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PHYSICS HIGHER LEVEL

EXTENDED ESSAY

INVESTIGATION OF THE EFFICIENCY OF AIR CONDITIONING VERSUS OPEN WINDOWS IN TERMS OF FUEL ENERGY USAGE OF AUTOMOBILES

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Word Count: 3935

CONTENT

ABSTRACT

This experiment was settled in order to see if there are available solutions for extra usage of energy while we are using the automobiles. The mechanism of the experiment is based on the movement of air and the automobile. In this extended essay, I have settled two different hypotheses which mainly state that using air conditioning instead of opening windows will help us save some energy. The experiment is made by choosing a constant route for the automobile to travel, where some trials will be made by opening windows for different values, and some will be made by using air conditioning only.

After recording these data, appropriate graphs will be sketched to see the relation between the gap of the window to the fuel usage. Conclusion will be made taking scientific data into consideration, resulting with social results, such as global warming.

ABSTRACT WORD COUNT: 142

A) BACKGROUND INFORMATION ON AIR CONDITIONING AND THE GAP OF TOP OF THE WINDOWS

As many of us know, breathing is the essential process to the way to live. If this essential process cannot be performed, unhealthy conditions will exist and therefore an unhealthy environment will show up. All that we need is an atmosphere with fresh air inside. Wherever we are, one of our needs will be fresh air.

As I have mentioned that we need to breathe fresh air everywhere, vehicles must have fresh air inside as well, so that we can breathe. In an automobile, the need for fresh air increases, as the time passed in a closed environment increases. If we are to deeply search the ways to get cooled in an automobile, we may reach the conclusion that two major ways have taken over worldwide, which have been placed in people's knowledge for many years;

1. **Cooling by Air Conditioning**
2. **Cooling by Opening Windows**

In this extended essay, these two issues which seem similar to each other but differ in many ways will be compared.

While using one of these ways, probably many people would not think of the fuel usage or any other causes that preferring only one of these features may cause. My hypothesis is that, usage of air conditioning in automobiles will save up energy, as less back force will be formed. My hypothesis is based on the fundamentals of "force". To describe force:

"We experience force as any kind of push or pull on an object." [(1)]

As described above, force is the pull or push that we exert on anything you can imagine. This can be both a surface or just a single object, or an automobile.

In our daily life, frictional force creates the stability of the objects by causing a negative force, which affects the object in the opposite direction of motion. Friction may exist both in the terrain and air. In this experiment, we will mostly deal with air friction, and the opposite force it creates and its results.

The air friction in such a case that a car will move along a line with constant speed which has windows open will be in such a way that, some of the air will just hit the car and flow back on its way, however some air will be escaped inside the car, unlike in the issue that a closed-window car will have.

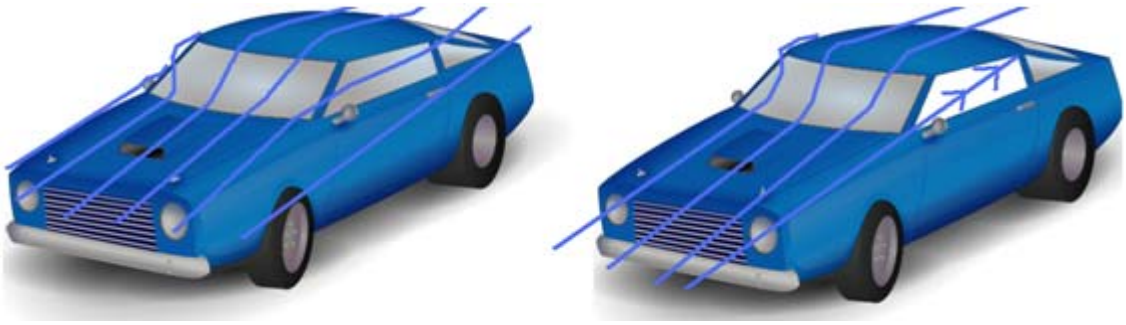


Figure 1 :The movement of air compared in two different samples, where one automobile has windows closed and other automobile has windows opened, letting the air particles move inside the automobile which cause an opposite force. (Figure is re-edited by candidate)[(2)]

This flow of air inside the window will create a back force, as it will act as an obstacle for the car to move on its way.

