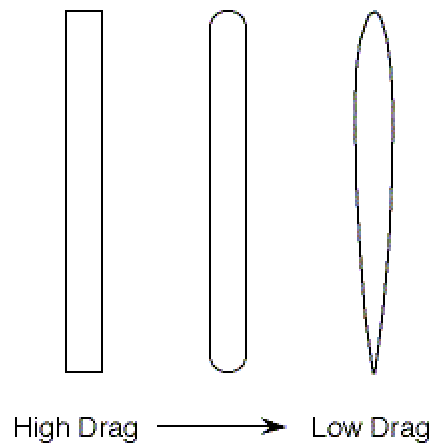
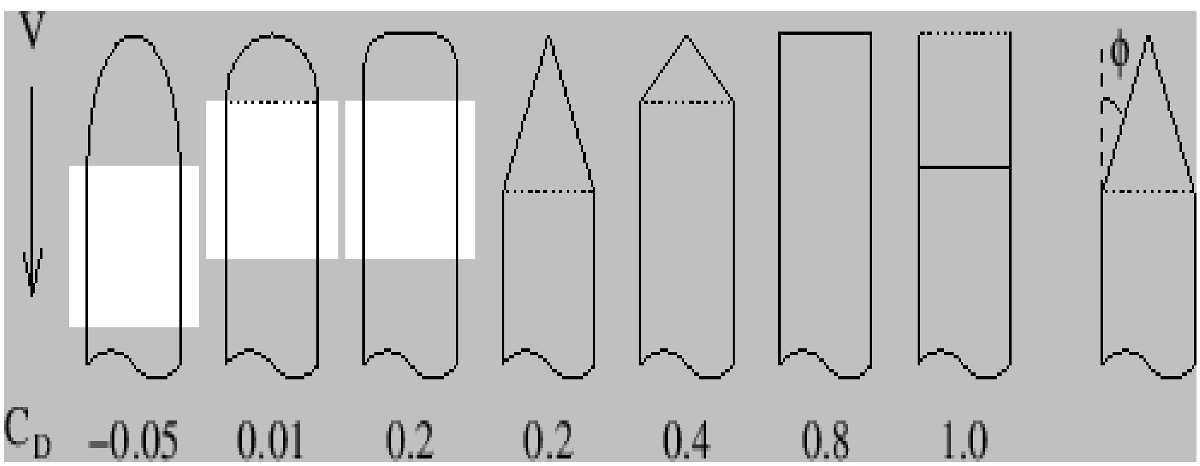
# The Shape of Fins to Come

## What Fin Cross Section Would Have the Least Amount of Drag?




**By: Rebecca Zurek**

**NAR #101490 / Division A**

**NARAM 60 / Pueblo Colorado / August 2018**

**Research and Development Report**

# SAFETY SHEET

**The Illinois Junior Academy of Science**

**Directions:** The student is asked to read these introductions carefully and fill out the bottom of this sheet. The science teacher and/or advisor must sign in the indicated space. By signing this sheet, the sponsor assumes all responsibilities related to this project.

**Safety and the Student:** Experimentation or design may involve an element of risk or injury to the student, test subjects and to others. Recognition of such hazards and provision for adequate control measures are joint responsibilities of the student and the sponsor. Some of the more common risks encountered in research are those of electrical shock, infection from pathogenic organisms, uncontrolled reactions of incompatible chemicals, eye injury from materials or procedures, and fire in apparatus or work area. Countering these hazards and others with suitable safety practices is an integral part of good scientific research. In the **chart** below, list the principal hazards associated with your project, if any, and what specific precautions you have used as safeguards. Be sure to read the entire section in the *Policy and Procedure Manual of the Illinois Academy of Science* entitled "Safety Guidelines for Experimentation" before completing this form.

| Possible hazards | Precautions taken to deal with each hazard |
|---|---|
| 1. Being shocked.<br>2. Objects becoming detached.<br>3. Fragile instruments can create sharp shards. | 1. Plug in cord with caution and make sure everything is off.<br>2. Tape or glue everything down securely.<br>3. Use instruments with caution.<br>4. Have a supervisor present for any of these safety hazards. |

Specific safety practices related to materials requiring endorsement sheets should be detailed on the specific endorsement sheet and not included on this safety sheet.

