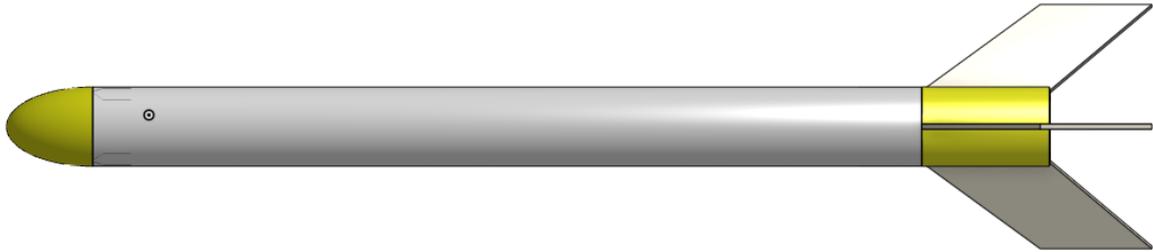


SPH - 4U101 2022/2023

Prepared for: Mr. Fletcher



A Floating Failure

Rocket Project Report

Ledio Gradeci

Ro Lee

Introduction

Model rockets are an incredibly fun activity for the casual rocketeer or the hardcore rocket enthusiast. Flight happens when a solid state rocket fuel is burnt and expelled out of the bottom nozzle, causing upward thrust. Once the propellant is spent, the charge at the top forces a nose cone off revealing the recovery device. The recovery device allows the rocket to (ideally) float back to the ground safely.

Purpose

The purpose of this experiment is to build a model rocket that achieves a minimum flight time of 30 seconds, and accurately predict the flight time of the rocket we construct. The winner of the competition is the rocket which archives an actual time with the lowest % error when compared to the predicted time.

The History of Rockets

It is believed that rocket propulsion was first discovered in the 12th and 13th centuries in Asia, where the first mixture of propellant was used for about 1,000 years for different purposes. This mixture contains sulfur, saltpeter (niter, potassium nitrate), and charcoal and is also known as black powder. This is almost identical to the mixture used in modern pre-purchased model rocket engines. The use of black powder in rockets was mostly used for military purposes, in which black powder charges which were used in bombardment weapons, one of which is the Congreve Rocket, named after William Congreve who was a British officer who was crucial to their development.

Due to the superiority of guns in the 19th century and early 20th century, black powder became less commonly used in weapons as it is not an ideal method of propulsion and provided

very poor results in comparison to more modern standards. Rocket technology started to gain traction in the late 1800's and early 1900's, where the public's interest in using rockets for space exploration began to grow. Russian scientist Konstantin Tsiolkovsky was one of the first scientists to develop modern rocketry by creating the concept of a multi stage propulsion system.

Robert Goddard, an American scientist, became the second pioneer of modern rocketry by taking the concepts that Tsiolkovski came up with and setting up experiments with them. He first experimented with solid state propellant rockets, but then realized that liquid fuel would be more effective. In 1926, Goddard attempted a launch with a rocket powered by liquid oxygen and gasoline. This rocket climbed a whopping 12.5 meters in the air and landed 56 meters away from the launch site; not very impressive. The third pioneer of modern rocketry was a German scientist named Hermann Oberth, who developed much of the theory that modern rockets use today. He was the man who made the V-2 Rocket in Germany during the 1930's, a liquid propelled rocket designed for use in the second world war. In more recent times, NASA's Apollo 11 took three astronauts to the lunar surface, and successfully brought them home; all with a rocket who's computer had around 1.5% of computing power found on a cell phone. Lately though, a private company by the name of SpaceX has been making booms in the space industry. Founded by Elon Musk, SpaceX is the first private company to take astronauts to the International Space Station (ISS). SpaceX has developed sophisticated systems for recovering boosters that are discarded during launch such as grid fin control surfaces and portioned fuel to kill velocity on descent into the atmosphere. SpaceX's rockets use an intricate system to land themselves safely on a droneship or landing pad in order to be reused, all



making the launching of rockets less expensive in the long run and much more eco-friendly.

