International Baccalaureate

PHYSICS HL EXTENDED ESSAY

THE EFFECT OF THE DRAG COEFFCıENT OF THE TıP OF A WATER ROCKET ON ıTS AVERAGE VELOCıTY

Research Question: How does the drag coefficient of the tip of a water rocket affect its average velocity during the flight?

Word Count:3073

INTRODUCTION

Research Question: How does the drag coefficient of the tip of a water rocket affect its average velocity during the flight?

Approach: An experimental approach is taken. Identical water rockets are designed with different tips which have varying drag coefficients. The maximum vertical height reached by the rockets is recorded by a highspeed camera. The average of each trial's altitude will be divided by the time to reach the apogee to find the average velocity. Calculated average velocities of each model are compared and evaluated. The drag equation is used to evaluate the drag force each rocket experiences and is used to determine the accuracy of the experiment.

Hypothesis: The value of the drag coefficient will be inversely and exponentially proportional to the rockets' average velocities.

Space missions have been a part of human progression for quite a while. The obsession with interplanetary travel started in the early 20^{th} century, 1903 to be exact with Konstantin Tsiolkovsky's "The Exploration of Cosmic Space by Means of Reaction Devices" and reached a milestone in 1944 with the German V-2 Rocket being the first rocket to reach space on a vertical flight test. The space race started in 1957 between USSR and the USA and space came even closer with the launches of the first Russian and American satellites Sputnik 1 and Explorer 1. Not much after we started sending people to the space with Vostok and Project Mercury programs. Today we're working in space on joint operations in International Space Station and even private companies such as SpaceX have their space programs. With this being said, the only reason we achieved this much is that our technology progressed alongside us. That new technology such as new computing systems, new fuel mixtures, and new structures allowed these rockets to overcome the challenges of space travel. In this essay, I will observe and study the effect of structural differences created by the shapes of the rockets' tips on the efficiency of a rocket.

My inspiration for this topic did not first start as an interest in aeronautical science. Instead, the inspiration came to me while I was watching a bike race. At bike races, bikers use special helmets. These helmets aren't completely round, they are streamlined. This makes those helmets less affected by drag and thus less energy loss to surroundings. Then I started to wonder "Does every field that needs to overcome drag use aerodynamic equipment?" The answer was, obviously, yes. From Formula 1 race car designs to NASA space rockets designs all use aerodynamic and streamlined surfaces to minimize drag.

After my research, I started to design an experiment in which I can observe and get numerical values to compare different tip structures. My initial thought was to make an inclined downwards ramp and threw the same weighted but different tipped identical wood boxes. I would measure the time it takes to finish the ramp. However, after trying my model in a simulation I couldn't see clear results. Then, I started to investigate why this model failed and came across NASA's original website's drag equation[1]. In the equation, I saw that drag force is also dependent on velocity squared. This meant that the force is most apparent in high velocities as velocity is an exponential factor in the equation. Therefore, I started to design a new experiment that could reach high velocities. That is how I came up with the water rocket. Since there were many calculations made by trustworthy sources such as MIT[2] on water rocket flights, I also could compare my experiment's results and calculate error propagations.

BACKGROUND

Part 1: Fluid Mechanics, Drag Force and Bernoulli's Principle

Definition of a fluid is a material that can be continuously deformed under shear stress. Solids, therefore, are excluded because their deformation is finite. Fluids are mostly in liquid, gaseous, and plasma forms of matter. Their properties include taking the shape of a container, also defined

[1] Hall, N. H. (2021, May 13). *The Drag Equation*. Grc.Nasa.Gov. https://www.grc.nasa.gov/WWW/k-12/airplane/drageq.html

[2] mit.edu. (n.d.). *Water Rocket Calculations*. web. MIT. Edu. Retrieved January 11, 2022, from http://web.mit.edu/16.unified/www/FALL/systems/Lab_Notes/wrocket.pdf

as flow, and the inability to resist deformation. Fluid mechanics is the area of physics investigating the reactions and responses of fluids to forces exerted such as a body moving through water. These responses cause the force called the drag force.

