AERODYNAMIC CHANGES WHEN TWO VEHICLES ARE IN PROXIMITY TO EACH OTHER

BY

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CERTIFICATION OF APPROVAL

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Approved by,

(DR. AHMED MAHER SAID ALI)

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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.

MUHAMMAD NAZRI BIN DZULKIFLI

Abstract

Aerodynamic of the fluid surrounding two vehicle changes when the vehicles are in proximity to each other, whether when overtaking, or moving back-to-back, or side-by-side from the same or opposite direction. Usually when the cars are moving near each other, aerodynamic changes, especially the wake that forms around the vehicle can create force variation on the vehicle, causing sometimes road accidents. For the Final Year Project (FYP), the aerodynamic changes will be studied on model vehicle using a wind tunnel equipped with the necessary measuring equipment. The study is focusing on the effects of the wake of a vehicle to another vehicle in tailing position (back-to-back), where the experiment is done using windtunnel and scaled vehicle models. The vehicle model used is a scaled model of a kelisa car. The results of the experiment show that there are certain ranges of distance between the two cars, where the drag force, as a result of the aerodynamic changes, increase and decrease. These distance ranges are where a driver should or should not be when tailing another vehicle on the road.

Acknowledgement

A thousand gratitude to the Almighty God, for making the project a success.

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Chapter 1: Introduction

1.1 Background of Project

When one is driving, either a car or a motorcycle, the wind changes can be felt when overtaking another vehicle or overtaken by another; or when moving along side another vehicle. This is due to the changes of aerodynamic flow around the vehicles. These aerodynamic changes are much more significance when there are larger difference between the size of the vehicles, and when the vehicles are moving with different speed.

1.2 Problem Statement

The aerodynamic changes from one vehicle can affect the other car 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. Lighter vehicle such as motorcycle will certainly feel more of the wake from larger heavier vehicles and this situation is dangerous to the motorcyclist and other lighter vehicle as well. Therefore, understanding the effect of this vehicle affecting aerodynamic changes could help in minimizing the risk of an accident.

1.3 Objectives

- To investigate the aerodynamic around a vehicle.
- To study the effect of the speed of the vehicle on the aerodynamics.
- To investigate the effect of an aerodynamic changes caused by a vehicle and another in proximity with each other at a different distances.

1.4 Scope of the Project

- Prepare wind tunnel scale model of vehicle that suited the size of the available wind tunnel.
- Prepare a wind tunnel that accommodates more than one model.
- Study the aerodynamics around the model vehicle.
- Run wind tunnel test on scale model vehicle when another model is in the flow field.

Chapter 2: Literature Review

2.1 Dimensional Similarity

In order to gain accurate result from the wind tunnel test, the model of the vehicle must have similarities to the real world [1]. These similarities are the concept of a technique called Dimensional Similarity. Dimensional Similarity is introduced so that the test can be done on scale model rather than a prototype. This results in lower cost as well as shorter time. There are three conditions that are needed to complete the similarity which are:

- Geometric similarity - model has the same shape with the size being scaled
- Kinematics similarity - velocity at any point in the model flow must be proportional (scale in magnitude and same direction) to the velocity at the corresponding point in the prototype flow.
- Dynamic similarity - all forces in the model flow are scaled by a constant factor to the corresponding force in the prototype flow.

Numerous studies have been done on vehicle aerodynamic on passing maneuvers by other researchers. Noger et al. [2] stated that at each time two vehicles are driven in close proximity, they influence the flow field of each other, creating gust loads as additional forces on the vehicle, such as drag, lift, side force and the yawing moment, that could cause accidents.

2.2 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. Drag is usually an undesirable effect, a resistant to movement like friction, and it is minimize by all means. 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 windtunnel and scaled model to measure the force change.

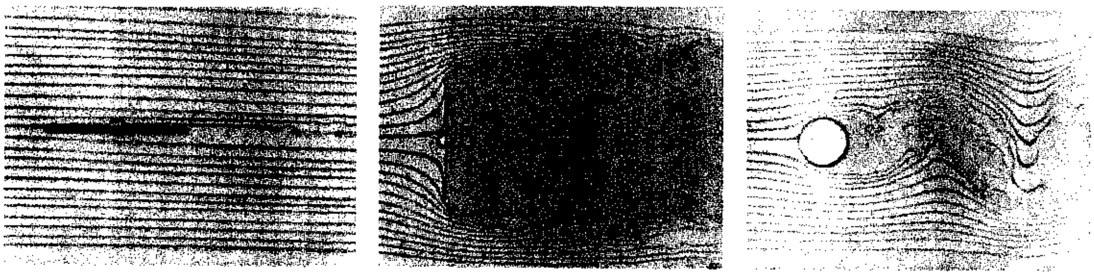


Figure 1: The visualization of the flow for different shapes. The drag is highest for a vertical plat and lowest for a horizontal plat.

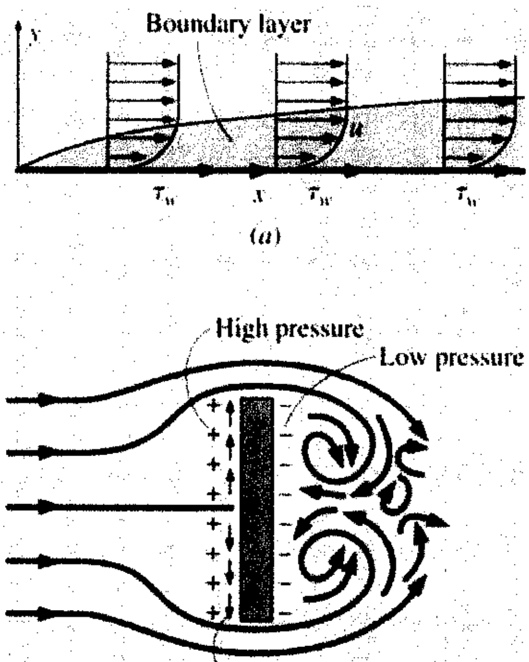


Figure 2: (a) The drag force acting on a flat plat parallel to the flow depends on the wall shear. (b) The drag force acting on a flat plat normal to the flow depends on the pressure.

2.3 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. Lift is usually related to aerofoil, used in aeroplanes design for upward force and spoiler design for more downforce. 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. However, there will be no 'ground' or 'road' in the experiment. The models of the vehicle will be supported by a metal rod, connecting it to the balance that will measure the forces acting on the model.

Figure 3: There is no 'ground' or 'road' for more accurate lift force measurement.

Chapter 3: Methodology

3.1 Problem Identification

One of the difficulties on 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.

The problem from the wind tunnel provided by the university is that it does not support the project fully. The wind tunnel is design to accommodate only one model at a time. This does not comply with the requirement of the project that need at least two models at one time. Modification to the original wind tunnel panel is not allowed by the lab technician, thus a new one has to be fabricated.

Another problem that rises is the fact that the size of the wind tunnel test section is quit small for a model to realy simulates the real situation. With the maximum speed of the wind to be $60ms^{-1}$, the size of the vehicle model has to be as large as possible to simulate the highest speed and at the same time does not block the air flow in the test section.

3.2 Fabrication and Setup

The current WT04 wind tunnel needs to be modified so that it can fit in two or more models at a time. Modification will only focus on the test section. The steel cage of the section will not be tempered with; only the left and right wall of the test section will be modified. The right panel is made from perspex while the left panel is made from tempered glass. Both side can be detached and reattached. The plan is to replace both sides with perspex with holes on each opposite side to support the second model in the test section. More detail diagram is available in the appendix.

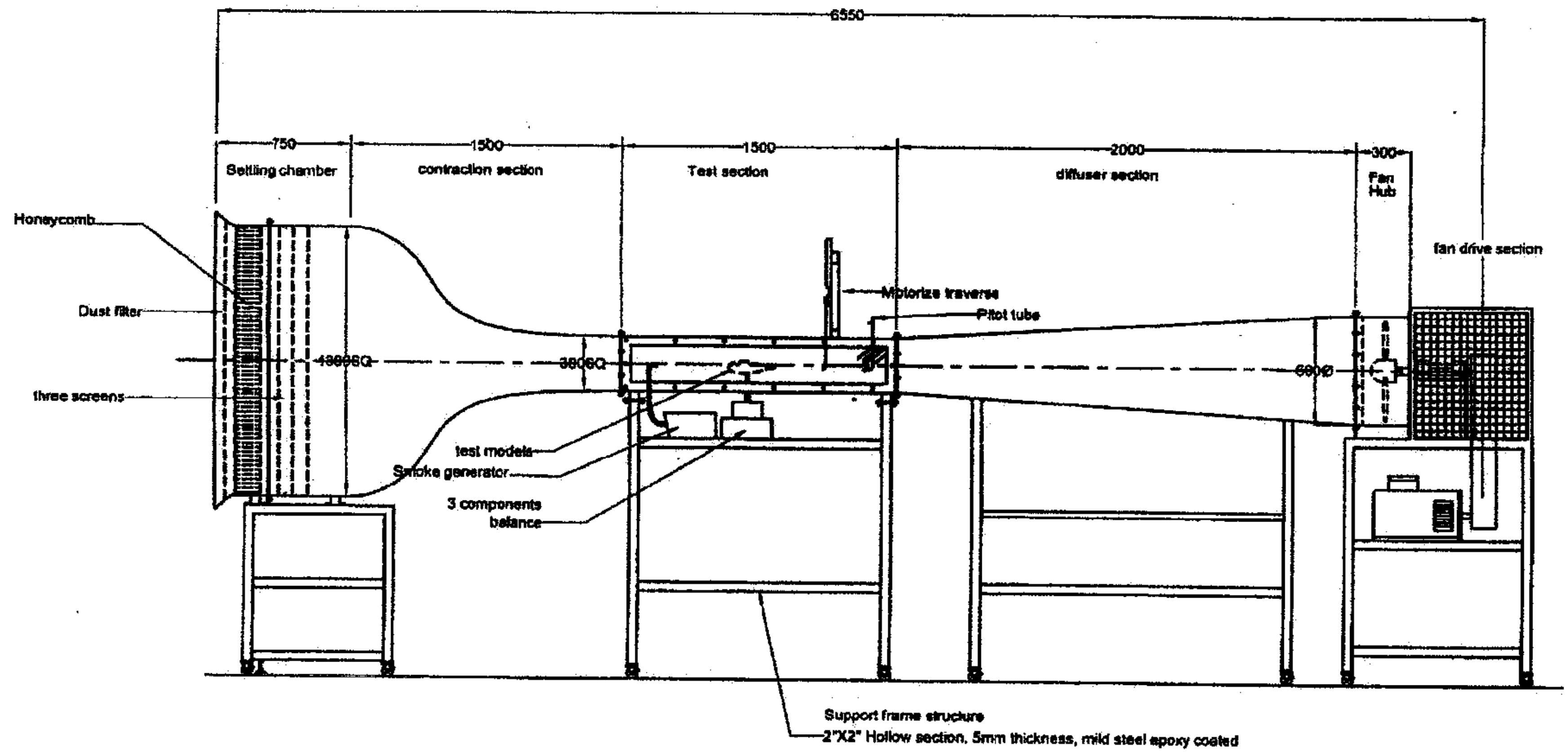
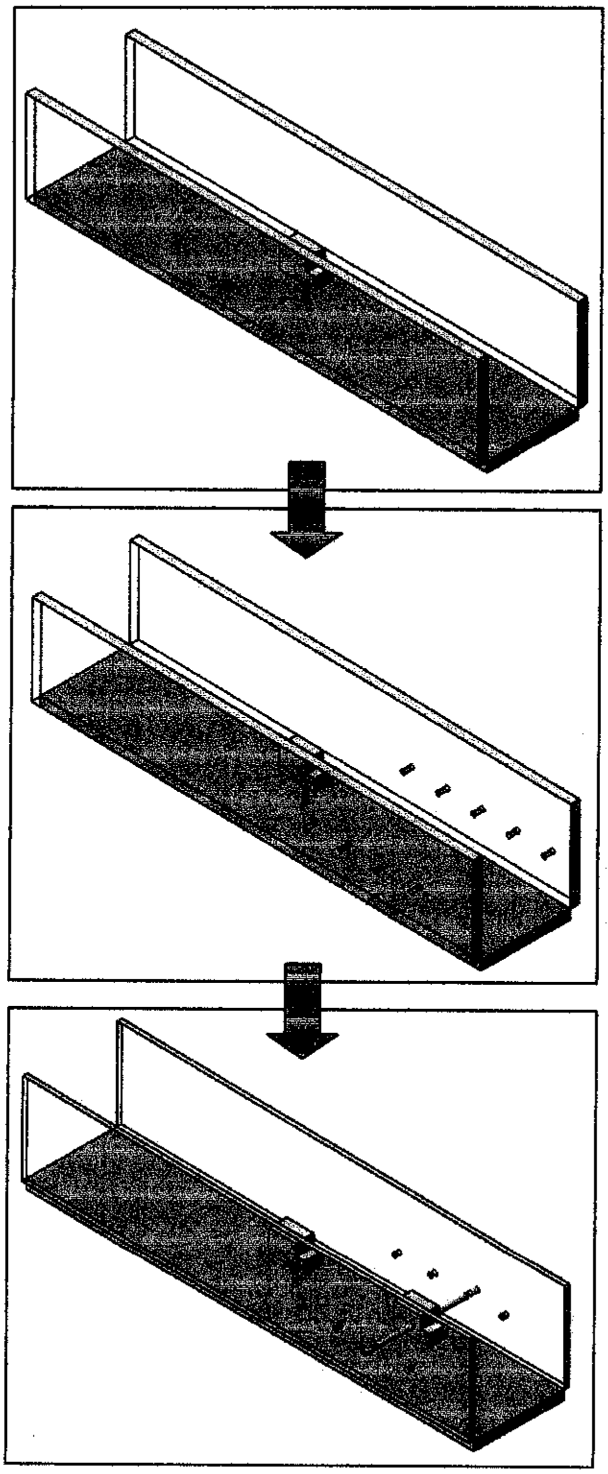


Figure 4: UTP WT04 Subsonic wind tunnel



a) Original setup of the wind tunnel.

b) Side replaced with drilled perspex.

c) The modified setup with model number two in front of the measured model.

Figure 5(a), (b) and (c): The setup for the testing is as follows. Both side of the wind test section is replaced with perspex with holes drilled to the side. A model will be supported using the hole and a rectangular bar, positioned in front of the measured model.

Because of the limitation on the size of the model as a result of a small test section, the windtunnel test will only be done in using two vehicles model in a **tailing position** (one model in the front and another model in the back). The other setups like the side-by-side position, or opposite direction position will be excluded from the project.

3.3 Documentation

For the fabrication of the wind tunnel panels, both sides have been detached and the detail dimensions of the panels are taken. Refer to the appendix from Figure 28-35 for the detail design of the wall panel. The new panels have to have the exact size and dimensions as the original panel. This is because the gap for the test section panel between the contraction section and the diffuser section is exactly fit to the panels. Plus, the wind tunnel does not have any symmetric property either left and right, or the front and the back. The placement of the bolts at the wind tunnel metal frame is somewhat random, as long as it holds the wall panels in place.

