Effects of Aerodynamics Changes on A Car Caused by Another in Its Proximity: An Experimental Study

by

Mohd Khairi B. Che Abdullah

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Ahmed Maher Said Ali)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD KHAIRI B. CHE ABDULLAH

ABSTRACT

The study of road vehicle aerodynamics is quite different from that of an aircraft aerodynamics which mainly focuses on producing lift. The subject does not lend itself to traditional methods such as mathematical analysis where there are no straightforward methods for predicting how air will flow around a given vehicle shape and no equivalent of the simple formulae used in earlier days for determining the lift and drag of an aircraft from its geometry. With regards to this Final Year Project (FYP), Experiments is to be conducted to study the effect of aerodynamics change on a car caused by another in its proximity. For this experimentation project, the Kelisa car's is to be considered as the model which enable in achieving dimensional similarity and more accurate in getting the experimental result. In the experiments, certain ranges of distance between the two cars were to be highlighted in order to show the drag force and other aerodynamic changes that might occur. The aerodynamic changes are to be studied on two model vehicles using a wind tunnel equipped with the necessary measuring equipment. The study is focused on the effects of the wake of a vehicle to another vehicle in tailing position (back-to-back), where the experiment is done using wind tunnel and scaled vehicle models. The model is to be manufactured by using CNC machining process.

ACKNOWLEDGEMENT

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CHAPTER 1
INTRODUCTION

1.1 Background

Aerodynamics is the study of the properties of moving air, and especially of the interaction between the air and solid bodies moving through it. In road vehicle application is also termed as “bluff bodies” there is very close proximity with the ground and it encompasses such criteria like the engine compartment, wheel, rear of the vehicle and etc. It can visualize as figure below.

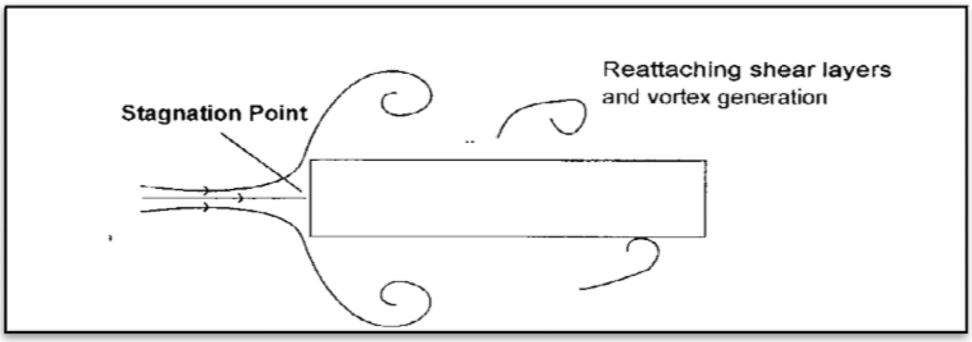


Figure 1:1: Basic bluff-body [1]

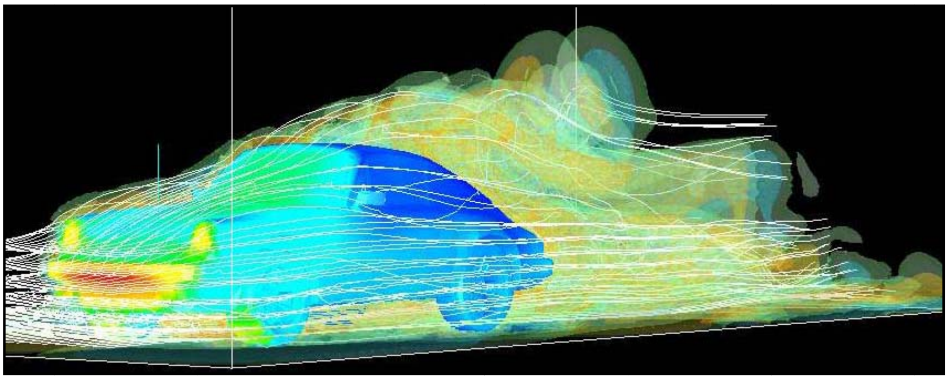


Figure 1:2: Flow visualization around the car [1]

The main objective in studying the aerodynamics of road vehicle is to avoid or at least to control the separation effects [1]. But in other ways, sometimes the objective may also differ widely when it goes to the specific purpose of the road vehicle that is being designed. Such an example of negative lift is decisive for the cornering capability of a race car, but not important to other road vehicles such as trucks. Regards to this project, the drivers should understand that such variations can be very dangerous depending on various parameters including the speed at which the road vehicle (car) travels which also matter to the size itself.

1.2 Problem statement

An aerodynamics force is one of the effects that are produced by the stream flow over a vehicle body. Other effects that can be produced are wind noise and also body-surface water flow and soiling. A car is also subject to lift which can be undesirable. The greater the speed, the greater the lift force, which increases the threat of instability. For this reason, builders of race cars design their vehicles for negative lift. A typical family car has a lift coefficient of about 0.03, whereas a race car is likely to have a coefficient of −3.00 [3]. Aerodynamics changes when a car travels on the road. Such changes can cause sudden variations on the forces acting on other vehicles found on the field. This situation needs others riders (drivers, bikers etc) to be alert and aware of it as to avoid possible accidents. . This condition can be seen when they are in proximity to each other when moving on the road. A vehicle generates a turbulence unsteadiness which can cause additional or reduced forces acting on another vehicle. This can cause the driver to lose control and crash. Therefore, wind tunnel experimental applications are to be carried out to investigate such variation and other undesirable effects which is the focus of this project. By understanding the effect of this vehicle affecting aerodynamic changes, it could help in minimizing the risk of an accident.

1.3 Objectives

When the aerodynamics effect change due to the car that travel on the road, forces acting on the vehicle's surrounding change consequently. Such variations can be very dangerous depending on various parameters including size and the speed of the vehicles that travel. This project is carried out to:

a. To investigate the aerodynamic condition around a small vehicle

   i. drag force; F_D
   ii. lift force; F_L

b. To study the effect of the speed of the vehicle on the aerodynamics

c. To investigate the aerodynamics changes when the two cars travel on the road that may cause sudden forces acting on other vehicles found on the field.

1.4 Scope of study

a. To study the real aerodynamics effect to the car that travels on the road.

b. To study the effect of variations that can be very dangerous to other cars which are travelling on the field of a car. (tailing condition)

c. To compare and analyze the previous result with the latest results and provide recommendations for future references and development.

d. Prepare smooth scale model of vehicle for wind tunnel experiment using CNC Machine.

e. Run wind tunnel test on scale model vehicle when another model is in the flow field by:

   i. Increase the speed of the wind tunnel
   ii. Modified the available wall of the test section of the wind tunnel

CHAPTER 2
LITERATURE REVIEW

2.1 Road Vehicle (car)

Road vehicles are bluff bodies which move in close proximity to the ground or road. Their bodies are very complex with detailed geometry which becomes one of the important criteria in car features and manufacturing process. This geometry (shape) also becomes the benchmark for the car maker in determining the functions, costs and speed that the car can travel at on the surface (ground/road) [1]. So, as the result from various car' geometries and also their specific purposes for used, it has cause an effect on the aerodynamics, drag force and lift of the car itself.

2.2 Dimensional Analysis

Dimensional analysis involves reducing the number of original variables to a number of groups which are dimensionless combinations of the original variables [2]. This concept is important in wind tunnel test in order to gain accurate result.

Purposes:

a. Generate non-dimensional parameters that help in designing experiment methods and result's reporting scheme
b. Obtain scaling laws that the prototype's performance can be predicted from model performance
c. Predict the trends relate between those parameters (real versus scale model)
d. Real world expectation in term of condition performance and measurement by imply the experimentation method using geometrically-scaled model. Result and experimental conditions are properly scaled which help in producing real condition of full-scale prototype later.