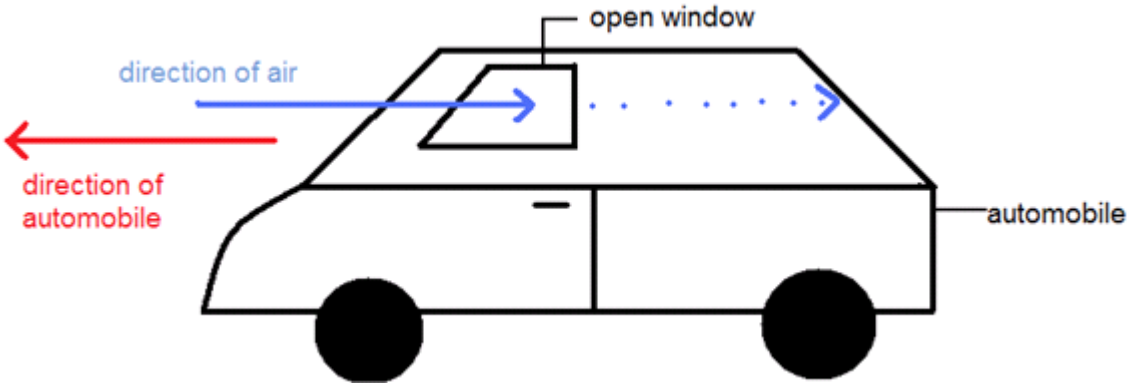


Figure 2: The opposite direction of air with respect to the automobile, which creates an opposite force that lowers the speed of the automobile.

There also is a massive role of pressure in this experiment. As we all know, where velocity increase, the pressure decreases. Due to this rule, we may think that entrance of air particles inside the automobile will not be present. However, as the velocity of the automobile increase, there will be some particles which will move inside the automobile, where the rate

of escaping molecules from the automobile will be higher. If none of the air that comes from outside had the chance to enter the automobile, we would not feel the properties of air that is present outside when we open windows. Thinking the properties of the particles, we can conclude that the rate of air exchange will be higher when windows are open more. Changing rate of air exchange is likely to cause more back force and therefore more usage of energy.

1. Cooling by AC

The history and denotation of AC is;

"The idea of air conditioning started before a machine was created to produce the cooling effect desired. The first attempt at building an air conditioner was made by Dr. John Gorrie (1803-1855), an American physician, in Apalachicola, Florida. During his practice there in the 1830s, Dr. Gorrie creating an ice-making machine that essentially blew air over a bucket of ice for cooling hospital rooms of patients suffering from malaria and yellow fever. […] it is an invention that is hard to live without." [(3)]

This simply helps us with the need of getting cooled, warmed or freshed. When we use the air conditioning in our cars, we are creating an inner circular air motion inside our automobile, due to the exchange of air from inner to external mediums.

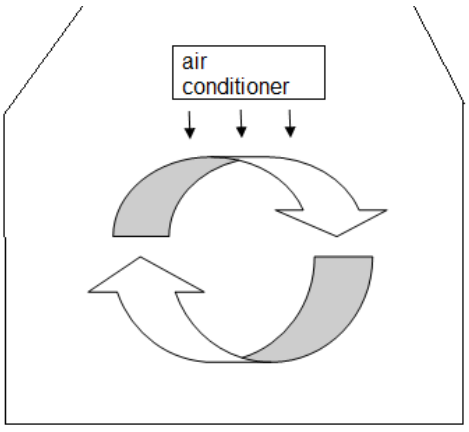


Figure 3: the circulation of air in a car while windows are closed and air conditioning is opened.

As I have mentioned before, the movement of everything in the world is made by the physical donation: “force”. If there are moving air particles only inside the automobile –as only AC is open which circulate the air inside the automobile- it mean that only inner forces exist which will have no effect on changing the velocity of the car. However some amount of energy must be used in order to give the first velocity to air particles, which is also is supplied by force. This internal circulation serves as the needed feeling that the passengers desire to obtain: fresh and cool air.

2. Cooling by Opening Windows

With the need of getting cool and fresh while we are having trips in our automobiles, also cause another possible behavior of the passenger: opening the windows of the car.

When every windows of the car were opened at the same ratio; same amount of particles which behave as an external force, creates a circulation inside the car which is externally supplied, instead of internal sources. External sources, as they have opposite directions of the automobile and the particles with respect to the automobile (see figure 2) create a force, which is called air friction. All particles that have gained velocity hit the inner walls of the automobile and create a force which is in the opposite direction of the car, making the car use more fuel to stay constant on velocity.