The wind tunnel test results are provided by the three way balance of the wind tunnel. It is displayed on the attached computer system, using software called GraphWorX32 by ICONICS. The readings given are for freestream velocity of the wind, drag force, lift force, velocity pressure and the fan speed.

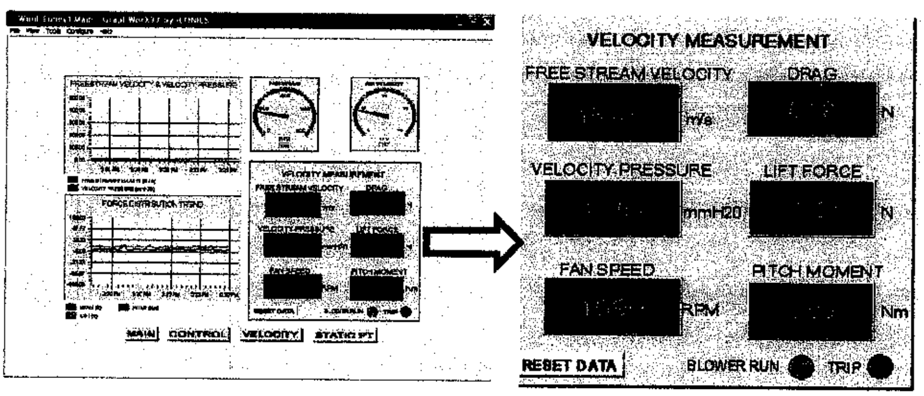


Figure 6: The result screen of the wind tunnel computer.

3.4 Testing

Several testing has been done using the wind tunnel equipments. This is rather important to get use to the setup and operation of the windtunnel. The first experiment is a test run using an available 1:40 scaled vintage truck model. The result is the drag and lift of the acting on the model. By plotting the drag and lift force against the wind velocity, a proportional relationship is observed. The result is in chapter 4.

Figure 7: A 1:40 Vintage truck model.

The next test is on an available 1:40 scaled sports car model. The relationship between the drag and lift force with the wind velocity is again observed. The next step is to calculate the Reynolds number, and then plotting it versus the drag. This step is to find the relationship of the flow that would be similar to the real situation. Further discussions are in chapter 4.

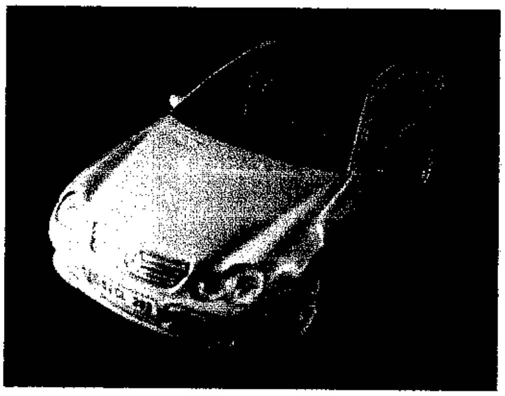


Figure 8: A 1:40 sports car model.

3.5 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.

$$\mathrm{Re}_{prototype} = \mathrm{Re}_{model}$$

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

Where

ρ = density of air
V = freestream velocity of the air
A_f = frontal area of the prototype/model
C_D = drag coefficient
C_L = Lift Coefficient
F_D = drag force
F_L = lift force

For the test, 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 side are cancel out, thus the equation become

$$(VA_f)_{prototype} = (VA_f)_{model}$$

From here, by using a spreadsheet, and by manipulating the velocity and scale of the model in the wind tunnel, the velocity in the real situation can be calculated; keeping in mind:

- The maximum wind velocity is 60m/s. for safety reasons, the run will be limited to 50m/s
- The size of the wind tunnel's test section is 30x30cm frontal area. Therefore, 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.

Chapter 4: Results and Discussion

4.1 Effects of free stream velocity on drag and lift force

The wind tunnel test on a **vintage truck** has been done using the wind tunnel. The test is done by exposing the model to different magnitude of free stream velocity from 10m/s followed by $20ms^{-1}$, 30 ms^{-1}, 40 ms^{-1}, and 50 ms^{-1}. The results are as follows:

Table 1: Results for wind tunnel test on 1:40 scaled vintage truck model

FREE STREAM VELOCITY (m/s)	VELOCITY PRESSURE (mmH_2O)	FAN SPEED (RPM)	DRAF FORCE (N)	LIFT (N)
10.52	6.63	1179	4.79	9.19
20.6	25.68	2231	6.09	14.84
30.52	55.52	3234	7.6	14.66
40.16	90.24	4211	8.71	15.87
50.12	149.67	5300	9.21	15.84

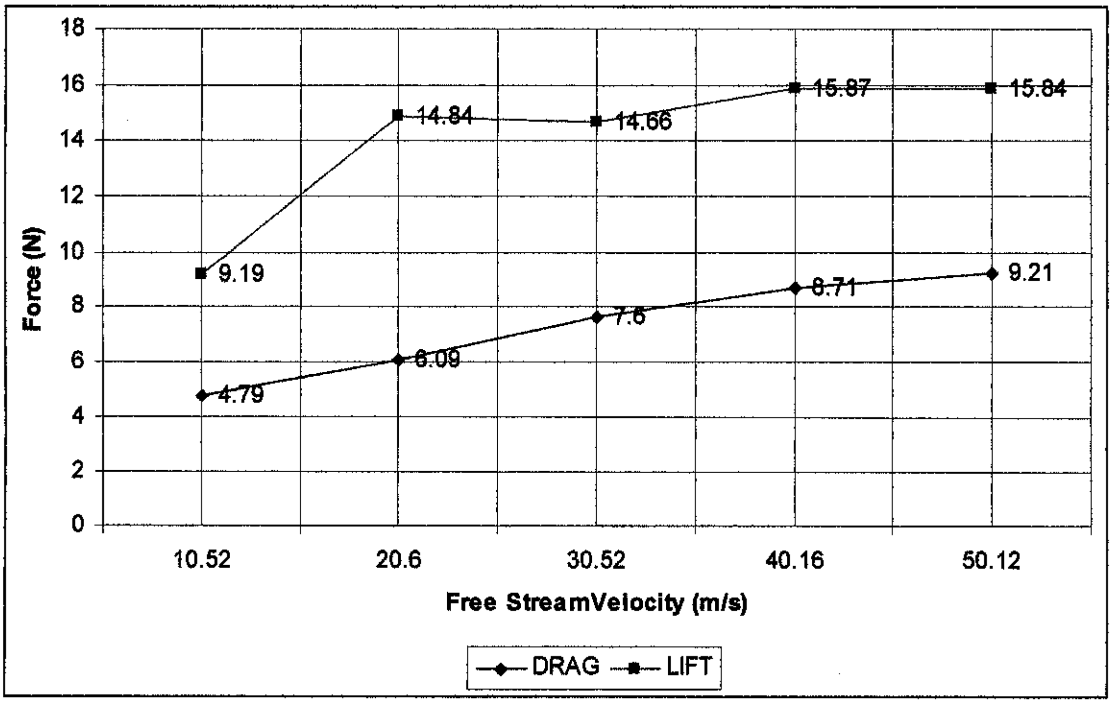


Figure 9: Drag and Lift against Free Stream Velocity

Another experiment has being tested using a 1:40 scaled sport car model. By increasing the free stream velocity carefully, the drag force and the lift force acting on the model can be obtained. Using these two values, the drag coefficient and the lift coefficient of the model can be calculated. The Reynolds number of the flow can also be calculated. The results of the experiment are as shown in Table 2.

Table 2: Results for wind tunnel test on 1:40 scaled sports car model.

Free stream Velocity (m/s)	Velocity Pressure (mmH_2O)	Fan Speed (RPM)	Drag Force (N)	Lift Force (N)	Drag Coefficient C_D	Lift Coefficient C_L	R_e
5	1.54	544	0.52	7.25	24.38	96.25	460.19
10	5.97	1072	4.56	13.25	53.45	43.98	920.39
15	13.55	1590	6.09	15.81	31.72	23.32	1380.58
20	23.95	2089	6.82	20.49	19.98	17.00	1840.78
25	37.95	2584	5.45	18.78	10.22	9.97	2300.97
30	54.30	3068	7.46	26.58	9.72	9.80	2761.17
35	74.25	3562	11.11	30.19	10.63	8.18	3221.36
40	95.63	4043	14.27	41.6	10.45	8.63	3681.55
45	121.39	4557	15.51	43.39	8.98	7.11	4141.75
50	150.32	5113	22.62	46.89	10.60	6.23	4601.94
55	183.53	5695	28.50	57.44	11.04	6.30	5062.14
60	214.40	6223	29.98	62.34	9.76	5.75	5522.33

Density of air =	1.185 kg/m^3
Temperature =	27 °C
Kinematic viscosity =	1.572×10^{-5} m^2/s
Frontal area model =	1.44×10^{-3} m^2
Top area model =	5.085×10^{-3} m^2
Density of air =	1.185 kg/m^3

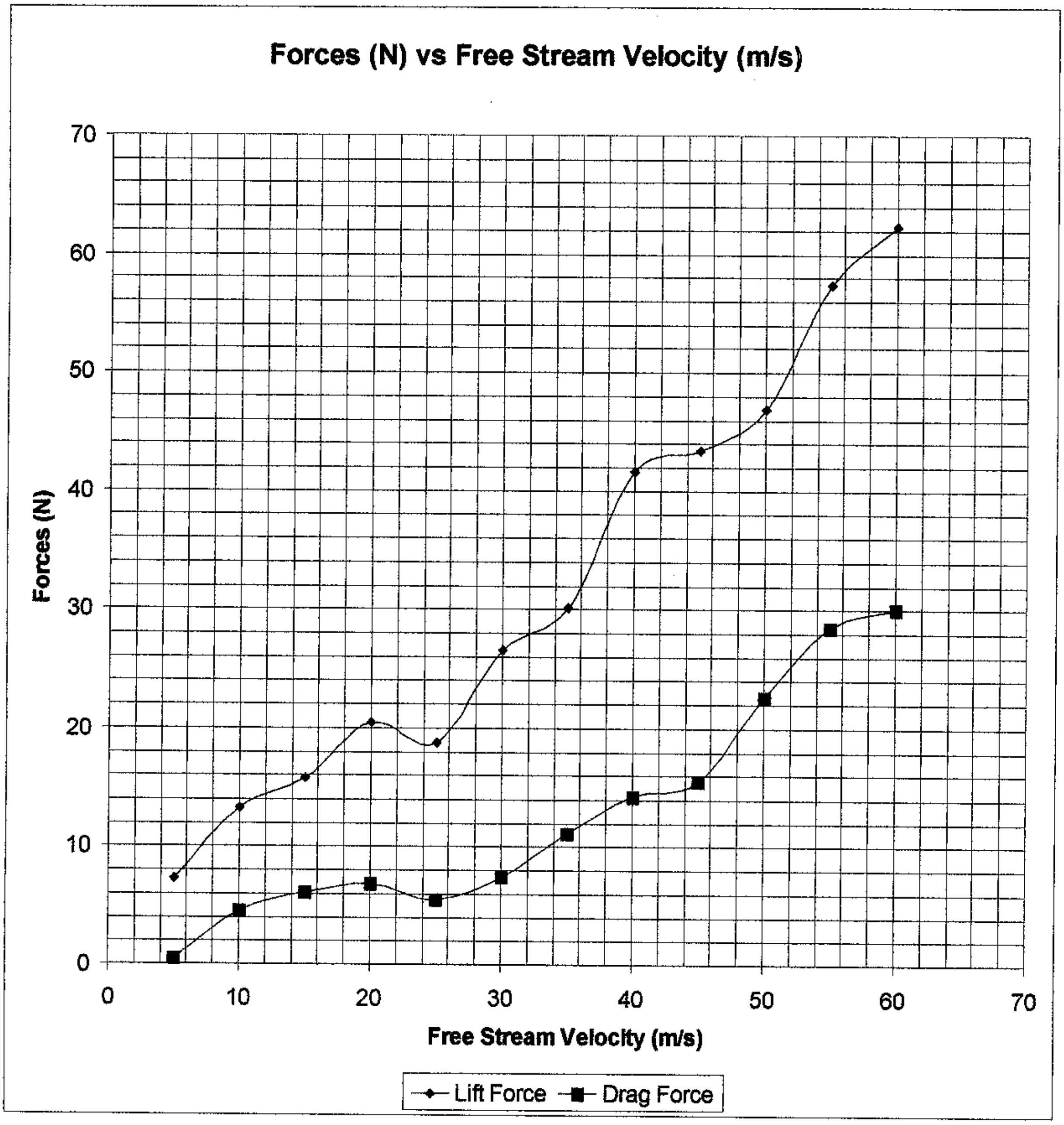


Figure 10: Drag and Lift against Free Stream Velocity

4.2 Sensitivity of experiments to Reynolds number

The wind tunnel test on the vintage truck shows that the higher the free stream velocity (simulating the speed of the truck) the higher the drag and lift acting on the truck.

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A_f} \text{ - - - - - (1)}$$

$$C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A_p} \text{ - - - - - (2)}$$

$$Re = \frac{\rho V A}{\mu} \text{ - - - - - (3)}$$

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

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 remain constant, and the velocity of the air increase, the drag and lift force will be increased as well. From the experiment on the sports car model, a drag force acting on the model is obtained. Using the drag coefficient equation above, the drag coefficient is calculated. The Reynolds number is also calculated by using the equation below. With ρ is the density of the air at the room temperature, V is the velocity of the model (the free stream velocity), A is the frontal area of the model, and μ is the kinematic viscosity of the air. A graph of C_D versus Re is plotted.

