Investigating Model Rocket Aerodynamics With 3D-Printed Parts

Quintin C., Korbin S.

Abstract

Model rocketry is a unique field of science that is nuanced, yet simple in its background. This paper aims to demonstrate the effects of different 3 designs of 3D printed parts on drag, lift, and stability using entirely self-designed model rockets, as well as show that model rocketry is an easy yet effective gateway into the world of engineering and physics. We collected data that summarizes that designs that balance minimizing drag and maximizing lift in tandem are more effective than leaning more towards one side over the other. We also concluded that, even without any notable experience in model rocketry, we were able to successfully launch 3 model rockets without major issues and learn about the data collected, further exemplifying that model rocketry is a good entry point for young aspiring engineers and physicists.

Introduction

Engineering and rocketry have long since been among the most important subjects of research and study. From the modern commodities such as commercial airline travel all the way back to the moon landing of 1969, engineering has long since proven itself in its importance **[1]**. Engineering has also been one of the most interesting subjects for me, and it's not hard to see why; the combination of creativity and logic mixed into one subject took me away the moment I looked into the field. The aerodynamics and design elements of this project reflect the skills needed in the real field. Furthermore, these skills are important for younger individuals who want a gateway into engineering to see that being able to engineer something isn't only limited to big, fancy tools, but also to small, simple things like model rockets and little designs. To that end, this project is focused on providing a way to introduce a younger audience to engineering and 3D design in a way that can be done at home.

This project focuses on the study of model rockets. More specifically, how the design of the model rocket influences its aerodynamic properties. A central goal of this project is to show that even novice engineers can be profound researchers, even if they don't have access to the fanciest or the grandest equipment for the subject. By handling the design *and* fabrication of the model rockets, this project aims to explore the properties of aerodynamics combined with the thrill of self-engineering parts to observe the effects of differently shaped aspects of the rocket, those being the cones and fins. I've chosen this project because of its incorporation of self-design into a study that's usually very competitive and nuanced, while making the entire project more loosely restrictive and open-ended. Young engineers can enter this aspect of engineering without too much experience, and still learn a ton of valuable ideas about what it means to be a designer and researcher.

