DEVELOPMENT OF AERODYNAMIC SMOKE TUNNEL UNIT
FOR TEACHING AND LEARNING

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This technical report is submitted in accordance with the requirements of the
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Faculty of Mechanical Engineering
Uuniversiti Teknikal Malaysia Melaka

APRIL 2009

## CONFIRMATION

"I admit that have read this work and in my opinion this work was adequate from scope aspect and quality to award in purpose Bachelor of Mechanical Engineering (Automotive)"

Signature :………………………………
1st Supervisor"s name:………………………………
Date :………………………………

Signature :………………………………
2nd Supervisor"s name:………………………………
Date :………………………………

# DECLARATION

"I hereby, declare this thesis entitled „Development of Aerodynamic
Smoke Tunnel Unit for Teaching and Learning"
is the result of my own research except as cited in the reference"

Signature :…………………………………………………………………….
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Date : 9 APRIL 2009

# DEDICATION

*To my beloved late father*

*To my beloved mother*

*To my beloved family*

## ACKNOWLEDGEMENT

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# ABSTRAK

Terowong asap adalah salah satu peralatan untuk melihat alur angin yang dihasilkan oleh aliran udara pada model kereta berskala kecil di dalamnya. Ia juga boleh digunakan sebagai peralatan eksperimen untuk belajar mengenai aliran aerodinamik. Tujuan utama bagi projek ini ialah menghasilkan terowong asap berskala kecil bagi tujuan pembelajaran dan pengajaran. Selain itu terowong ini juga digunakan untuk melihat alur angin yg dihasilkan oleh aerodinamik. Antara cara-cara yg digunakan untuk mendapatkan hasil seperti di atas ialah dengan melakukan kajian ilmiah melalui jurnal-jurnal mengenai terowong asap yang yang pernah dilakukan dahulu. Kesimpulannya, terowong asap ini boleh digunakan untuk melihat alur angin yang dihasilkan oleh aerodinamik.

## ABSTRACT

The smoke tunnel unit is one of method to visualize the aerodynamic flow trajectory occurred on small scale vehicle model. It can also be used as an experiment apparatus to study about aerodynamic. The main goal of this project is to design the aerodynamic smoke tunnel unit (small scale) for T&L and to visualize the aerodynamic flow trajectory occurred on vehicle model using the smoke tunnel. Aiming to achieve this goal, several techniques were carried out with method. In the first phase of the case study, the step taken such as do the literatures review on the previous journal of smoke tunnel. The conclusions of this project that are the aerodynamic flow trajectory can be visualize using the smoke tunnel.

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# LIST OF ABBREVIATIONS, SYMBOLS AND SPECIALIZED NOMENCLATURE

| | | |
|---|---|---|
| AC | = | alternating current |
| CFD | = | Computational Fluid Dynamic |
| $C_D$ | = | drag coefficient |
| F | = | Fahrenheit |
| $ft^3$ | = | feet cubic |
| lbs | = | pounds |
| $m^3$ | = | meter cubic |
| mph | = | miles per hour |
| psi | = | pound per square inch |
| $p$ | = | air pressure |
| $\rho$ | = | air density |
| µm | = | micrometer |
| $V$ | = | speed. |
| V | = | volt |

# APPENDIX

# CHAPTER 1

# INTRODUCTION

## 1.0 Introduction

Aerodynamic is important factor consider in design stage. Though the term "aerodynamics" is most commonly associated with airplanes and the overall science of flight, in fact, its application is much broader. Simply put, aerodynamics is the study of airflow and its principles, and applied aerodynamics is the science of improving manmade objects such as airplanes and automobiles in light of those principles. Aside from the obvious application to these heavy forms of transportation, aerodynamic concepts are also reflected in the simplest of manmade flying objects and in the natural model for all studies of flight, a bird's wings.

The smoke tunnel is one of method to visualize the aerodynamic flow trajectory occurred on small scale vehicle model. This equipment designed to help the lecturer to visualize and explain about aerodynamic effect on frontal edge or etc. Student will know and learn the term practically to support the theory or simulation (CFD). This equipment will be used as a practical lesson through experiment in order to compare theoretical with simulation.

The smoke tunnel itself was designed to be a complete, stand-alone, sub-scale subsonic project; small enough to be carried anywhere, but it can be used to gain meaningful data. Besides, student will be given a chance to learn to use the smoke tunnel by themselves as an experiment.

## 1.1 Objectives

- To design the aerodynamic smoke tunnel unit (small scale) for T&L.

## 1.2 Scope

- Literature study on standard smoke tunnel and aerodynamic effect.
- Design an appropriate scale and concept for measure and experimental purpose.
- Drawing design of the smoke tunnel using Engineering Tools (Catia VR16).
- Data comparison from experiment expected result with theory (using present CFD result).