Rocket Design & Physics

Model rockets have a fairly distinct shape, with a cylindrical body, aerodynamic nose cone, fins at the bottom along with an engine, but why are they shaped like this and what does each part do? For starters, we must investigate the physics behind how a model rocket works, and we can start this by talking about the requirements to fly a rocket. A model rocket can come in all sorts of shapes and sizes, but they all have a rocket engine at the bottom. This is essential to propel the rocket into the sky, but it does not necessarily mean it will be stable, so we use the body shape and weight distribution to achieve the desired flight. A large mass at the bottom of a rocket throws off the center of mass and building a frame with different dimensions helps distribute the weight more evenly. In **Figure 1** below, you can see the center of mass (Also referred to as Center of gravity, CG) of the rocket as well as a red circle below it that represents the center of pressure (CP).

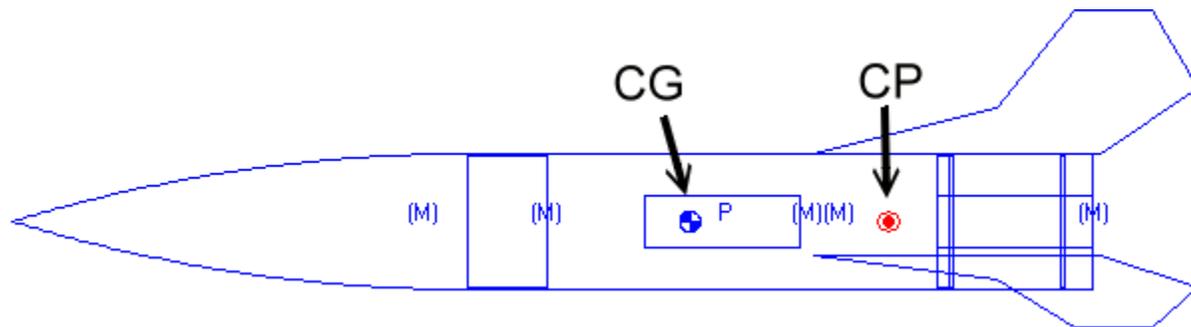


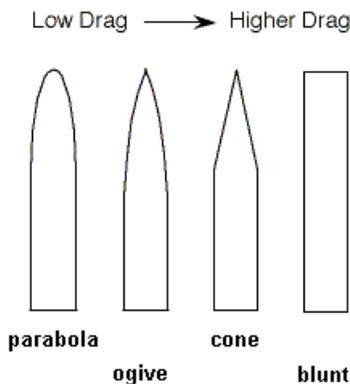
Figure 1 - <https://www.rocketreviews.com/what-is-cp.html>

The CP must be located behind the CG because when the rocket tries veering off course, it rotates about its CG and during upwards motion if the CP is located below the CG the deviation will be corrected due to CP being pushed by the oncoming air, lining itself up with the CG, thus going up. So how does one bring the CP below the CG?

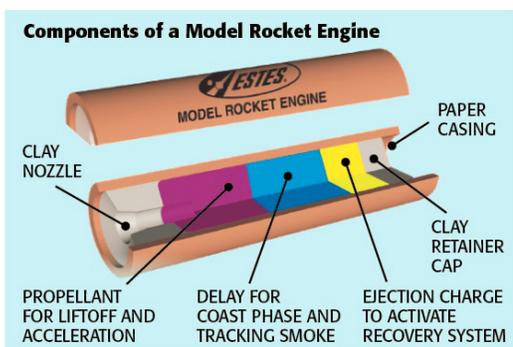
This is one of the reasons fins are used. Fins keep the rocket stable by producing more drag toward the point at which the fins are located. Using the equation to find drag, $F_D = \frac{1}{2}\rho v^2 C_D A$, we can see that the coefficient of drag (C_D) and the reference area (A) have a direct effect on drag. Different shapes, placement, and sizes can result in different values and effects. Placement of fins is very important because it heavily influences the center of pressure, which determines the stability of the rocket.

