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International Baccalaureate

Extended essay cover

Candidates must complete this page and then give this cover and their final version of the extended essay to their supervisor.									
Candidate session number	0	0	0	2	5	0			
Candidate name									
School number				0	0	0	2	5	0
School name	St. Petersburg High School								
Examination session (May or November)	May		Year	2013					

Diploma Programme subject in which this extended essay is registered: Physics

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: To what extent does changing the material on the exterior of a cone affect the force of drag acted upon the cone by the air passing by it?

Candidate's declaration

This declaration must be signed by the candidate; otherwise a grade may not be issued.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

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Assessment form (for examiner use only)

Candidate session number	0	0	0	2	5	0			

Achievement level

Criteria	Examiner 1	maximum	Examiner 2	maximum	~~Examiner 3~~ Mr. Smith
A research question	1	2	2	2	2
B introduction	0	2	0	2	1
C investigation	0	4	2	4	1
D knowledge and understanding	0	4	1	4	1
E reasoned argument	0	4	1	4	3
F analysis and evaluation	0	4	0	4	1
G use of subject language	1	4	1	4	1
H conclusion	1	2	1	2	2
I formal presentation	1	4	1	4	1
J abstract	0	2	1	2	1
K holistic judgment	0	4	0	4	2
Total out of 36	4		10		16

Name of examiner 1: FERDi KAYA Examiner number: 088164
(CAPITAL letters)

Name of examiner 2: J. Godin Examiner number: 0292
(CAPITAL letters)

Name of examiner 3: ______ Examiner number: ______
(CAPITAL letters)

IB Cardiff use only: B: ✓

IB Cardiff use only: A: [illegible] **Date:** [illegible]

Supervisor's report and declaration

The supervisor must complete this report, sign the declaration and then give the final version of the extended essay, with this cover attached, to the Diploma Programme coordinator.

Name of supervisor (CAPITAL letters) KYLE J. SMITH

Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.

The student conducted his data collection in a wind tunnel built by a previous year's student. His data analysis is flawed by the use of surface area instead of cross-sectional area. The student chose this subject because he is interested in aeronautical engineering.

This declaration must be signed by the supervisor; otherwise a grade may not be issued.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

I spent 6.0 hours with the candidate discussing the progress of the extended essay.

Supervisor's signature: [signature] Date: 2/26/18

This was just like a IA. No graph, no evaluation, very few sources, no physics background. No intellectual initiative and I could not see any understanding.

R.Q is too broad in scope. He used the wind tunnel which was built by another student. (k)

Physics Extended Essay

To what extent does changing the material on the exterior of a cone affect the force of drag acted upon the cone by the air passing by it? ✓

Candidate #

February 25, 2013

St. Petersburg High School

Mr. Smith

Word Count: 2845

✓

Abstract

In this paper, the research topic that was investigated was that changing the material on the exterior of a cone would have a profound effect on the force of drag acted upon the cone. This theory was tested by attaching, one at a time, five cones, each wrapped in a different material, to a force sensor suspended within a wind tunnel. The materials tested were 36 grit sand paper, wax paper, polypropylene page protectors, and cotton. Each cone was tested five times for ten seconds in each trial, gathering over five hundred reading per trial. The results were recorded using a Vernier Dual-Range Force Sensor, a Vernier LabQuest device, and a computer running the program LoggerPro. To deduce whether or not the exterior material of the cones affected the amount of force from drag acted upon the cones, the equations for drag and the drag coefficient were used. To do so, the other components of the equation like fluid density (p), cross-sectional area (A), and the velocity at which the fluid travelled through the tunnel, were obtained and kept at a constant.

The variable altered in this investigation, or the independent variable, was the type of material wrapped around the exterior of the cone. This altered the coefficient of drag, which, in turn, led to the change in the dependent variable, the force acted upon the cone due to drag.

The results from the investigation showed that altering the material on the exterior of the cone, changed the drag coefficient, which, in turn, caused the force of drag to increase when the cones wrapped in coarser materials were tested. This investigation, exhibits that changing the material wrapped around the exterior of a cone significantly affects the amount of force acted upon the cone due to drag.

Word Count: 296

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Introduction

Millions of people around the world choose to travel via aircraft every year. Since fuel and maintenance are large expenses for airline companies, the price of a ticket to board an airplane is usually expensive. Therefore, if the airlines had to pay less on jet fuel, the price of the airline tickets would ideally drop. It is then necessary to minimize the forces acting against the airplane to conserve fuel. Drag, the force of friction between the air and the skin of the aircraft, must be minimized to let the aircraft travel easily through the air. To do so, the skin of the aircraft must have properties to reduce the friction from the air to the smallest amount possible.