As mentioned in the introduction of the essay, pressure difference obviously causes more particles to move out of the system. However we cannot neglect the particles that enter inside the automobile. This is why we feel the fresh air when we open windows. As the windows will be opened more in each trial, the entrance rate of air molecules will increase.

If we are to define “air friction” which causes back force in this experiment;

“Air friction is a type of fluid friction. Different from the nature of surface friction, types of fluid frictions are velocity dependent. At low speeds, for small particles, the air resistance is proportional to the velocity of the system.

$$f_{drag} = -bv$$

However as the experiment was made with a massive object, that can be included as a heavy object, where the air resistance is proportional to the square of the velocity.

$$f_{drag} = -\frac{1}{2} C \rho A v^2$$ „ (4)

This opposite motion of the particles is known as *air friction* in physics. It is dependent to the air density, cross-sectional area and the square of velocity.

As we can see from the formula of air friction (f_{drag}); or in other words, the effect of the air friction is dependent on velocity.

The velocity of the particles with respect to the car will increase and the force applied to the inner wall of the automobile will increase therefore the automobile will need to use up more energy to stay constant on velocity. Under this consideration, we will test the hypothesis that states that usage of AC is more efficient than opening windows.

B) DEVELOPING THE EXPERIMENT

Thinking of the two possible cooling styles; by opening windows and by using air condition, an experiment should be developed where all other factors will be kept constant but only the effect of these two different cooling styles can be observed. For a more clear design of the experiment, a research question must be developed.

1. Research Question

To clearly reach a conclusion, a specific research question should be chosen.

“Does using AC instead of opening our windows is more efficient in terms of fuel usage because the effect of the air friction will not be present while the windows are closed where ac was used?”

In addition, I will investigate the effect of the rate of gap of top of the window on the fuel usage.

2. Hypothesis

To find the answer to this research question, two hypotheses were stated:

1. Air conditioning is more efficient than opening windows in an automobile to save up energy.
2. The rate of gap of the top of the window is directly proportional to the energy usage.

Due to my hypotheses, closing windows will save up energy because less air friction or in other words, less external circulation forces will be present. However starting the air conditioner also requires some amount of energy, however the engineers improve the physical inner structure of any machine and develop the most efficient product; therefore an efficient air conditioner.

3. Variables

Before a method is created, all variables should be identified clearly as we need to control some variables during the experiment.

a. Independent Variables

- The rate of gap of the top of the four windows of the automobile (cm) ±0.1

b. Dependent Variables

- Fuel usage (lt) ±0.1
- Average fuel usage (lt/km) ±0.1

c. Constants

- Distance (x) ±0.1
- Average Speed ($\bar{v}$)±0.1

- Automobile used in the experiment
- Passenger weight
- The driver of the car
- The air density where the car travel.

4. Controlling the variables

- **Distance (x)**
    - The distance is the value for the total distance taken from the start point to the end of the automobile. This value should be kept constant as the more distance taken mean the more fuel will be used, which is not related with the rate of gap of top of the window or air conditioner. Not only the displacement but also the properties of the road should also be kept constant. As pits and bumps are present in the road that is chosen as the route, fuel usage is very dependent on the properties of the road, which can again be controlled by the distance consistency. Therefore, in every trial same part of the same road is covered.

- **Average Speed**
    - Average speed is dependent on the speed is controlled by the driver, which is most likely to cause random errors. However, the driver should concentrate and keep the velocity same. Because if the driver pushes the gas pedal much more on a trial, obviously, the usage of fuel will increase not related to the rate of gap of top of the window or air conditioner. Therefore average velocity of the automobile, during the experiment should be controlled. How much the velocity was controlled can be understood by the variable “Average Speed” which will be recorded in every trial in the data presentation part. The

"Average Speed" data were collected by a special data counter of the automobile.

- **the Automobile**
    - As different models of automobiles cause different usage of fuel, this constant should also exist. This is because; different models are not related with the gap of top of the window or the air conditioner. The automobile will be kept constant during the experiment.
- **Passenger weight**
    - The weight of an object changes the velocity of the object while the same amount of energy is used on an object. This is due to the laws of conservation of momentum. ($P = m.v$) even if the change of mass will not be that much, it may cause the usage of very small amount of fuel. Therefore, there were only two people in the car, the driver and me in every trial.
- **The driver of the car**
    - The driver of the car can control the velocity, which is a factor that affects the fuel usage. As the driver will not change, the way that the automobile was driven will be constant and there will be no change in the fuel usage due to random issues.
- **Type of air (air density) (ρ)**
    - Air density is one of the factors that are included in the air friction formula. This density is due to the components of the air. Different ratio of different gases may cause a denser or less dense environment. For example; in our city, Ankara, it is known that vicinities like OR-AN or İncek involve more percentage of oxygen. Therefore the environment should be the same if we wish to keep this value constant.