The fuselage of a model rocket is typically cylindrical for a few reasons. One of the main factors is due to the very high ratio of area compared to the perimeter of a circle. Smaller perimeter with the same internal area means that walls can be lighter while still providing the same inner area. Circles are also very strong, and their strength does not depend where an impact happens. Cylindrical tubes are also much easier to manufacture, as they are made by roll-wrapping cardboard around a tube and gluing the seams.

The nose cone of a model rocket is a piece that typically detaches from the rocket body



tube and allows the recovery device to be deployed, and is connected to the body tube via a shock cord. The shock cord is usually elastic and will absorb the force of the ejection charge. A rocket with a flat nose has a lot of drag, whereas an ellipsoid (parabola) shape efficiently pushes the oncoming air around the rocket, causing less drag.



Finally, the most important part of a model rocket, the motor. Solid state rocket motors share many similarities with early rockets, namely the fact that they use black powder as propellant. The solid fuel is ignited by the electric igniter, and

the reaction starts to thrust the rocket into the air. Based on Newton's third law of motion, every action has an equal and opposite reaction, the action of thrust pointing down reacts by pushing the rocket in the opposite direction.

Stored Chemical Energy - Estes A8 - 3

At apogee, the kinetic energy of the rocket is 0, due to the fact that its velocity is 0 for the instant it is at apogee.

$$\text{Therefore, } \Delta E_g = E_{gf} - E_{gi} = mg(h_{max} - h_i)$$

Lauch #1

$$\Delta E_g = 35.48 \text{ J}$$

Lauch #2

$$\Delta E_g = 32.87 \text{ J}$$

Since the chemical energy stored in the A8 Motor is 36000 J, the energy lost from each launch can be found using the formula $Efficiency = 1 - \frac{E_c - \Delta E_g}{E_c}$

Lauch #1

$$Efficiency = \text{less than } 0.01\%$$

Lauch #2

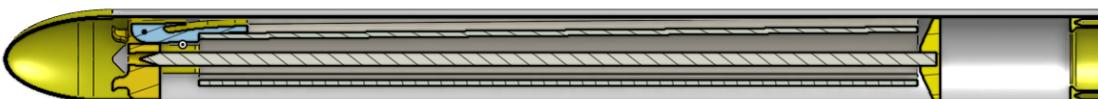
$$Efficiency = \text{less than } 0.01\%$$

While the engines are powerful enough to propel the rocket, they are not very efficient. The lost energy is converted mainly to heat, sound, and light energy.

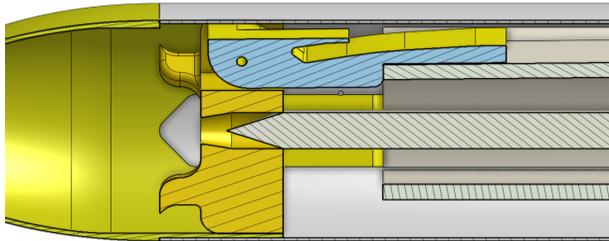
Design

The design of our rocket is formulated around the idea of using a helicopter recovery system to slow the rocket during descent. The helicopter recovery system is not very common due to it being heavier and mechanically complex. With the system being mechanically complex, there are also many ways to design it. Some models have the rotor blades on the outside, but we chose to design our rocket so that the rotors are stored inside the tube (See **Figure 2** below for section view CAD Model).

Figure 2



The design we came up with for the helicopter recovery device consisted of some 3D printed parts, such as the nose cone, plunger, hinge mount, and rotor mounts. The rotor mounts are connected to the hinge mount via a copper wire pin, allowing the rotor mount to swing out



with the rotor (See **Figure 3** for close up). The rotor is made of custom cut balsa wood that is bent around a tube using hot water to achieve the desired curve.