Please check off any other possible endorsements needed. Include these documents in your paper and on your boar
_____Humans as Test Subjects –for any projects involving humans including survey administration;
_____Microorganisms-for any projects involving bacteria, viruses, yeasts, fungi or protazoa;
_____Non-Human Vertebrates -for any projects involving fish, amphibians, reptiles, birds or mammals;
_____Tissue Culture-for any projects involving growing eukaryotic tissues or cell cultures;
_____Letter from institution where research was done or IJAS SRC, if an exception to the IJAS rules has been gran

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_______________________________________
Student Exhibitor(s)

SIGNED
_______________________________________
Sponsor *

*As a sponsor, I assume all responsibilities related to this project.

**This Sheet Must Be Typed and** This form **must** be displayed on the front of the exhibitor's display board. It may reduced to half a sheet of paper 8.5 inches (vertical) X 5.5 inches (horizontal).

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## Abstract

Drag is a very important factor in the design of performance rockets. Based on the research I have done, there seems to be a lack of comparative studies concerning symmetric fin cross sections. My experiment was to determine which cord fin cross section would have the least amount of drag. I 3d printed four different types of fin cross sections – square, 45° chamfer, full taper, and elliptical - for accuracy and tested them in my home-made wind tunnel. I took three one minute long tests on each of the three wind speeds and measured the force with a load cell. I then put my data into the equation for the coefficient of drag and compared my results with results from past research that I found. The elliptical fin cross section had the least amount of drag with the full taper having the second least amount; the square fin cross section had the most amount of drag with the 45° chamfer having the second most amount. Overall, the elliptical fin cross section had the least amount of drag and was the most efficient.

## Acknowledgments

I would like to thank my dad, Robert Zurek, for helping me through all of the calculations, being my supervisor, and getting me more involved in rocketry. I would also like to thank the Prince of Peace Catholic Church for letting me borrow space to test my experiment in. I would further like to thank the Fox Valley Rocketeers for helping me find sources and getting me more involved in rocketry. I would like to thank my teacher, Ms. Bader for being my sponsor and helping me throughout the process of the science fair. Finally, I would like to thank Carmel Catholic High School for supporting my scientific inquiry by joining IJAS so that I could participate this year.

## Purpose

The purpose of this experiment was to grow my knowledge of rocketry by observing which fin cross section would have the least amount of drag, and to learn the physics behind the shapes and drag to determine why these results happened.

## Hypothesis

I think that the elliptical shaped fin cross section will have the least amount of drag. This is because the elliptical shape has more gradual transitions and the air can flow more easily over the surface.

## Summary of Pervious Research

My experiment mostly revolves around drag and how the shape of the fin affects drag. There are four major forms of drag that I will focus on; skin friction drag, form drag, interference drag, and induced drag. Skin friction drag is caused by the airstream being slowed down by the surface of the object as it travels through the air. Form drag is related to the shape of the object. A good way to see this is if you look down the direction in which the air stream will flow. Both skin friction drag and form drag combined make profile drag. Induced drag is made whenever and airfoil, or a structure with curved surfaces designed to give the most favorable ratio of lift to drag in flight, makes high lift. Interference drag is when two parts of a rocket are in close proximity to each other.(Barrowman, J.)

The drag coefficient is a number which engineers use to model all of the complex dependencies of drag on shape and flow conditions. What is interesting about the drag coefficient is that it has no unit of measurement. The drag coefficient (Cd) is equal to the force due to the drag ($F_D$) divided by the quantity: density (r) times the reference area (A) times one half of the velocity squared (V). (spaceflightsystems.grc.nasa.gov)

$$Cd = \frac{F_D}{(.5 * r * v^2 * A)}$$

This equation is then used to find the drag coefficient of different objects. When it was tested at NASA, a flat plate held the highest drag coefficient whereas a streamlined symmetric airfoil had the lowest drag coefficient.

I will be using this equation, but in a different form. I rearranged the equation with the data I will use. I will use this equation to predict the drag at other velocities as well as the ones I will test.

$$F_D = Cd * r * A * .5 * v^2$$

Wind tunnels are used so engineers can control the flow conditions that affect the forces on the object being tested. There are two types of wind tunnels; open and closed wind tunnels. An open wind tunnel draws air from outside of the tunnel into the test section, and is then drained back outside. The closed wind tunnel recirculates air, and doesn’t have an opening for the wind to exhaust back out. There are four major parts to a wind tunnel; the fan, the flow straighteners, the test object, and the data transfer lines. The fan blows the air to the certain speed an engineer wants. The flow straighteners make the air flow straight into the model and not in many directions. The data transfer lines collect and transport the information collected from the test object to the control room or equipment.(www.grc.nasa.gov/WWW/K-12/rocket/dragco.html)

Fins on a rocket control the stability of a rocket while it is in flight. Fins act like the fletching, or the feathers, at the end of an arrow. The greater drag on the feathers keeps the tail of the arrow at the back so that the point of the arrow travels straight into the wind.(Science Learning Hub)