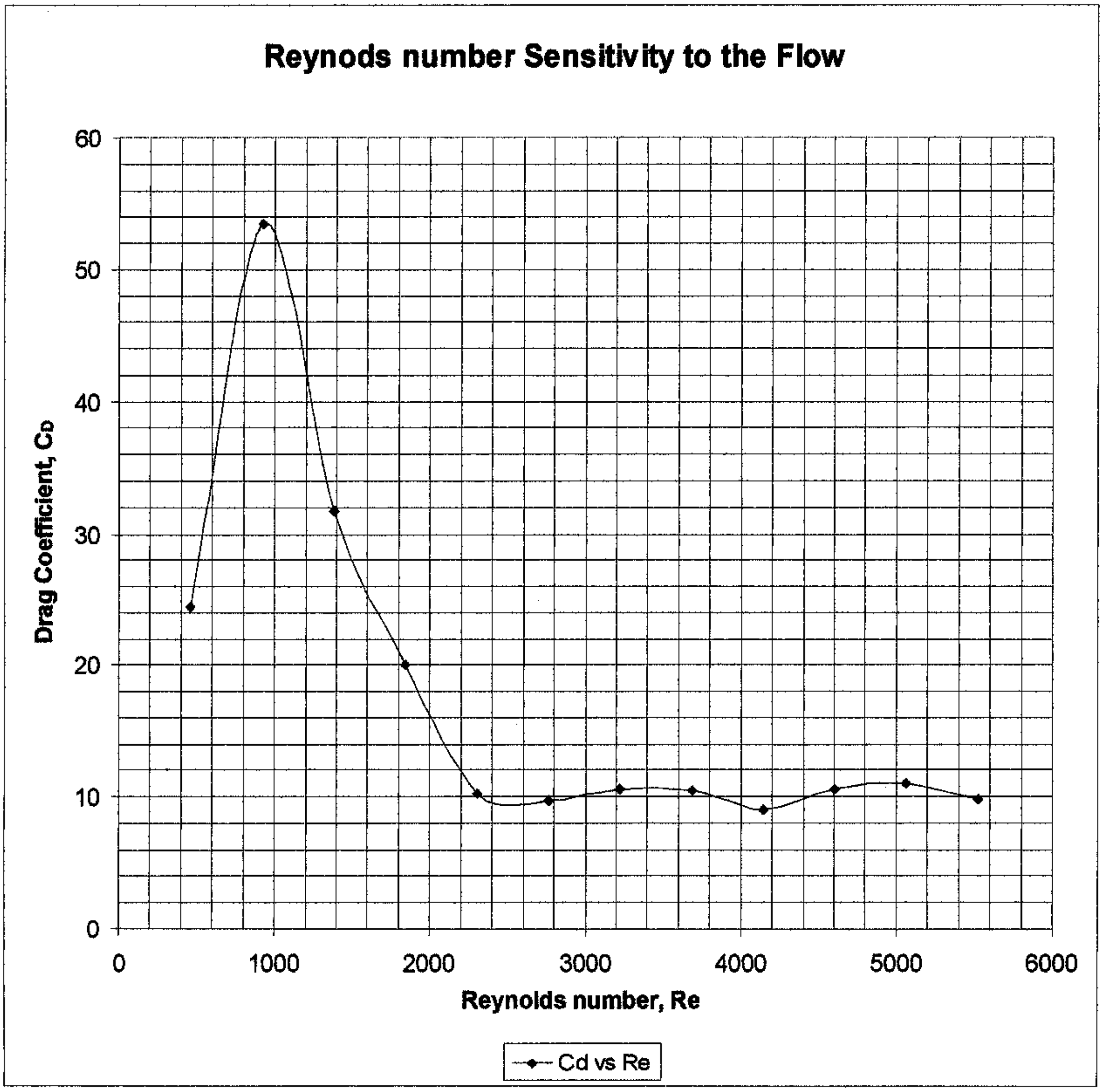


Figure 11: Drag coefficient, C_D against Reynolds number, Re

It is observed from the graph that at a certain Reynolds number, the drag coefficient from the flow will become constant (for this run, at $C_D = 10$). Thus, from this result, it can be assumed that the next wind tunnel test will produce the same curve; giving a constant reading of C_D for a certain range of Re. From here onwards, the C_D for the models is constant and the only variables would be the velocity of the wind and the drag force.

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

From the formula, by controlling the wind velocity, we can then found out how much drag force acting on the model. For Re $\leq$ 2300, we use the C_D from the graph. However, for $Re \geq 2300$ (larger than the maximum Re provided by the wind tunnel), the C_D is assumed constant.

4.3 Model size determination

The distance between the holes is based on the chosen model scale, which is **1:12 scale**. The scale is chosen after careful consideration of the similarity needed together with the speed the wind tunnel can provide, and the size of the wind tunnel. Thus, for a car that is 348cm originally, the model would be approximately 30cm.

4.4 Windtunnel test using two 1:12 scaled models

The test run using the 1:12 scaled models are done for three setups. The first setup will be for a single model without any wind obstruction from the second model. This setup objective is to find the normal readings of the drag force that will be used as a reference to the other readings.

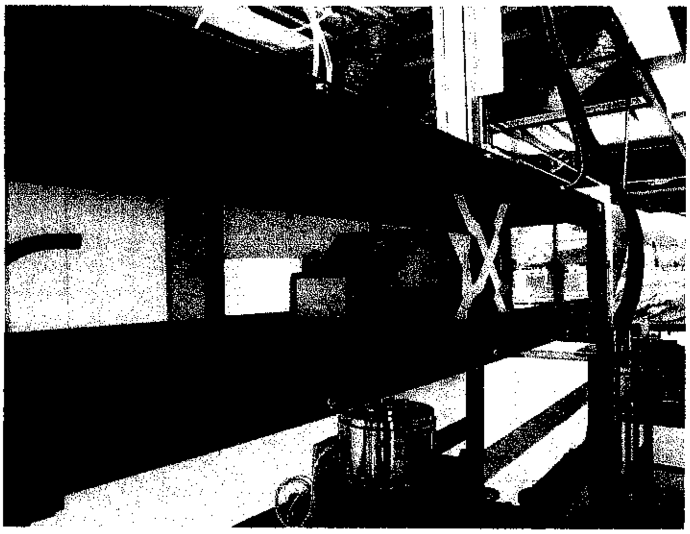


Figure 12: The single model windtunnel setup.

The test is run at wind speed of $5ms^{-1}$ with increment of $5ms^{-1}$ until $50ms^{-1}$. Six readings are taken for each speed, and the average are calculated, noted and plotted. The results of the test are as the following table.

Table 3: The windtunnel results for single model setup.

V (m/s)	Drag (N)	Lift(N)	Cd	Re	Cl
5	11.70	15.36	53.52	4715.71	28.83
10	18.06	24.90	20.66	9431.42	11.69
15	22.38	30.96	11.38	14147.14	6.46
20	26.84	35.50	7.68	18862.85	4.17
25	27.88	36.39	5.10	23578.56	2.73
30	28.94	38.41	3.68	28294.27	2.00
35	32.34	41.20	3.02	33009.98	1.58
40	35.66	42.78	2.55	37725.70	1.25
45	38.85	43.05	2.19	42441.41	1.00
50	41.53	44.59	1.90	47157.12	0.84

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

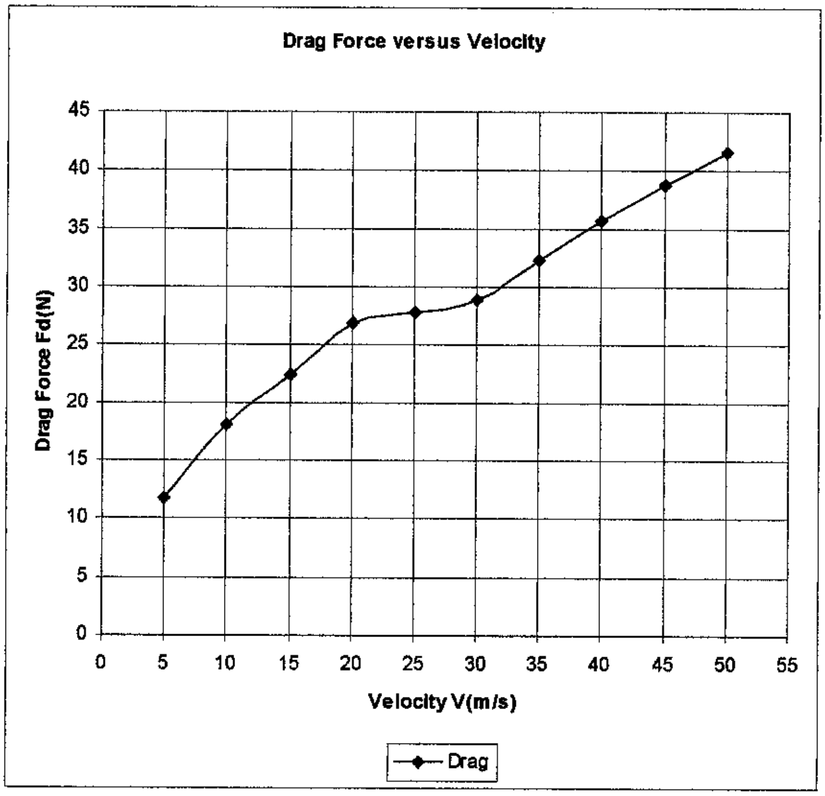


Figure 13: The drag increase with increasing wind speed.

Plotting the drag Coefficient against the Reynolds number reveals the Reynolds number independency of the flow.

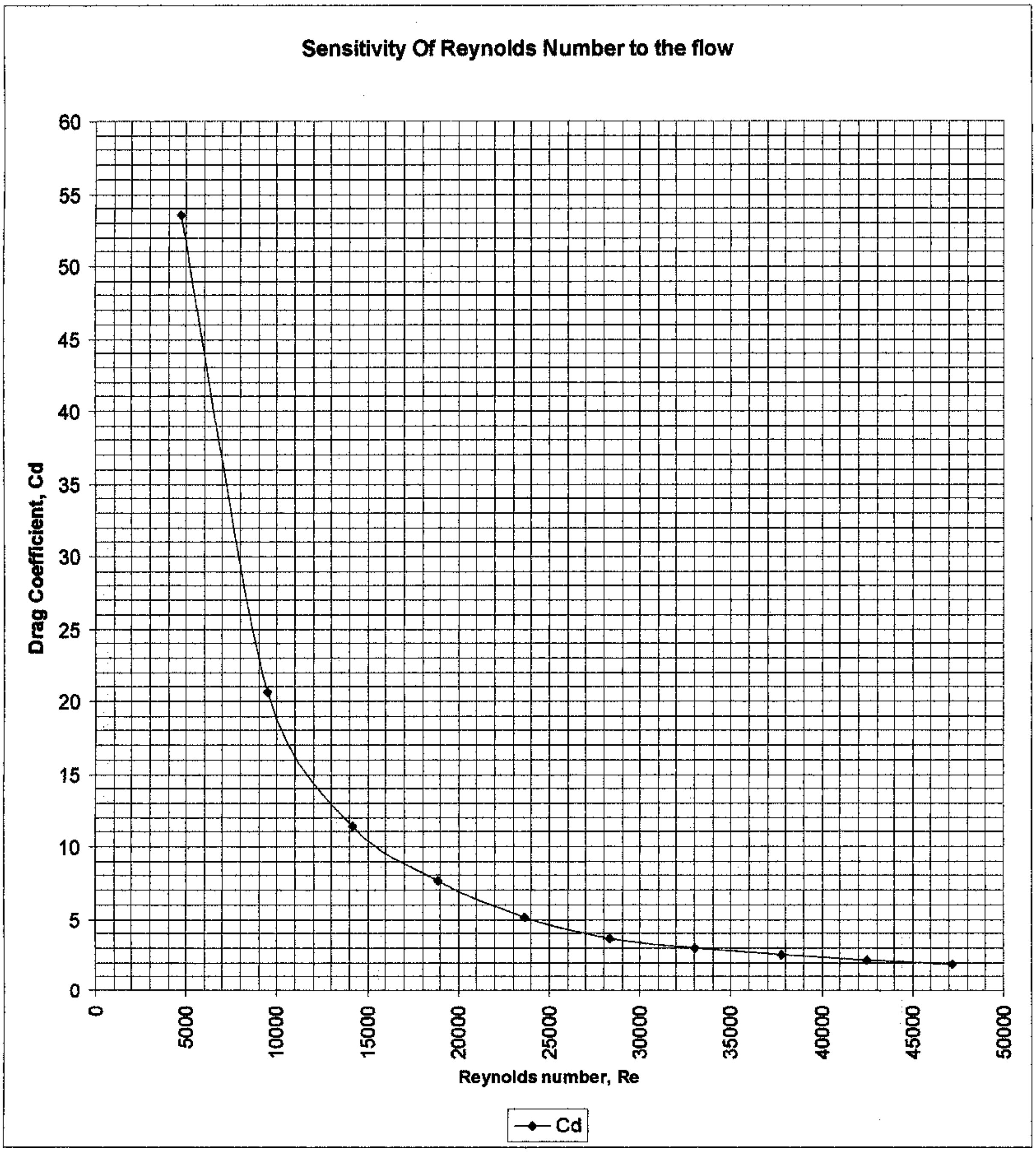


Figure 14: Graph of Drag Coefficient versus Reynolds number. The slope decrease until a certain constant C_D value.

The next setup will be using two models at the same time in the windtunnel. Both models are set to be at a certain distance between each other. The distance is based on the width of the car model, which is, for 1:12 scaled model, the width is 12.5cm. Therefore the setups are:

- One width distance (1W) between the models – approximately 12.5cm
- Twice width distance (2W) between the models – approximately 25.0cm
- Half width distance (0.5W) between the models – approximately 6.25cm
- One Half width distance (1.5W) between the models – approximately 18.75cm

The front model will be 'model 1'. The readings are taken from the model at the back (model 2), which is attached to the three way balance of the windtunnel. This will show the aerodynamic changes effects of the front model on the back model.

For the research, it is important to state that the only concern for the test is the drag force. The balance also gives the lift force reading. However, the lift force is neglected because there is no ground (road) for the wind tunnel setup. Because the lift force is highly affected by the ground, the readings for the lift will not be accurate enough for the study.

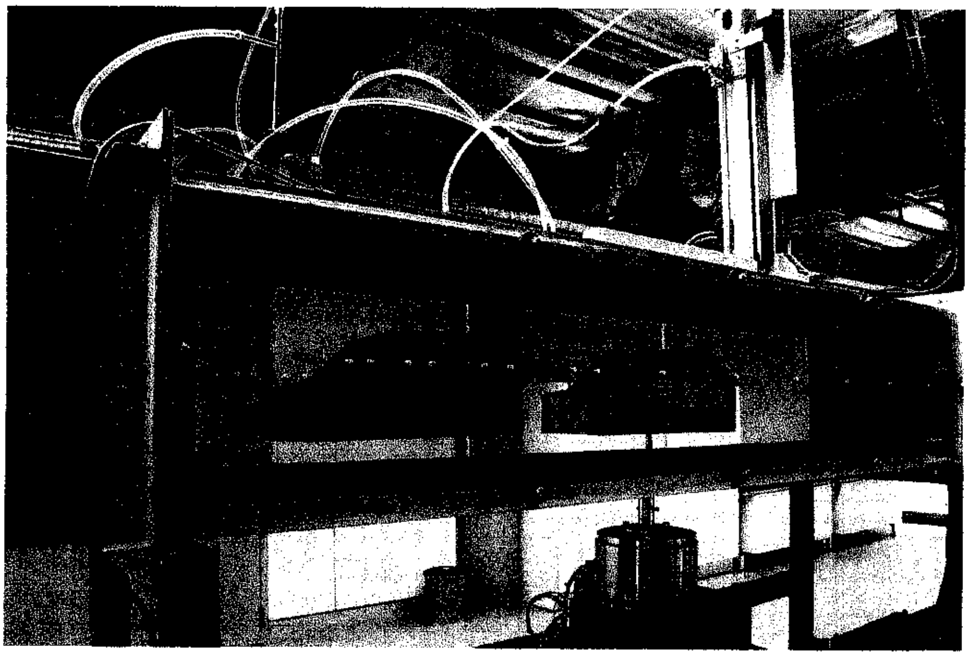
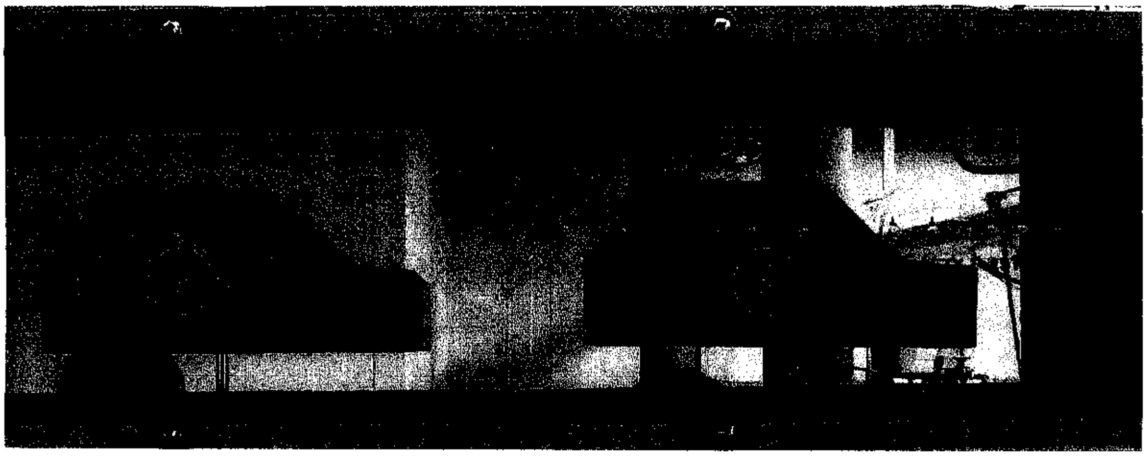


Figure 15: The windtunnel test setup using two models.