FIGURE 1

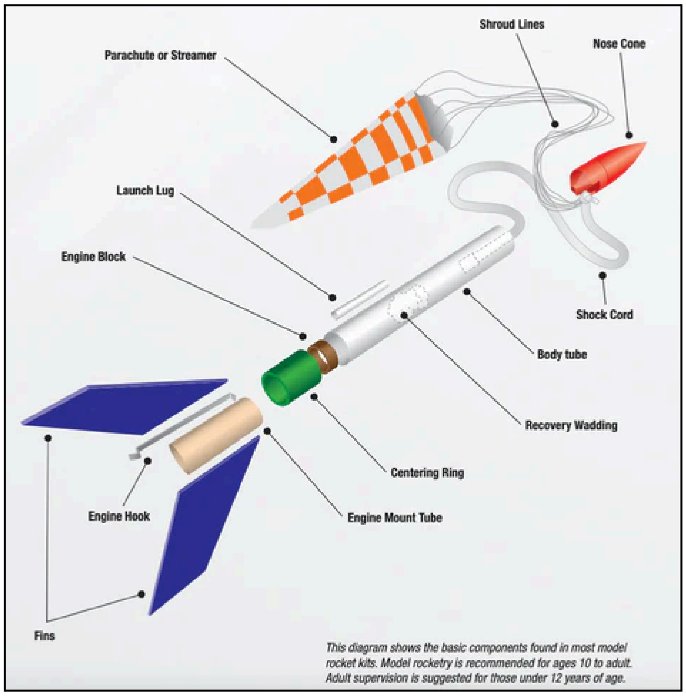


Diagram of how a model rocket is assembled

FIGURE 2

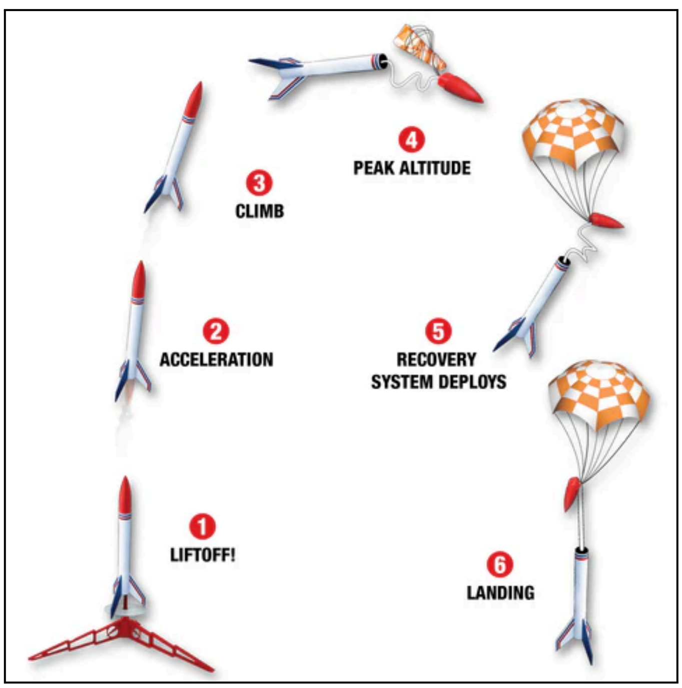


Diagram of the process of launching a model rocket

In this project, we'll be testing various aerodynamic properties of certain shapes of various rocket parts by 3d printing the individual shapes and launching a model rocket using those shapes in a controlled location. Variables like fin size, fin shape, and cone shape will be tested to see which design is most effective during the rocket launch. **[2]** The shapes will be self-designed in AutoCAD, then 3D printed and assembled to create our model rockets to be used in testing. The rockets will be rated based on how high they fly, which will be measured using a barometric altimeter from Estes rockets. Readers will gain insight into the different properties of the shapes used in this experiment, and will also be able to compare their results to different models of the same nature.

This project looks into the effects of the different rocket parts on the rocket's ultimate altitude, which will largely be affected by core physics concepts like drag and lift **[3]**. Because the lift should be identical between all of the designs presented in this project, the ultimate height of the rocket should be primarily a result of its efficiency at reducing drag. More specifically, drag is a mechanical force that an object experiences as it travels through a fluid, whether that be a liquid or a gas **[4]**. Unlike "field" forces, such as gravity, drag occurs only when an object is in contact with the fluid it is moving through. Because of this, larger surface areas generally result in high values of drag resistance. It is analogous to friction in the sense that the object must put forth energy to push away the particles of the fluid it is moving through, such as gas molecules, to maintain a given velocity. There are multiple strategies to minimize drag, and this project will investigate a few of them to see which has the largest effect. Our first design, the control, was based on the standard perception of what rockets are: 4 fins, a long base, and a cone on the top. The second design was modeled for a more efficient rocket shape, changing the simple straight cone and fin shapes with more streamlined, complex shapes for the cone and fin. The last design was modeled after the idea that stability would be much improved if the rocket spun while flying, which is why it uses slightly tilted fins and a softer, more blunt cone. Apart from just investigating the effects of different designs on drag and lift, this project aims to show that model rocketry is an effective and easily accessible method of introducing students to engineering without much prior knowledge or experience.

Materials & Equipment

Table 1: Materials and Equipment Used

Materials	Equipment
PETG 3d printing material	3d modeling Software - AutoCAD
B6-4 Estes Rockets model rocket engine	Estes Rockets launch controller
Estes Rockets 15 in. parachute	Estes Rockets launch pad
Kevlar shock cord	Estes Rockets Altimeter - (Barometric)

Experimental Methods

Step 1: Design your rocket

Design the cone, fin, exhaust, and body separately. Depending on what you're trying to test, create multiple designs of each part of the rocket. Each part should serve a specific purpose, and should all be unique unless the part you're creating is meant to be a control part and not changed in any way. Should be done on 3d modeling software so you can export it as an STL file to be able to print.

Step 2: Print and assemble your rocket

After designing all your rocket parts for each variation of your design, you should print your rockets using the STL files and have them ready. Make sure all the pieces fit rather snugly so they don't fall off or out during launch. Finally, stuff the flame-resistant wadding into the tube of the rocket. Additionally, make sure to attach your parachutes and altimeter to the rocket via rings in the rocket or very strong adhesive and the shock cord.