To know how large to make the fins, or to know where to place them, a key term to know is the center of gravity. The center of gravity is the general location of the weight of a certain

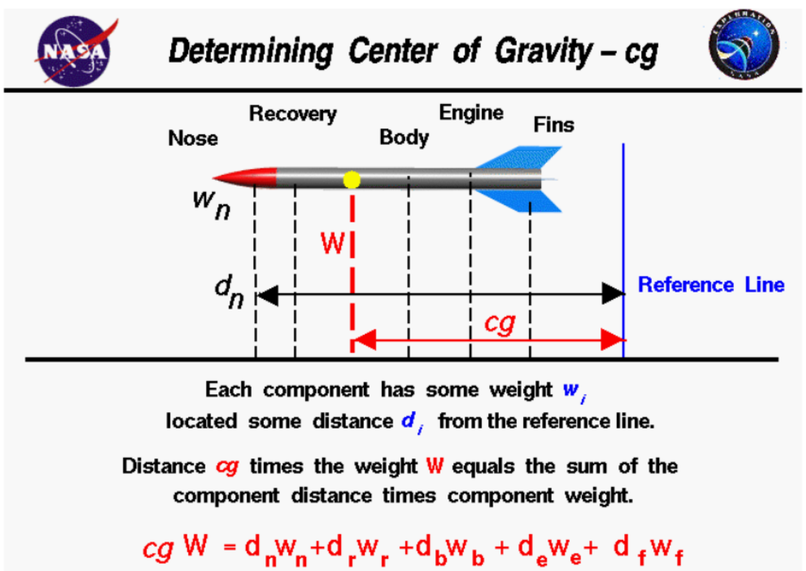



**Figure 1**

object. One way to find the center of gravity is using the equation: W*cg = [w*d] + [w*d] + … Where the “W” is the weight of the rocket times the “cg” or center of gravity; which is equal to “w” or the weight of each component of the rocket times “d” or the distance that the piece is from the reference location. Another way you could find the center of gravity for a smaller rocket is by balancing the piece, or whole rocket, on a string. The point where it balances is the center of gravity. Figure 1 shows a depicted version of the description above.

To figure out what the fins do on a rocket, you also have to know about the center of pressure. The center of pressure is where all of the pressure forces are concentrated. The fins act to move the center of pressure of a rocket towards the rear end of the rocket. If a rocket is in flight and is not disrupted, it will continue to fly in a straight path into the air flow. But, if the rocket catches a wind gust, then the rocket will fly at an angle. "It has been found that the C.P.(Center of Pressure) moves forward as the angle-of-attack increases. This fact is very important since it can affect a rocket's stability."(Barrowman) When looking for stability, the space in between the center of gravity and the center of pressure is named the static margin. When the center of pressure is behind the center of gravity and the static margin is large, that means that the rocket is more stable. Fins on a rocket help with the static margin because, "…its fins produce a moment to correct the rocket's flight. The corrective moment is produced by the aerodynamic forces perpendicular to the axis of the rocket."(Sampo Niskanen)

Before I finished my research project this year, I wanted to make sure that if there were other projects similar to mine, I would give them credit for their work. Although there was nothing on the cross section of fins, the closest project was done by Tom Milkie in 1972, and it was about the planform, or outline, of fins and wings on both rockets and airplanes, but not the cross section through the fins. Although Mr. Milkie's report dealt with the fin planform and not the cross section, he found that the most efficient shape of the planform was an ellipse as well.

The reason that I chose this topic for my research project this year was the lack of available material comparing symmetric fin cross sections.

## Variables

There are two independent variables and one dependent variable in this experiment. The independent variables are the fin shape and the air speed. I chose four different fin shapes for this experiment; the square, forty five degree chamfer, full taper, and the ellipse. (see image on page 16) I also chose three different air speed settings from the fan to test on the fins for one minute. The dependent variable is the drag force on the fins.

## Materials List

- D/C amplifier (optional)
- Power supply
- Voltmeter
- 2 cables
- Load cell
- Wind tunnel
- Baffles
- Legs
- 2x6 pieces of wood
- Fan
- Fins
- Notebook

- Pencil
- Pliers
- Blue tape
- Duct tape
- X-acto
- Razor knife
- Power strip
- Extension cord
- Anemometer

Procedure

Before doing these steps, be sure to make the wind tunnel.