The formation of drag can be explained by Bernoulli's Principle. The Bernoulli Principle states that the pressure of a flowing fluid is inversely proportional to its velocity. This phenomenon is proved by the continuity equation[3]:

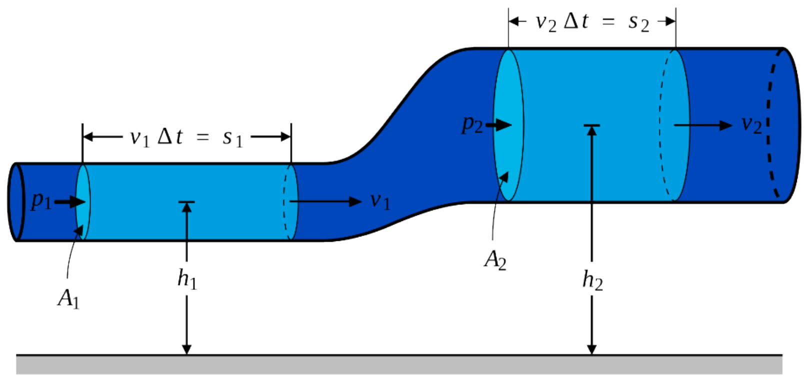


Figure 1: One-dimensional pipe to show the relation between Bernoulli's Principle and Continuity equation

$$volume\ at\ A_1 = A_1 v_1 dt$$

$$volume\ at\ A_2 = A_2 v_2 dt$$

$$Thus,$$

$$mass\ at\ section\ 1 = \rho A_1 v_1 dt$$

$$mass\ at\ section\ 2 = \rho A_2 v_2 dt$$

We can apply the mass conservation principle by neglecting the friction and assuming the fluid has a constant density with a steady flow. Since the mass of fluid flowing in over a designated area, A_1, should be equal to the fluid flowing out over A_2 over the same short time interval, dt. Stating this in an equation using our derived equations results in the continuity equation:

$$A_1 v_1 \rho = A_2 v_2 \rho$$

Equation 1:Continuity equation where ρ is the density of the fluid.

[3] Princeton.edu. (n.d.). *Bernoulli's Equation*. www.Princeton.Edu. Retrieved January 1, 2022, from https://www.princeton.edu/~asmits/Bicycle_web/Bernoulli.html https://www.princeton.edu/~asmits/Bicycle_web/continuity.html

Drag force is due to the difference in velocities of the solid object moving and the fluid it is moving through. Therefore, without fluid to be contacted with or movement, there is no drag force being experienced. Since the moving fluid will cause less pressure because of the Bernoulli's Principle the other fluid will form forces upwards and opposing to the body's movement. The upwards force is called lift and the opposing is called drag. Some additional sources of drag include ram and wave drag. Ram drag occurs when stream air gets inside the body moving which may be done by cooling inlets. Wave drag occurs when the body moving reaches the speed of sound and the shockwaves produced by this also cause a change in pressure thus creating drag. All these drag affect the craft from the centre of pressure. In this investigation, the effect of drag that is opposing the movement will be investigated. This drag is called form drag as it depends on the shape of the body moving.[4]

$$F_D = \frac{\rho \times Cd \times v^2 \times A}{2}$$

Equation 2: Drag Equation where: F_D is Drag Force, ρ is fluid density, v is velocity, A is reference area.[5]

Form drag can be calculated by the drag equation. In the equation we can see that velocity is an exponential factor causing the relation:

$$F_D \propto v^2,$$

This causes drag force to be most apparent at high velocities. ρ represents the density of the fluid the object is moving through. In this experiment this fluid is air, and it is considered in a static equilibrium which means the fluid is only subjected to the shear stress produced by the movement of the body[6]. "Cd" is the drag coefficient of the object. This variable helps us to collect various complex factors in a single component. The drag coefficient is determined empirically using wind tunnels, including the object's shape and inclination. This coefficient is also based on a number

[4] Bar-Meir, G. B. M (2008, August 11). *Basics of Fluid Mechanics.* https://ufdcimages.uflib.ufl.edu/aa/00/01/17/21/00001/fluidmechanics.pdf

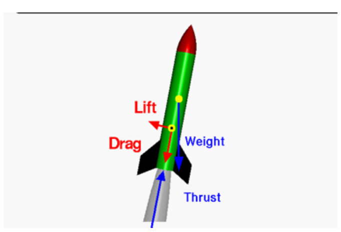
[5] Hall, N. H. (2021, May 13). *The Drag Equation*. Grc.Nasa.Gov. https://www.grc.nasa.gov/WWW/k-12/airplane/drageq.html

[6] Stern, F. (Fall 2013). *Fluid Statistics*. https://user.engineering.uiowa.edu/~fluids/Posting/Lecture_Notes/Chapter2.pdf

called Reynold’s number. This number is a ratio of inertial forces, the forces that are resistant to movement, to viscous forces such as drag. The value of the ratio expresses the flow pattern, a low Reynold’s number corresponds to a laminar flow whereas a higher one, order of 10^7, results in a turbulent flow. These numbers are used for aerodynamic structures such as airfoil designs.