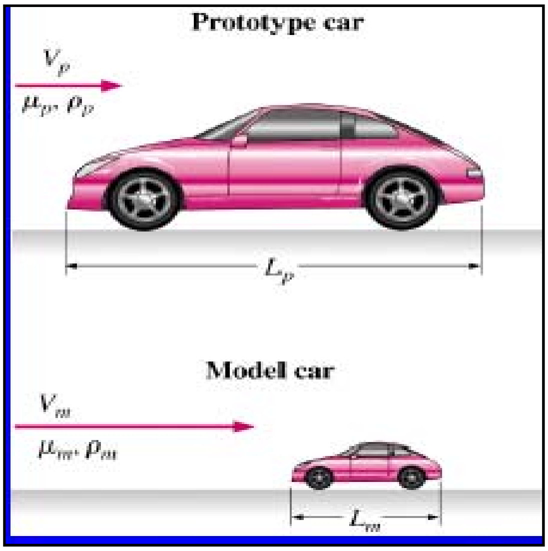


Figure 2:1: Dimensional Analysis concept in model car experiment

The equation use to find the similarity of the model use to the wind tunnel conditions.

$$\frac{\rho_m . V_m \, . \, l_m}{\mu_m} = \frac{\rho_p . V_p \, . \, l_p}{\mu_p}$$

Since ρ_m=ρ_p and $\mu_m = \mu_p$, so:

$$V_m = \frac{l_p}{l_m} \, . V_p$$

Assume that the speed of the wind tunnel is at 30 m/s. So the actual speed of the model should be run is:

$$V_m = \frac{18}{1} \, .30$$

$$V_m = 550 m/s$$

If consider the speed of the prototype model, the actual speed should be:

$$V_p = \frac{1}{18} \, .30$$

$$V_p = 6 \ km/h$$

2.3 Size of the models

It is very important to determine the size of the model before completing the new wind tunnel walls. To determine the appropriate size, some calculations of dimensional analysis are used.

The size of the wind tunnel must be as large as possible (to achieve higher velocity in real situation) and not blocking the flow field in the wind tunnel. So after some consideration and discussion with regard to the scale model size, a 1:18 scale size is considered.

Note that the size of the wind tunnel's test section is 30cm x 30cm (frontal area).

The scale size also can be obtained using theoretical methods. So referring to the experiment procedure, the flowing fluid will be air. The density of the air remains constant as the temperature of the air is assumed to be constant. Therefore, ρ and μ of both sides are cancelled out, thus the equation become:

$$Re(prototype) = Re(model)$$

$$\left[\frac{\rho V A_f}{\mu}\right] prototype = \left[\frac{\rho V A_f}{\mu}\right] model$$

where:

ρ = density of air (kg/m$^{3)}$

V = flowstream velocity of air

A_f = frontal area of prototype / model

C_D = drag coefficient; C_L = lift coefficient

Fd = drag force; F_L = lift force

μ = viscosity (kg/ m-s)

Hence, by manipulating the velocity and scale of the model in the wind tunnel, the drag coefficient; C_D and Reynolds number; *Re* in the real situation can be calculated (Using a spreadsheet).

2.4 Wind Tunnel

A wind tunnel is a duct through which air is either blown or pulled out to stimulate air flow over objects. The model used is known as scale model (prototype) which used as tested model and placed in the test section of the wind tunnel. By using special transducers as the measurement tools, the model will experience pressure, forces and moments at various wind speeds and in different orientation with reference to the wind. Practice shows that wind tunnel testing, when correctly proceeded has an accuracy of about 90% [6].

2.4.1 Scale Model

Scale model testing is recommended because it is inexpensive and more convenient. The scale must be chosen carefully based on the test section size of the tunnel. This would greatly reduce the magnitude of aerodynamic problems introduced by the wind tunnel walls (solid blockage) and stationary floor. However, inaccuracy in fabrication of the scaled model will not yield exact full-scale conditions, thus resulting in data that is different from full-scale road testing. Statistic shows that in United States, for passenger cars 3/8 scale is widely used, while in Europe 1/4 scale is the most common though 1/5 scale is also used in small wind tunnels. For commercial vehicles, a scale of 1/2.5 is recommended [3].

2.4.2 Blockage Ratio

One of parameter that plays a dominant role in this experiment is the blockage ratio of the test section. It can be defined as the ratio of model frontal-area to test-section-area.

$$\text{Blockage} = \frac{Height\ of\ model\ \times Width\ of\ model}{Test\ section\ size} \times 100$$

Hence;

$$\frac{7.9\ \times 9.2}{30\ \times 30} = 0.081 \times 100 = 8.1\%$$

2.5 Drag Force

Drag force is the force that a flowing fluid exerts on a body in the flow direction. Drag force act in the opposite direction of the movement of the body and usually caused an undesirable effect and a resistant to movement like friction. In automotive industry, drag is related to the performance and fuel consumption of a car, as well as the design of the car's body that gives value to style. The dimensionless quantity that describes the characteristic of the drag on a body is called the drag coefficient. This project will focus more on the drag force as the results of the aerodynamic changes when two vehicles are in proximity to each other, using the wind tunnel and scaled model to measure the force change [3].

2.6 Lift Force

Lift force is the force that a flowing fluid exerts on a body normal to the flow direction. Lift force are caused by difference in pressure acting on a body and usually related to spoiler design for more downforce factor. The dimensionless quantity that describes the characteristic of the lift on a body is called the lift coefficient. For the experiment, the lift will not be considered, as the wind tunnel testing will not be accurate as the lift is associated with the ground effect. The models of the vehicle is to be hanging to the wall of the wind tunnel by a metal rod, connecting it to the balance that will measure the forces acting on the model [3].

2.7 Aerodynamic Forces and Moment

Aerodynamic resistance mainly generated by two main sources; the flow over the exterior of the vehicle body (external flow) and the flow through the engine radiator system and also the flow inside of the vehicle itself for cooling and ventilating purposed (internal flow) [1].

For the external flow, normal pressure and shear stress will be generated on the vehicle body. Two components will be involved which is the pressure drag cause from the normal pressure of the vehicle body acting against the motion of the vehicle and the skin friction which due to the shear stress in the boundary layer adjacent to the external surface of the vehicle body [7]. In practice the aerodynamics resistance; Ra is usually expressed by:

$$R_{A=}\ \frac{\rho}{2} C_D\ A_f\, V_r^2$$

Which

R_A = aerodynamics resistance

P = mass density of air

C_D = coefficient of aerodynamics resistance that represent all the combined effect in aerodynamics studies

A_f = characteristic of the vehicle involve; frontal area of that vehicle which is the projected area of the vehicle in the direction of travel.

V_r = speed of the vehicle relative to the wind

Note

ρ can be affected by the present of atmospheric condition such as temperature. For instance, an increase in ambient temperature from 0^0c to 38^0c will cause a 14% of reduction in aerodynamics resistance

Hence because of this significant effect there are commonly used standard conditions such as, temperature of 25^0c and the barometric pressure of 101.32 kPa

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

Research has been carried out to gather all required information understanding the concept of aerodynamics change variations. The studies also involve wind tunnel applications. A thorough literature review will be done through reference books, internet and journals for further understanding. All the works, effort and procedures used in this project will closely follow the provided Gantt chart (see appendix).

The list of options below will be used with regards to carrying out the experimental studies about the effect of aerodynamics changes by the car to other cars in its proximity:

a. Own research on previous available case studies
b. Sample of case studies from related journal and paper work.
c. Build scale model of the car for wind tunnel purposed
d. Digitizer Process
e. CNC Machining Process
f. Testing the car models in the wind tunnel
    - single car position
    - double car position (tailing condition)
g. Experiments will be carried out to observe the aerodynamics variations changes in different conditions
h. Discuss the result obtained from the experiments in the wind tunnel. The measurements are recorded and graphs are plotted (observation). Discussion and recommendation are to be done based on the result gathered.

This project will involve the design and development activities as state below.