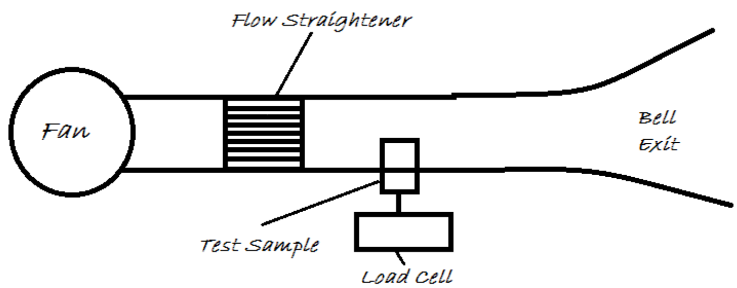
1. Set up the wind tunnel, fan, power strip, extension cords, power supply, and voltmeter on one or two tables and test them quickly to make sure nothing will become detached from the wind tunnel.
2. Tape the anemometer in the back of the wind tunnel facing towards the exit so you can read the temperature and wind speed.
3. Tape the baffle of the first fin cross section you are going to test onto the bottom of the wind tunnel hole.
4. Screw the fin cross section onto the load cell system and align the fin in the right position in the hole without the test piece touching any of the walls.
5. Tape the other baffle of the shape onto the top of the hole and make sure the baffle is not touching the test piece.
6. Hook the wires of the load cell up to the power supply and voltmeter.

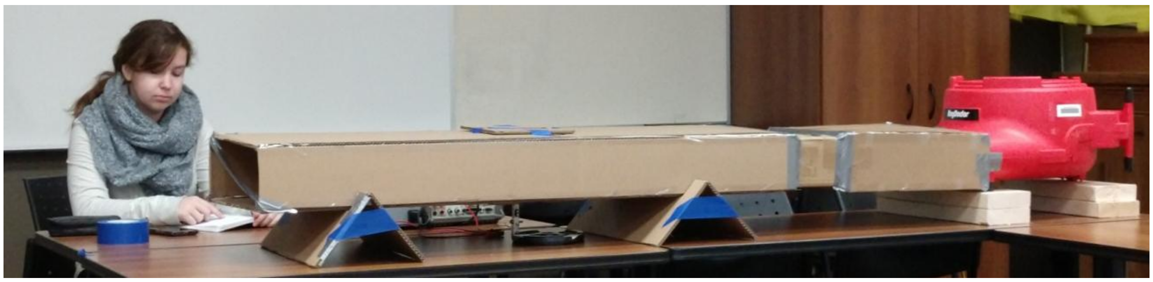
7. Before you start the fan, note the reference Voltage, or original Volts, for later use.
8. Turn the fan on the first setting and write down the temperature and wind speed.
9. Have the voltmeter average the readings of the experiment for one minute.
10. Repeat the averaging, wind measurement and temperature measurement three times.
11. Turn the fan off and record the reference Voltage again.
12. Turn the fan to the second setting and repeat steps eight through ten.
13. Turn the fan off and record the reference Voltage for the third time.
14. Turn the fan to the third setting and repeat steps eight through ten.
15. Turn the fan off and record the reference Voltage for the last time.
16. Repeat steps three through fifteen for each fin cross section.

## Build Apparatus

### Wind Tunnel

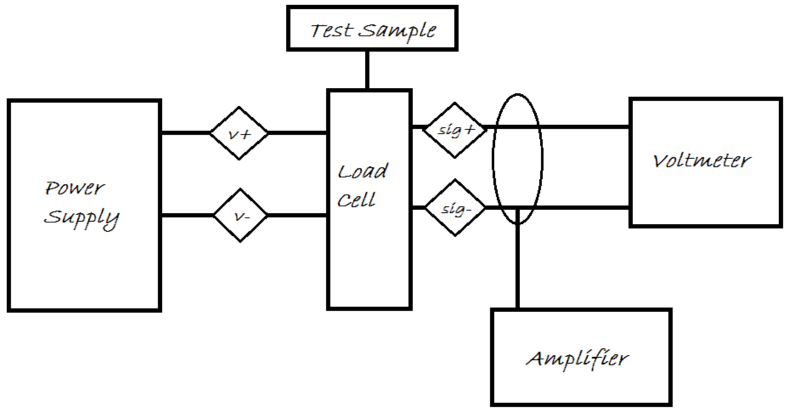
This will be an open wind tunnel. At the entry side, there will be a fan with three speeds. Around .3048 meters away in the tube, there will be a flow straightener made out of cardboard tubes. After the flow straightener, there will be the main chamber which will have a test sample and a hole for the test sample. There will be an anemometer approximately 1m downstream from the test sample. At the end of the tunnel, there will be an opening to let the air flow out. The height of the tunnel is 127mm to have the 152.4mm fin be able to pass through without having the top or bottom in the wind tunnel. The tunnel was 355.6mm wide to allow as much room needed for the air to freely flow around the sides of the sample.



