fin Technology: https://en.wikipedia.org/wiki/Grid_fin

Appendix C: Figures

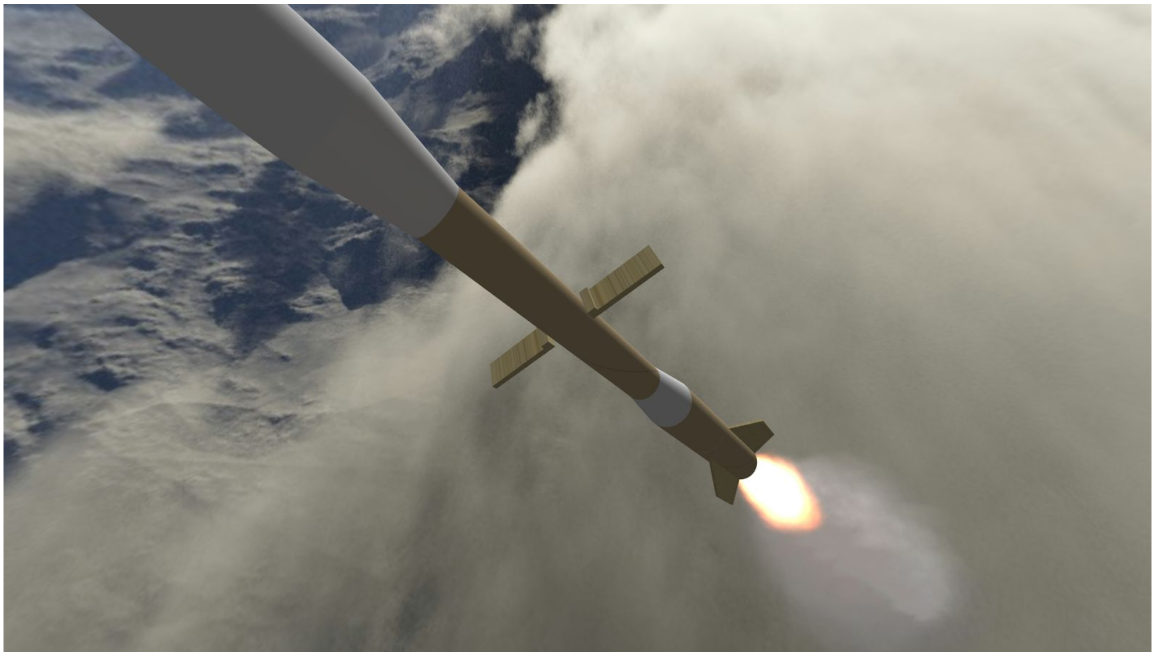

Figure 2: 3D representation of deployed active drag system

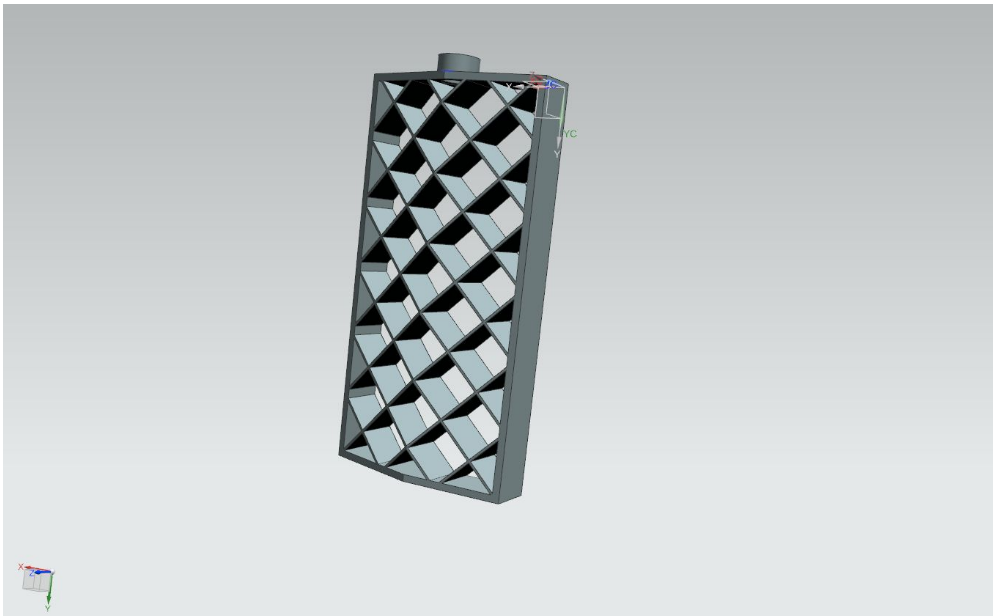

Figure 3: 3D representation of a grid fin, based on opensource design from www.GrabCad.com by Isaac Young