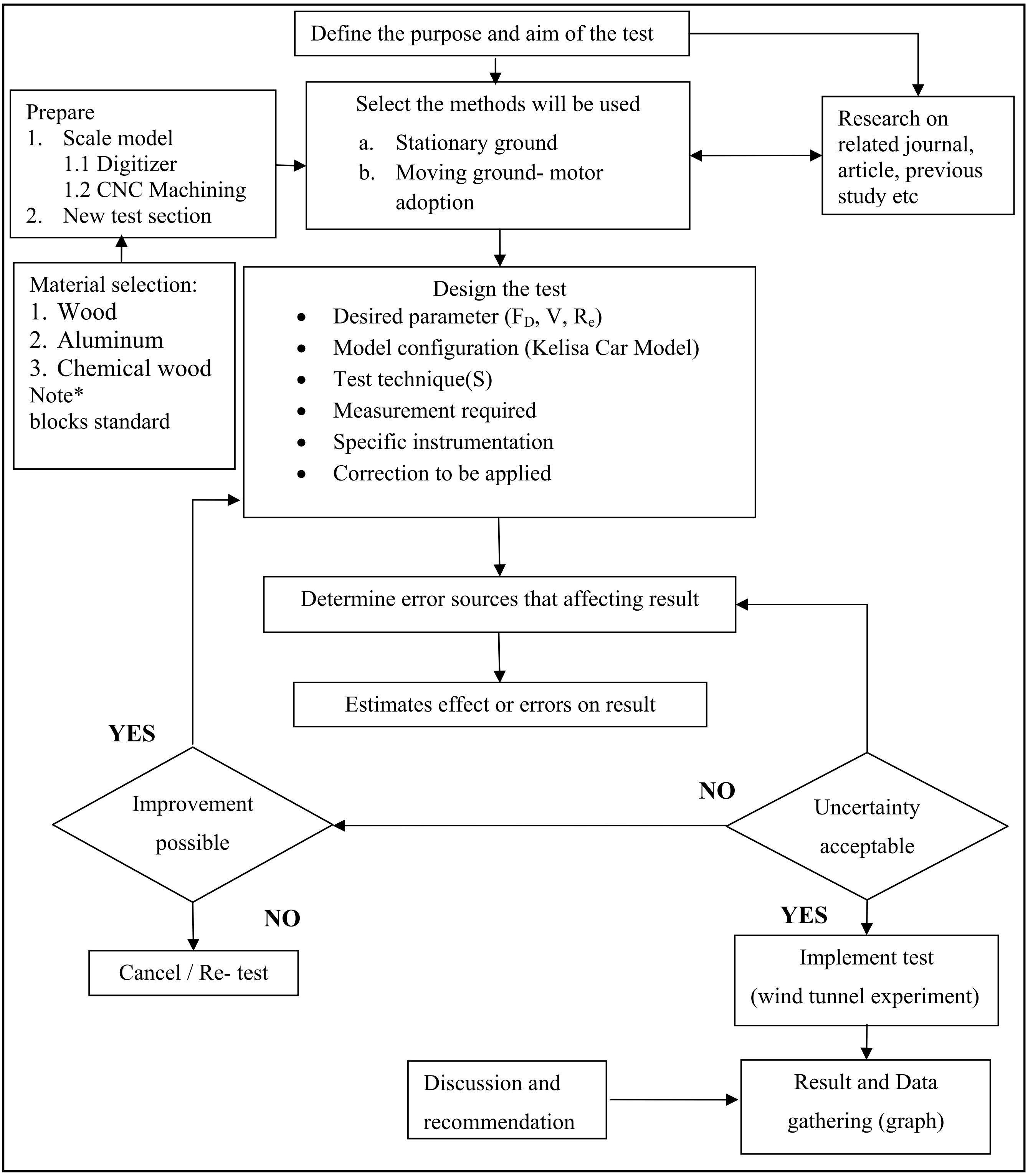


Figure 3:1: Flow of experiment process [5]

3.2 Problem Identification

One of the difficulties of using the wind tunnel test is that the similarity of both the wind tunnel flow and the real world flow need to be achieved. Similarity can be found through assumptions and experiments, finding the relationships that can relate both the simulation and the real world. A number of testing has to be done to find the relationship between the two situations, plus some calculation for dimensional analysis.

There is complication to conduct the experiments since the size of the wind tunnel provided by the university did not comply with the FYP project requirements. The cross-sectional area of the test section available is 300 x 300 x 600 (mm). Therefore, the wall of the test section needs to be modified.

The wind tunnel lab only accommodate with small or regular scale model which used for lesson purpose only. A new scale model has to be built; so that it is much bigger than available models (scale 1: 18).

In order to produce smooth and better surface finish of the new scale model, it require sophisticated software known as "computer reverse aided engineering". This university still do not has this type of specialized technology which had caused the FYP student either to go outside hiring specialist or looked for available model in the market.

3.3 Tools required

Below is the list of equipments used in running the experiment:

3.3.1 Scale model manufacturing purpose

i. Renishaw 3D Laser Digitizer Equipment (Figure 3.2)

- Renishaw use for:
    1. Automated process control
    2. Optimized machine performance
    3. High speed tool setting

- The objective of using digitizer are
    1. Use to digitize complex shape component which not posses engineering drawing
    2. Generate C-code for CNC machining of digitized component
- Digitizer equipments are (refer appendix):
    1. Renishaw Stylus set
    2. Wolf & Beck Sensorik Laser set
    3. Holder
    4. Non-Chlorinated Solvent Based Developer
    5. Tracecut Renishaw software (Figure 3:2)

Figure 3:2: Renishaw 3D Laser Digitizer Equipments

3.3.2 CNC Machining

Figure 3:3: MAZAK VARIAXIS 630-5X

3.3.3 Open Circuit Wind Tunnel; Serial no: 180666/51 D

This open type circuit wind tunnel is designed for testing large size and high speed models. Main characteristics of the tunnel are it is an open type tunnel, the maximum speed it can go is 36m/s which equal to 130 km/h that can be obtained via an electronic speed variator of the fans. The test section used transparent perspex windows. The cross-sectional area is 300 x 300 (mm) with length of 600 (mm). It permits to carry on test of small size models, in the absence of edge effects or tests on large size models with the above mentioned effects at current value within acceptable limits. There is Pitot-Prandtl tube sliding along the test section for surveying the speed. The overall dimension of the tunnel is approximately about 5500 x 1400 x 1900 (h). Its drive system consists of two-stage axial fans; with two electric motors separately operate the two stages and the fan wheels are counter-rotating. A computer based system is used for data acquisition, processing experiment data; tunnel operation and control

Figure 3:4: Open Circuit Wind Tunnel; Serial no: 180666/51 D

3.3.4 Model car (1:18)

As result from the breakdown in the digitizer process, second option had been considered where two car's models which have similar dimensions as required had been bought. Some modifications have been done in other to make the model more reliable to the experiment later.

Figure 3:5: Modified model car

3.3.5 Others tools used:

a. Screwdriver

b. L-square

c. Model holder

3.4 Software required

This software used to connect together a patchwork of individual surfaces that had been traced over the triangulated model (refer 4.2) before G-code can be generated

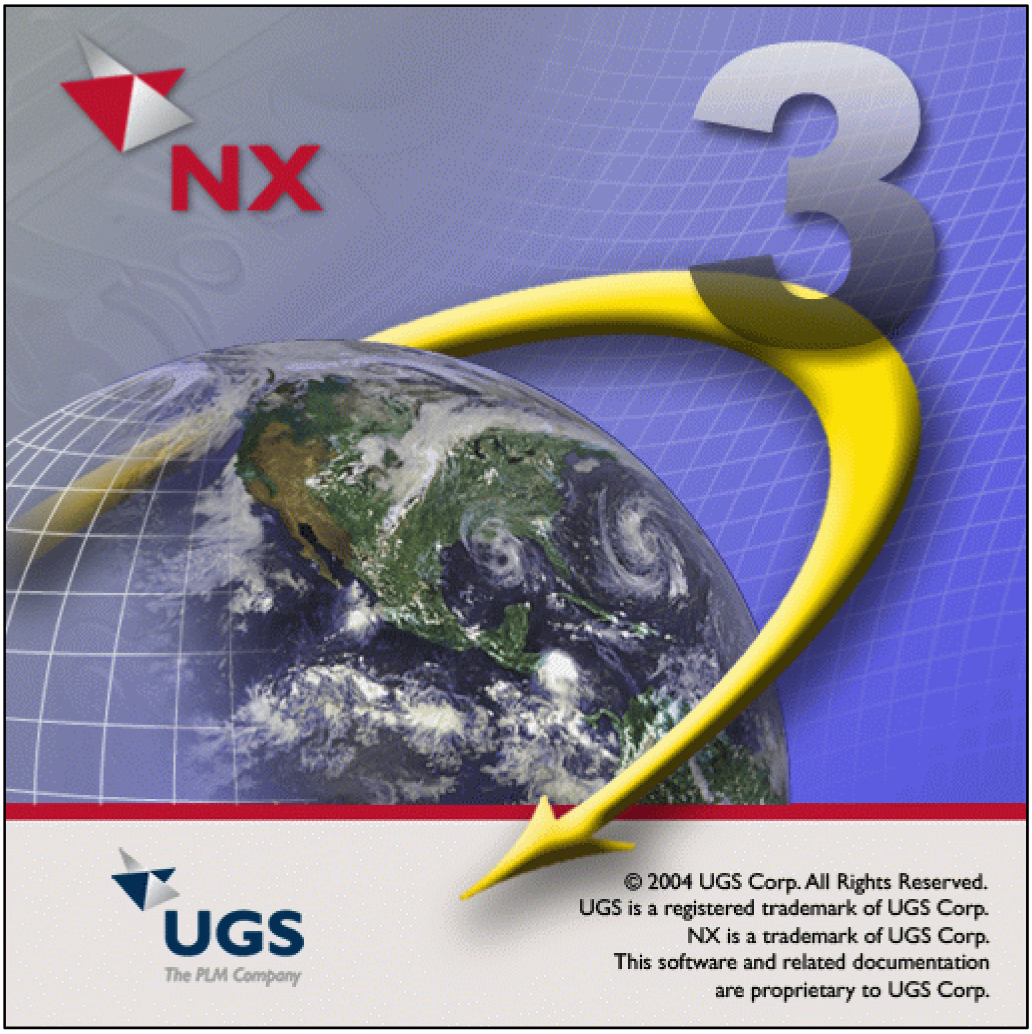


Figure 3:6: Unigraphic NX3 software

3.5 Material required

For scale model purposes, I had prepared two pieces of chemical wood blocks. This block later will be translated to car model by using CNC machining process.