Figure 3

The bottom end of our rocket uses a 3D printed bottom section, which is used as a centering ring, motor mount, and fin mount all in one piece. The fins are attached via the built in slots, which also strengthen the connection between the inner and outer circles. The motor stop is also built into the part, which consists of a ring protruding towards the center to prevent the engine from flying up through the tube. (See **Figure 4**)

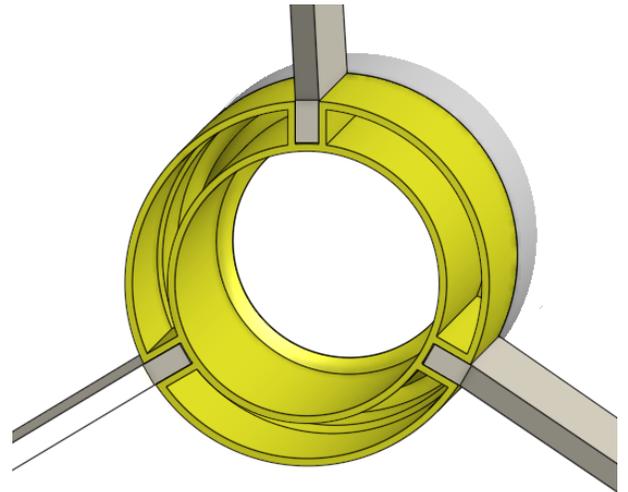
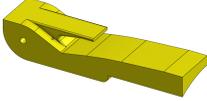
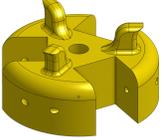
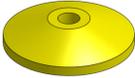


Figure 4

Parts List

Part	Information
	<p><u>Nose Cone</u> Quantity: 1 Mass: 1.1g Material: PLA</p>

Part	Information
	<p><u>Rotor Mount</u> Quantity: 3 Mass: 0,6g (ea) Material: PLA</p>
	<p><u>Body Tube (BT50)</u> Quantity: 1, (26cm length) Mass: 6.3g Material: Spiral wound cardboard</p>
	<p><u>Fins</u> Quantity: 3 Mass: 0.3g (ea) Material: 1.6mm thick balsa</p>
	<p><u>Helicopter Rotors</u> Quantity: 3 (18cm length) Mass: 0.47g Material: 1.6mm thick balsa Notes: Curved profile using hot water forming method</p>
	<p><u>Bamboo Skewer</u> Quantity: 1 Mass: 2.4g Material: Bamboo</p>
	<p><u>Hinge Mount</u> Quantity: 1 Mass: 2.6g Material: PLA</p>
	<p><u>Plunger</u> Quantity: 1 Mass: 1.8g Material: PLA</p>

Theoretical and Experimental Determinations

Center of Gravity

The center of gravity (CG) of a rocket is fairly easy to find. Using a theoretical calculation, the CG of a rocket can be found using the formula $cg = \frac{\sum d_n W_n}{W}$. With a projected mass of 40.7g, we determined that the theoretical CG must be 20.5cm from the tip of the nose cone. Experimentally, we can load the rocket with an unused motor allowing us to determine where the rocket balances when placed on its side. Using this method we have determined that the actual CG is 19.8cm from the tip of the nose cone; 7mm higher than expected. The cause of this has been narrowed down to the use of adhesives during assembly, and the rubber bands which put tension on the rotors.

Center of Pressure

The Center of pressure (CP) of a rocket can also be found using a formula, in this case that formula is $cp = \frac{\sum d_n a_n}{A}$. The fins have a combined surface area of approximately 22cm² which means the calculated center of pressure is 25.4cm from the tip of the nose cone. An experimental test which is also quite entertaining, is to tie a string of considerable length to the CG of your rocket, and swing it in a circular motion above your head. If the rocket is stable, it will point in the direction it is going. An unstable rocket will tumble uncontrollably. In our case, we determined that the CP is fairly accurate, and the rocket is stable.