## 1.3 Problem Statement

Normally wind tunnel is used as a medium to gather any information that related to aerodynamic such as velocity, pressure, density and temperature. However, wind tunnel cannot be used to visualize the air flow trajectory over the vehicle body. That is why smoke tunnel was invented. Smoke tunnel can be used to visualize the air flow trajectory because smoke can visualize the aerodynamic air flow that occurs over the vehicle model.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Introduction

This literature review is discussed about research which had been made previously about smoke tunnel. It also discussed the points which related to this project such as smoke tunnel design and aerodynamic flow trajectory. The objective of the literature review is to appreciate and explain in detail about journal read as the guideline for this project research. All information about wind tunnel can also be use because it is not much differing from smoke tunnel. Since the current project is to design an experiment for aerodynamic flow visualization, all the information regarding aerodynamic, wind/smoke tunnel, CFD and any related information should be collected.

## 2.1 Aerodynamic

Aerodynamics is a dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Aerodynamics is closely related to fluid dynamics and gas dynamics, with much theory shared between them. Aerodynamics is often used synonymously with gas dynamics, with the difference being that gas dynamics applies to all gases. Understanding the motion of air (often called a flow field) around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties. The use of aerodynamics through mathematical analysis, empirical approximation and wind tunnel experimentation form the scientific basis for heavier-than-air flight.

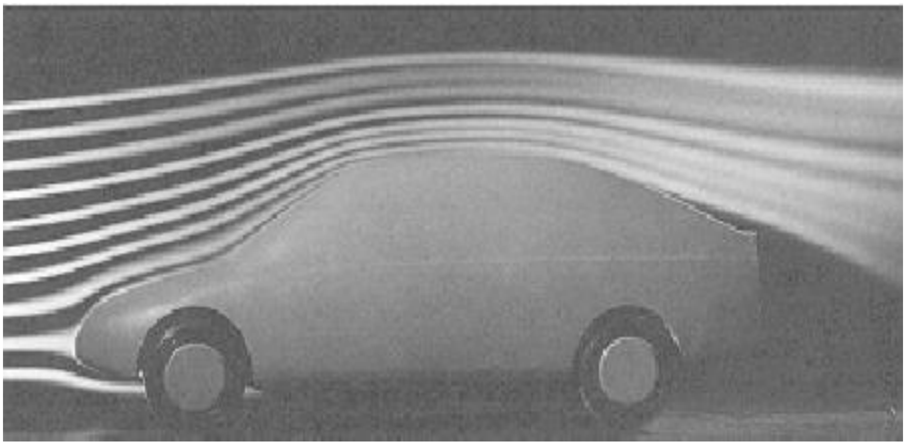

Figure 2.1: The picture shows the streamlines over the vehicle body.
(Source: www.kasravi.com)

When air flows from a region of high pressure to one at a lower pressure, the pressure difference provides a force in the direction of flow, and the air therefore accelerates. Conversely, flow from a low pressure to a higher one results in a decrease in speed. As illustrated in Figure 2.2, region of high pressure are therefore associated with low speeds, and areas of low pressure are associated with high speeds (in the absence of friction effects).

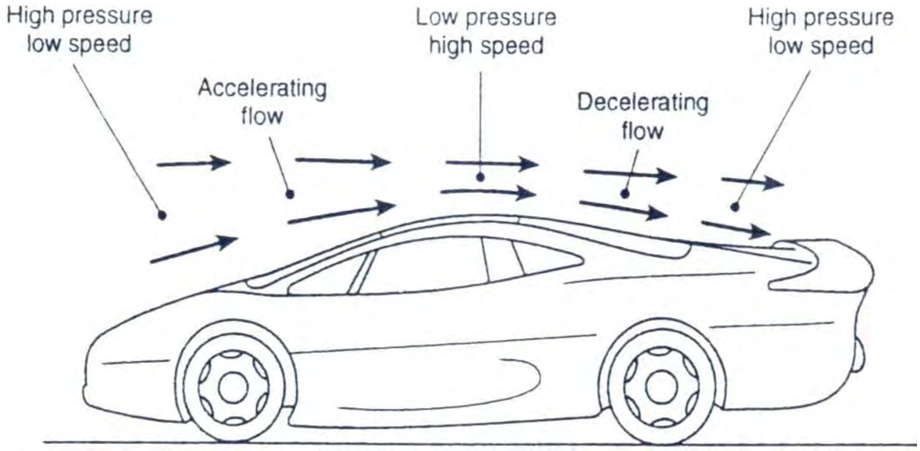


Figure 2.2: Pressure and speed. (The air accelerates when flowing from a high pressure to a low one and slows down when flowing from a low pressure to a high one). (Source: Barnard, 2001)

There is one relationship that is absolutely fundamental to the study of air flows and that is the Bernoulli equation. Bernoulli‟s equation can be written as below:

$$p + \frac{1}{2}\rho V^2 = \text{constant}\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where $p$ is the pressure, $\rho$ is the density and $V$ is the speed.