Figure 3:7: Wood block

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results

4.1.1 Digitizer images

For this FYP project, the digitizer equipments have been used in other to produce smooth scale model for the experimental purposed. The first profile produced is the 2-D profile which can be obtained by allowing the stylus (refer appendix) to move around the model.

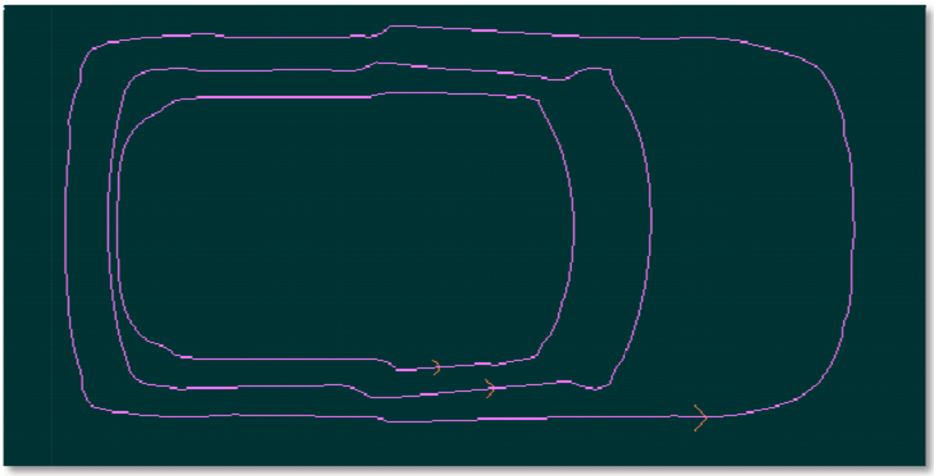


Figure 4:1: 2-D image

The 2-D profile then is defined to the 3-D profile in other to see the outcome (full surface) of the capturing process.

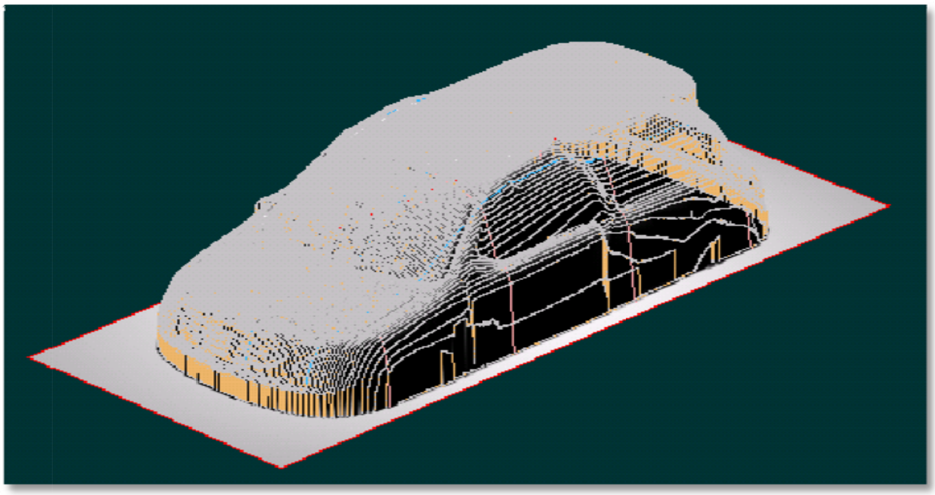


Figure 4:2: 3-D image

Figure 4.3: Finish model (simulation)

4.1.2 Tracecut surfacing

The last step in digitizer process before the profiles translated to G-code in CNC machine. This surfacing method used to create a complex CAD surfaces from digitized point data collector using the Renishaw Tracecut software. It also worked as guides through the process of triangulating and editing the scanned data and provides the tool needed to create smooth and accurate surface model. The surfaces can then be saved as IGES files.

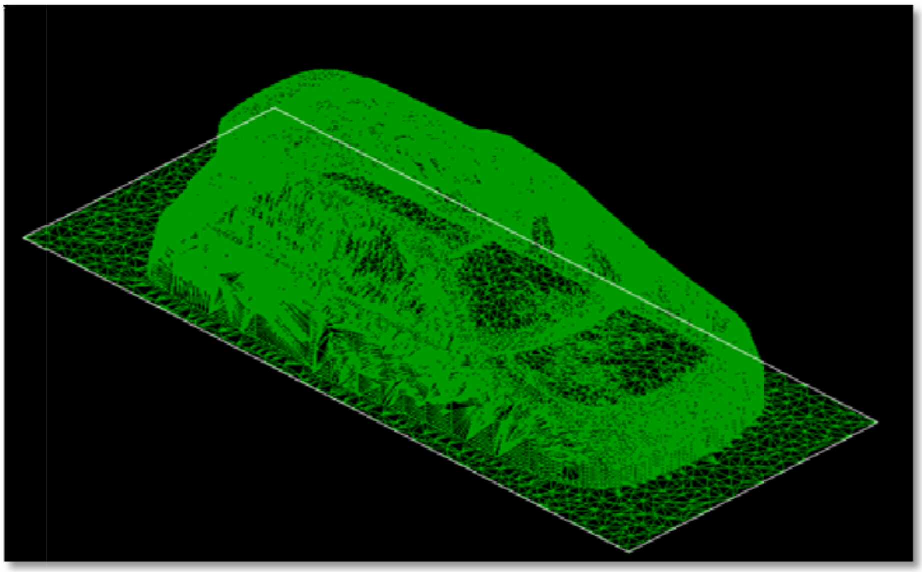


Figure 4.4: Tracecut surface model

4.2 Model size determination

As stated before, the chosen model scale is 1:18 scale. The scale size is chosen after considering the similarities needed together with the speed of the wind tunnel can provide and the size of the test section at the wind tunnel. Thus, the car with its original length of 348cm will be scaled to 19.8cm.

The first experiment setup is using one model car which aims to investigate the trend and force variation occurred around the car (Figure 4.5).

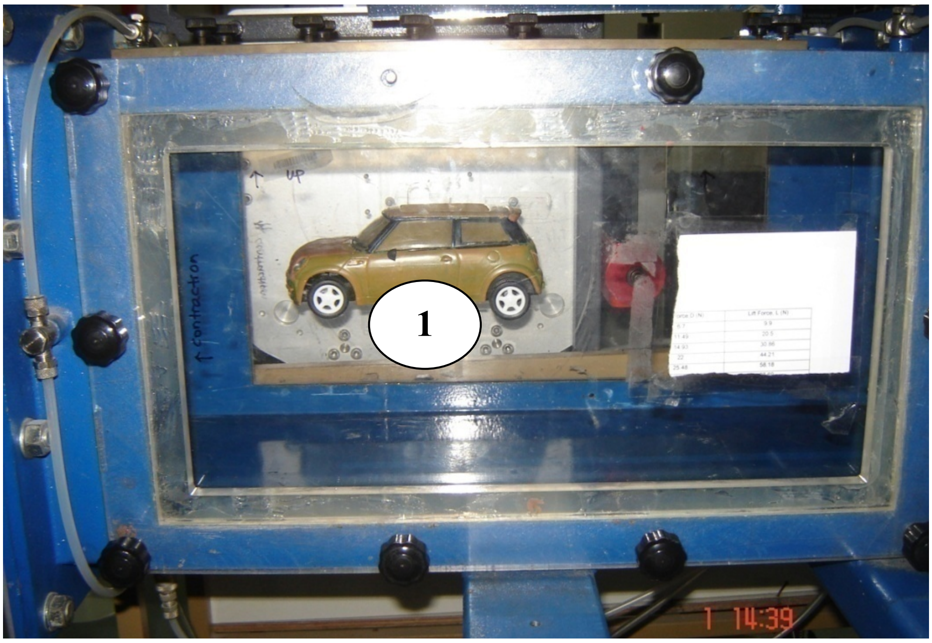


Figure 4:3: One car model condition

The condition then changed to two car models at the same time in the wind tunnel test section (Figure 4.5). Both models are set to be at a certain distance between each other. The distance is based on the measure define before each experiment (width of the car model).