Part 2: Rocket Aerodynamics

Aerodynamics is crucial for aircraft design. However, this importance doesn’t mean that drag affects every aircraft the same. The drag forces on a rocket and an airplane are given in Figures 2.1 [7]and 2.2[8] respectively. The drag forces here consist of two vectors as stated before, lift and the movement opposing drag. In airplanes, the lift is used to overcome the weight of the plane so plane aerodynamics are designed to utilize this drag component. However, in a rocket lift is a rotational force. A rocket uses its thrust to overcome the weight. This lift is generated because the center of gravity and center of pressure isn’t the same. The drag force that will be investigated in this essay is the one that opposes the movement, form drag. Form drag can be thought of as aerodynamic resistance. The source of this drag is skin friction. Skin friction is the interaction of the solid molecules with the fluid molecules. This causes drag to be dependent on both air’s and the rocket’s Reynold’s number. The Reynold number for the gas molecules will mostly be dependent on their viscosity. For the rocket, it will be dependent on its structure. It will depend on if the body is waxed and the tip is aerodynamically suitable. A rough, box-shaped rocket would generate more drag.



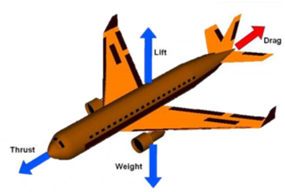


Figure 2.1 and 2.2: Drag forces’ effect on a rocket and an airplane.

[7] Benson, T. B. (2021, May 13). *Rocket Aerodynamic Forces*. www.grc.nasa.gov. https://www.grc.nasa.gov/www/k-12/rocket/rktaero.html

[8] Hall, N. H. (2021b, May 13). *What is Drag?* Www.Grc.Nasa.Gov. https://www.grc.nasa.gov/www/k-12/airplane/drag1.html

Part 3: Ideal Rocket Nose Cone Design

The aerodynamics of a rocket is mostly dependent on its nose structure. The nose is the first part of the aircraft to make contact and push the air out of the way. The more the air is pushed the more skin friction is created. In addition, for velocities below Mach 0.8 (980kmph) wave drag is essentially negligible as moving at a subsonic speed does not create sound waves. If the aircraft was moving with a supersonic velocity the ideal nose shape should be the sharpest ended conical structure. According to my research the best nose shape for a rocket going at subsonic velocities, our water rocket, for example, are elliptic, parabolic, and ogive nose cones.[9] The equations and models of these shapes are given below[10]:

Part 3.1: Elliptic Nose cone

An elliptic or an ellipsoidal nose cone is created by rotating a half ellipse 360° over its central line. The equation that gives an ellipse nose cone is:

$$y = R\sqrt{1 - \frac{X^2}{L^2}}$$

Equation 3.1.1: Elliptical nose equation where R is the radius of the cone, L is the length, and x is a point between 0 and L

Using integration to find the volume of revolution of the object we get:

$$V = \pi \int_0^L \left[R\sqrt{1 - \frac{X^2}{L^2}}\right]^2 dx$$

Equation 3.1.2: Model of an elliptic nose cone

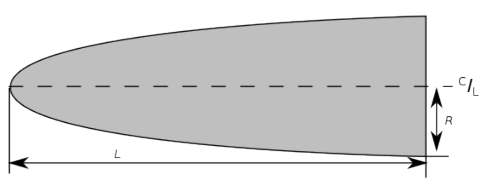


Figure 3.1: Ellipsoidal nose cone depiction.