5. Developing The Method

1. A start and stop point was chosen. In my experiment the start point is the intersection of Yeni Boulevard and Anadolu Boulevard. The stop point is again the same point; however one tour is made through the Yeni Boulevard. (see Figure 4 in Appendix B) where the distance is 14.2 km (±0.1)

2. The driver is informed that a constant speed is needed, so that he does the initial and final movements of the automobile in such a way that it does not use up extra fuel, or in other words, any random errors in the automobile will be same on every trial. (The reason why the route existed of two similar halves is that the pit and bumps cause different fuel usage as explained in the "variables" section.)

3. The data counter of the automobile was reset. Data that will be recorded due to the recording system of this automobile are: "Fuel Usage", "Average Fuel Usage", "Displacement", "Average Speed" and the data that will be used in this experiment is: Fuel usage, Average Fuel Usage, Average Speed.

4. Starting from the intersection of the boulevards explained in step 1 (see Figure 4 in appendix B), complete one tour and record the quantitative and qualitative data that have been observed during the experiment.

5. This experiment will be made for different opening levels of all four windows of the automobile, and only one group should be made to see the effect of air conditioner. The control group is where the windows and the air conditioner are closed. The following table represents how many trials and groups will exist in the experiment.

Groups	Number of Trials to be made
AC off and Windows closed	10
Windows are 10 cm open	10
Windows are 15 cm open	10
Windows are 20 cm open	10

Windows are 25 cm open	10
windows are 30 cm open	10
Windows closed AC open	10
Total Data to be collected (including other variables)	210

Table 1: Groups and trial numbers decided for the experiment.

The reason of opening all windows of the automobile is that the circulation effect of AC can only be supplied by creating external circular forces.

C) COLLECTED DATA

Data will be collected according to the variables examined in the method section. The data are mainly categorized into two sections;

1. Qualitative Data

Qualitative data are collected due to observations. During the experiment, I have observed that different traffic conditions cause instant change of the speed of the car. For instance, an automobile with more speed may cause you to change your lane therefore; the driver has to instantly rotate the steering wheel. This instant change cause the automobile to lose some of the constant energy created and hence, the driver needs to push the gas pedal in order to gain the velocity back. This extra usage of fuel, occur because of the environmental impossibilities.

Another thing I have observed that, the time to reach to the constant velocity determined is also very important. An instant change in velocity is more likely to cause more fuel usage. While recording some trials in every group, I observed that some of the trials are unwontedly high. This is because of the driver's attitude towards the gas pedal.

To reduce the error caused by the limitations 10 trials were performed for each case.

2. Quantitative Data

A chart should be made to serve the quantitative data. (See Appendix A)

D) PROCESSING AND PRESENTING COLLECTED DATA

The data collected were presented in Table 2. These data are analyzed by taking the research question into consideration.

1. Processed Data Table

Collected data may be presented via graphs. To sketch these graphs, the raw data table (Table 2) must be processed.

The gap of top of the window (cm) ±0.1	Average of "Fuel Used ±0.01 (lt)	Average of Trials of "Average Fuel Used per km (lt/km) ±0.01
0.0	0.60	4.97
0.0 (with AC)	0.60	5.02
10.0	0.65	5.18