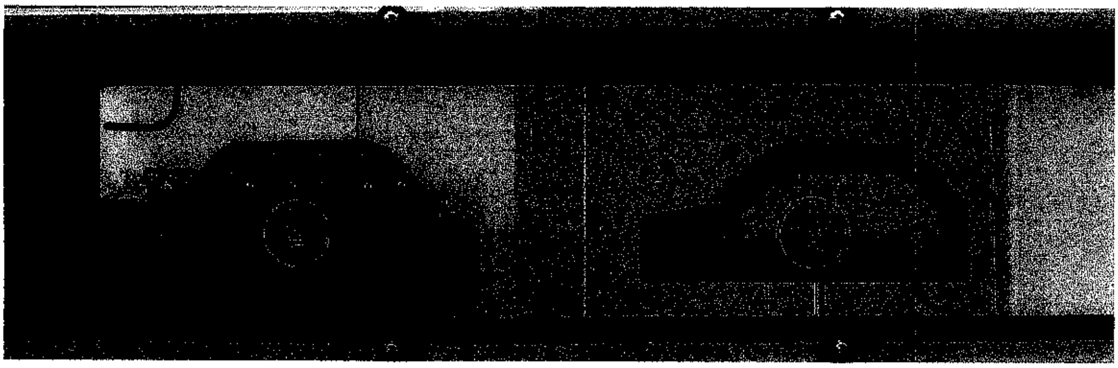


(a)

(b)

Figure 16: (a) The double model setup for 1W distance (12.5cm) and (b) for 2W distance (25 cm)

The test are run as the single model test where the speed is increase starting from $5ms^{-1}$ to $50ms^{-1}$ by the increment of $5ms^{-1}$. Six readings are taken for each speed and the average are calculated for both setups.



(a)

(b)

Figure 17: (a) The double model setup for 1.5W distance (18.75cm) and (b) for 0.5W distance (6.25 cm)

Right after the 2W windtunnel test, the windtunnel motor malfunctions. After some repair work, the test run for 1.5W and 0.5 W distances are done. However, the maximum allowable speed is reduced to $45ms^{-1}$ as a safety precaution to avoid any more malfunctions; by the increment of $5ms^{-1}$. Six readings are taken for each speed and the average are calculated for both setups.

The results for the **one width distance (1W)** setup are as follows.

Table 4: The windtunnel results for double model setup, one width distance.

V (m/s)	Drag (N)	Lift(N)	Cd	Re	Cl
5	12.83	19.13	58.68	4715.71	35.91
10	22.92	25.29	26.21	9431.42	11.87
15	28.69	33.95	14.58	14147.14	7.08
20	31.35	38.27	8.96	18862.85	4.49
25	36.20	43.73	6.62	23578.56	3.28
30	40.58	51.30	5.16	28294.27	2.68
35	42.94	51.35	4.01	33009.98	1.97
40	43.65	53.29	3.12	37725.70	1.56
45	46.67	54.17	2.64	42441.41	1.26
50	47.92	54.84	2.19	47157.12	1.03

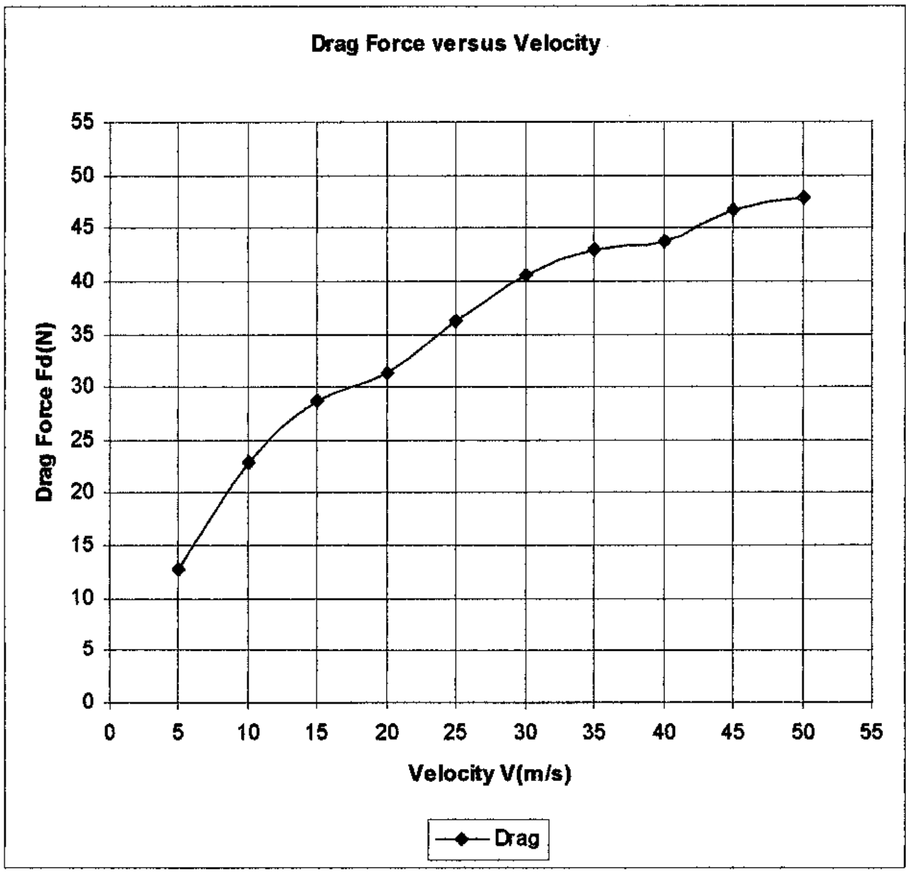


Figure 18: The direct proportional relationship of the drag and the wind speed, for the one width distance setup.

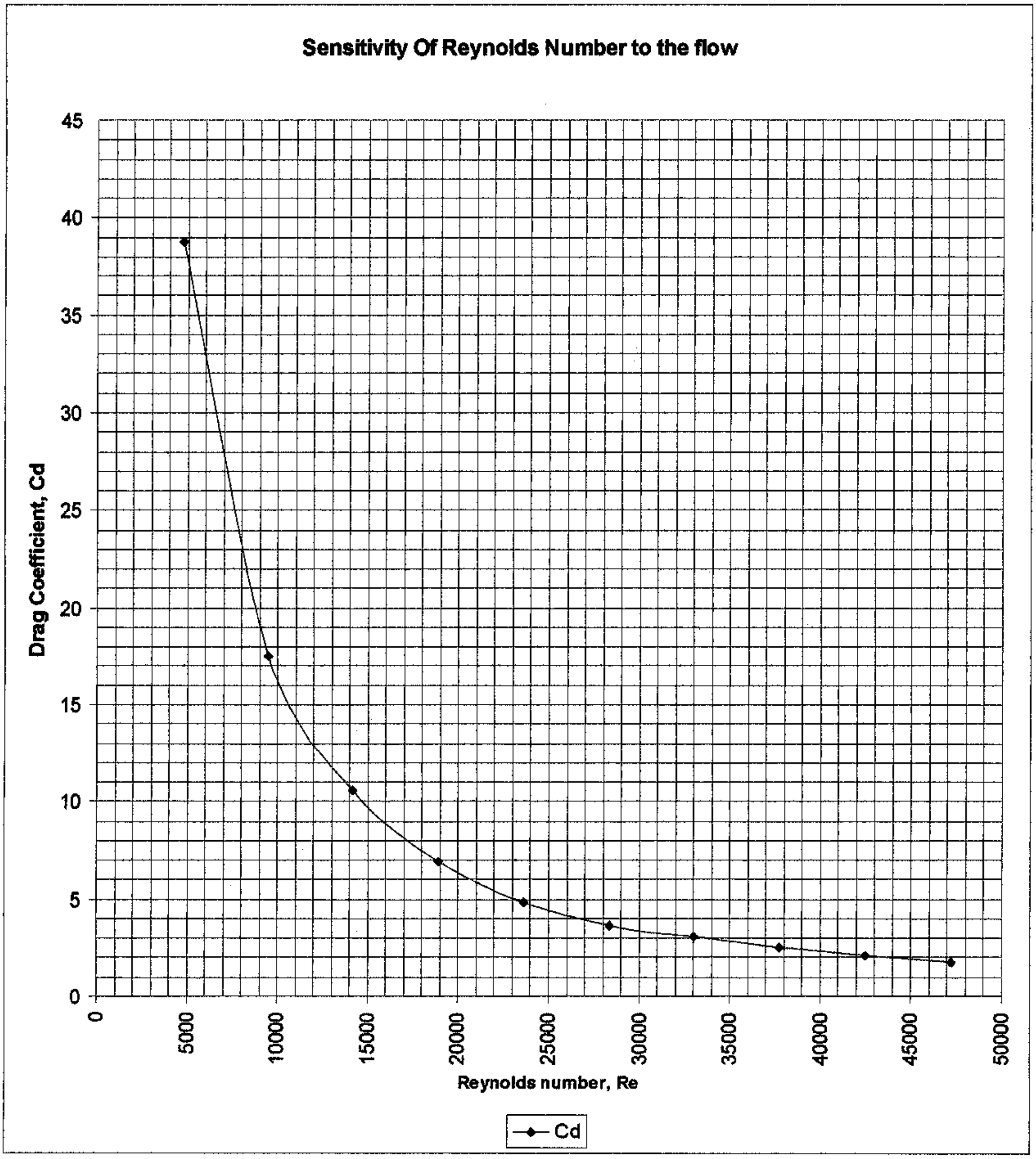


Figure 19: Plotting the drag coefficient against the Reynolds number shows the inverse relationship where C_D value decreases to a constant.

The results for the **twice width distance (2W)** setup are as follows.

Table 5: The windtunnel results for double model setup, one width distance.

V (m/s)	Drag (N)	Lift(N)	Cd	Re	Cl
5	8.48	11.97	38.77	4715.71	22.47
10	15.32	20.53	17.52	9431.42	9.63
15	20.87	26.77	10.61	14147.14	5.58
20	24.20	31.52	6.92	18862.85	3.70
25	26.49	35.45	4.85	23578.56	2.66
30	28.42	37.88	3.61	28294.27	1.98
35	33.13	41.02	3.09	33009.98	1.57
40	35.10	42.90	2.51	37725.70	1.26
45	37.47	44.42	2.12	42441.41	1.03
50	38.71	45.49	1.77	47157.12	0.85

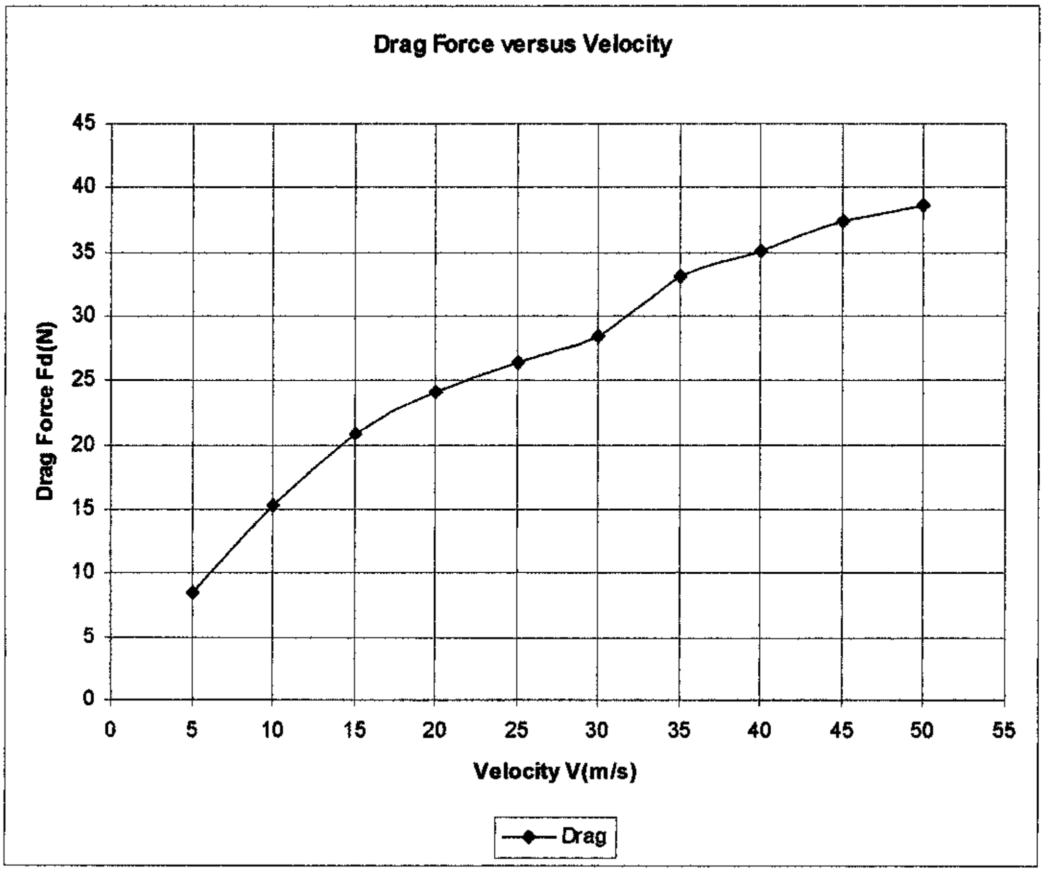


Figure 20: The drag force plotted against the wind speed for the twice width distance setup.