There are three pressure related to aerodynamic, that are static pressure, dynamic pressure and stagnation pressure. Static pressure is air pressure at any point while dynamic pressure actually represents the kinetic energy of a unit volume of air ($m^3$ or $ft^3$). Dynamic pressure represented as $\frac{1}{2}\rho V^2$ in mathematical symbol. Aerodynamic forces such as lift and drag are directly dependent on the dynamic pressure. At any point in the flow where the speed is zero (the lowest possible value), the pressure must reach its maximum value because this maximum pressure is associated with stagnant condition (zero flow speed). It is known as the stagnant pressure. In the context of cooling air flows and engine air intakes, the stagnant pressure is commonly referred as the ram air pressure.

There are three types of aerodynamic forces that are lift force, drag force and side force (Figure 2.3). The most important aerodynamic factor for the design of

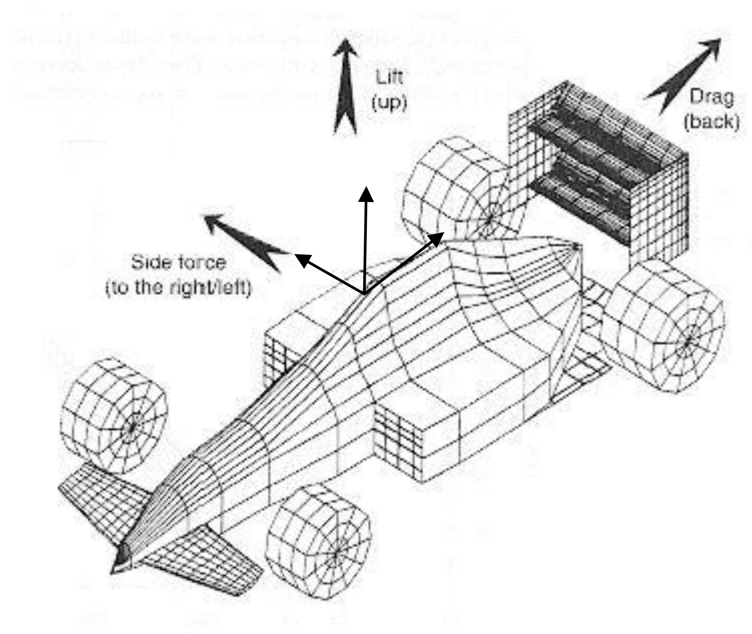


Figure 2.3: Aerodynamic forces. (Source: www.kasravi.com)

normal road vehicles is the drag force. The total force resisting the forward motion of a road vehicle comes partly from the rolling resistance of the wheels and partly from aerodynamic drag. The aerodynamic drag dominates at speeds above about 65-80 km/h (40-50 mph) and there are considerable economic and performance advantages to be gained from drag reduction. Drag coefficient ($C_D$) is mainly dependent on the shape of the vehicle. The aerodynamic drag also depends on the frontal area of the vehicle, the air density and the square of the relative air speed. The relationship between drag and these factors can be expressed by:

$$\text{Drag} = \frac{1}{2}\rho V^2 A C_D \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $A$ is the frontal area

$\rho$ is the density of the air

$V$ is the speed of the vehicle relative to the air

Knowing the drag coefficient and the projected frontal area, formula above can be used to work out the drag at any speed. Unfortunately, drag coefficient also dependent on a Reynolds number ($\rho Vl/\mu$). The dependence on Reynolds number means that drag coefficient varies with speed, but fortunately, over the normal range of road vehicle cruising speeds, the changes are usually insignificant and $C_D$ can be treated as if it were a constant. It is only when testing small scale vehicle model in a wind tunnel that the variation of $C_D$ with Reynolds number becomes important. The lower value of $C_D$ means the car has larger frontal area. As an example, VW Microbus has 0.45 value of $C_D$ compared to F1 car is 1.00 value of $C_D$. (Table 2.1)

Table 2.1: $C_D$ and $C_DA$ values for various vehicles. (Source: Barnard, 2001)

| Vehicle | $C_D$ | $C_DA$ |
|---|---|---|
| Bugatti type 51 (1933) | 0.74 | 0.96 |
| VW Beetle | 0.48 | 0.87 |
| Jaguar D-type (1955) | 0.49 | 0.59 |
| Citroen DS (1958) | 0.37 | 0.81 |
| VW Microbus (1958) | 0.45 | 1.04 |
| Ford Sierra | 0.34 | 0.67 |
| Tiga G83 Group C Sports racer (1983) | 0.24 | 0.38 |
| Formula 1 G.P. Slow circuit | 1.00 | 0.98 |
| GM Calibra | 0.26 | 0.49 |

Figure 2.4 shows how the boundary layer grows on the surface of a vehicle. There are two distinctive types of boundary layer flow. Near the front edge, the flows smoothly with no turbulent perturbations and appear to behave like laminae sliding over each other with friction, the outer ones moving faster than the inner ones. This type of flow is called laminar flow. Further long, there is a sudden change or transition to a turbulent type in which random motion is superimposed on the average flow.