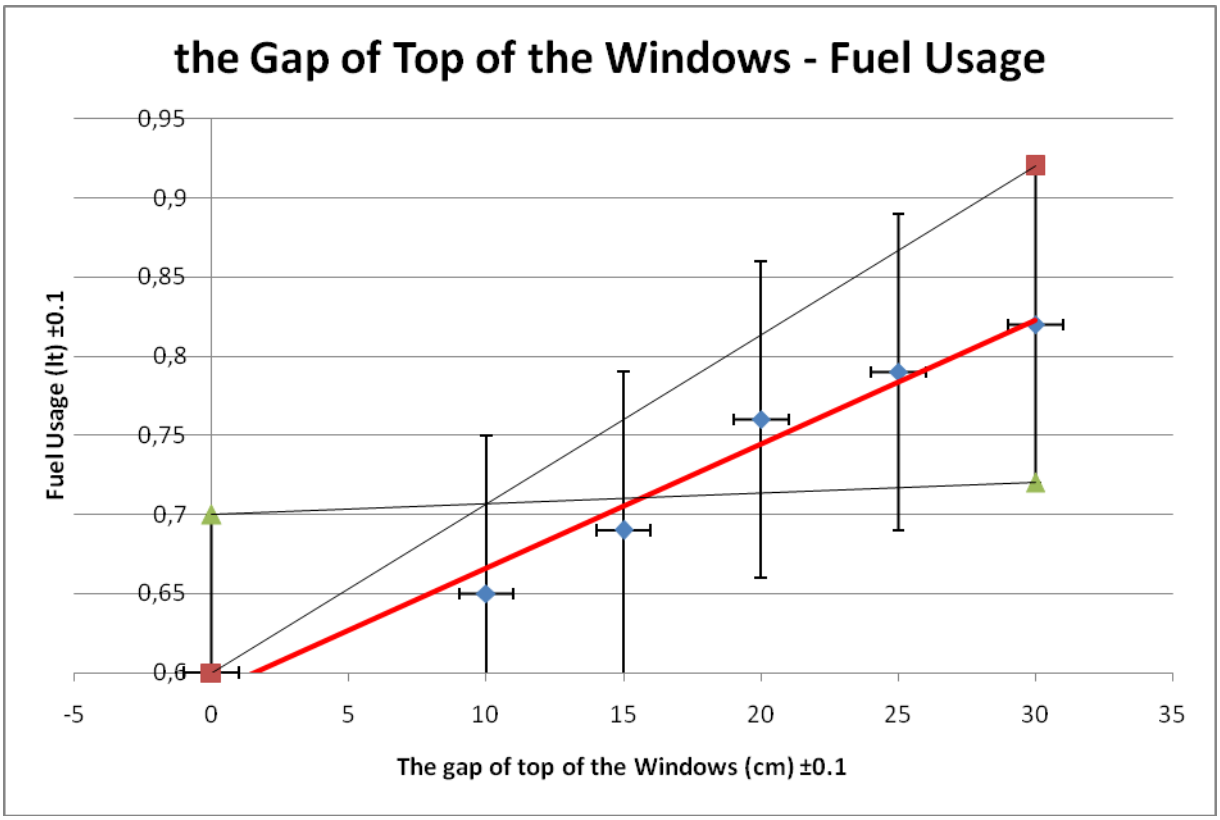
15.0	0.69	5.33
20.0	0.76	5.88
25.0	0.79	5.92
30.0	0.82	5.96

Table 3: The processed form of raw data, where calculations were made by finding the average value of all collected data to create a single value for each group.

2. Graphs

Two graphs: “The Gap of Top of the Windows - Fuel Usage” and “the Gap of Top of the Windows - Average Fuel Usage” is sketched as shown:

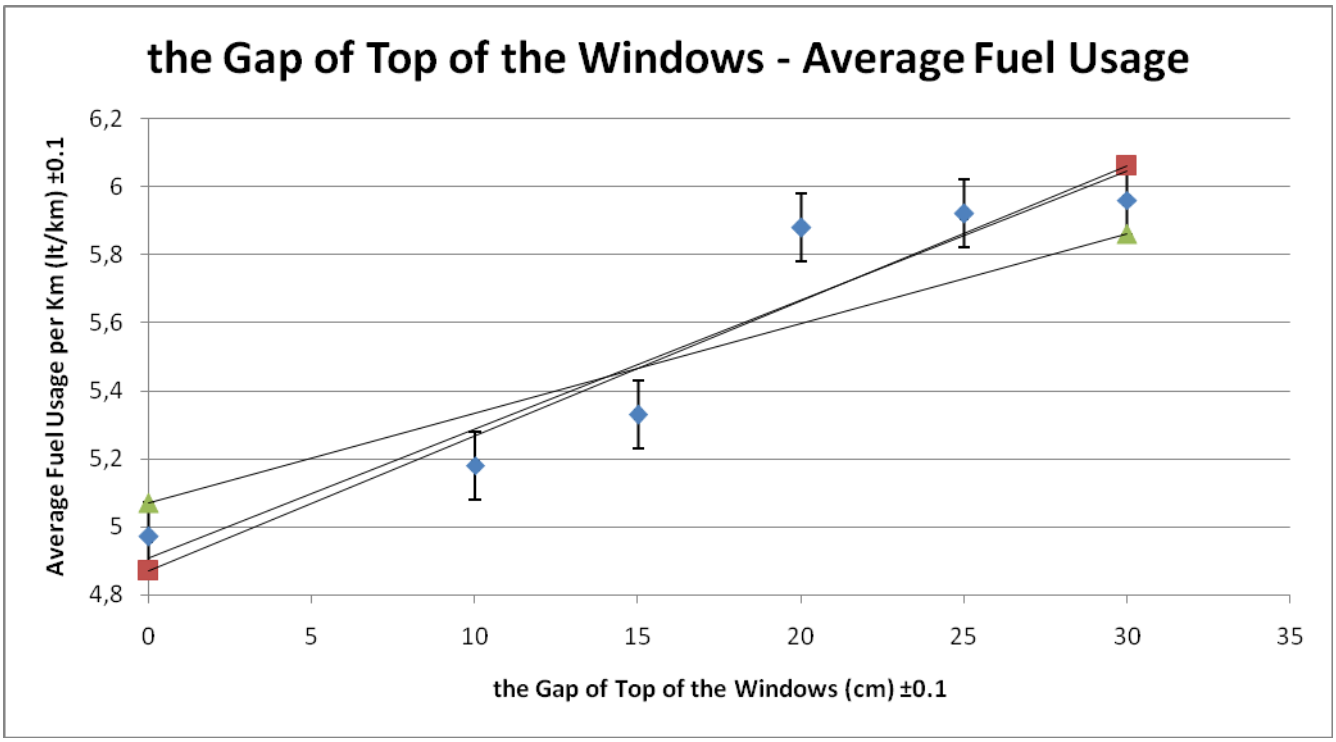
a. the Gap of Top of the Windows - Fuel Usage



Graph 1: The relation between the Gap of Top of the Windows and Fuel Usage was shown in the graph above.

When the graph the gap of top of the window-fuel usage is examined, it is obviously seen that the Gap of Top of the Windows (cm) is directly proportional to the Fuel Usage (lt). Which mean, the more the open windows are the more fuel we will need to use in order to stay in the same speed level.

b. The Gap of Top of the Windows - Average Fuel usage



Graph 2: The relation between Average Fuel Usage per Km and the Gap of Top of the Windows, where the fuel usage is more relevant on the speed as the calculated raw data include changes in the velocity level.

Another type of graph that is to be examined is about the average fuel usage, which is more relevant on velocity, and therefore more reliable. As this graph also includes the calculations for velocity, relevant with fuel usage, random errors on velocity can almost be denied.

On both graphs sketched, it is seen that the Gap of Top of the Windows is a factor that changes fuel usage. As the conclusion is reached and now the processed data are ready to be combined with the results and the research question, the overall results of the experiment are ready to be concluded.

E) CONCLUSION & EVALUATION

a. Conclusion & Evaluation of Graphs

As two sub-problems were stated at the first part of the essay, we can reach the conclusion: “As the gap of top of the window increase in an automobile, usage of fuel increases directly proportionally.” The conclusion I have reached due to data and graphs clarify the research question, making the gap of top of the window a relative factor on usage of fuel.

The gap of top of the window has caused more air to create an external air circulation as expected. This external air circulation have created back force on the automobile and therefore caused such changes in the fuel usage.

Terrestrial friction and normal levels of air friction are normal conditions in our daily life. Therefore they cannot be blocked. Hence, the need of usage of automobiles almost every single of their motion is because of friction. An object which rests in the vacuum state, where no friction exists, any force applied on that object will cause it to gain velocity and continue its motion forever, or until the object loses the energy it have gained.

To sum up, we can say that the external forces caused by the gap of top of the window have created the inner circulation of air particles, which caused the automobile to lose its velocity, and therefore attempt to re-gain the energy it has lost, causing the automobile to use more fuel.

b. How would it affect our life?

Usage of extra fuel would affect the social issues: “Global Warming” and “Absence of Limited Fuel Sources”.

Such social issues may be found as usage of fuels has been an indispensable issue.

Global warming is caused by the greenhouse gases, which are mostly produced by automobiles and factories, as a result of the usage of fuels. These gases are released as bi products and if we are to be more careful while travelling in our automobiles, preferring AC instead of opening windows, will save out ozone layer and create a natural and peaceful environment for next generations.