Load Cell System

This system will consist of three major pieces and one optional piece. At the center of the system will be the load cell. It will be attached to a 2.3kg weight to hold it down. The output of the load cell is voltage, so the manufacturer provided a Volt to Newton ratio. To the right of the load cell will be the voltmeter. On the left of the load cell will be the power supply for the load cell. The load cell will be connected to the test sample from the top. The optional amplifier, if needed, can be put in between the load cell and the voltmeter.

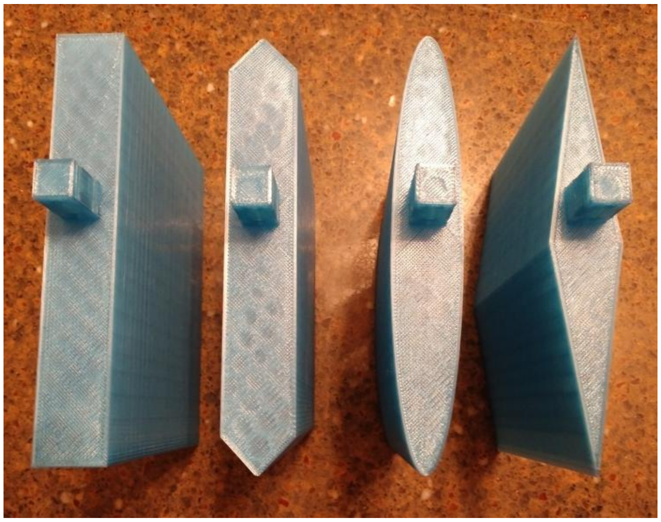



Design of Experiment

In this experiment, there were many items that needed to be prepared before the test procedure. I made the fins in CAD then 3d printed them so that they were exactly the size and shape I wanted to test. They are all the same weight, height, and length. The wind tunnel was also made beforehand with cardboard, paper towel tubes, glue, and tape. It was the slightest bit smaller in height than the fin samples so that I would not get the excess drag from the top or bottom of the fin. The baffles for the fin had the cut-out shape of a certain fin a little larger so that the fin could fit through the baffle without touching it. The reason for the baffles is to lessen the drag and close the open parts of the hole. The load cell system was underneath the wind tunnel, with the load cell being held by a weight, otherwise it would detach from the system and break from going down the wind tunnel.