The aim of my investigation is to find a material that produces the least amount of drag, by reducing the drag coefficient the greatest, when completely covering a cone. Through testing this in a wind tunnel, I am led to the following **research question**:

To what extent does changing the material on the exterior of a cone affect the force of drag acted upon the cone by the air passing by it?

Investigation

Equipment

- A wind tunnel constructed out of plywood was used to house the cones while testing was occurring. A fan at the rear of the tunnel sucked the air through making the air travel at a higher velocity through the tunnel. A middle section of the tunnel is made of plexiglass for observational purposes, which is where the cone was situated during the testing.

- A metal rod capable of holding a force sensor and a Styrofoam cone.

- A hole drilled through the plexiglass allowed a metal rod to be positioned such that a force sensor could be attached to the rod and have its sensor facing perpendicular to the direction of the wind.

- A Venier Dual-Range Force Sensor was attached to the metal rod perpendicular to the direction of the wind.

- Five lightweight Styrofoam cones. Each cone 30.2 cm in height and 10.2 cm in diameter at its base.

- A 30.5 cm threaded metal rod was securely fastened inside each cone through the center of it base such that 1.27 cm of the rod was left protruding from the cone.

- A Vernier LabQuest was connected to the Dual-Range Force Sensor, then to a MacBook running LoggerPro to record the data from the experiment.

- A computer with LoggerPro installed.

- An anemometer to measure the velocity of the air traveling through the wind tunnel.

- A thermometer to record the temperature of the air during experimentation.

- Metal sewing pins to attach materials to the exterior of the cones.

- Five different materials to wrap around the cone:

  - 36 grit sand paper
  - thin cotton
  - wax paper
  - aluminum foil
  - polypropylene page protectors

Setup

A screen that serves to minimize turbulent flow and maximize laminar flow covers the front end of the wind tunnel. Conversely, a fan located at the rear end of the tunnel pulls air through front of the tunnel and pushes it out the back. In the middle of the tunnel a plexiglass portion serves to provide means to visual observation of the experiment. A hole was drilled through this plexiglass to allow a metal rod to be positioned upright through it (Figure 1) such that the Dual-Range force sensor faces perpendicular to the direction of the airflow (Figure 2). The 30.2 cm threaded rod was secured inside the cone through the center of the circular base. Since the radius of the base is 10.2 cm, a hole was drilled 5.1 cm in from the edge. Once secured, 1.27 cm of the threaded rod remains outside of the base on the cone. The Dual-Range force sensor is equipped with a threaded sleeve that the threaded rod (protruding from the cone) is screwed into to connect the two together. Once connected, the Dual-Range force sensor is connected to the LabQuest device (Figure 2) that is then connected to a computer running LoggerPro for data recording. A full diagram of the wind tunnel can be seen Figure 4.

The cones being used for testing are made of a lightweight green Styrofoam and wrapped completely in five different materials. The five materials used are 36 grit sandpaper, polypropylene page protectors, aluminum foil, cotton, and wax paper. The cones in their various exterior wrappings can be seen in Figure 5. Each material was pinned onto the cone using small sewing pins in order to best fit the material over the cone.