Max Rocket Height

A Rocket's maximum height can be determined by doing some calculations. Luckily, OpenRocket is a free software which allows us to model our rocket and run simulations based on

our design. Using drag coefficient information from OpenRocket we can substitute values into our equation.

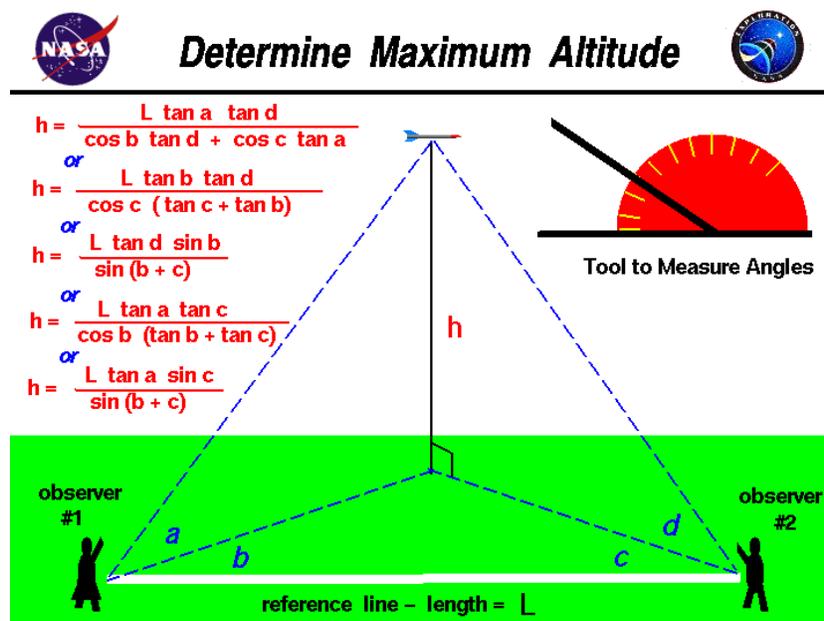
Mass $m = 0.0394 \text{ kg}$	Gravitational Acceleration $g = 9.8 \text{ m/s}^2$	Drag Coefficient $Cd = 0.59$	Gas Density $r = 1.22 \text{ kg/m}^3$	Reference Area(w/o fins) $Ap = 0.000483 \text{ m}^2$
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$$V_t = \sqrt{\frac{2mg}{Cd r Ap}} = 47.13 \text{ m/s}$$

$$V_0 = 49.2 \text{ m/s}$$

$$y_{max} = \frac{V_t^2}{2g} \ln\left(\frac{V_0^2 + V_t^2}{V_t^2}\right) = 83.53 \text{ m}$$

This formula is helpful to get an idea of what our max height is going to be, but there are many other uncontrollable factors that contribute to a rocket's maximum height such as wind, temperature, and weather. In order to determine experimentally what height we achieved, we can use some basic trigonometry and ground stations set up with people tracking the rocket as it ascends.