The more usage of fuel mean the quicker our sources will end. If we are not to develop such a technology that will not be dependent on fuel oil, it will be very hard to produce energy, and the life will almost stop. Saving and using our fuel sources is very, very important. This can be supplied by using the fuel we receive efficiently. Therefore while travelling; if the passengers feel that they need fresh and cool air, using AC instead of windows will help us save our precious world.

F) ERRORS

Some errors that can be made throughout the experiment is that, the automobile was very dependent on the driver's mood and roadholding that to avoid such wide and random error, an electronically mechanism which would allow us to control the velocity and movement of the car could be developed and used.

Another random error may be that the experiment was completed on a road where traffic existed. With the existence of these and similar other factors may cause a change on driver's roadholding, that would obviously change the fuel usage as so sudden changes cause loss of energy, and therefore velocity.

An error which is systematic is that, the air conditioner of the automobile was sensitive to changes in the temperature of the environment. And hence changes in temperature is a natural being that cannot be controlled by the experimenter, the only solution may be to make this experiment in a closed place, where temperature may also be controlled.

G) HOW THE EXPERIMENT CAN BE IMPROVED

As the experiment that was made for this extended essay was a part of the real life, it does not include the ideal conditions that we wanted to create. For instance, a smaller system may be constructed to reach ideal conditions. A smaller system will be easy to make changes on, and a smaller car that will fit into that system will not require that much energy that we have used up to end this experiment. By constructing our own model car, we can make the variables that we want to observe easier to reach. Such as, we may construct a glass fuel-oil fuel tank and sketch some graduals on the fuel so we can see the usage of fuel in terms of mL.

All other variables can be observed in such ideal conditions, which will obviously reduce the amount of errors made. By developing a device which will make the model car gain a

The Gap of Top of the Windows (cm) ±0.1	Trials	Fuel Used (lt) ±0.1	Average Fuel used (lt/km) ±0.1	Distance (X) (km) ±0.1	Average Speed (v) ±0.1	The Gap of Top of the Windows (cm) ±0.1	Trials	Fuel Used (lt) ±0.1	Average Fuel used (lt/km) ±0.1	Distance (X) (km) ±0.1	Average Speed (v) ±0.1

constant velocity, we also can avoid random errors and create a more systematic system to work on.

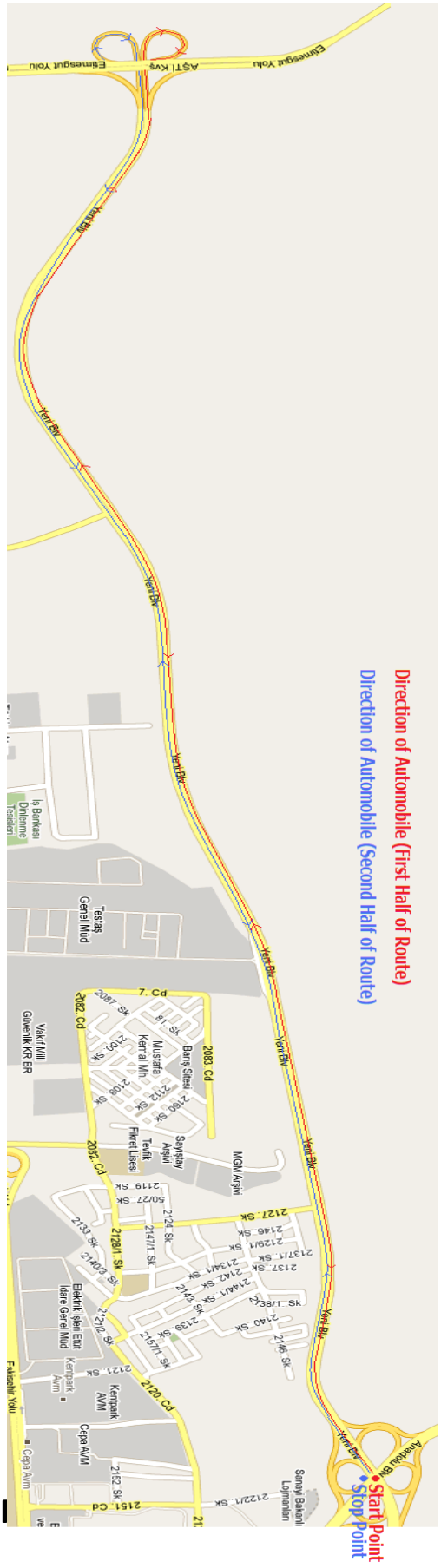
Such a system will not only make us reduce systematical errors but also help us perform more trials as we will spare less time on a trial. Therefore, we can use our time efficiently and also we can make more trials to clearly see the relation between the variables throughout the experiment.