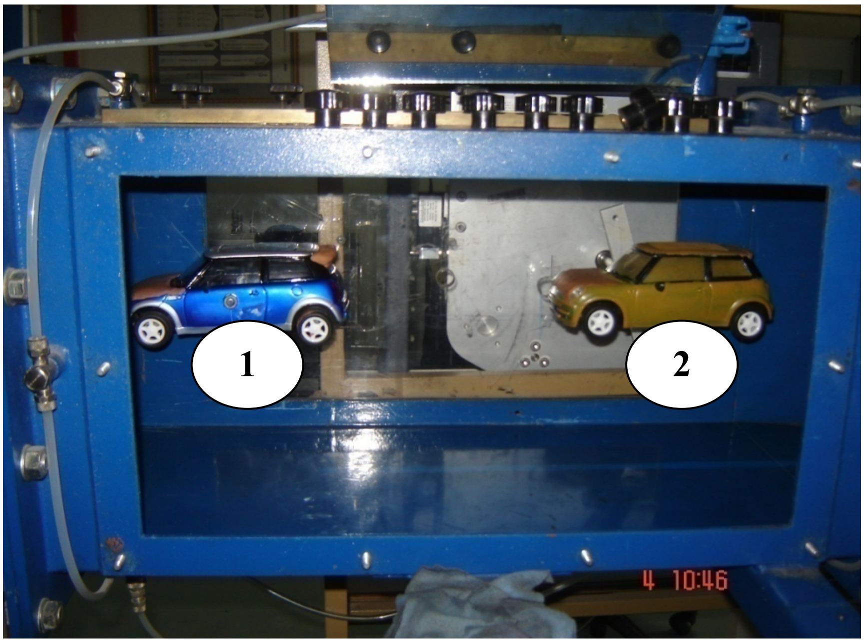


Figure 4:4: Two car models condition

The setup is as follows:

a. ·First distance between the models – one width of the model (9.2cm)
b. Second distance between the models – double width of the model (±18.7cm)

Other measurements noted down were:

i. The distance of the model from the ground/floor- approximately (11cm)
ii. The front model is tightened to the constructed wall of the wind tunnel refer as 'model 1'. The readings are taken from the model at the back which is assumed as the tailing car (model 2), that is attached to the three–component electronic aerodynamic balance (Appendix III). The balanced is assembled outside the test chamber in other not to affect the stream and is supported by a proper column. This will show the aerodynamic change effects of the front model on the back model.
iii. For the research, it is important to state that the only concerns for the test are the drag force; F_D and the Reynolds number; R_e whereas the velocity; V or speed of the car will be increase by manually. The balance also gives the lift force reading. However, the lift force is neglected because there is no ground (road) built in the wind tunnel setup due to unavailability of the facilities. As added information, lift force is highly affected by the ground conditions, hence in this experiment; the readings for the lift will not be accurate enough for the study.
iv. The tests were run at the speed increase starting from $5ms^{-1}$ to $\pm30ms^{-1}$ (maximum speed: 36 $ms^{-1)}$ by the increment of $5ms^{-1}$. Three readings are taken for each speed and the average are calculated for both setups. At every speed increments, the system will be allowed to run for at least two to three minutes before any reading is taken.
v. The above steps then were repeated again for the other two tests. Speed increment will be same as the previous. The only change will be the distance between the models as stated above. Three readings are taken for each speed and the average is calculated for all setups.

4.3 Wind tunnel test using two 1:18 scale models

The testing will start with one model setup using the 1:18 scale model without any obstruction from second model. The objective is to find the normal reading of the drag force that will be used as a reference to the other readings

Table 4.1: Wind tunnel result for single scale model

ρ	Frontal Area	Top Area	V(m/s)	F_D(N)	F_L(N)	C_D	R_E	C_L
1.18	0.01476	0.005085	4.95	0.09	0.02	0.42179	5484.30	0.27207
1.18	0.01476	0.005085	10.03	0.27	0.04	0.30819	11112.63	0.13253
1.18	0.01476	0.005085	15.01	0.56	0.04	0.28542	16630.16	0.05918
1.18	0.01476	0.005085	20.01	1.02	0.00	0.29253	22169.86	0.00000
1.18	0.01476	0.005085	24.99	1.59	-0.01	0.29237	27687.39	-0.00534
1.18	0.01476	0.005085	30.00	2.27	0.02	0.28963	33238.17	0.00741
1.18	0.01476	0.005085	32.16	2.64	0.02	0.29311	35631.32	0.00645

Plotting the graph of the drag force against the velocity will show the relationship of the two variables which directly proportional to each other.

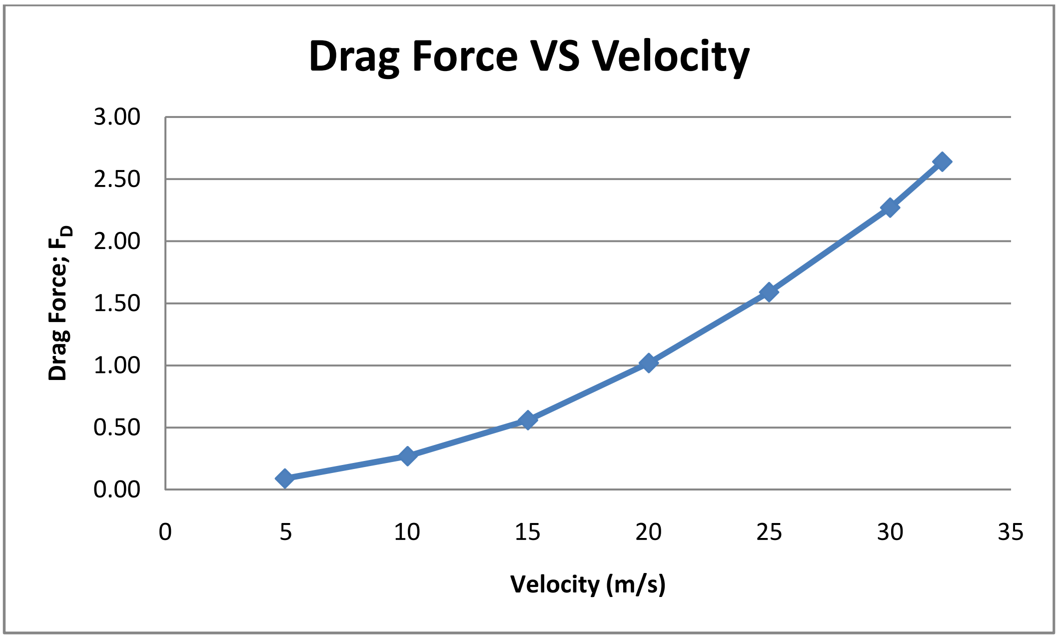


Figure 4:5: The drag is increasing with every increased of the speed

Plotting the data of Drag Coefficient against the Reynold number reveals the Reynold number independency to the flow

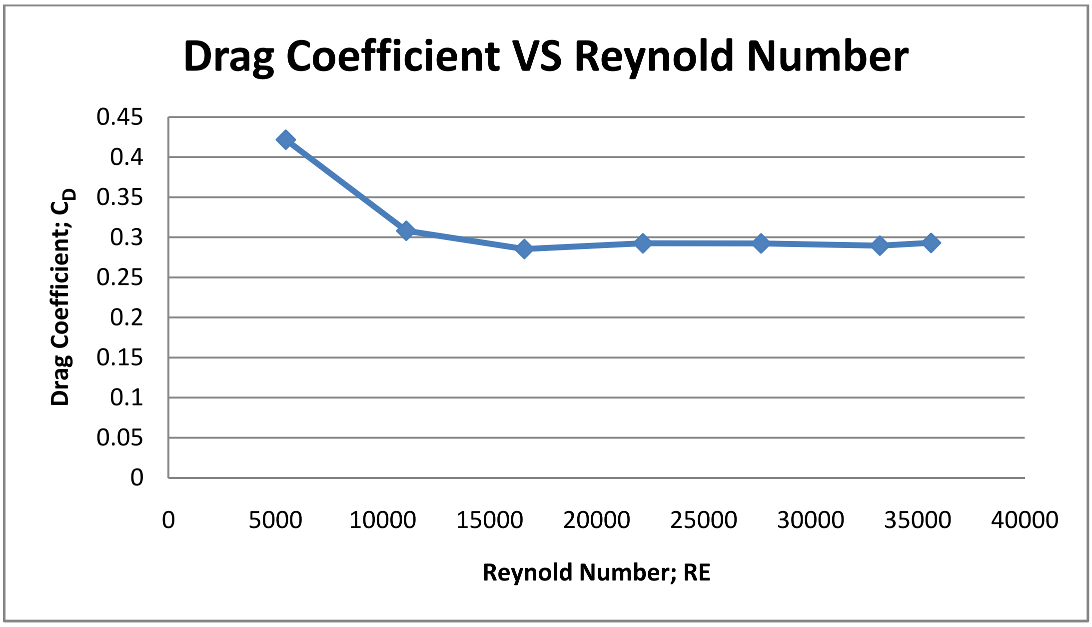


Figure 4:6: Graph of Drag Coefficient versus Reynolds number. The slope decrease until a certain value of C_D

4.4 The relationship of the drag force to the distances between the models

4.4.1 The result for one width distance (1W) is as follow:

Table 4.2: The wind tunnel results for double model setup, one width distance.