Figure 1

Figure 2

Figure 3

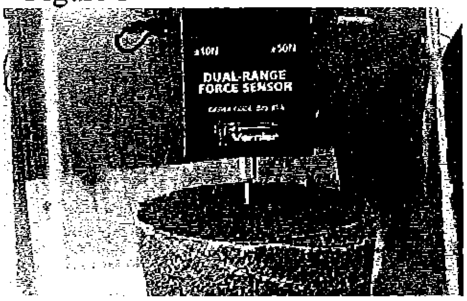
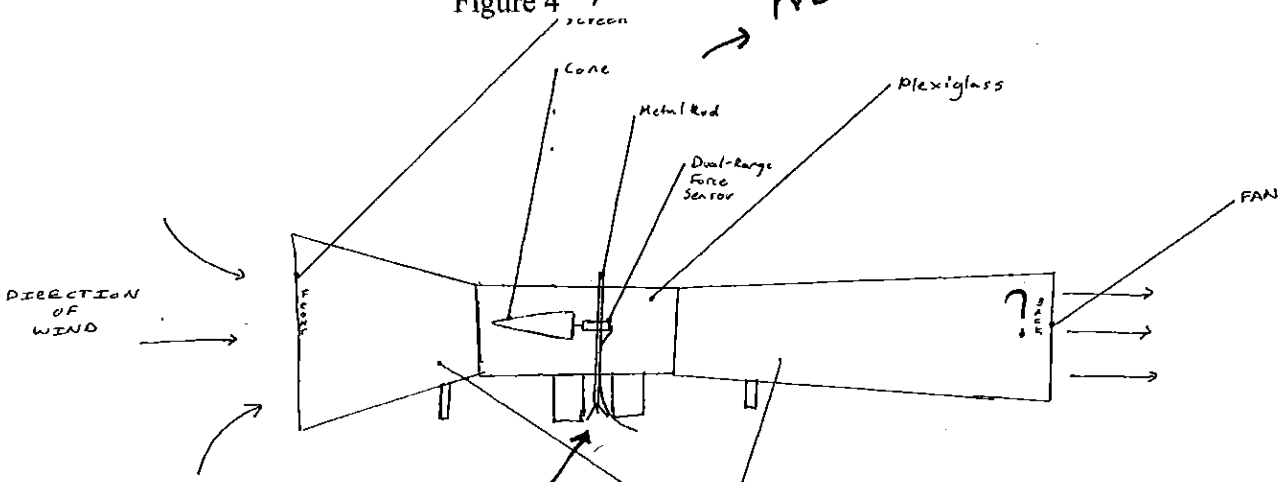


Figure 4



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hard to read

enlarge and explain v. important

Figure 5 ———

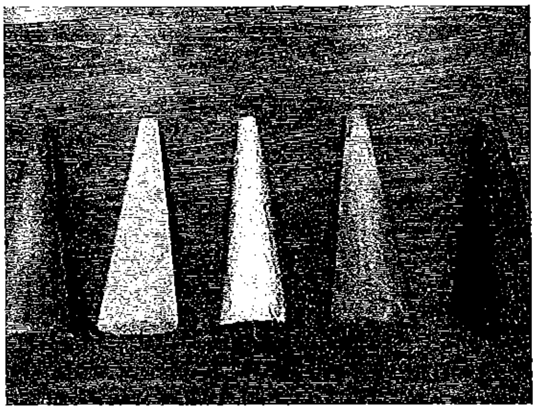
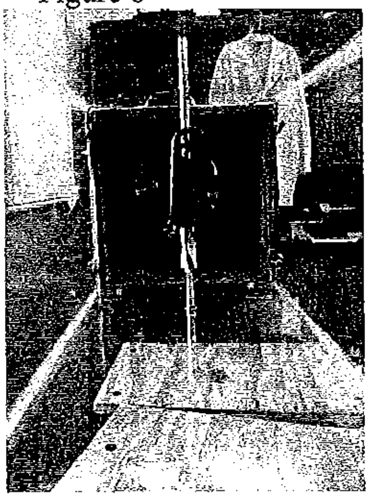


Figure 6 ———



Defining Variables

In order to test the research question, it must first be deduced what is necessary to derive a numerical value for the force of drag acted upon the cones. The equation for drag is as follows:

$$F_d = \frac{1}{2} p v^2 C_d A$$ [1],

Where F_d is defined as the Force of drag upon the object, p is defined as the density of the fluid (in this case air), v is defined as the velocity of the object in relation to the fluid through which it is moving (in this case the fluid is moving, while the cone is stationary), C_d is defined as the coefficient of drag, and A is defined as the cross-sectional area of the object that is travelling through the fluid.

Furthermore, the variables can be identified through measurements of the conditions during experimentation.

P, the density of fluid that passes by the cones, can be found by researching air density. The densities of fluids vary as temperatures and atmospheric pressures vary. The

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1 "The Drag Equation." *The Drag Equation.* N.p., n.d. Web. 25 Feb. 2013.

site, being at sea level, had an assumed atmospheric pressure of 1 atm. The temperature of the air in the testing facility was 26.2 degrees Celsius, giving the air a density of [2]1.1839 kg/m^3. Since this is defined and remains constant throughout experimentation, this is one of the controls.

V, the velocity at which the object is travelling through the fluid, is in this case the velocity at which the fluid is travelling past the cone. To obtain this value, an anemometer was set up inside the wind tunnel. Using the same rod that was used to secure the force sensor and cones, the anemometer was placed directly where the peak of the cone was during experimentation (as seen in Figure 6). To accurately determine the velocity of the air travelling through the tunnel, five trials took place recording the maximum velocity of the tunnel. The data is as follows:

Trial #	Velocity of air (m/s) Error: +/-0.05 (m/s)
1	6.8
2	6.8
3	6.7
4	6.8
5	6.7

Therefore, on average the velocity of the air travelling through the wind tunnel was 6.76 m/s, or approximately 6.8 m/s. Since this, too, remains constant throughout the experiment, the velocity of the air can be classified as a control.