[9] A. Iyer, A. Pant (August 2020). *A REVIEW ON NOSE CONE DESIGN FOR DIFFERENT FLIGHT REGIMES.* https://www.irjet.net/archives/V7/i8/IRJET-V7I8605.pdf

[10] Carvalho, L. (2019, October). *CFD analysis of drag force for different nose cone design*. Scribd. https://www.scribd.com/document/455946343/IX-FoPi-Aero

Part 3.2: Parabolic Nose Cone

This nose cone is obtained by rotating a segment of a parabola. The equation is as follows:

$$y = R\left[2\left(\frac{x}{L}\right) - \left(\frac{x}{L}\right)^2\right]$$

Equation 3.2.1: Parabola equation where R is the cone radius and L is the length.

$$\boldsymbol{V = \pi \int_0^L \left[R\left[2\left(\frac{x}{L}\right) - \left(\frac{x}{L}\right)^2\right]\right]^2} \mathrm{dx}$$

Equation 3.2.2: Model of a parabolic nose cone.

Part 3.3: Ogive Nose Cone

An ogive nose cone is similar to a conic nose cone, but the nose cone's edge is not a straight line but the arc of a circle. The body of the rocket is taken tangent to the curve and the arc is revolted 360° to form the tangent ogive. The equation for the radius of the circle can be expressed as:

$$r = \frac{R^2 + L^2}{2R}$$

Equation 3.3.1: Radius of the circle where R is the radius of the nose cone and L is the length.

$$y = \sqrt{r^2 - (x - L)^2} + (R - r)$$

Equation 3.3.2: Tangent ogive equation

$$V = \pi \int_0^L \left[\sqrt{r^2 - (x - L)^2} + (R - r)\right]^2$$

Equation 3.3.3: Model of a tangent ogive nose cone

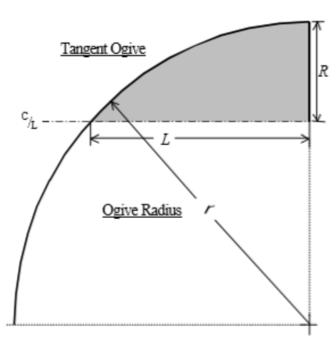


Figure 3.2: Tangent ogive nose cone depiction.

Part 4: Drag Coefficients

As drag coefficients are variables including complex factors, they need to be calculated empirically. This is done by using a wind tunnel. Since this experiment is a small scaled one using a wind tunnel will be far-fetched. Fortunately, drag coefficients have been calculated and published by many resources. The drag coefficients of the shapes used as nose cones are as follows:

Shapes	Drag Coefficient
Cone	0.32± 0.04
Ogive	0.23±0.05
Parabolic	0.29±0.04
Blunt	1.13± 0.08
Spheric	0.42±0.06

Table 1: Drag Coefficients of the nose types that will be used in the experiment.

As seen the best possible nose shapes of ellipsoidal cone, ogive, and parabolic are the lowest drag coefficients. Following that comes a spheric, half spheric to be exact, and lastly a blunt end such as a cylinder end. These are the five types of noses that will be used in the experiment.

Part 5: Principle of Water Rocket Flight

All rockets work on the same principle of Newton's third law stating that forces are always in pairs and to every force exerted there is a reaction force with the same magnitude and in opposite direction. This is caused by the conservation of momentum. In rockets, the thrust exerts a force towards the ground, resulting in a reaction force pushing the rocket upwards. In spacecraft, the thrust is achieved by chemical combustion. However, in a water rocket, the thrust is created physically: using pressure. Air is pumped into the water rocket increasing the number of moles of the gas and consequently the pressure in a constant volume.

$$PV = nRT$$

Equation 4: Ideal Gas Law where P is pressure, V is volume, n is the amount of gas in moles, R is the universal gas constant and T is the temperature in Kelvin

As seen in the equation pressure is proportional to the number of moles of the gas and volume is kept constant due to the volume of water staying the same during the pumping sequence. The increased pressure eventually pushes the water out of the bottle to increase its volume creating the thrust. According to my research, the ideal amount of water is between 1/3 and 1/2 of the bottle.[11]

PROCEDURE

Part 1: Building a water rocket

Materials	Amount
1.5 L Water bottle	5
50x70 cm Cardboard	5
Utility Knife	1
Duct Tape	1
Cork	5
Bicycle Pump	1
Needle	1
Pencil	1
Ruler	1
Tennis Ball (7.00 cm diameter)	1
Parabolic Nose Cone (length 7.00 cm, 5.50 cm radius)	1
Conic Nose Cone (length 7.00 cm, 5.50 cm radius)	1
Ogive Nose Cone (length 7.00 cm, 5.50 cm radius)	1
Protection Glasses	1
High-Speed Camera	1