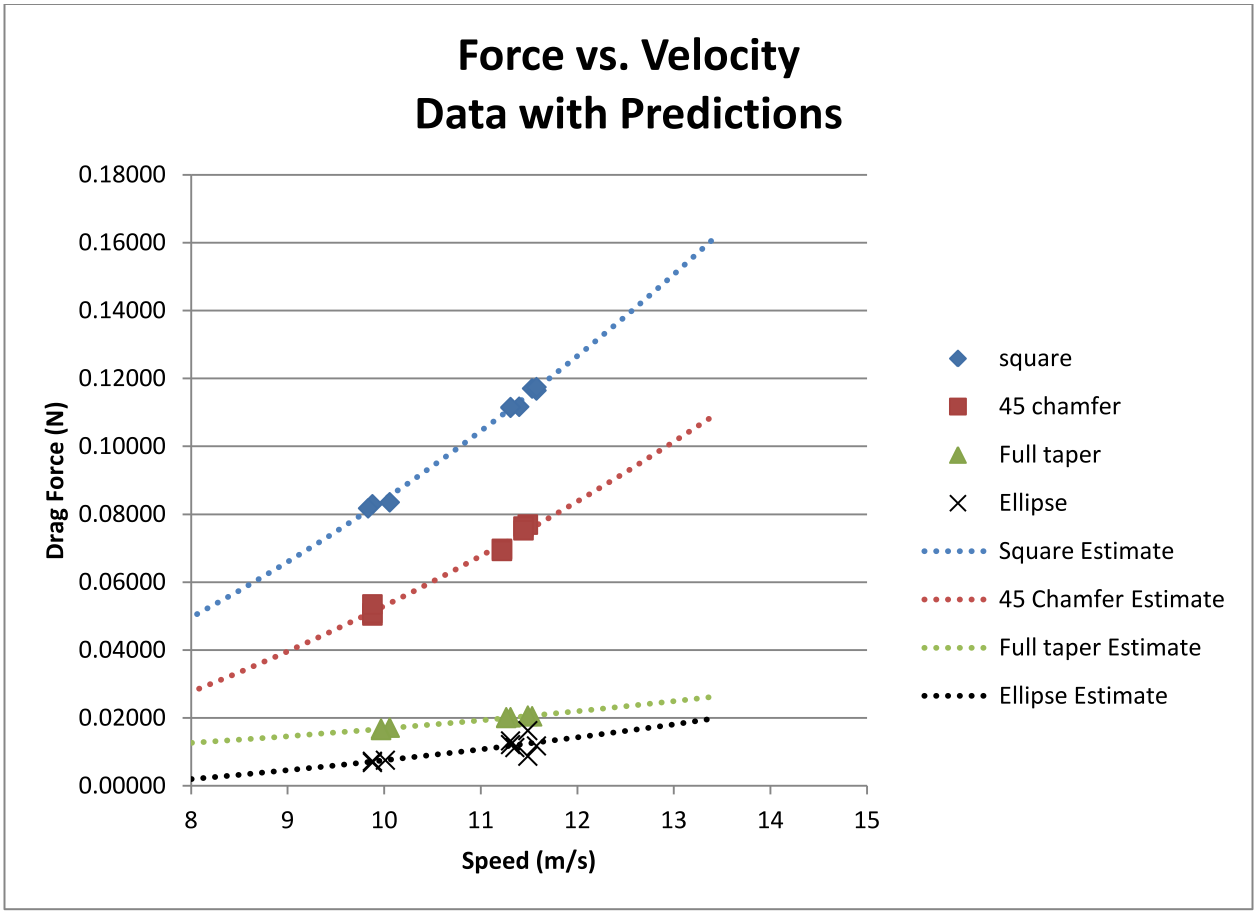
I chose to use four different cross sections in my experiment. They were all 152.4mm tall, 152.4mm long, and 25.4mm wide. The fin shapes that I used in my experiment are the square, forty five degree chamfer, full taper, and an ellipse shape. The reason I choose these shapes, was because these are the most common types and are widely used. Another reason is that they also represent a spectrum of fins from least aerodynamic to the most aerodynamic. Based on my research, I predict that the square is the least aerodynamic, whereas the ellipse is the most aerodynamic.

During my experiment, I tested each fin sample in the wind tunnel at three different wind speeds. The drag force was measured with a load cell connected to a voltmeter. I took three measurements of each sample at each wind speed. Each measurement was a 1 minute time average of the load cell output calculated by the voltmeter.



# Data & Results

| Piece | Velocity(mph) | Velocity(m/s) | Voltage(mV) | Ref. Voltage(mV) | Diff Voltage(mV) | Drag Force(N) |
|---|---|---|---|---|---|---|
| square | 22.5 | 10.058 | 0.730 | 0.645 | 0.085 | 0.084 |
| square | 22.1 | 9.880 | 0.730 | 0.645 | 0.085 | 0.083 |
| square | 22 | 9.835 | 0.728 | 0.645 | 0.083 | 0.082 |
| square | 25.5 | 11.400 | 0.759 | 0.645 | 0.114 | 0.112 |
| square | 25.3 | 11.310 | 0.759 | 0.645 | 0.114 | 0.111 |
| square | 25.3 | 11.310 | 0.759 | 0.645 | 0.114 | 0.112 |
| square | 25.8 | 11.534 | 0.764 | 0.645 | 0.119 | 0.117 |
| square | 25.9 | 11.578 | 0.764 | 0.645 | 0.119 | 0.116 |
| square | 25.9 | 11.578 | 0.765 | 0.645 | 0.120 | 0.117 |
| | | | | | | |
| 45 chamfer | 22.1 | 9.880 | 0.698 | 0.647 | 0.051 | 0.050 |
| 45 chamfer | 22.1 | 9.880 | 0.699 | 0.647 | 0.052 | 0.051 |
| 45 chamfer | 22.1 | 9.880 | 0.702 | 0.647 | 0.055 | 0.053 |
| 45 chamfer | 25.1 | 11.221 | 0.718 | 0.647 | 0.071 | 0.070 |
| 45 chamfer | 25.1 | 11.221 | 0.718 | 0.647 | 0.071 | 0.070 |
| 45 chamfer | 25.1 | 11.221 | 0.718 | 0.647 | 0.071 | 0.069 |
| 45 chamfer | 25.7 | 11.489 | 0.726 | 0.647 | 0.079 | 0.077 |
| 45 chamfer | 25.6 | 11.444 | 0.725 | 0.647 | 0.078 | 0.076 |
| 45 chamfer | 25.6 | 11.444 | 0.724 | 0.647 | 0.077 | 0.075 |
| | | | | | | |
| Full taper | 22.5 | 10.058 | 0.665 | 0.647 | 0.018 | 0.017 |
| Full taper | 22.3 | 9.969 | 0.664 | 0.647 | 0.017 | 0.017 |
| Full taper | 22.3 | 9.969 | 0.664 | 0.647 | 0.017 | 0.016 |
| Full taper | 25.2 | 11.265 | 0.668 | 0.647 | 0.021 | 0.020 |
| Full taper | 25.3 | 11.310 | 0.668 | 0.647 | 0.021 | 0.020 |
| Full taper | 25.2 | 11.265 | 0.667 | 0.647 | 0.020 | 0.020 |
| Full taper | 25.7 | 11.489 | 0.668 | 0.647 | 0.021 | 0.020 |
| Full taper | 25.8 | 11.534 | 0.668 | 0.647 | 0.021 | 0.020 |
| Full taper | 25.7 | 11.489 | 0.668 | 0.647 | 0.021 | 0.021 |
| | | | | | | |
| Ellipse | 22.4 | 10.014 | 0.657 | 0.649 | 0.008 | 0.008 |
| Ellipse | 22.1 | 9.880 | 0.656 | 0.649 | 0.007 | 0.007 |
| Ellipse | 22.1 | 9.880 | 0.656 | 0.649 | 0.007 | 0.007 |
| Ellipse | 25.4 | 11.355 | 0.660 | 0.648 | 0.012 | 0.011 |
| Ellipse | 25.3 | 11.310 | 0.660 | 0.648 | 0.012 | 0.012 |
| Ellipse | 25.3 | 11.310 | 0.662 | 0.648 | 0.014 | 0.013 |
| Ellipse | 25.9 | 11.578 | 0.662 | 0.650 | 0.012 | 0.012 |
| Ellipse | 25.7 | 11.489 | 0.667 | 0.650 | 0.017 | 0.016 |
| Ellipse | 25.7 | 11.489 | 0.659 | 0.650 | 0.009 | 0.009 |