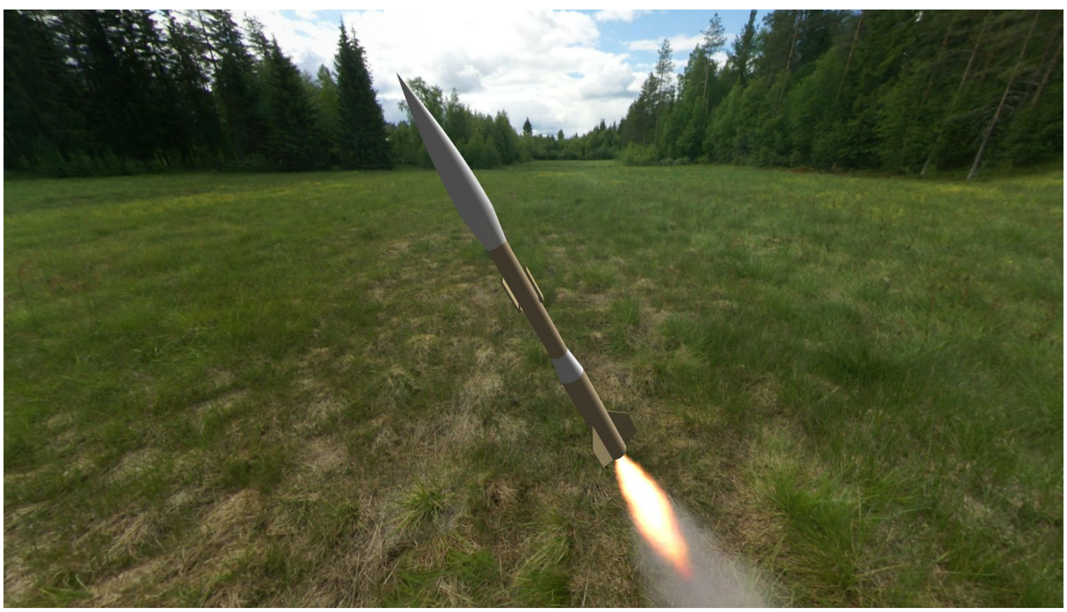

Figure 4: 3D representation of the rocket blasting off, modeled in OpenRocket

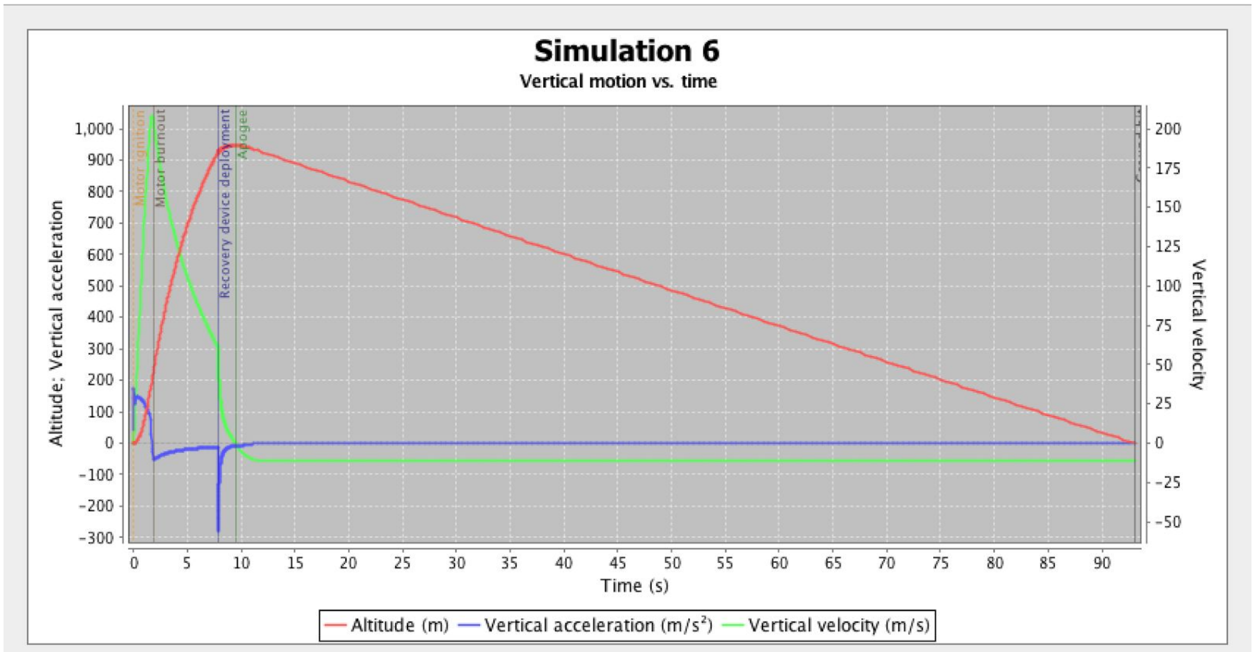

Figure 5: Graph showing the vertical acceleration, vertical velocity and altitude vs time for the rocket