Table 2: Material List

[11] AntiGravity Research Corporation. (n.d.). *How Does a Water Rocket Work? Get Ready To Learn!* AntiGravity Research. https://waterockets.com/how-does-a-water-rocket-work/

1. To create the fins for the rockets mark each cardboards' half-line using the ruler and draw a line through the middle. Cut over the line using the utility knife. This will leave you with two pieces of rectangular cardboard.
2. Cut over the diagonals. This will leave you with four fins.
3. Attach the fins to the 4 sides of the cap side down water bottle leaving 25cm of fins hanging from the bottle in contact with the ground using tape. (Full model seen at Figure 4.)
4. Insert the needle through the cork opening a space wide enough for the pump to be inserted.
5. Fill the water bottle with $350cm^3$ of water and shut with the pump inserted cork.
6. If there is water leaking tape the spaces leaking lightly.
7. Put your rocket down on the fins acting as a platform cork side down and start pumping air. Eventually, it will take off.
8. Be aware of your surroundings and take precautions as eyewear.

Part 2: Building and Attaching Nose Cones

Spheric:

- Place the tennis ball to the top of your rocket and tape firmly around it. This will create a spheric nose tip. The 3.5 cm radius of the tennis ball will leave 1.5 cm of space from each side of the nose, but these spaces will be filled by the tape.

Parabolic, Ogive, and Conic:

To create these nose cones you need a 3D printer.

1. Model the nose cones using the equations given before and set L as 7.00 cm and R 5.50 cm using a sketching program such as AutoCAD.
2. Print the cones and tape them to the top of the rocket.

Blunt:

1. Cut another 1.5L water bottle's bottom with a length of 7.00 cm.
2. Tape the extra part to the tip of the rocket to match with the other rockets' length.

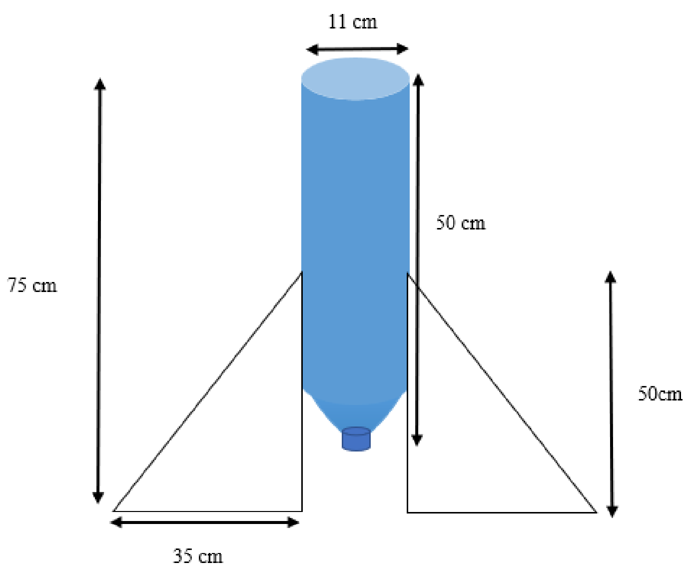


Figure 4: Model of base of the rocket.

Figure 4.2 and 4.3: Real model of the rocket base and the rocket base with spheric nose.

Part 3: The Experiment

Independent Variable	Dependent Variable	Controlled Variables
Drag Coefficient	Apogee Height (m) Time to Reach Apogee(s) Average Velocity (ms^{-1})	Same environment Same wind conditions Equal rocket length (m) Equal rocket mass (kg) Equal volume of fuel (cm^3)

Table 3: Variable Table

1. Now the rocket is prepared with the selected tip with a different drag coefficient.
2. Set the high-speed camera 15 meters away from the launch site. This will allow you to film the whole flight and see the apogee.
3. Capture the flight of the rocket with the selected tip. Each tip should be tested at least five times to increase precision.
4. Use the footage of the flight to determine the apogee height by counting grids and note the time the rocket reached the apogee.
5. Doing this you will have the distance and time, and by dividing them together you can calculate the average velocity.
6. Using the drag equation calculate the drag force affected on each rocket.