## Analysis

In the tests, there was little fluctuation in the wind speeds. For the first setting, the speed ranged from 9.83488m/s to 10.0584m/s. The second setting ranged from 11.2247m/s to 11.39952m/s. The third setting on the fan ranged from 11.44422m/s to 11.57834m/s. After the first test with the square fin, I was able to determine that I had enough voltage out of the load cell and did not need to use the D/C amplifier.

I tested the square profile with the three speeds mentioned before. The average force measured for the low speed of 9.92429m/s was .08275N. The average force measured for the medium speed of 11.33991m/s was .11154N. The average force measured for the high speed of 11.56343m/s was .11699N. I then used this data in the equation from page eight to calculate the coefficient of drag. The coefficient of drag for the low speed range was 0.423164934. The coefficient of drag for the medium speed range was 0.437156284. The coefficient of drag for the high speed was 0.444959185. The average coefficient of drag for the square shape would be 0.435093468. Based on this information, the square shape is the least aerodynamic because it had the highest drag force and the highest coefficient of drag. I believe this is true because it has the most drastic transitions along its surface, which results it creates the most turbulence.

I tested the forty five degree profile with the three speeds mentioned before. The average force measured for the low speed of 9.87958m/s was 0.051503268N. The average force measured for the medium speed of 11.22070m/s was 0.069542484N. The average force measured for the high speed of 11.45913m/s was 0.07620915N. I then used this data in the equation from page eight to calculate the coefficient of drag. The coefficient of drag for the low speed range was 0.268089859. The coefficient of drag for the medium speed range was 0.281458443. The coefficient of drag for the high speed was 0.293718271. The average coefficient of drag for the square shape would be 0.281088858. Based on this information, the forty five degree angle shape is the second least aerodynamic because it had the second highest drag force and the second highest coefficient of drag. I believe this is true because, while it had two corners on each side like the square, they were more shallow, which results in less turbulence.

I tested the full taper profile with the three speeds mentioned before. The average force measured for the low speed of 9.99879m/s was 0.016830065N. The average force measured for the medium speed of 11.28031m/s was 0.020130719N. The average force measured for the high speed of 11.50383m/s was 0.020555556N. I then used this data in the equation from page eight to calculate the coefficient of drag. The coefficient of drag for the low speed range was 0.085055818. The coefficient of drag for the medium speed range was 0.079812582. The coefficient of drag for the high speed was 0.078494683The average coefficient of drag for the full taper shape would be 0.081121028. Based on this information, the full taper shape is the second most aerodynamic because it had the second least drag force and the second least coefficient of drag. I believe this is true because it has only one drastic corner change, which results in the second least amount of turbulence.