Launch #1

$L = 108 \text{ m}$	$a = 70^\circ$	$b = 40^\circ$	$c = 10^\circ$	$d = 44^\circ$
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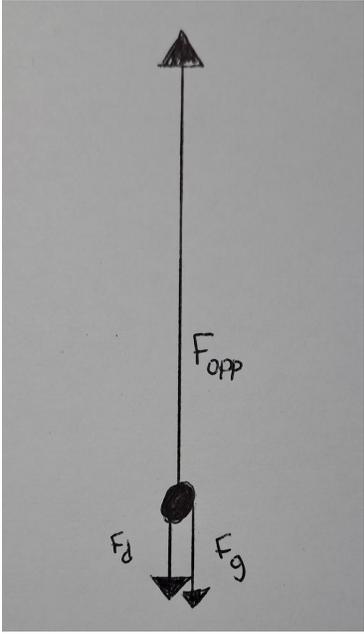
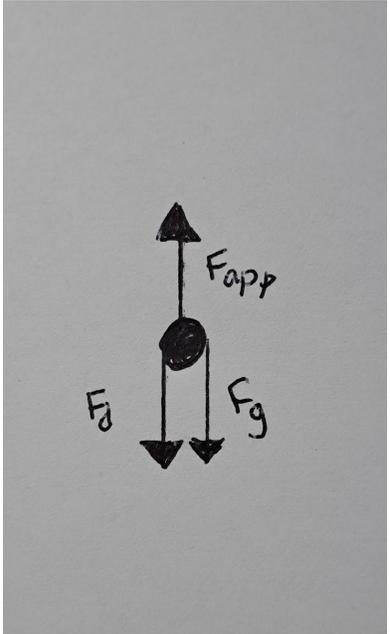
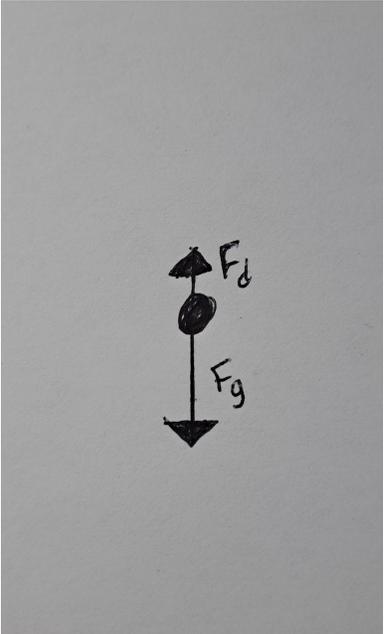
$$h_{max} = 85.13 \text{ m}$$

Launch #2 (Updated Design)

$L = 100 \text{ m}$	$a = 66^\circ$	$b = 50^\circ$	$c = 21^\circ$	$d = 48^\circ$
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$$h_{max} = 91.9 \text{ m}$$

Force Diagrams

<u>Ascent Phase</u>	<u>Coasting Phase</u>	<u>Descent Phase (Recovery Device deployed)</u>
		

<p>During the ascent phase, the applied force of the rocket motor is much higher than the forces of gravity or drag that slow it down, causing the rocket to accelerate upward. The launch rod provides vertical stability until the model reaches a speed where fins keep it stable.</p>	<p>While coasting, the rocket is still moving upwards, but the forces of gravity and drag are greater than the delay stage of the motor, causing the rocket to slow as it approaches apogee.</p>	<p>When the rocket is descending, the recovery device is deployed, causing the force of drag to help keep the rocket in the air for a longer duration of time, but gravity has a much greater effect. Therefore the model falls down. In the case of the <i>Niner Collider</i> the force of drag can also be considered the force of lift, due to the rotors which provide lift as they spin.</p>
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Mistakes

Flight Time Error

The error in flight time for our rocket can be calculated by using the formula

$$\% \text{ Error} = [(t_{\text{Actual}} - t_{\text{Theoretical}}) / t_{\text{Theoretical}}] \times 100$$

Launch #1

$$\% \text{ Error} = [(8.2\text{sec} - 22.5 \text{ sec}) / 22.5 \text{ sec}] \times 100$$

$$\% \text{ Error} = -63.555555\%$$

Launch #2

$$\% \text{ Error} = [(18 \text{ sec} - 22.5 \text{ sec}) / 22.5 \text{ sec}] \times 100$$

$$\% \text{ Error} = -20\%$$

Due to the fact that the minimum required flight time for the competition is 30 seconds, the calculations above are inadmissible. Below are the % Error calculations with the minimum theoretical time of 30 seconds.

Launch #1

$$\% \text{ Error} = [(8.2\text{sec} - 30 \text{ sec}) / 30 \text{ sec}] \times 100$$

$$\% \text{ Error} = -72.66666666\%$$

Launch #2

$$\% \text{ Error} = [(18 \text{ sec} - 30 \text{ sec}) / 30 \text{ sec}] \times 100$$

$$\% \text{ Error} = -40\%$$

Design Mistakes

The design that was explained in the ‘Design’ section above was not the first version of our rocket. That was a modified and updated version that fixes the mistakes of our previous version.