DATA

Part 1: Raw Data

Rocket Features	Values
Fuel Capacity (dm^3)	1.50 dm^3
Fuel Used (dm^3)	0.35 dm^3
Dry Mass (kg)	0.53 ± 0.01 kg
Rocket Diameter (cm)	11.00 ± 0.05 cm
Nozzle Diameter (cm)	4.60 ± 0.05 cm

Table 4: Rocket Features table where fuel is water, dry mass is the rocket's mass without the fuel, and nozzle diameter is where the water will flow out.

Nose Cones/Drag Coefficients	Apogee Height (m) ($\pm$ 0.10)	Time to Reach Apogee (s)(± 0.05)
Conic: 0.32 ± 0.04	30.90	2.50
	30.50	2.40
	30.80	2.40
	30.80	2.50
	31.30	2.60
Tangent Ogive: 0.23 ± 0.05	31.90	2.50
	32.50	2.50
	31.80	2.40
	31.30	2.50
	31.80	2.50
Parabolic: 0.29 ± 0.04	31.20	2.50
	31.10	2.40
	30.80	2.50
	31.70	2.50
	31.10	2.50
Blunt: 1.13 ± 0.08	24.50	2.10
	24.10	2.10
	24.50	2.10
	25.00	2.20
	24.70	2.20
Spheric: 0.42 ± 0.06	29.90	2.40
	29.30	2.40
	30.50	2.40
	30.20	2.50
	30.00	2.40

Table 5: Raw Data Table

Part 2: Processed Data

Apogee Height (m)	$\frac{Absolute\ Uncertainty}{Data\ Mean} \times 100 = \frac{0.10}{29.69} \times 100 \approx \mathbf{0.34}\%$
Time to Reach Apogee (s)	$\frac{0.05}{2.42} \times 100 \approx \mathbf{2.07}\%$
Average Velocity (ms^{-1})	**2.40%**

Table 6: Percentage Uncertainty Calculation

Nose Cones/Drag Coefficients	Average Velocity(ms^{-1}) ($\pm$ 2.40%)
Conic: **0.32± 0.04**	$\frac{\boldsymbol{Apogee\ Height\ Total(m)}}{\boldsymbol{Time\ to\ Reach\ Apogee\ Total(s)}} = \frac{\mathbf{154.30}}{\mathbf{12.4}} \approx \mathbf{12.44}$

Table 7.1: Average Velocity Sample Calculation

Nose Cones/Drag Coefficients	Average Velocity(ms^{-1}) ($\pm$ 2.40%)
Conic: **0.32± 0.04**	**12.44**
Tangent Ogive: **0.23±0.05**	**12.85**
Parabolic: **0.29±0.04**	**12.57**
Blunt: **1.13± 0.08**	**11.48**
Spheric: **0.42±0.06**	**12.10**

Table 7.2: Average Velocity with Different Tips

Reference Area: A (widest section of the rocket opposing the movement) (cm^2)	$\pi R^2 = \pi(5.50)^2 \approx 95.03\ cm^2 \approx \mathbf{0.095\ m^3 \pm 1.81\%}$
Air -Fluid Density at STP: ρ (kgm^{-3})	**1.23**

Table 8: Reference Area (A) calculation where R is the radius and ρ is air-fluid density

Drag Coefficients	Percentage Uncertainty
Conic: **0.32± 0.04**	$\frac{Absolute\ Uncertainty}{Data\ Value} \times 100 \approx 12.50\%$

Table 9.1: Sample Calculation for Drag Coefficients' Percentage Uncertainty

Drag Coefficients	Percentage Uncertainty
Conic: **0.32± 0.04**	**12.50%**
Tangent Ogive: **0.23±0.05**	**21.74%**
Parabolic: **0.29±0.04**	**17.24%**
Blunt: **1.13± 0.08**	**7.08%**
Spheric: **0.42±0.06**	**14.29%**

Table 9.2: Percentage Uncertainties of Drag Coefficients

Nose Cones/ Drag Coefficients	Drag Force Experienced (N)
Conic: **0.32 ± 12.50%**	$F_D = \frac{\rho \times Cd \times v^2 \times A}{2} = \frac{1.23 \times 0.32 \times 154.75 \times 0.095}{2} \approx \mathbf{2.89 \pm 19.12\%}$