A, the cross-sectional area of the cone, is derived by using the equation:

$$A=\pi r(\sqrt{(r^2+h^2)})$$

R is defined as the radius of the base of the cone, which in this case is 5.1 cm. H is defined as the height of the cone, which in this case is 30.2 cm. Therefore, with these values, the equation is as follows:

$$A=\pi(5.1)(\sqrt{((5.1^2)+(30.2^2))})$$

$$A= 490.7\ cm^2$$

Therefore, since all the cones are premade to the same dimensions, the five cones have equal lateral areas and this can be defined as a constant in the equation for drag.

The **independent variable** in this investigation is the type of material used to wrap the exterior of the cones. In the equation for drag, this would correlate to the

[2] *Density of air*, http://en.wikipedia.org/wiki/Density_of_air (August 2012)

coefficient of drag, or C_d. The coefficient of drag is obtained by rearranging the equation for the force of drag to the equation as follows:

$$C_d=(2F_d)/pv^2A$$

The **dependent variable** of this investigation is the force of drag that is acted on the cones. In the equation for drag, this would correlate to F_d. The force of drag is obtained by using the Dual-Range force sensor that records the force in Newtons that is acted on the cones.

Hypothesis

When air travelling around the cone meets obstacles to go around, the drag will be more intense. Therefore, this investigation will show that the materials used to wrap the exterior of the cones will, in fact, have a profound effect on the force of drag acting on the cones. A material like sand paper is coarse due to its many edges, while polypropylene and aluminum foil are smooth and have little to no edges. Since air, the fluid that which will be passing the cones, is matter, in itself, the air will be forced to travel around the jagged edges of the sand paper and pass smoothly across the surface of the polypropylene and aluminum foil. Therefore, the air will have to be in more contact with the cone if wrapped in certain materials, while if wrapped in other materials, the air will pass freely alongside.

Data collection

In order to collect the data, each cone was attached to the Dual-Range force sensor using the threaded rod protruding from the cone and the threaded sleeve attached to the force sensor. Once screwed into the sensor, any forces acted on the cone is recorded and sent to the LabQuest device that is then connected to the computer running LoggerPro. LoggerPro takes the readings in real time and generates graphs of the readings. Each cone, wrapped in a different material, was tested five separate times to ensure consistent, precise and accurate data.

Procedure

1. Wrap five cones in five different materials completely such that no Styrofoam is exposed and no material is loose or in a position that could obstruct the airflow and thus skew the data.

2. Locate the center of the base of each cone. The diameter of the base is 10.2 cm. Therefore, from the center, the edge is 5.1 cm away in every angle. Drill a hole perpendicular to the base of the cone.

3. Place a small amount of adhesive on the threaded rod and insert it into the drilled hole such that 1.27 cm of the threaded rod is protruding from the base of the cone.

4. Attach the Dual-Range force sensor to a rod running perpendicular to the airflow inside the tunnel such that the sensor faces the airflow. Set switch on top of the sensor to +/- 10 N

5. Screw in one cone using the threaded rod and the threaded sleeve from the force sensor.

6. Attach the force sensor to the LabQuest device. Then attach the LabQuest device to a computer running LoggerPro.

7. Turn the wind tunnel on and wait for it to reach maximum power.

8. Once at full power, record five different, 10 second long readings of the force sensor. The sensor should take readings every 0.02 seconds, giving 501 readings in a 10 second period.

9. Replace cone with another cone wrapped in a different material and repeat.

Data

Each cone was tested and recorded over a period of 10 seconds, gathering over 500 readings, five times each. The averages of each trial are listed below in the tables. Then, the average value of average values from each trial is derived. The final table illustrates the average force of drag of each material comparatively.

Cone # and type of exterior wrapping	Average Force of Drag (N) Error +/- $5.0x10^{10}$
Cone 1: Polypropylene Page Protectors	0.095143419
Cone 2: Cotton	0.102561267
Cone 3: Aluminum Foil	0.089333563
Cone 4: Wax Paper	0.100911372
Cone 5: 36 Grit Sand Paper	0.113308601

Calculations/Data Breakdown

Now that the data has been processed, the average force of drag has been calculated for each of the five materials used to cover the cones. Now, the dependent variable has been obtained, the equation to obtain the independent variable, or the drag coefficient, can be solved. All calculations to obtain the drag coefficient are done in the same manner. The calculations for Cone 1 (polypropylene page protectors) are shown below.