The results for the **one half width distance (1.5W)** setup are as follows.

Table 6: The windtunnel results for double model setup, one half width distance.

V (m/s)	Drag (N)	Cd	Re
5	3.68	16.84	4715.71
10	6.26	7.16	9431.42
15	8.54	4.34	14147.14
20	10.97	3.14	18862.85
25	12.99	2.38	23578.56
30	14.70	1.87	28294.27
35	17.10	1.60	33009.98
40	17.96	1.28	37725.70
45	19.24	1.09	42441.41
50	0.00	0.00	47157.12

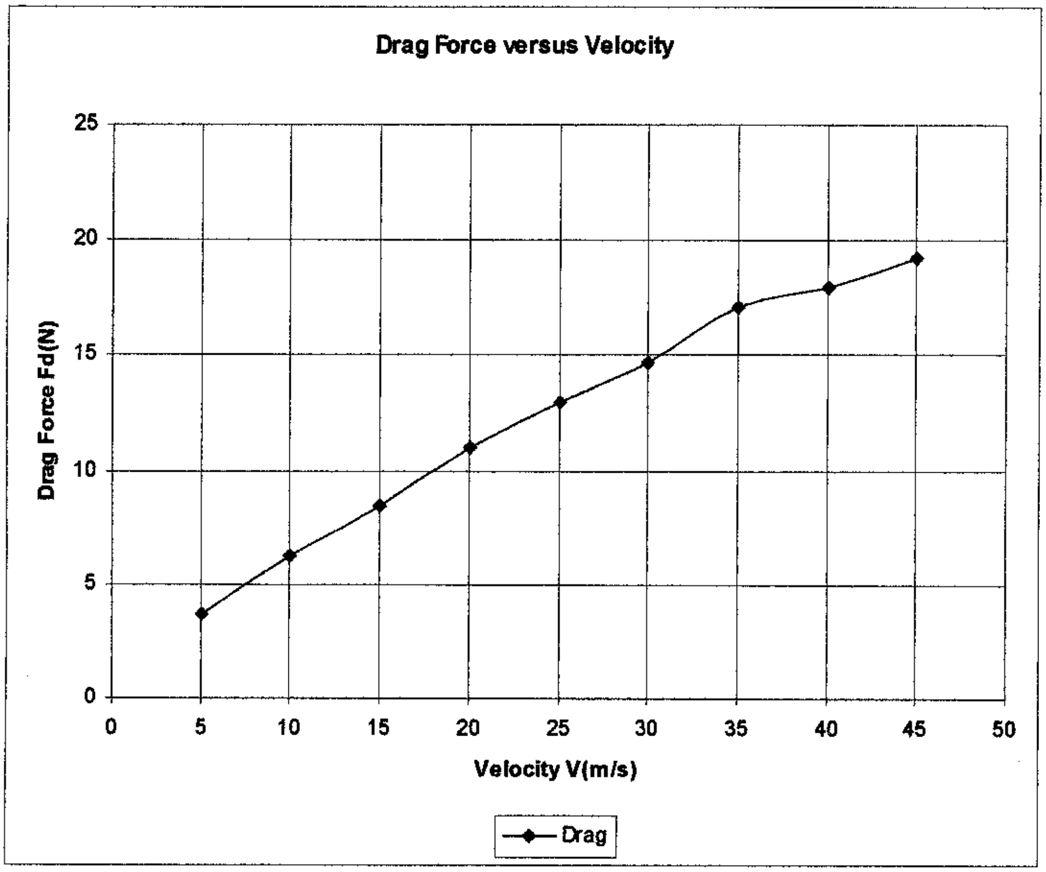


Figure 21: The drag force plotted against the wind speed for the one half width distance setup.

The results for the **half width distance (0.5W)** setup are as follows.

Table 7: The windtunnel results for double model setup, half width distance.

V (m/s)	Drag (N)	Cd	Re
5	0.55	2.50	4715.71
10	0.98	1.12	9431.42
15	1.70	0.87	14147.14
20	1.92	0.55	18862.85
25	2.50	0.46	23578.56
30	4.30	0.55	28294.27
35	6.02	0.56	33009.98
40	8.09	0.58	37725.70
45	9.30	0.53	42441.41
50	0.00	0.00	47157.12

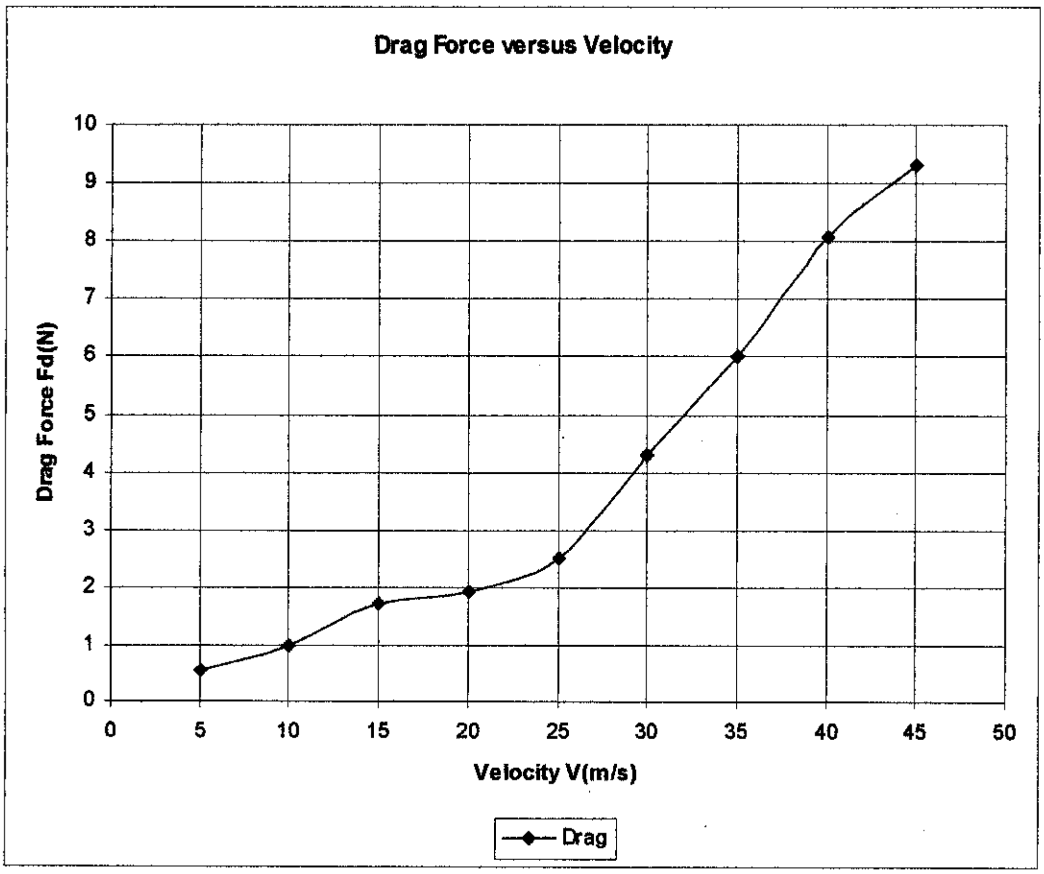


Figure 22: The drag force plotted against the wind speed for the half width distance setup.

The results of all test setup are plotted together to see the difference between the flow.

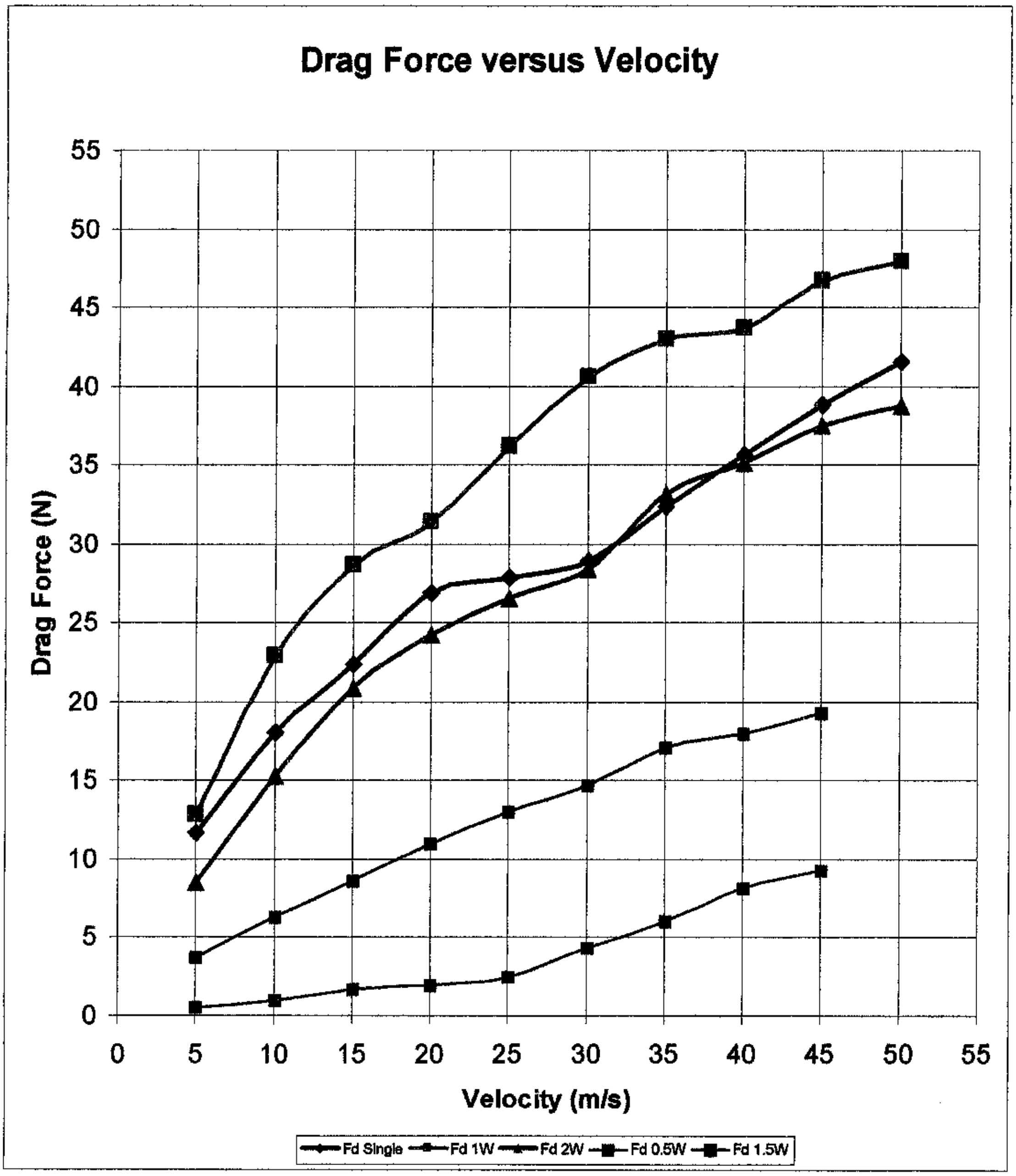


Figure 23: Drag Force versus the wind velocity, with all five distance setups.

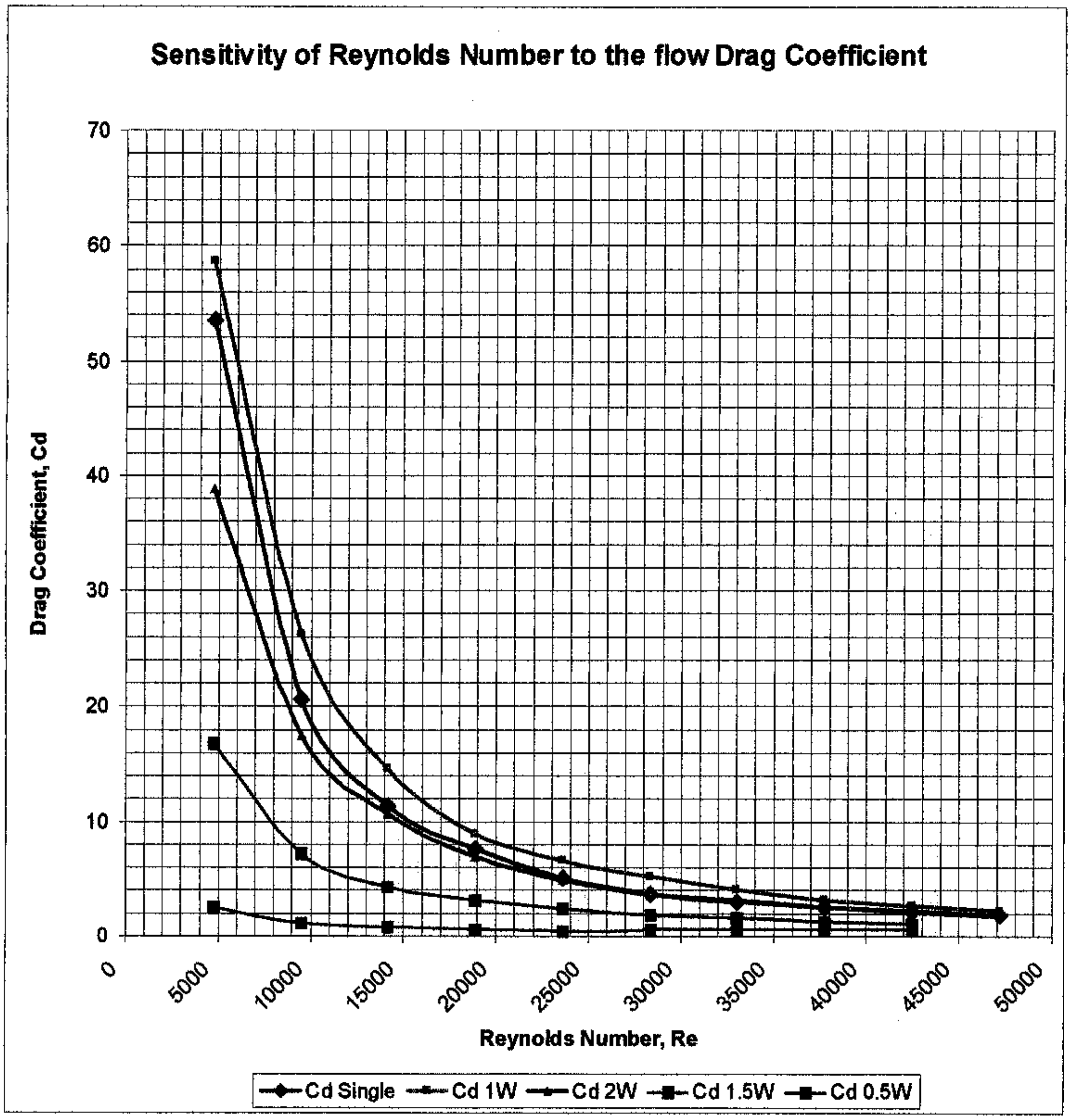


Figure 24: Drag Coefficient versus Reynolds number for all five setups.