Step 3:

After assembling each rocket for launch, make sure you find a desolate, open area where it is safe to legally launch your rocket. Set up the Estes Rockets launch pad, and make sure you have successfully inserted the launch starter into the engine of your rocket. Then, attach the 2 points of your Estes Rockets launch controller and turn the key to enable it. After stepping back to a reasonable distance away, launch your rocket by pressing the large button on your controller.

Step 4:

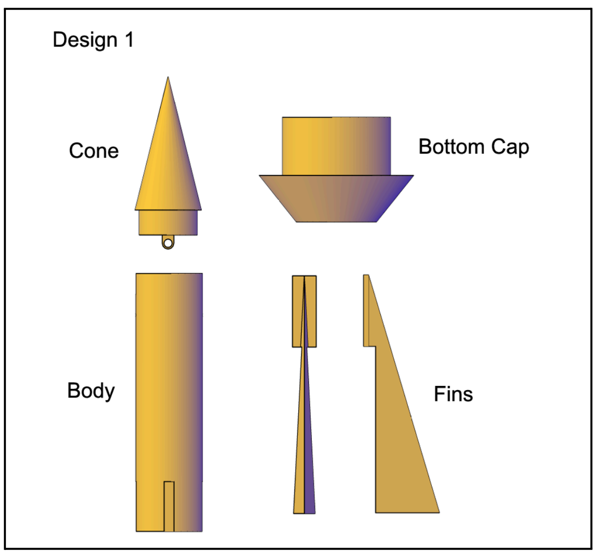
After each launch, collect the data from the altimeter within the rocket. Keep in mind that the altimeter will automatically collect the data as soon as the launch reaches its apex. Record each number onto a piece of paper and compare.

Model Rocket Designs

First - Control Model

This model was created as the control for this experiment, to see whether the other 2 designs would actually outperform it or get beaten out by the control. It uses a simple, triangular cone at the top and delta fins. However, the rocket might be prone to flutter, which is the shaking of the body at higher speeds.

FIGURE 3

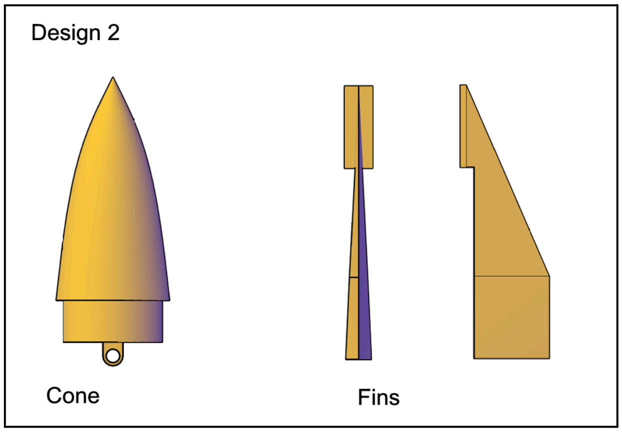


A diagram of all parts of the 1st design

Second - Sharper, More Aggressive Mode

This model was designed with more speed and stability in mind, using clipped delta wings to make sure the rocket doesn't flutter at the higher speeds it's meant to go. It also utilizes a tangent ogive that provides more stability and less air resistance than the basic cone does.

FIGURE 4

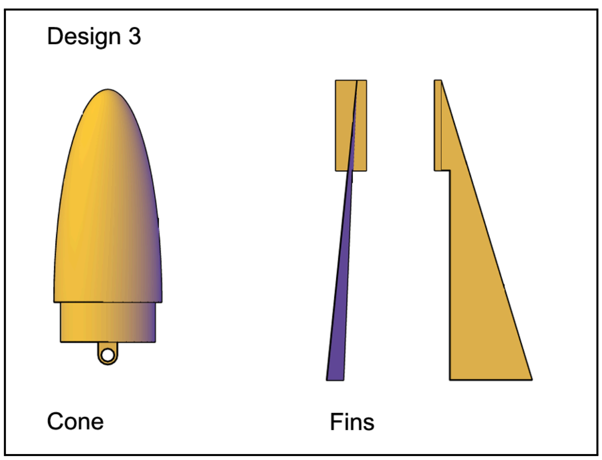


A diagram of all meaningful changes to the 2nd design

Third - Rotational Stability Model

This model was designed to be different from the other 2. Instead of using more slim, aerodynamic shapes, this model was designed to rotate while flying through the air to maintain stability. While rotational energy saps power from the overall launch, this rocket was designed to test whether that stability would allow this design to fly higher than the other two designs.