Unfortunately, The first attempt at launching the rocket did not go very well. The rocket flew up gracefully, before a failed deployment of the recovery device which caused it to come down to the ground like a lawn dart. The damage caused is pictured below in **Figure 5**.

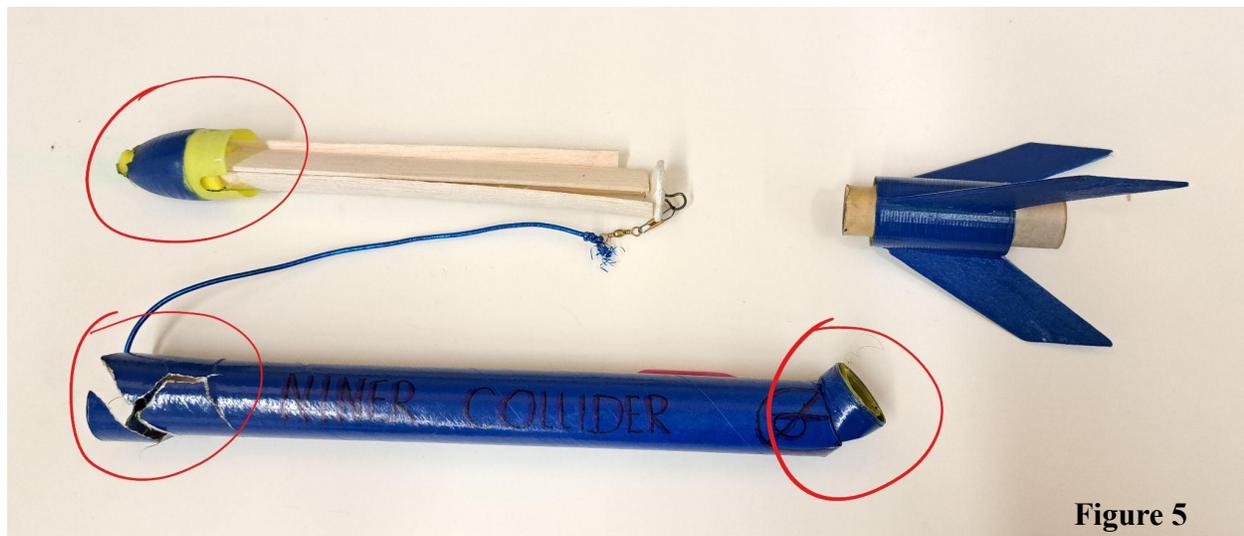
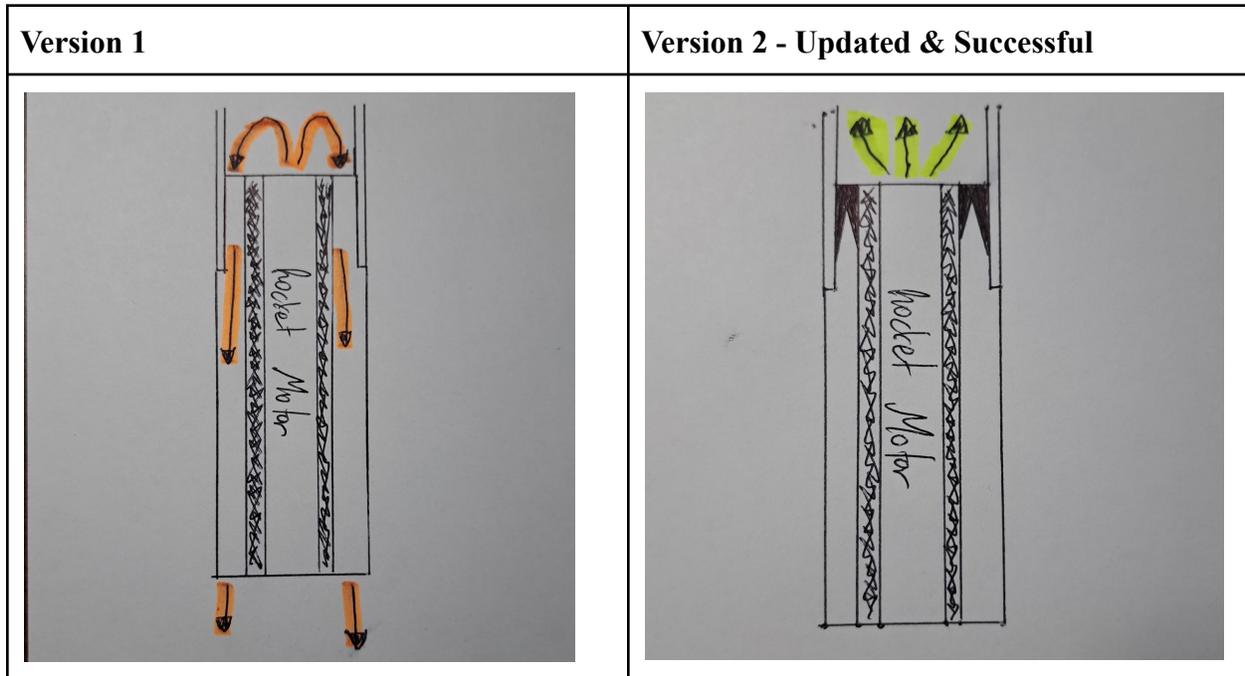