V(m/s)	F_D(N)	F_L(N)	C_D	R_E	C_L
5.12	0.082	0.043	0.3592	5672.65	0.5467
10.03	0.182	0.017	0.2077	11112.63	0.0563
15.02	0.342	-0.047	0.1741	16641.24	-0.0694
20.03	0.668	-0.122	0.1912	22192.02	-0.1014
24.99	1.038	-0.185	0.1909	27687.39	-0.0987
30.02	1.477	-0.262	0.1882	33260.33	-0.0969
30.75	1.518	-0.262	0.1844	34069.12	-0.0924

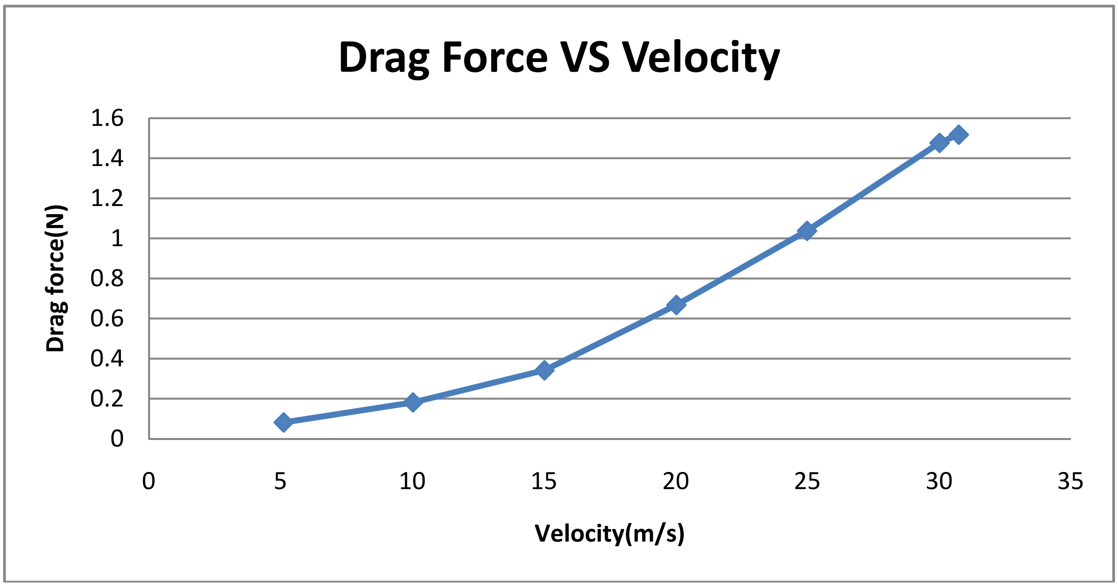


Figure 4:7: The direct proportional relationship of the drag and the wind speed, for the one width distance setup

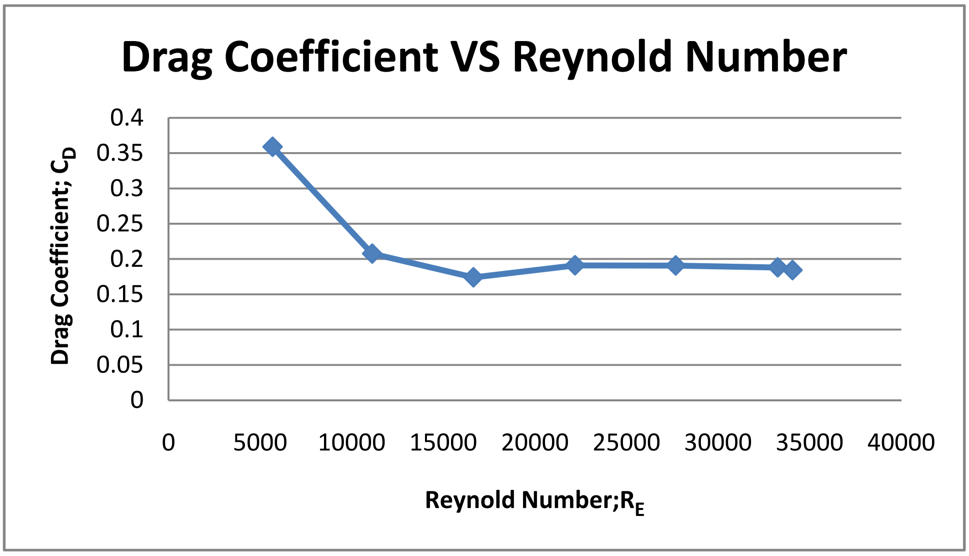


Figure 4:8: Plotting the drag coefficient against the Reynolds number shows the inverse relationship where the C_D value decrease to a constant

4.4.2 Result for twice width (2W) setup

Table 4.3: The wind tunnel results for double model setup, twice width distance.

V(m/s)	F_D(N)	F_L(N)	C_D	R_E	C_L
5.03	0.056	-0.026	0.2542	5572.93	-0.3425
10.13	0.18	-0.055	0.2014	11223.42	-0.1786
15.02	0.372	-0.08	0.1893	16641.24	-0.1182
20.03	0.648	-0.086	0.1855	22192.02	-0.0714
25.06	1.02	-0.13	0.1865	27764.95	-0.0690
29.99	1.3825	-0.185	0.1765	33227.09	-0.0686
30.75	1.518	-0.26	0.1844	34069.12	-0.0917

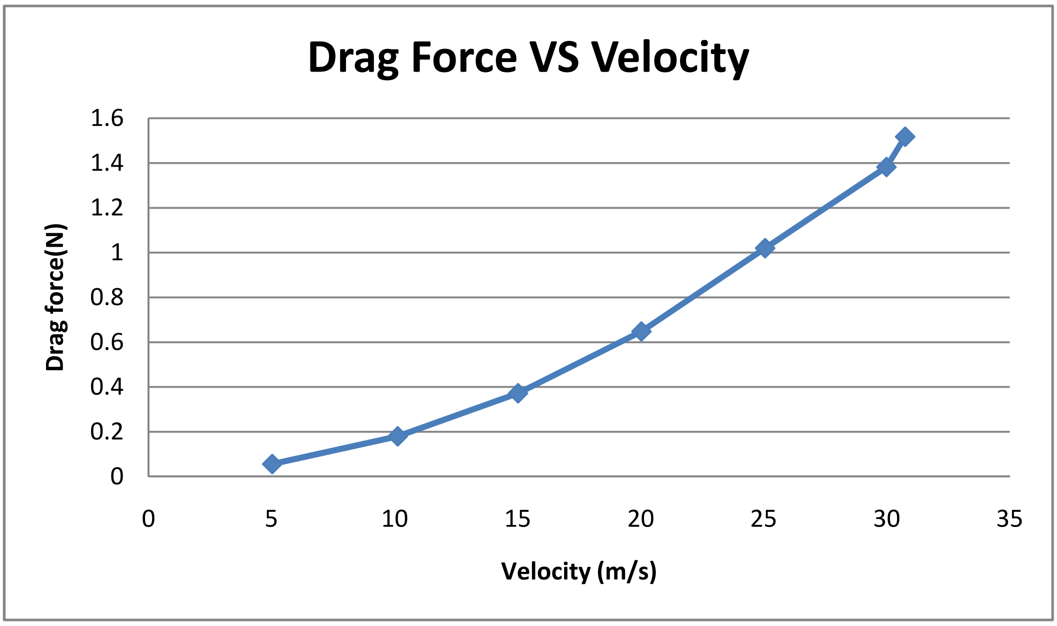


Figure 4:9: The drag force plotted against the wind speed for the twice width distance setup