FIGURE 5



A diagram of all meaningful changes to the 3rd design

Table 2: Model Rocket Component Summary

	Model 1	Model 2	Model 3
Body	Control	Control	Control
Exhaust	Control	Control	Control
Fins	Delta	Clipped Delta	Slanted Delta
Cone	Control	Tangent Ogive	Elliptical

A summary of all parts of each design

Results

Table 3: Design 1 - Mass: 3.97 oz (~112.5 g)

Altitude: 40 m	Peak Acceleration: 7.8 G
Top Speed: 25 m/s	Average Acceleration: 3.4 G
Thrust time: 0.82 sec	Duration: 14.2 sec.

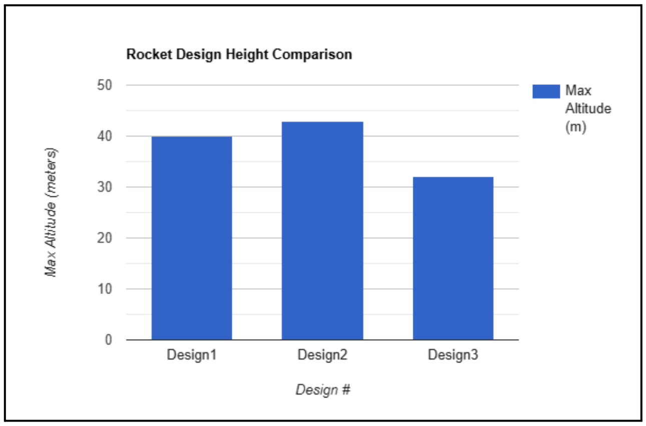
Table 4: Design 2 - Mass: 3.97 oz (~112.5 g)

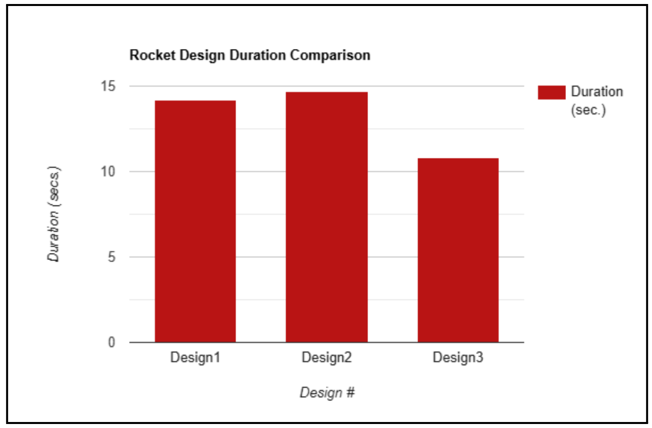
Altitude: 43 m.	Peak Acceleration: 8.0 G
Top Speed: 27 m/s	Average Acceleration: 3.5 G
Thrust time: 0.82 sec	Duration: 14.7 sec.

Table 5: Design 3 - Mass: 4.01 oz (113.5 g)

Altitude: 32 m	Peak Accel: 6.4 G
Top Speed: 19 m/s	Average Accel: 2.7 G
Thrust time: 0.82 sec	Duration: 10.8 sec

FIGURES 6, 7, & 8





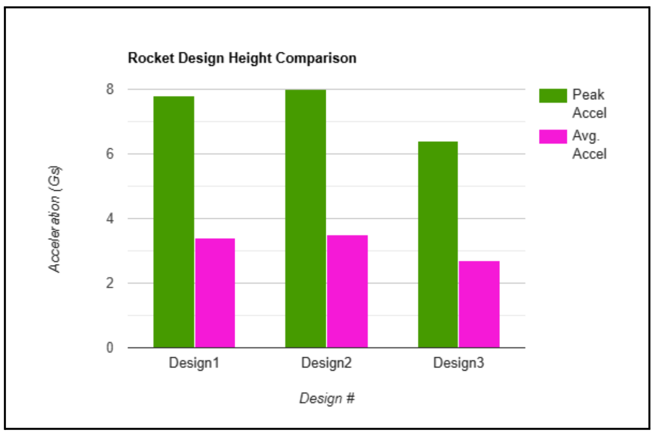


Figure 10 shows the height graph, Figure 11 shows the Duration graph, and Figure 12 shows the Average & Peak Acceleration.