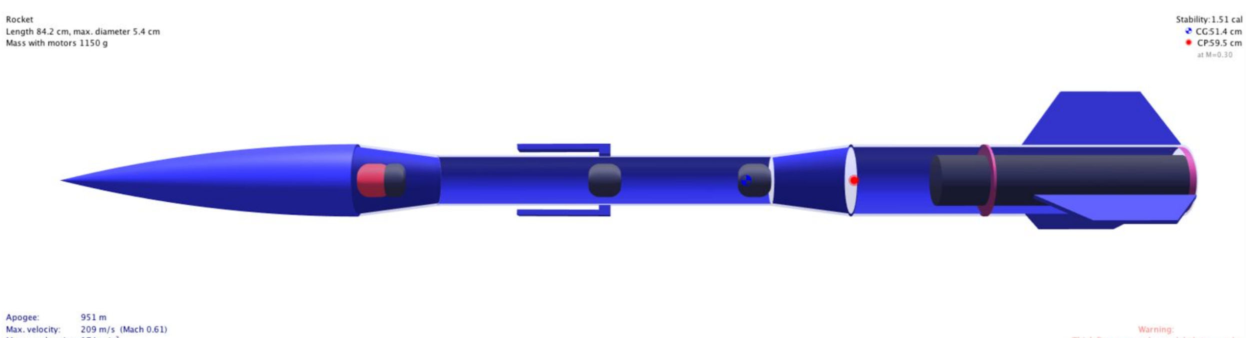

Figure 6: 3D representation of the rocket, modeled in OpenRocket

Parts Detail

Sustainer

Nose cone	Fiberglass (1.85 g/cm³)	Ogive	Len: 22.2 cm	Mass: 88.6 g
Streamer	Ripstop nylon (67 g/m²)	Length 50 cm Width 5 cm	Len: 5 cm	Mass: 1.68 g
Transition	Fiberglass (1.85 g/cm³)	Fore Dia: 5.4 cm Aft Dia: 3.8 cm	Len: 6 cm	Mass: 30.9 g
Camera		Dia_{out} 2.5 cm		Mass: 60 g
Parachute	Ripstop nylon (67 g/m²)	Dia_{out} 45 cm	Len: 2.5 cm	Mass: 13.9 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 30 cm	
Shock cord	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)		Len: 40 cm	Mass: 0.72 g
Body tube	Blue tube (1.3 g/cm³)	Dia_{in} 3.5 cm Dia_{out} 3.8 cm	Len: 25 cm	Mass: 55.9 g
Electronics		Dia_{out} 2.5 cm		Mass: 300 g
Freeform fin set (2)	Cardboard (0.68 g/cm³)	Thick: 2.5 cm		Mass: 11.7 g
Servos - Active Drag System		Dia_{out} 2.5 cm		Mass: 200 g
Transition	Cardboard (0.68 g/cm³)	Fore Dia: 3.8 cm Aft Dia: 5.4 cm	Len: 6 cm	Mass: 11.4 g
Body tube	Cardboard (0.68 g/cm³)	Dia_{in} 5 cm Dia_{out} 5.4 cm	Len: 25 cm	Mass: 55.5 g
Engine block	Blue tube (1.3 g/cm³)	Dia_{in} 5 cm Dia_{out} 5 cm	Len: 0.5 cm	Mass: 0 g
Trapezoidal fin set (3)	Cardboard (0.68 g/cm³)	Thick: 0.3 cm		Mass: 22 g
Centering ring	Cardboard (0.68 g/cm³)	Dia_{in} 3.8 cm Dia_{out} 5.4 cm	Len: 0.2 cm	Mass: 1.57 g

Figure 7: Various physical values of each component and material used in the construction of the rocket (epoxies excluded).

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:

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

Equation 10:

$$S = \frac{2W}{\rho \mu_{air}(v^2)}$$

Appendix E: Team Members

Rohit Banda	Electrical/Computer Engineering	Budget Lead
Naveen Ninan	Biomedical Engineering	Report Lead
Josh Larson	Electrical Engineering	Electronics Lead
Victor Sun	Mechanical Engineering	Manufacturing Lead
Shao Yang Zhang	Biomedical Engineering	Manufacturing Support
Cameron Elias	Mechanical Engineering	Manufacturing support
Conrad Tebbe	Mechanical Engineering	Design Team
Zane Bodensteiner	Mechanical Engineering	Design Team
Conor Bryant	Biomedical Engineering	Manufacturing support
David Arrington	Biomedical Engineering	Manufacturing support