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

From Figure 23, it is observed that the drag increase for 1W setup, compared to the normal reading (the reading for single model). However for the 2W setup, the drag force decrease; and the drag decrease even lower for the 1.5W setup. The drag for the 0.5W setup is incredibly low compared to the other readings.

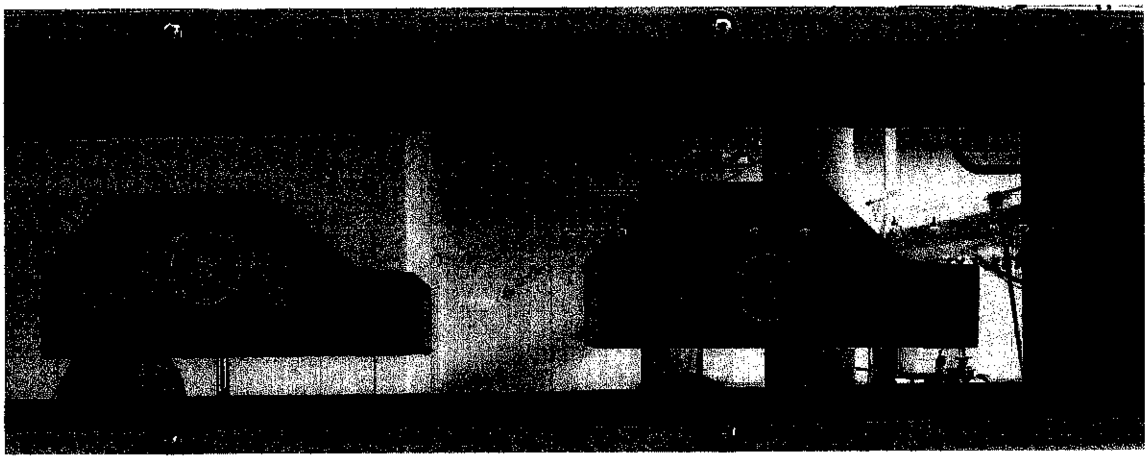


Figure 25: The double model setup.

4.5.1 Drag increase for 1W (12.5cm) distance between models:

This is because model 1 creating a turbulent flow that is directly in front of the 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 wind tunnel test, model 2 seems to shake much more than usual, conforming the higher force acting on it.

4.5.2 Drag decrease for 2W (25cm) distance between the models:

The distance is increased once for this setup. Thus, when the wind flow hit model 1, turbulence is created at the back of model 1. However, this time the flow has time to steady itself and become less turbulent. When it hits model 2, the drag force acting on the model is lesser. The drag reading shows that this setup is almost the same as the single model setup, almost as if there is no second model.

4.5.3 Drag rapid decrease for 1.5W (18.75cm) distance between the models:

The distance is between 1W and 2W. However the drag for this setup is not located between the drag of the previous distance. This setup's drag is much lower compared to 1W and 2W. This result maybe due to the back pressure caused by model 2. For setup 1W, the turbulence is rapid and strong, thus it does not sense the back pressure. But for the 1.5W, the turbulence flow is less strong (as there are more time for the flow to settle down) and it could sense the backpressure from model 2. This backpressure cause the drag to be very low compared to normal readings.

4.5.4 Very low drag for 0.5W (6.25cm) distance between the models:

In this situation, model 2 is very near, directly behind model 1. The drag that is felt by model 2 is very much lesser than normal. This is because, the two models are so near to each other, they are considered to be one body, instead of two. Thus the flow streamline continues until the back of model 2, resulting and almost no drag in front of model 2.

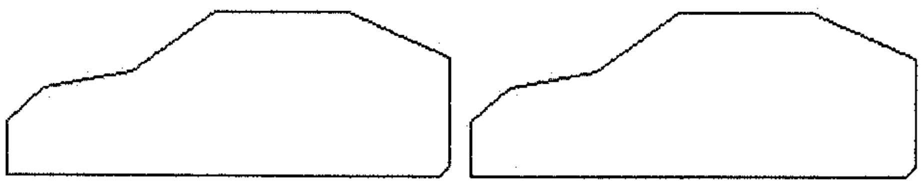


Figure 26: A car tailing another car directly behind it.

4.6 Further Discussion of the windtunnel test results

Based on the data shown in Figure 23, it is to be predicted that for the distance between 1.1W until 1.4W, the drag force reading will decrease until the at the range between 1W's drag and the normal's drag. However, the drag reading for distance setup from

1.6W to 1.9W will be at the range between the two setup's drag, increasing from 1.5W's drag until it becomes the same as the normal drag. For further understanding of the prediction, refer to Figure 27 below.

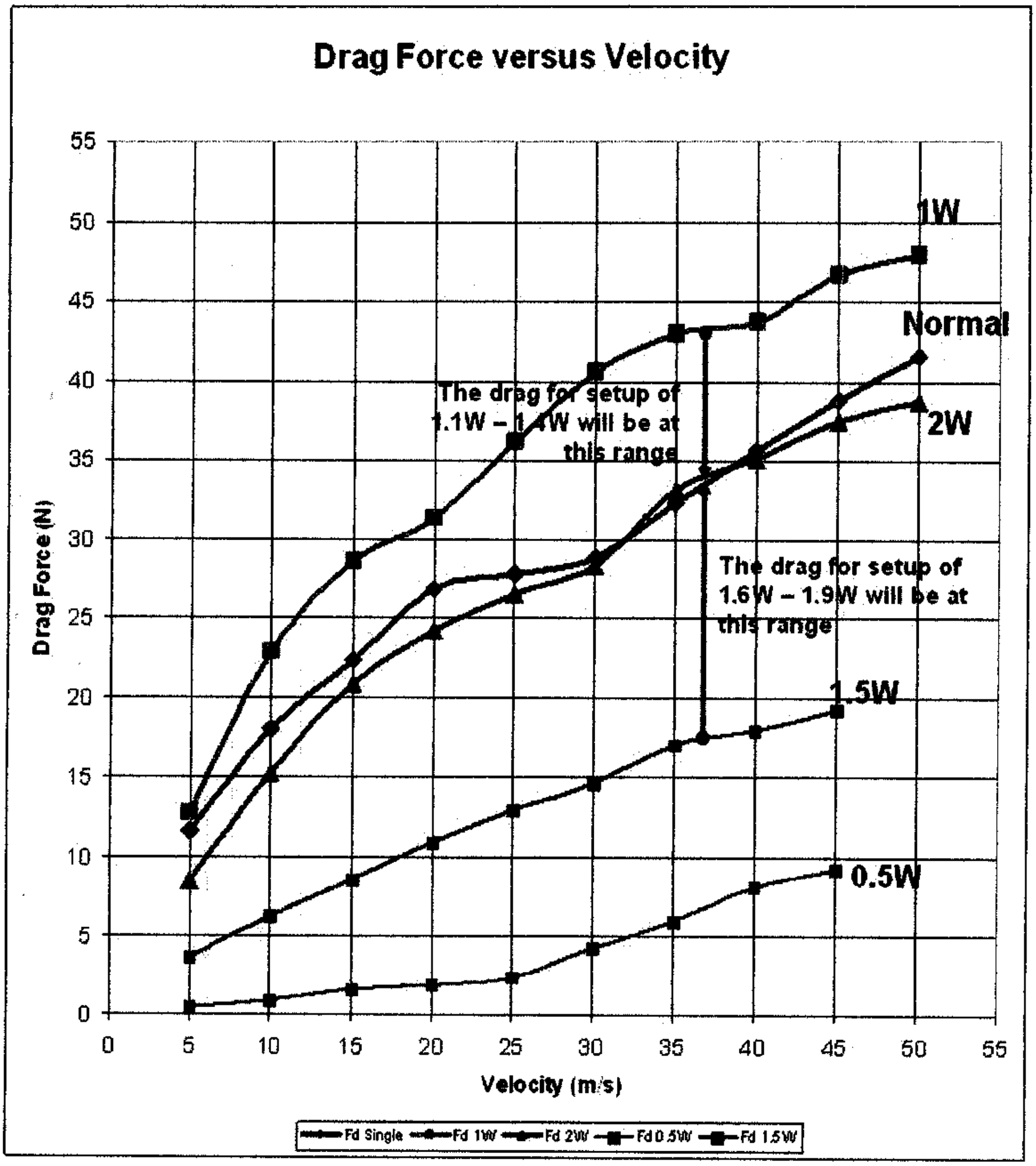


Figure 27: The drag predictions for the different setups from 1.1W – 1.4W and from 1.6W to 1.9W.

4.7 Sensitivity of the wind tunnel test flow to Reynolds number

It can be observe from Figure 21 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 this 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.

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

ρ = density of fluid (air)

A_f = Frontal area of the model

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. This is supposed to be where the driver wants to be as it is safer to drive in a less turbulent wind, and at the same time reduce the petrol consumption for the same speed.

The best position aerodynamically, with the most reduced drag is certainly directly behind the front vehicle (0.5W distance), where the two vehicles will be as one body. However, driving in this position is extremely dangerous as the front vehicle might break suddenly, resulting a crash from the tailing vehicle.

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

Thus **the best position for safety and for better aerodynamic condition** would be at a further distance (**1.5W distance**). In this position, the car will be under much lesser drag force, and the distance from the front vehicle is safe enough. 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 experiment is enough to identify 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

Journals

1. Y. A. Cengel, J. M. Cimbala, 2006, Fluid Mechanics Fundamentals and Applications, Mc Graw Hill.
2. C. Noger, C. Regardin, E. Széchényi, 2005, Investigation of the transient aerodynamic phenomena associated with passing manoeuvres, Journal of Fluids and Structures 21 (2005) 231-241
3. Bruce Reeve, 2001, What makes the Suzuki Hayabusa faster than the more powerful Kawasaki Zx-12R?, Sport Rider.
4. V. Sumatran, G. Sovron, 1996, Vehicle Aerodynamics; PT-49 SAE International.

Website

1. www.boonsiew.com.my
2. www.sportrider.com
3. www.carpages.co.uk
4. www.grc.nasa.gov

Appendixes

Original Right Panel of the Test Section

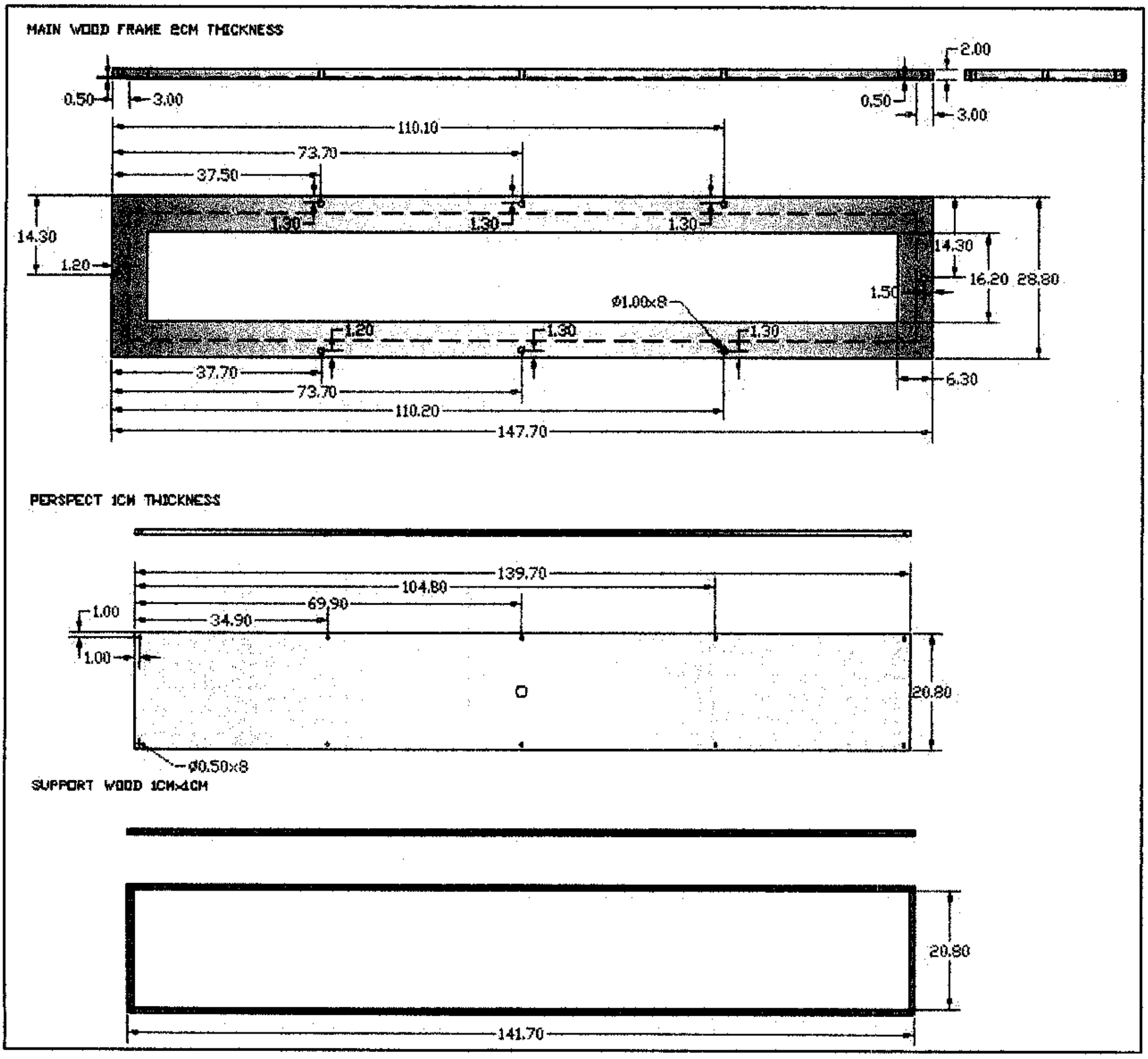


Figure 28: Left panel detail drawing.