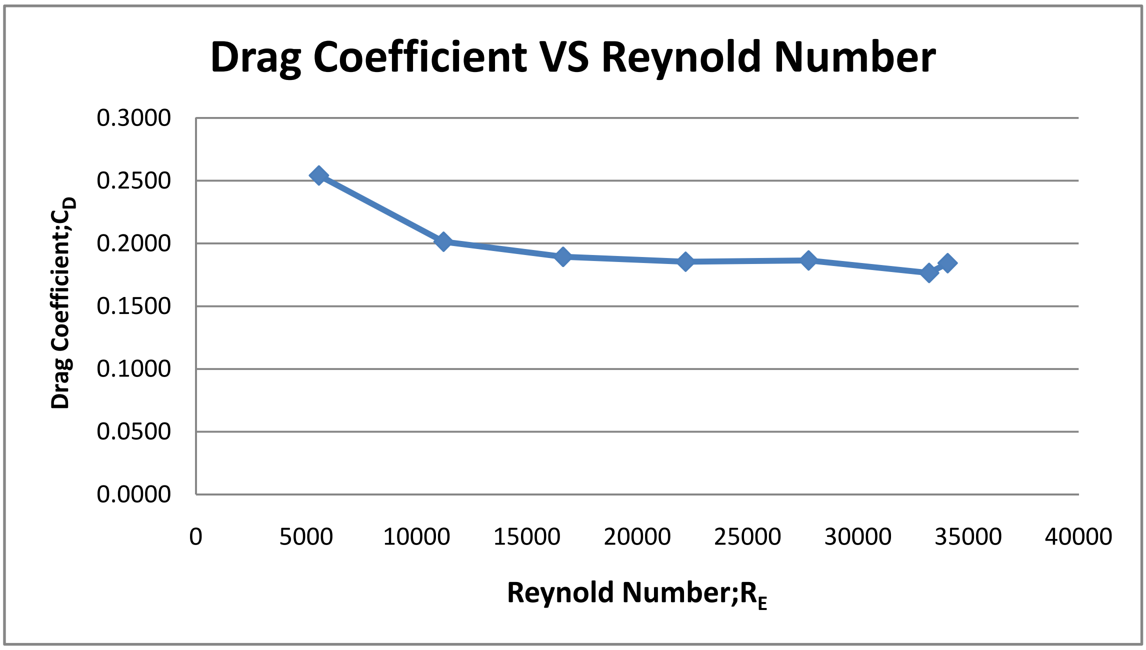


Figure 4:10: Plotting the drag coefficient against the Reynolds number shows the inverse relationship where the C_D value decrease to a constant

4.4.3 Result for all test setup

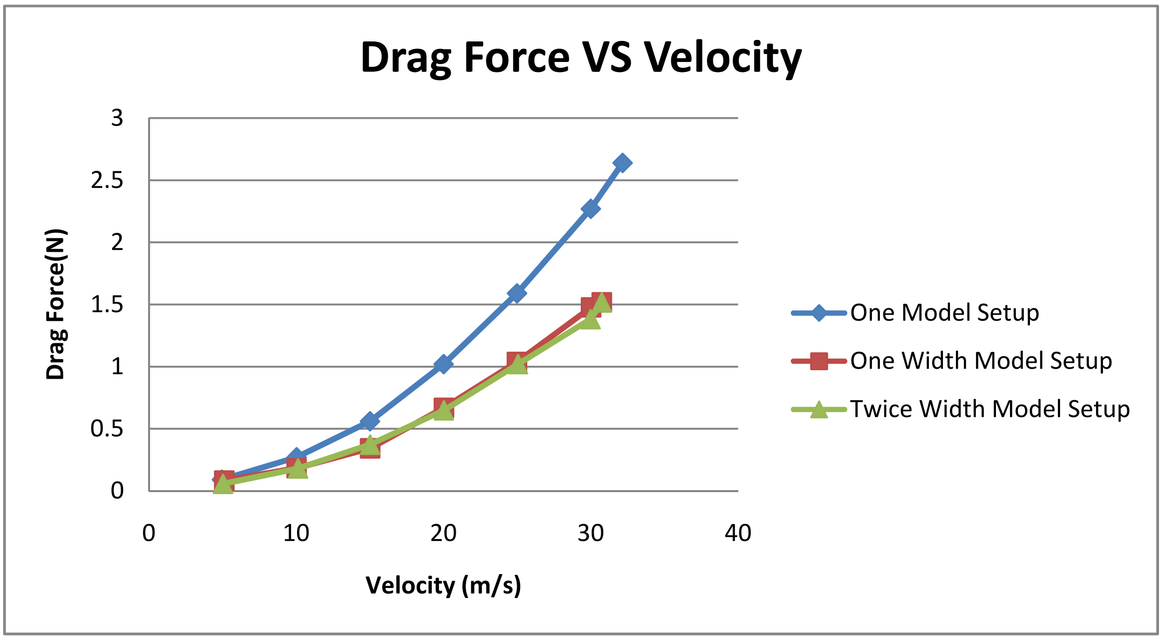


Figure 4:11: Drag Force versus the wind velocity, with all three distance setups.

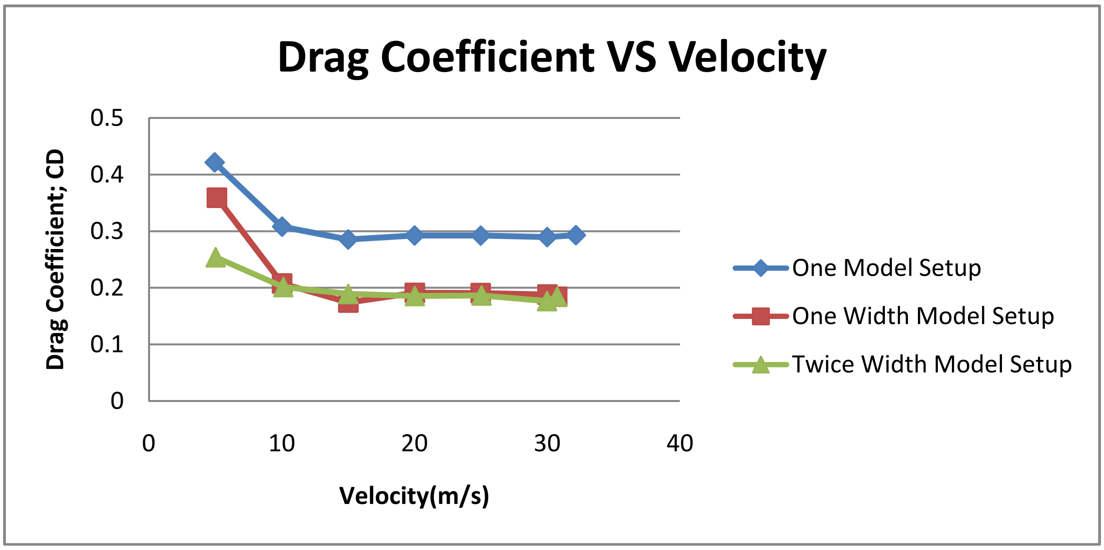


Figure 4:12: Drag Coefficient versus Reynolds number for all three setups.

4.5 Discussions

4.5.1 Relationship of the drag force to the distance between the models

From Figure 4:12, it is observed that the drag increase for every setup reading. The data shows that 1W setup give the highest drag force value, compared to the normal setup (single model) and 2W. For the normal setup (single model) and 2W setup, the drag forces slowly increase.

4.5.2 Drag increase for 1W (9.2cm) distance between models:

Model 1 creates a turbulent flow that is flow directly in front of model 2. Because the distance between the models is short, the difference in time is short as well. The turbulent flow created by model 1 has no time to steady down, resulting higher drag force when it hits model 2. During the experiment, the test section is in good condition, the front wheel of the models rotates slowly and model 2 a bit shaking conforming the force acting on it.

4.5.3 Drag decrease for 2W (±18.7cm) distance between the models:

The distance increased once for this setup. Thus, when the wind flow hit model 1, turbulence is created at the back of model 1. The drag force acts on model 2 much lesser which show that less turbulent flow from the back of model 1 and the flow is quite steady. The drag reading shows that this setup is almost the same as the 1W model setup

4.6 Sensitivity of the wind tunnel test flow to Reynolds number

It can be observed from that for all three flows, they show the independency of the Reynolds number. By plotting the drag coefficient (C_D) against the Reynolds number (Re), the graph shows the inversely proportional relationship where the drag coefficient value decreases until a certain point of Re. For the wind tunnel test, the value of C_D that is independent to Re is $C_D = 2$ at Re value approximately 47000. Therefore, by assuming that for any other flow that runs at higher Reynolds number value of 47000, the C_D can be assumed to be approximately 2. Thus, by knowing the value of C_D, and by controlling the velocity (V) of the wind, the drag force (F_D) that acts on the model can be calculated using the following formula.

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A_f}$$

$$Re = \frac{\rho V A}{\mu}$$

Where; C_D = drag coefficient

C_L = lift coefficient

F_D = drag force

F_L = lift force

Re = Reynolds number

ρ = density of the air at room temperature

μ = viscosity

V = velocity of the air

A_f = frontal area (perpendicular to the flow) of the object/model for C_D equation

A_P = top/platform area (parallel to the flow) of the object/model for C_L equation

Thus, with C_D, ρ and A remaining constant, and the velocity of the air increasing, the drag and lift force will increase as well. Using the two equations above, the drag coefficient and the Reynolds number can be calculated. A graph of C_D versus *Re* is plotted as shown below.