I tested the ellipse profile with the three speeds mentioned before. The average force measured for the low speed of 9.92429m/s was 0.007222222N. The average force measured for the medium speed of 11.32501m/s was 0.012222222N. The average force measured for the high speed of 11.51873m/s was 0.012254902N. I then used this data in the equation from page eight to calculate the coefficient of drag. The coefficient of drag for the low speed range was 0.037117707. The coefficient of drag for the medium speed range was 0.048319346. The coefficient of drag for the high speed was 0.047130645. The average coefficient of drag for the full taper shape would be 0.044189233. Based on this information, the ellipse shape is the most aerodynamic because it had the least drag force and the least coefficient of drag. I believe this is true because it has no corners or drastic changes, which results in the least amount of turbulence.

Although I have not yet learned about error analysis in school, I did the best of my ability to make sure my data was valid. I did this by looking at the data for the given speed for each fin, and observed that I had no overlap; because of that, I believe I have four separate populations at each wind speed, therefore making my data valid.

I then used my experimental data to create models to predict performance at other wind speeds. In order to create mathematical models for each shape, I looked at three forms of equations to try and get the most accurate prediction. The equations were generated from either linear or nonlinear regression equations. I found the regression for each data set and chose the equation with constant C closest to zero. I found the equation that best fit the data was $F_d$=B$v^2$+C which agreed with my initial research. With this information I could figure out the equations for each of the different test objects. For the square piece, the equation would be, $F_d = .0009624 * v^2 - .01199$. The equation for the forty five degree chamfer would be, $F_d = .0007017 * v^2 - .01724$. The full taper equation would be, $F_d = .0001172 * v^2 + .005127$. The equation for the ellipse would be, $F_d = .0001536 * v^2 - .007839$. In the graph above you can see that the ellipse shape had the least amount of drag with the full taper having a little more drag than the ellipse shaped fin cross section. I used the data table above to provide the information for the graph and find the drag coefficient. I also could see the data more clearly and work out equations with this table. The square had the most drag, while the ellipse had the least amount of drag. The forty five degree chamfer had the second most drag, while the full taper had the second least amount of drag.

## Conclusion

In conclusion, my hypothesis appeared to be correct and my experiment provided much information to support my hypothesis. The ellipse(Independent variable) did have the least amount of drag(Dependent variable) because of the smooth transitions in the front and back, so the air could flow easily over the surface. All types of drag contribute to this experiment; some being frontal drag, interference drag, and skin friction drag. I measured the drag force for all of the fin cross sections and then calculated the estimated drag force at other velocities using the equations that I obtained from the data. I also did many tests to further contribute information to this project. Overall, the main reason for the least amount of drag on the test objects was because of the smooth transitions, therefore allowing the air to flow over the surface easily and not create turbulence which increases drag.

## Future Research

All of the shapes that I investigated were symmetric around two axes. Future work in this area could include the study of fin shapes that are not symmetric fore and aft.

## Citation List

Barrowman, J. (n.d.). *Technical Information Report 33: Calculating the Center of Pressure of a Model Rocket*. Centuri Engineering.

“Determining Center of Gravity - Cg.” NASA,
NASA, spaceflightsystems.grc.nasa.gov/education/rocket/rktcg.html.

Figure 3.11: Pressure drag of various nose cone shapes [15, p. 3-12]. OpenRocket Simulation Master's Thesis

Milkie, Tom. "Why Elliptical Fins." *Model Rocketeer*, Sept. 1972, pp. 8–9.

NASA, NASA, www.grc.nasa.gov/WWW/K-12/rocket/dragco.html.

*NASA*, NASA, www.grc.nasa.gov/www/k-12/rocket/shaped.html.

Niskanen,Sampo. "OpenRocket Technical Documentation." 2013.

"Rocket Aerodynamics." Science Learning Hub, www.sciencelearn.org.nz/resources/392-rocket-aerodynamics.

Figure 3.11: Pressure drag of various nose cone shapes [15, p. 3-12]. OpenRocket Simulation Master's Thesis

# Project Costs

| Item | Cost | |
|---|---|---|
| PLA filament fin material | $24.95 | |
| Wind tunnel | $0.00 | recycled old cardboard boxes |
| Flow straighteners | $0.00 | used toilet paper rolls |
| Machine screws | $0.82 | |
| Load cells | $17.82 | first one had broken wire had to order a replacement |
| Power supply | $79.99 | can be used for future projects |
| Cables | $5.99 | |
| Fan rental | $29.98 | |
| Total | $159.55 | |