Original Left Panel of the Test Section – Left side

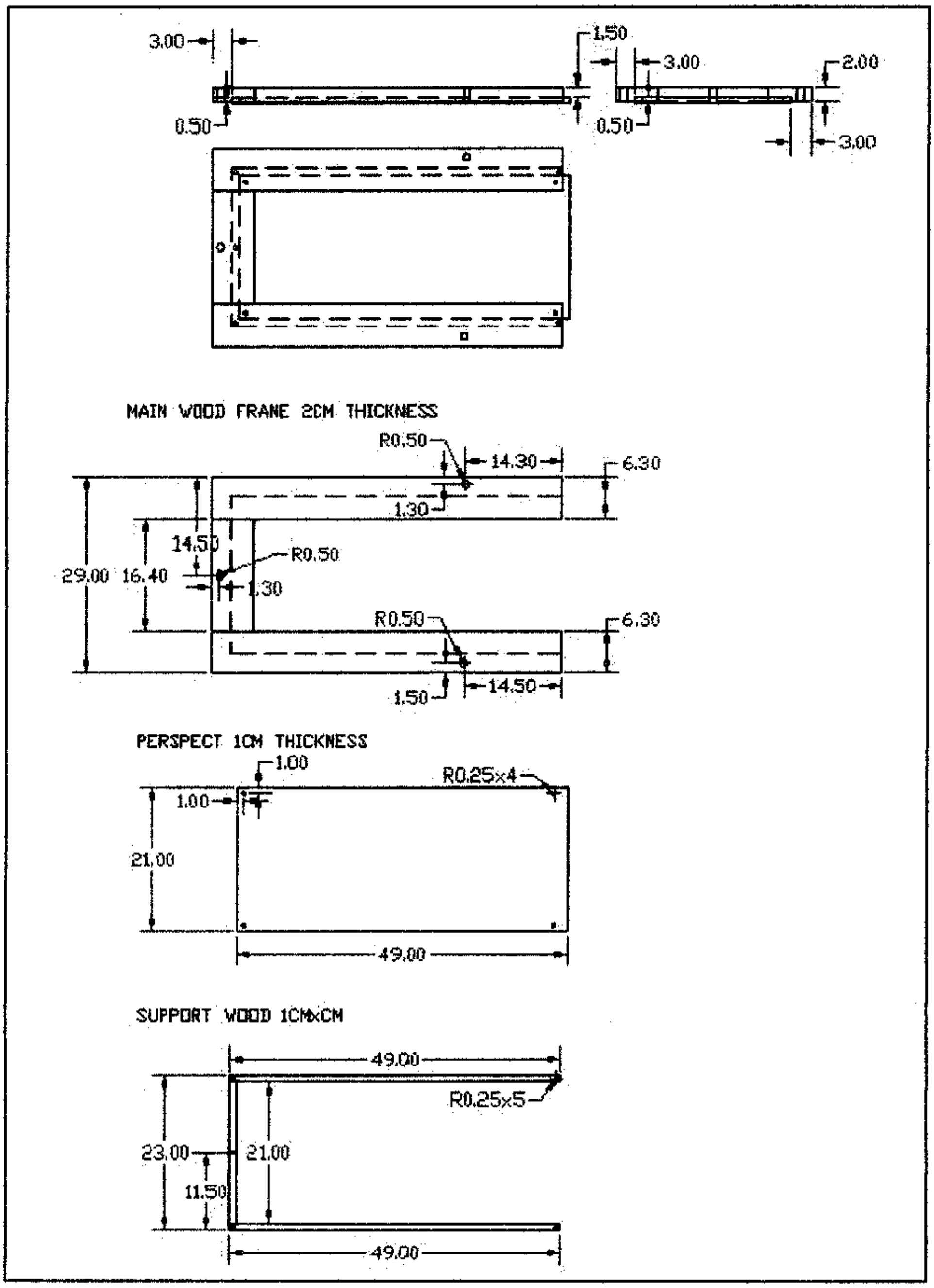


Figure 29: Right panel left side detail drawing.

Original Left Panel of the Test Section – Right side

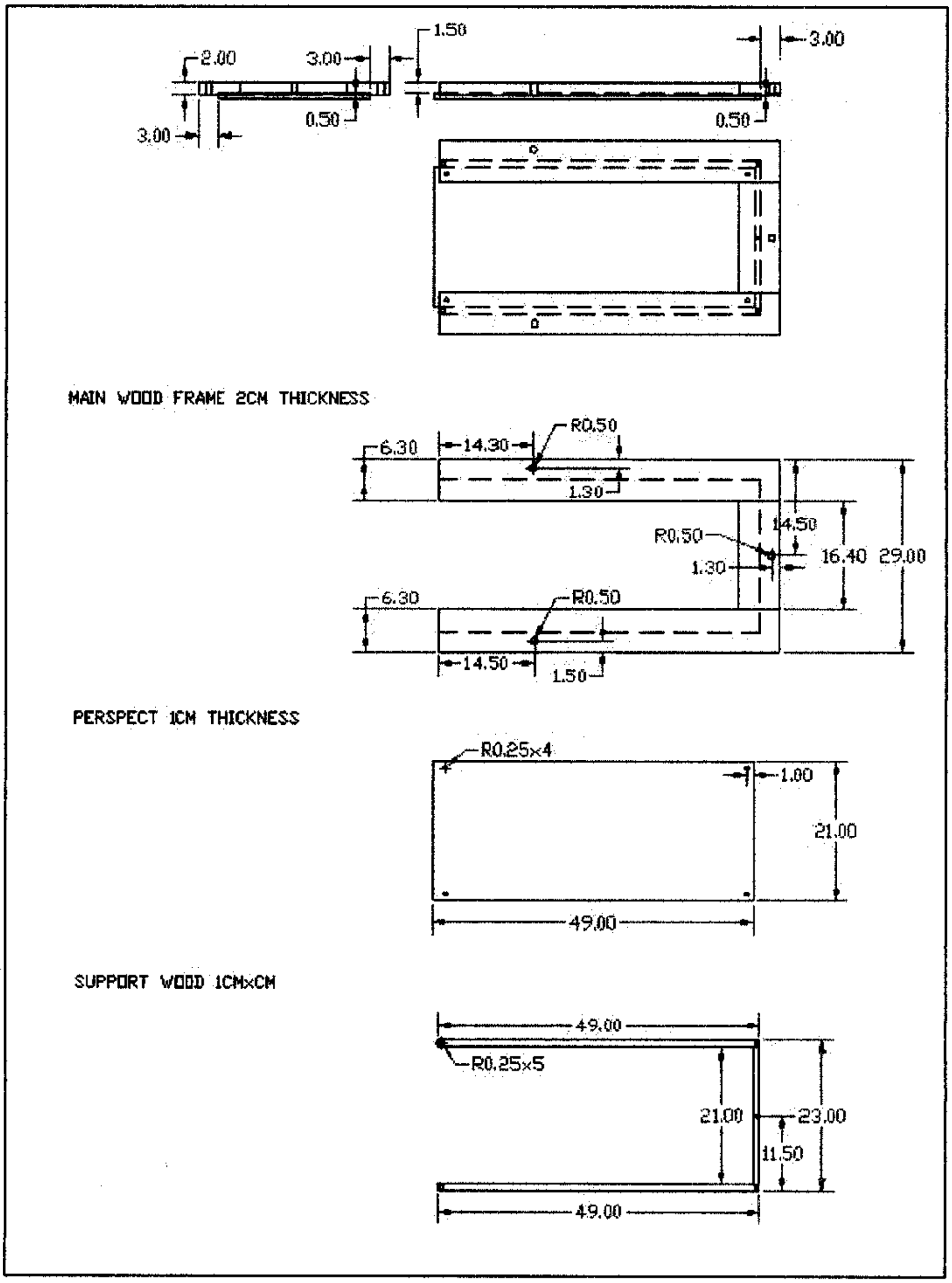


Figure 30: Right panel right side detail drawing.

Original Left Panel of the Test Section - Cover

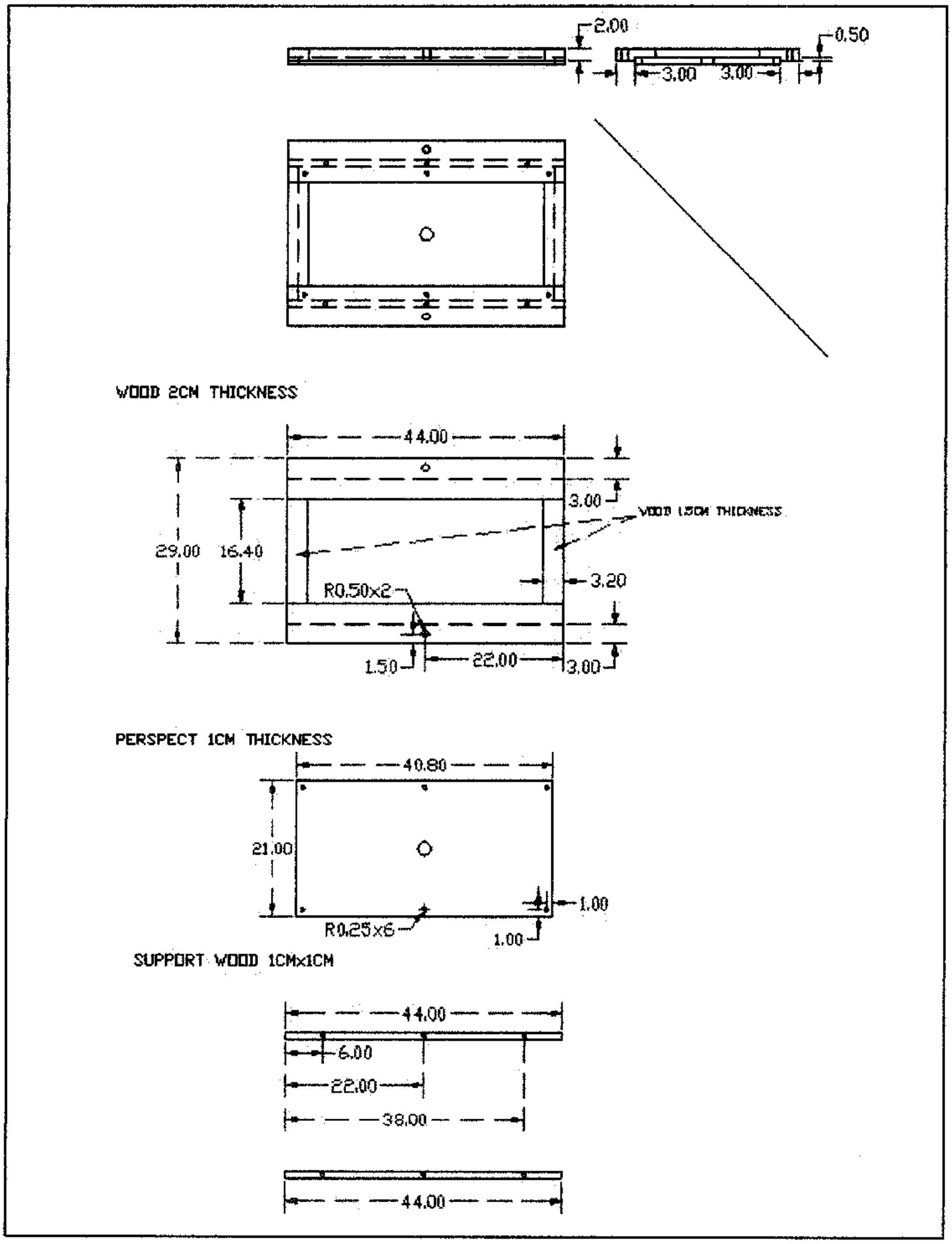


Figure 31: Right panel cover detail drawing.

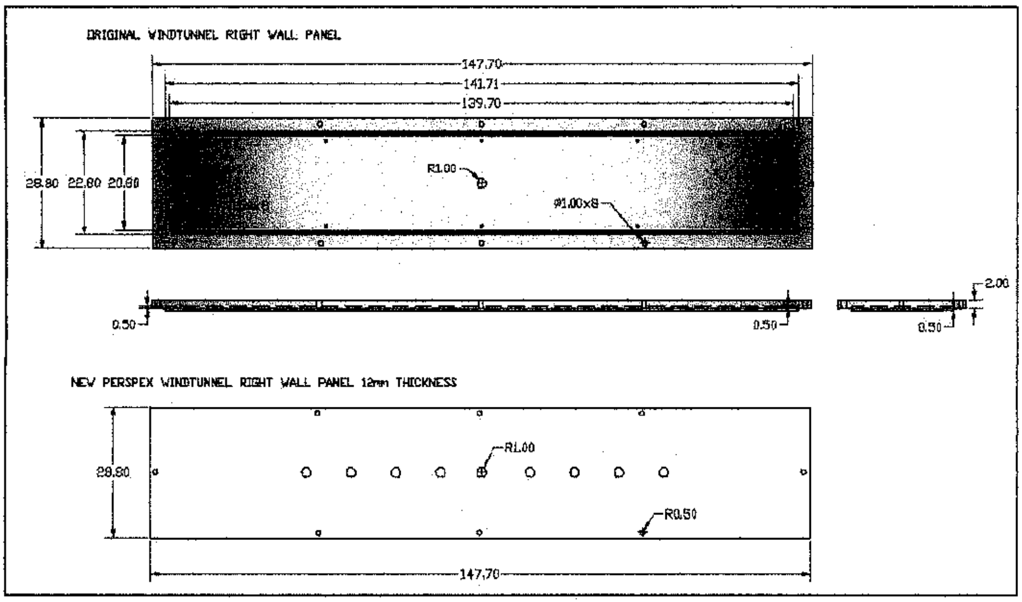


Figure 32: Detail of the right wall perspex panel

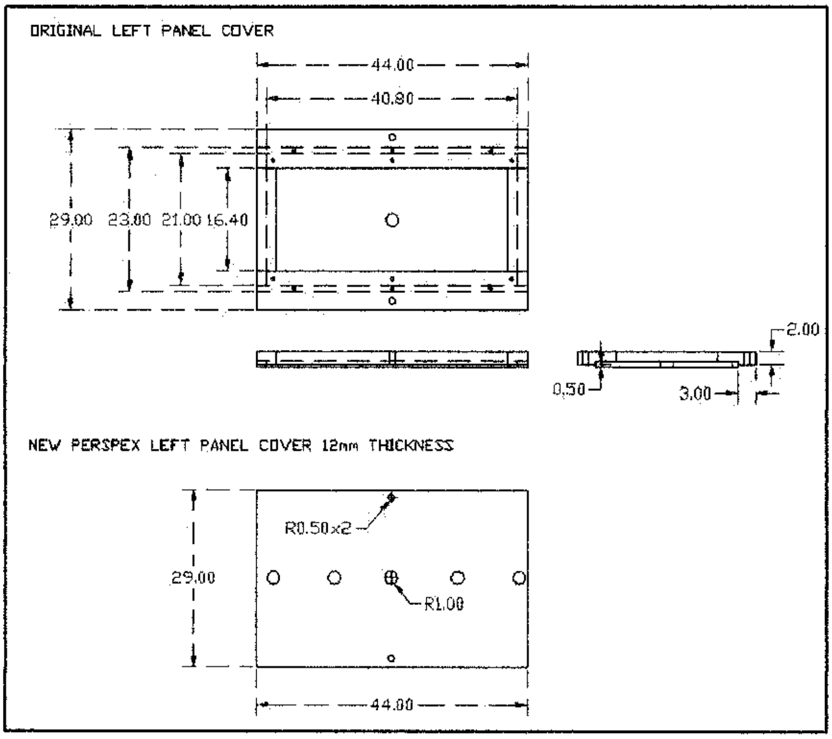


Figure 33: Detail of the left wall cover.