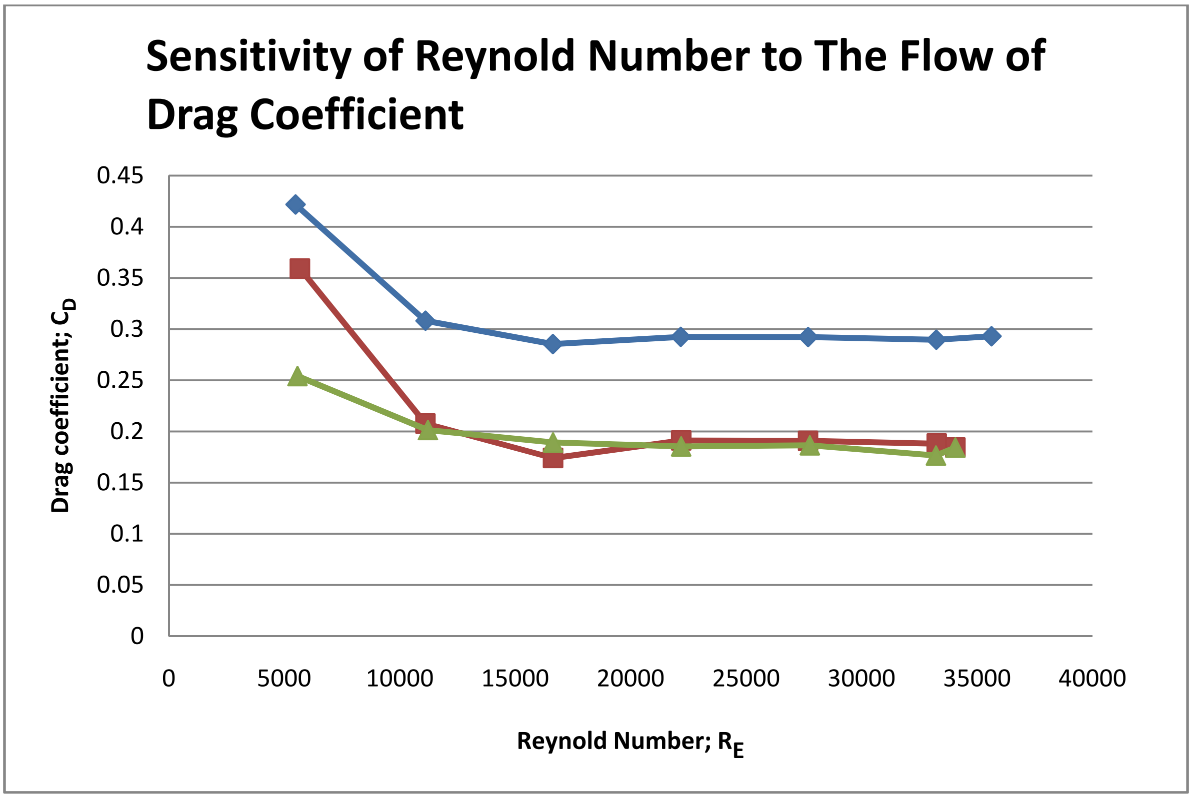


Figure 4:13: Sensitivity of Reynolds Number to the flow Drag Coefficient

CHAPTER 5
CONCLUSION AND RECOMMENDATION

From the wind tunnel results, it is found that there is a distance between two vehicles in proximity to each other, tailing one another, that the drag force acting on the tailing vehicles is actually less than when it is not tailing anything.

When applied to real driving on the real road; driving further away behind the front vehicle (1W distance) will result higher drag force, leading to harder car control and more fuel consumption for that same speed. This is due to the aerodynamic changes caused by the front vehicle. The turbulent flow created at the front result in higher drag force on the back vehicle. This can be a caused for the driver to loose controls of their vehicle as it would felt heavier and the effect is sudden and rapidly changing.

Driving much away (2W distance) will only result the same drag as if there are no car in front. The wind tunnel test run may not be sufficient enough to determine more precisely the value of the distance range between two tailing vehicle, that the drag force acting on the back car is much less than the normal drag force.

However, the experiments were not enough to identify or clarify the changes on the drag that will affect a vehicle when moving on the road tailing each other. Further experiments will certainly give a much better predictions with better distance setups.

REFERENCES

[1] Hucho, W.-H., & Sovran, G. (1996). Aerodynamics of Road Vehicle. In D. V. Sumatran, & D. G. Sovran, *Vehicle Aerodynamics* (pp. 3-5). Society of Automotive Engineers, Inc.

[2] M. Cimbala & Yunus A. Cengel, (2006).*Fluid mechanics (*Chap 7; Dimensional Analysis and Similarity)

[3] . V. Sumantran and Gino Sovran (editor)(2006); Vehicle Aerodynamics PT-49 – Historical Background/ Overview, Aerodynamics of Road Vehicle, Section I, pages 3 – 55. Wind tunnel Testing; Testing Methodology, Section II pages 61- 72

[4] Minato, K., Ryu, H., & Kobayashi (2006), T. Aerodynamicd of Road Vehicle in Tunnels-Flow Visualization Usingthe Laser Light Sheet Method and Its Digital Image Processing. In D. V. Sovran, *Vehicle Aerodynamics* (pp. 199-205).

[5] Automotive Wind Tunnel Emmen, RUAG Aerospace Defend Technologies

[6] Barlow, J. B., Jr., W. H., & Pope, A. (1999). *Low Speed Wind Tunnel Testing* (3rd ed.). John Wiley and Sons, Inc.

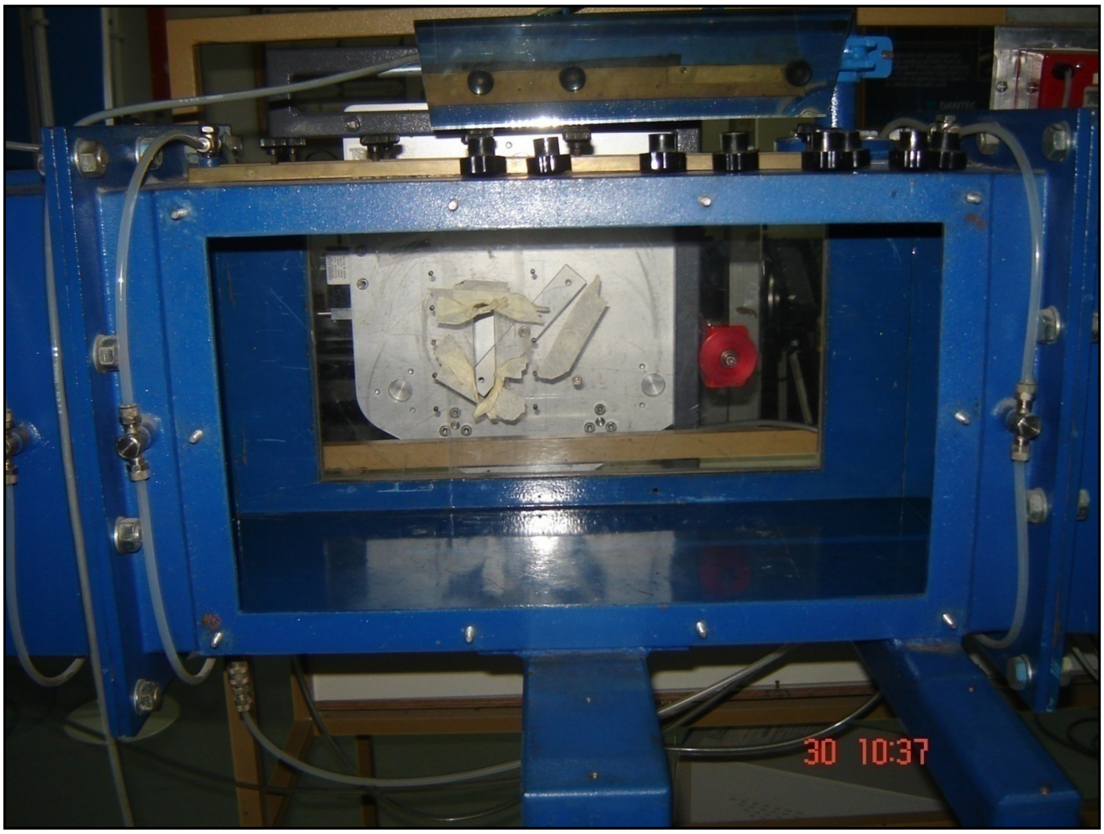
[7] Barnard, R. (1996). *Road Vehicle Aerodynamics Design:an Introduction.* Longman.

LIST OF APPENDIX

APPENDIX I

APPENDIX II

APPENDIX III



APPENDIX IV

APPENDIX V

APPENDIX VI

APPENDIX VI

APENDIX VIII