Table 10.1: Drag Force Experienced Sample Calculation

Nose Cones/ Drag Coefficients	Drag Force Experienced (N)
Conic: **0.32 ± 12.50%**	$\mathbf{2.89 \pm 19.12\%}$
Tangent Ogive: **0.23 ± 21.74%**	$\mathbf{2.21\ \pm 28.36\%}$
Parabolic: **0.29 ± 17.24%**	$\mathbf{2.68\ \pm 23.89\%}$
Blunt: **1.13 ± 7.08%**	$\mathbf{8.70\ \pm 13.70\%}$
Spheric: **0.42 ± 14.29%**	$\mathbf{3.59\ \pm 20.91}$

Table10.2: Drag Force Experienced by the Rocket

CONCLUSION & EVALUATION

The results of the experiment supported my hypothesis. The hypothesis claimed that any change in drag coefficient would have affected the average velocity of the rocket inversely and in an exponential factor. I made this claim using the drag equation and in those calculations velocity is the only factor that was used exponentially and on the power of two. Using mathematics and average velocity-drag coefficient graph should give the best fit line using an exponent "n" raised to the power of -2. However, using my data I found out using a natural exponent gave the best curve fit, including all of the error bars as seen in Figure 5.

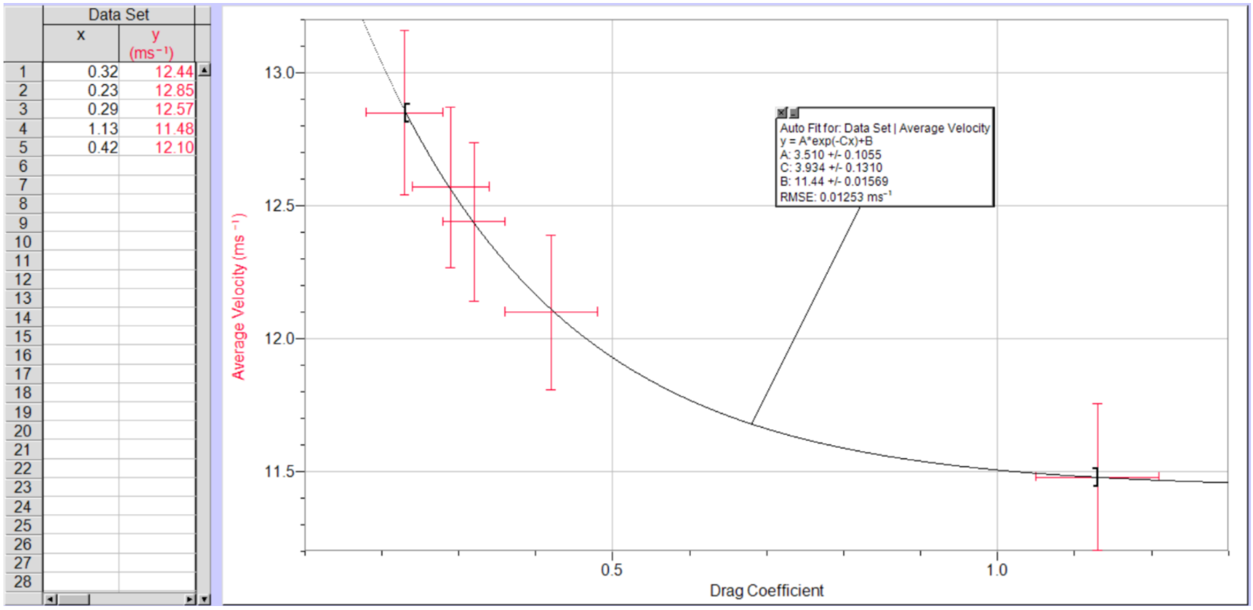


Figure 5: Graph of average velocity against drag coefficient.

The main reason for this factor difference is the random and systematic errors in the experiment. The experiment has been done in an open environment due to safety issues and the projectile nature of the rocket. This causes some random factors that can not be written as controlled variables such as momentarily different wind conditions. To reduce these trials can be repeated more times to increase precision however this will take a long time as launching the rockets is a time-consuming process. In addition to random errors, a systematic error also occurs. Because the rocket is in movement and some random factors tilt it in uncontrollable directions turbulence occurs. This is a systematic error because as long as the rocket goes through a fluid not perpendicularly, turbulence will always affect the result. Although these problems didn't change the outcome of the experiment, I can suggest an alternative model to improve the experiment. Using a wind tunnel for all calculations should give more accurate results. In a wind tunnel, most of the random turbulent factors are eliminated as the rocket remains still and the fluid around it moves. Referencing to the background section, skin drag occurs when in contact with a moving fluid and it is not important whether the fluid is moving or the object is moving as long as one of them remains still calculations will yield accurate results.