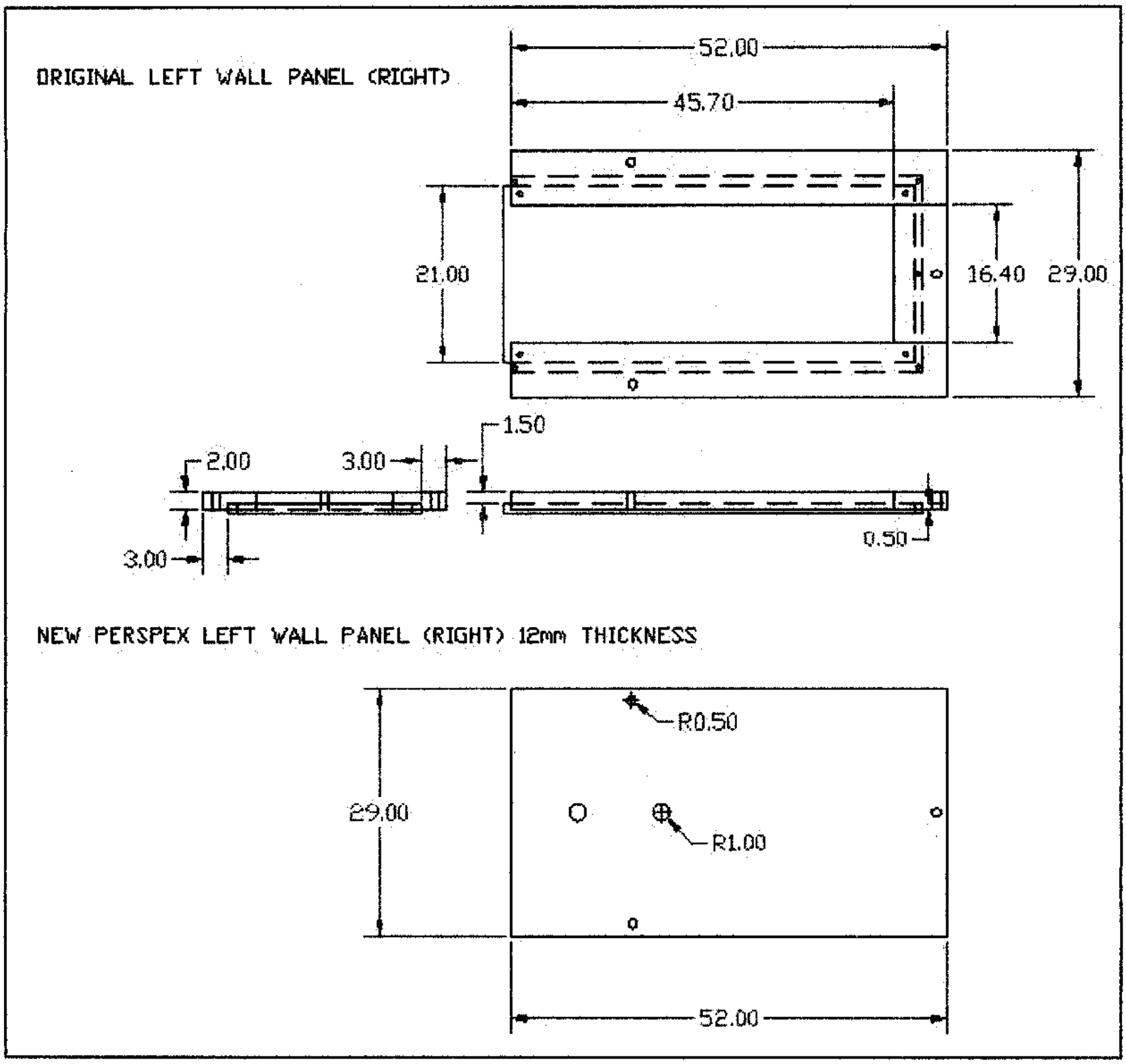


Figure 34: Detail of the left wall panel (right)

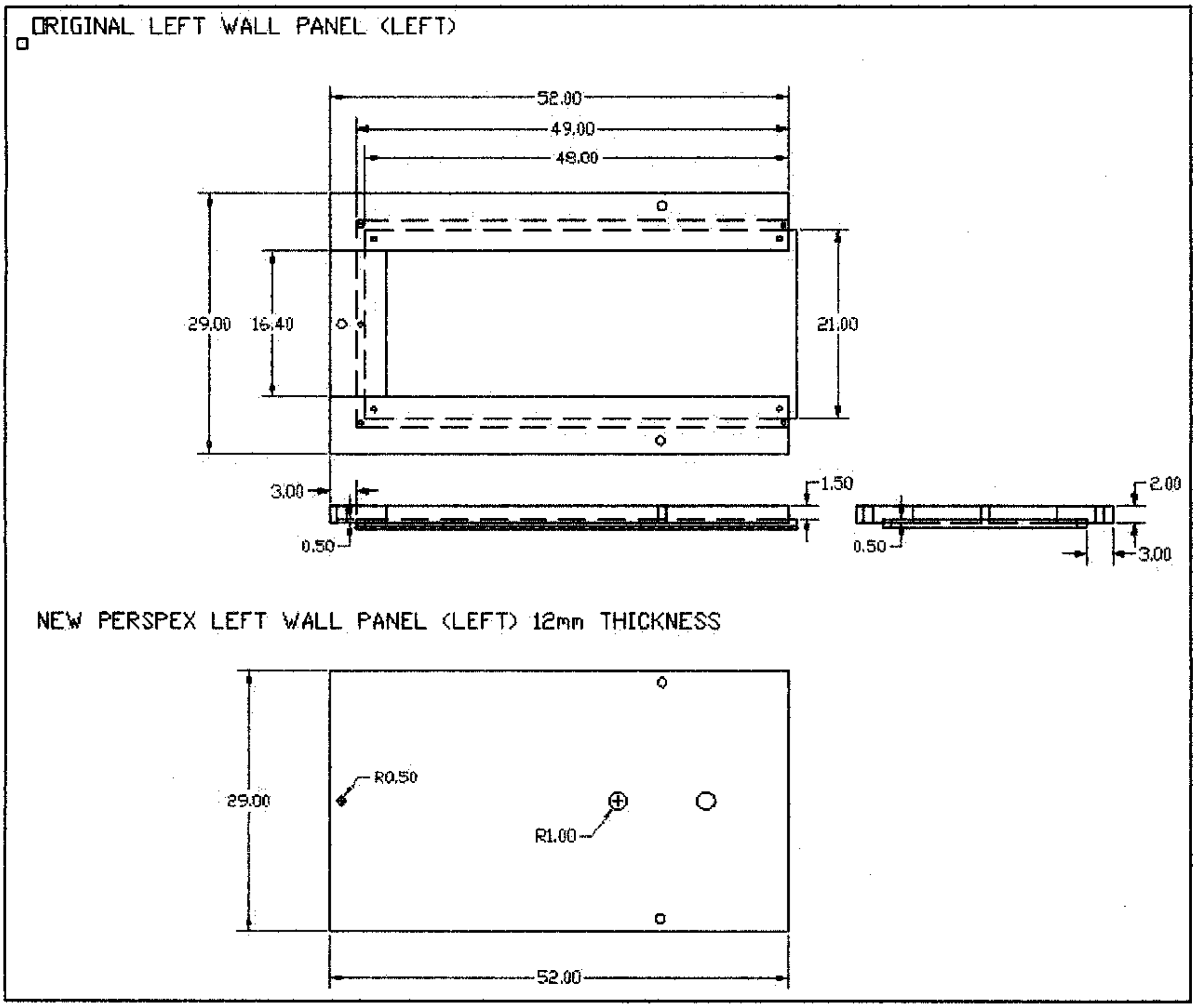


Figure 35: Detail of the left wall panel (left)

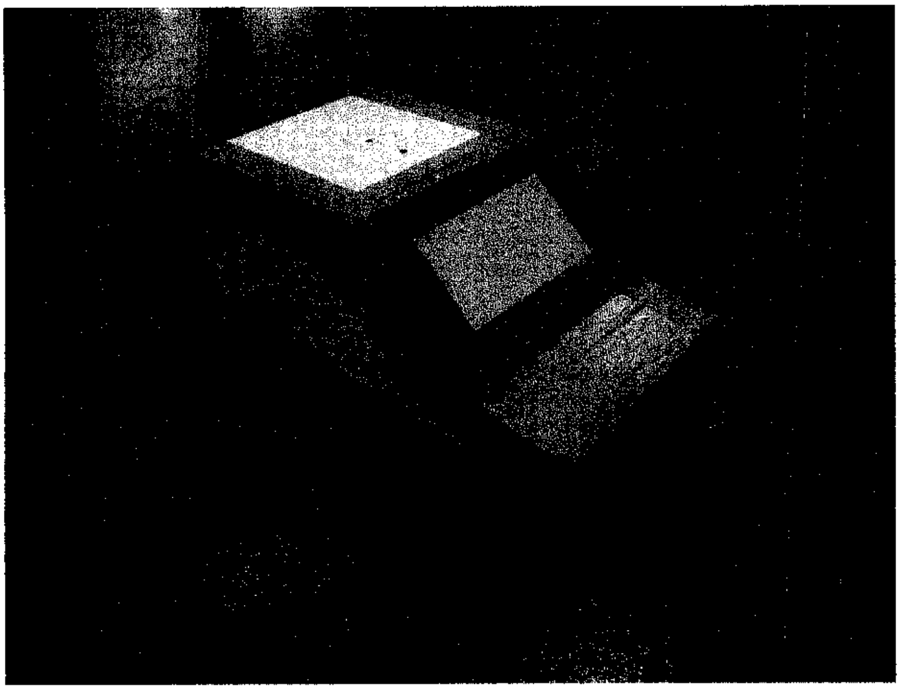


Figure 36: The 1:12 scaled model of a car. The model is the one used at the back (model 2).

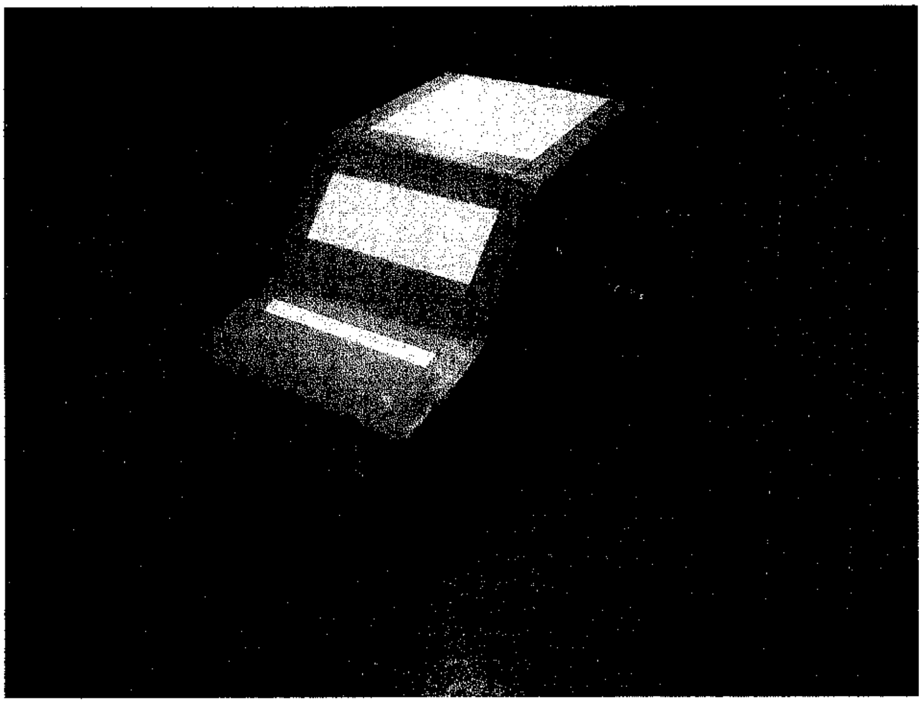


Figure 37: The 1:12 scaled model of a car together with the side supports. The model is the one used at the front (model 1).

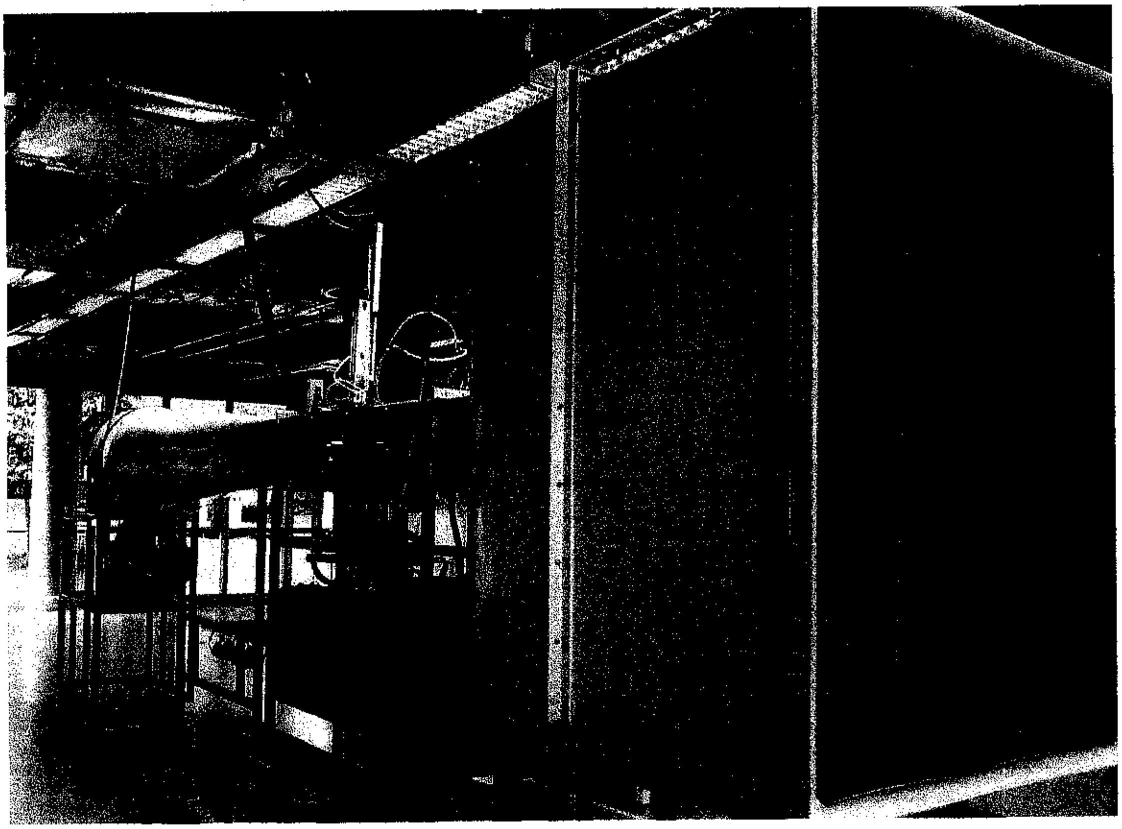


Figure 38: The WT04 Subsonic Windtunnel