Figure 5

There are a few things that may have caused the catastrophic failure of the *Niner Collider*. After the flight, we immediately worked on determining what the issue with the rocket was so we could re-build the rocket. Initially, we speculated that the cause of failure was the nose cone’s connection to the body tube was too tight, not allowing the recovery device to deploy. Upon further inspection and review of flight footage, we determined that the cause of the failed deployment was in fact a flaw in our design. In the table below, there are two images of a cross section from the fin can designs. The first version was hollow between the motor mount adapter, which caused all the pressure and exhaust gasses from the ejection charge to be rerouted out the

back of the rocket. Evidence of this can be found in the crashed rocket, where the fin can melted due to the heat, and the impact caused it to bend. **(Figure 5)** The updated fin can design features a bridge that seals the inside of the fuselage, forcing all the ejection pressure out the top of the rocket and deploying the rotors.



Limitations

The rotor based design is very interesting, as the mechanically complex nature of the design causes mass to increase substantially. The requirement of rotor length also means that the fuselage must be longer to accommodate all the inner components. All these limitations in design make up for a very engaging engineering challenge, because every time something is given in one area, we must take from another. In a precision duration challenge, balancing all the gives and takes is essential to put together a rocket which is capable of meeting minimum

requirements. This is especially important as we have more gives and takes than a conventional model rocket.

We were also limited by the small motor size that was required. The A8 worked very well but possibly moving up to a B6 motor would allow us to increase the takeoff weight, apogee and use longer rotors, all helping increase flight time.

In terms of flight time, The required minimum duration was set at 30 seconds. Unfortunately, the *Niner Collider* Did not reach this time. Our projected flight time was 22.5 seconds, which is inadmissible due to the 30 second minimum. The actual flight time was 18 seconds. During the flight the rocket landed in a tree on top of a hill, so this time doesn't not fully speak to the capabilities of the rocket, but it provides an insight into its performance.

Conclusion

In conclusion, when speaking of the *Niner Collider's* flight, it ended up being very successful. All the time spent designing and constructing the rocket quickly became worthwhile when the rocket successfully deployed its helicopter recovery system and gracefully spun to the ground. The complex system came with an increased number of possible failure points, but the rocket held up well. Although the flight went well, the competition did not. With our lowest admissible % error of flight time being 40%, our time was nowhere near where it needed to be to meet the minimum requirements of the competition. The complexity, mass, and drag of our rocket all came together to make our actual flight time last only 18 seconds; 22 seconds away from the target minimum.

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