0 (no AC)	1	0.6	5.0	14.2	56.5	25	1	0.7	5.2	14.2	56.3
	2	0.6	4.9	14.2	56.5		2	0.8	5.9	14.2	56.3
	3	0.6	4.9	14.2	56.5		3	0.8	6.0	14.2	56.3
	4	0.5	4.7	14.2	56.5		4	0.8	6.0	14.2	56.3
	5	0.6	5.3	14.2	56.5		5	0.8	5.7	14.2	56.4
	6	0.6	5.1	14.2	56.5		6	0.7	6.1	14.2	56.3
	7	0.7	5.0	14.2	56.5		7	0.8	6.3	14.2	56.4
	8	0.6	4.9	14.2	56.5		8	0.8	5.9	14.2	56.3
	9	0.6	4.8	14.2	56.5		9	0.9	6.1	14.2	56.3
	10	0.6	5.1	14.2	56.5		10	0.8	6.0	14.2	56.3
10	1	0.7	5.3	14.2	56.6	30	1	0.8	5.7	14.2	56.5
	2	0.6	4.9	14.2	56.3		2	0.8	5.9	14.2	56.5
	3	0.7	5.2	14.2	56.3		3	0.8	6.0	14.2	56.5
	4	0.6	5.0	14.2	56.4		4	0.8	6.0	14.2	56.4
	5	0.7	5.3	14.2	56.4		5	0.9	6.2	14.2	56.5
	6	0.6	5.2	14.2	56.3		6	0.9	5.8	14.2	56.5
	7	0.7	5.2	14.2	56.3		7	0.8	5.9	14.2	56.3
	8	0.7	5.3	14.2	56.3		8	0.8	6.0	14.2	56.6
	9	0.6	5.0	14.2	56.4		9	0.8	6.2	14.2	56.5
	10	0.6	5.4	14.2	56.4		10	0.8	5.9	14.2	56.5
15	1	0.7	5.1	14.2	56.3	0 (with AC)	1	0.5	5.2	14.2	56.5
	2	0.7	5.2	14.2	56.4		2	0.6	4.9	14.2	56.3
	3	0.6	5.0	14.2	56.4		3	0.5	5.1	14.2	56.6
	4	0.7	5.4	14.2	56.4		4	0.6	5.0	14.2	56.5
	5	0.7	5.5	14.2	56.4		5	0.6	5.1	14.2	56.5
	6	0.6	5.4	14.2	56.4		6	0.7	5.2	14.2	56.3
	7	0.8	5.6	14.2	56.3		7	0.5	4.8	14.2	56.5
	8	0.7	5.4	14.2	56.4		8	0.6	5.0	14.2	56.5
	9	0.7	5.3	14.2	56.4		9	0.7	4.9	14.2	56.6
	10	0.7	5.4	14.2	56.3		10	0.7	5.0	14.2	56.5
20	1	0.7	5.7	14.2	56.5						
	2	0.8	5.9	14.2	56.5						
	3	0.8	6.0	14.2	56.4						
	4	0.8	6.0	14.2	56.4						
	5	0.7	5.9	14.2	56.4						
	6	0.7	5.7	14.2	56.4						
	7	0.8	5.8	14.2	56.4						
	8	0.8	6.1	14.2	56.5						
	9	0.7	5.7	14.2	56.4						
	10	0.8	6.0	14.2	56.4						

APPENDIX A

APPENDIX B (5)

Figure 4: The distance that is to be made for each trial, which exist of two half routes.



H) BIBLIGIOGRAPHY

(1): Description taken from;

GIANCOLI, Douglas C. PHYSICS for SCIENTISTS AND ENGINEERS with Modern Physics, Third Edition, Prentice Hall, 2000, Upper Saddle River - NJ, Page Number: 77

(2): The figure was re-edited by candidate. Original car clip art was taken from;

<http://www.clker.com/cliparts/7/b/8/2/11949851553944911 09car_jamin_ellis_.svg.hi.png>

(3): Description taken from;

<http://www.facstaff.bucknell.edu/mvigeant/therm_1/ac_final/bg.htm>

(4): Description taken from;

<http://hyperphysics.phy-astr.gsu.edu/hbase/airfri.html>

(5): Map was re-edited by candidate. Original map figure taken from;

Google Maps.