Each model was launched within 20 minutes of each other in order to ensure ambient conditions were near equivalent for each launch. On the day of the launch, the temperature was ~19 ℃, with wind speeds at around 5 mph from SSW, and pressures around 0.995 atm, all at around 9:30 am.

Design 1, the control model, came in at an altitude of 40 meters, with a peak acceleration of 7.8 Gs and an average acceleration of 3.4 Gs. Other metrics measured were a top speed of 25 m/s and a total flight duration of 14.2 secs. After the flight, design 1 sustained minimal damage, with only one of the fins being broken off upon landing. The rest of the body, cone, and fins were intact and could be flown again after replacing the damaged fin. This was likely because the rocket had started spinning after the parachute was deployed, leading to a slightly harsher landing than expected.

Design 2, the streamlined design, beat the control by a minor degree, with an altitude of 43 meters, a peak acceleration of 8.0 Gs, and an average acceleration of 3.5 Gs. Other metrics measured were a top speed of 27 m/sec and a duration of 14.7 secs. Due to the rocket's streamlined design, it was able to slightly surpass the control design. After the flight, design 2 was able to fully survive and not sustain any damage to the fins, cone, or body.

Design 3, the rotational design, was the outlier of the 3 in the sense that its performance was far worse than the other 2 due to a collision shortly after launch, which damaged the model. With an altitude of 32 meters, a peak acceleration of 6.4 Gs, and an average acceleration of 3.5 Gs, Other metrics measured were a top speed of 19 m/s, a peak acceleration of 6.4 Gs, and an average acceleration of 2.7 Gs. Design 3 performed by far the worst out of the 3 designs. Design 3 was the most damaged rocket out of the 3, with all the fins broken or cracked in some way, and the cone and body being shattered after the impact with the ground.

A summary of the pertinent flight statistics is shown in Figures 7 - 12.

Discussion

Out of all the experiments, what surprised me the most was the performance of the rotational stability design. It was expected at subsonic speeds that having the most drag would lead the rocket to perform comparatively worse than the other 2 designs, but the rocket actually hitting the launch rod was definitely not expected to happen. The cause may have been due to the rocket trying to spin on the launch rod on the way up, causing the launch rod to collide with the rocket after it had left the rod, or the fins on the rocket making contact with the launch rod as they spun with the rocket. Regardless of the reason for the contact between the launch rod and the rotational rocket, it performed vastly under expectations, being over 10 meters lower in final altitude than the top rocket and 8 meters lower than the rocket with the second highest altitude.

The second rocket design **(Figure 4)** was able to outperform the first rocket design because of the elliptical cone and clipped delta fins, as opposed to the control design's triangular cone and regular delta fins **(Figure 3)**. A triangular cone has a sharp edge that separates the surface of the cone from the body, which disrupts the flow of air around the rocket and creates a substantial enough difference in air pressure to create a low-pressure wake behind the rocket, increasing overall drag. In contrast, the elliptical cone has a gradual taper to the body of the rocket, which keeps the flow of air intact and therefore lessens the wake around the rocket, leading to less drag and a higher speed **[5]**. Additionally, the clipped delta fins of the second design provide more stability compared to the full delta fins because of their overall larger surface area **[6]**, which allowed the rocket to put more energy into flying straight up, increasing the performance of the second design further compared to the control design.

Conclusion

From this experiment, we can conclude that it is possible to create, assemble, and launch a model rocket from scratch without significant background or firsthand experience in model rockets. While it is noted that this experiment did not have a very large sample size, it is still to be noted that every rocket was able to be launched and gained significant air time. This project shows that the field of model rocketry is easily accessible to a wide range of students or interested people who want to learn more about the field of engineering and/or physics without extensive experience beforehand. Although limited, design 2 did show a slight improvement over the control, which gives promise in continued studies.

This experiment could be taken further, like taking more sets of data from the existing rockets and creating a few more designs to further understand and determine the optimal design for subsonic rockets. Additional tests could be done, like using different engines and mixing & matching the different cones to see the effects of the aerodynamics. Apart from just the specifics of the rockets, aspects like top speed and acceleration can be compared more thoroughly to determine which specification of rocket is the most optimal in each respective aspect.

References

- Introduction

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