Cone 1, which is covered with polypropylene page protectors, had an average force of drag of 0.095143419 N. The lateral area of the cone was 490.7 cm^2, the velocity of the air travelling past the cone was 6.8 m/s, and the density of the air travelling through the tunnel was 1.1839 kg/m^3. Therefore, the equation can be solved as follows:

F_d= 0.095143419 N
P= 1.1839 kg/m^3
V= 6.8 m/s
A= 490.7 cm^2 = 0.04907 m^2

$$C_d = (2F_d)/pv^2A$$

$$C_d = \frac{2(0.095143419\ kg\ m / s^2)}{(1.1839\ kg/m3)(6.8\ m/s)^2 (0.04907\ m^2)}$$

All units cancel, leaving:

$$C_d = 0.0708369487$$

Furthermore, after the same arithmetic is completed for all cones in the investigation, the drag coefficients are as follows:

Cone # and type of exterior wrapping	Drag Coefficient
Cone 1: Polypropylene Page Protectors	0.0708369487
Cone 2: Cotton	0.0763597449
Cone 3: Aluminum Foil	0.0665113476
Cone 4: Wax Paper	0.0751313517
Cone 5: 36 Grit Sand Paper	0.0843614370

Analysis/Conclusion

After processing and calculations, the drag coefficient is reached. Since the aspects of the equation for drag is as follows:

$$F_d = \frac{1}{2} pv^2C_dA$$

And density (p), velocity (v), and area (A) are all constant in this investigation, it is safe to say that the only dynamic aspects of this equation are the force of drag (F_d), the dependent variable, and the drag coefficient (C_d), the independent variable. Moreover, since the only change to the cones being tested on was the material wrapped around the exterior of the cone. It can be deduced that the change in material exterior caused the drag coefficient to change, which then caused the force of drag to change. Therefore, the drag coefficient is directly relative to the type of material on the exterior of the cone.

It can also then be deduced that, since the cones that had higher drag coefficients also had more force from drag acted on them, that the cones with higher drag coefficients are less aerodynamic and attract more drag.

Furthermore, the results of this investigation show that since aluminum foil had the least drag coefficient of 0.0665113476, it has the least amount of force acting upon it due to drag, and is thus more aerodynamic than the other materials.

Moreover, the data supports the hypothesis that different materials wrapped about the exterior of a cone do have a profound effect on the force of drag being acted upon the cone.

With this discovery, the areas of possible error must be considered. The equipment used to measure the force acted upon the cones was all electronic and for that reason, very precise. However, the technology used to facilitate the experiment was not. The wind tunnel used to house the cones was homemade, and for that reason, less reliable than a professional grade alternative. With this being said, the wind tunnel, though fashioned out of plywood and plexiglass, provided a consistent and effective means of testing the aerodynamic properties of the materials on the exterior of the cone. It should also be noted that since the Styrofoam cones were so lightweight, the readings picked up by the force sensor were very miniscule. Proportionally, given the weight of the cones and the low velocity at which the air travelled through the tunnel, the two were scaled well to each other to give accurate results.

(I) not all cited in core of essays
what is cited in " "
does not correspond to a listed here => unclear
specific reference

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Appendix A

Cone 1: Polypropylene Page Protectors	
Trial #	Average Force over period of 10 seconds (N) Error +/- 5.0x10^{10}
1	0.093473727
2	0.096873821
3	0.097862835
4	0.094611216
5	0.092895496
Average	0.095143419

Cone 2: Cotton	
Trial #	Average Force over period of 10 seconds (N) Error +/- 5.0x10^{10}
1	0.10122746
2	0.101173844
3	0.101782594
4	0.102857394
5	0.105765044
Average	0.102561267

Cone 3: Aluminum Foil	
Trial #	Average Force over period of 10 seconds (N) Error +/- 5.0x10^{10}
1	0.088235008
2	0.089607584
3	0.089609233
4	0.090675784
5	0.088540208
Average	0.089333563

Cone 4: Wax Paper	
Trial #	Average Force over period of 10 seconds (N) Error +/- 5.0x10^{10}
1	0.100169983
2	0.098191956
3	0.101285201
4	0.102661901
5	0.102247818
Average	0.100911372

Cone 5: 36 Grit Sand Paper	
Trial #	Average Force over period of 10 seconds (N) Error +/- 5.0x10^{10}
1	0.113566619
2	0.115928208
3	0.111473111
4	0.112191568
5	0.113383499
Average	0.113308601