Evaluating the data further we can see that tangent ogive gave the highest average velocity with 12.85 meters per second while the blunt end gave the slowest average velocity with 11.48 meters per second. Comparing both of these tips, the tangent ogive has the smallest coefficient value whereas the blunt end had the highest. This alone can show the inverse effect drag coefficients have on average velocity.

Another aim of this experiment was to observe the drag force change depending on the nose tip. The drag force experienced was calculated theoretically by using the drag equation. According to the drag equation, the drag force experienced should be directly proportional to the drag coefficient and the results using the data support this. A direct proportion suggests a linear fit and as seen in figure 6 this is the case.

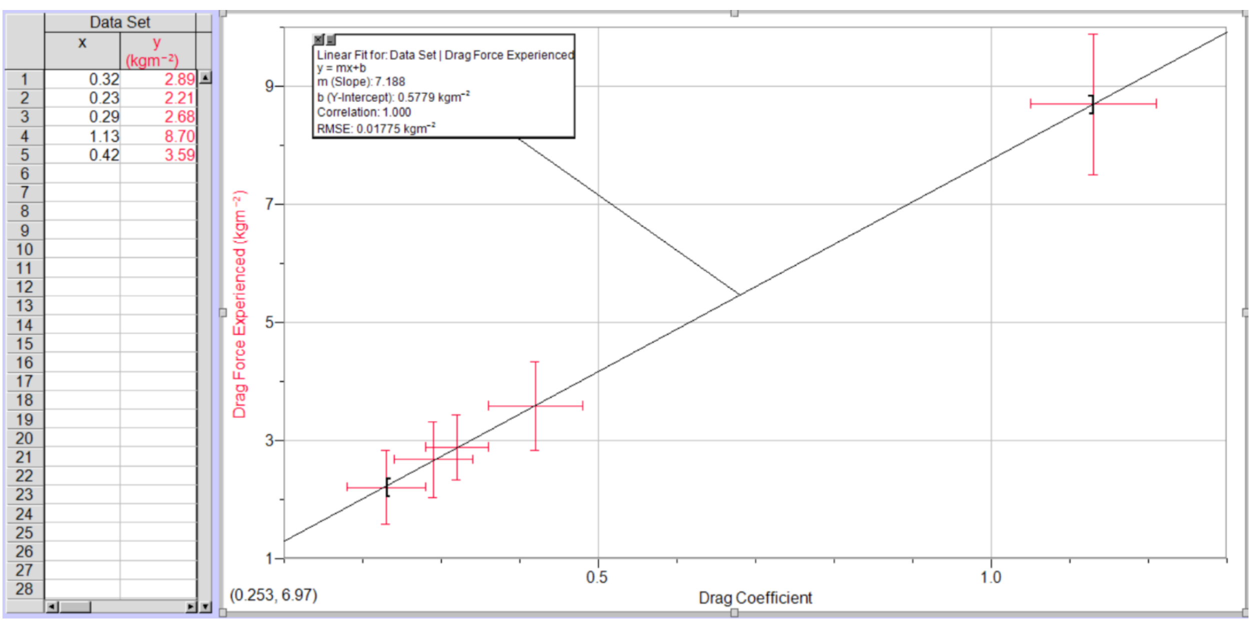


Figure 6: Graph of Drag Force Experienced against the Drag Coefficients

This theoric calculation was done to make another correlation with the drag coefficient's effect on velocity using reasoning and the conservation of energy. Thinking of the thrust as the force that pushes the rocket up and the movement in the same direction, the net force should be in the same direction as the force created by the thrust. However, there are other forces such as the weight vector of the rocket and the drag force it experiences. During the tip changes, the weight of the rockets remains the same as we adjust it with additional weights. So only the drag force changes. This drag force change affects the net force. Assuming the net force decreases and the rocket takes the same distance (not apogee height), the work done by the net force decreases thus the energy. Using the kinetic energy formula we should see a decrease in the velocity.

$$E_K = \frac{1}{2}mv^2$$

Equation 5: Kinetic Energy formula where m is mass and v is the velocity.

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