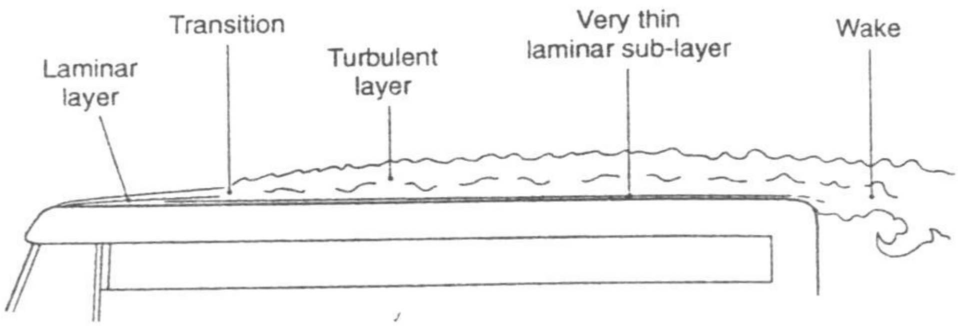


Figure 2.4: Boundary layer growth on the roof of a bus. (Source: Barnard, 2001)

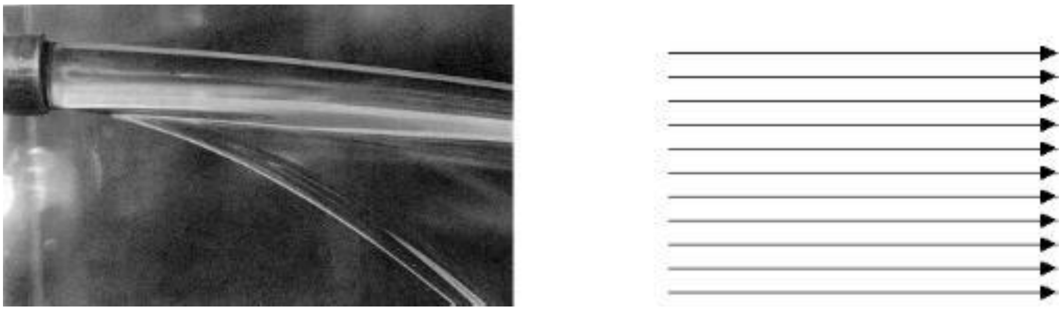

Figure 2.5: Laminar Flow. It has the ideal aerodynamic properties.
(Source: www.kasravi.com)

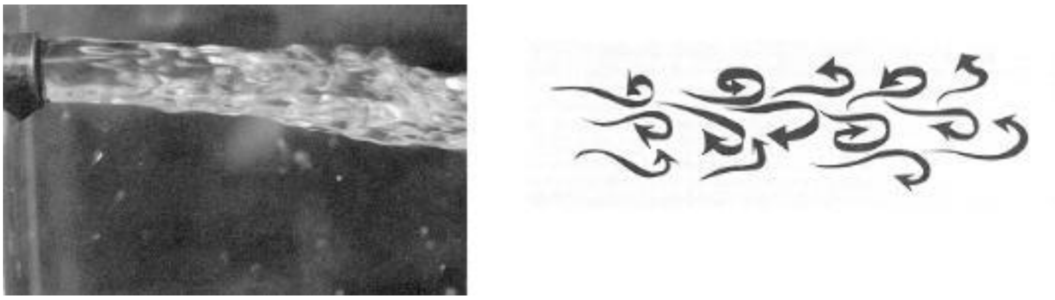

Figure 2.6: Turbulent Flow. It has undesirable properties.
(Source: www.kasravi.com)

The two types of boundary layer flow (Figure 2.5 and Figure 2.6) have important differences in their properties and these can be exploited in aerodynamic design. The main practical effects are that the laminar layer produces less drag due to friction with the surface but in a turbulent boundary layer, the flow is more likely to follow the contour of the body which usually results in lower „pressure drag‟.

Aerodynamic problems can be identified in a number of ways. The flow environment defines the first classification criterion. External aerodynamics is the study of flow around solid objects of various shapes. Evaluating the lift and drag on an airplane, the shock waves that form in front of the nose of a rocket or the flow of air over a hard drive head are examples of external aerodynamics. Internal aerodynamics is the study of flow through passages in solid objects. For instance, internal aerodynamics encompasses the study of the airflow through a jet engine or through an air conditioning pipe.

## 2.2 Smoke Tunnel

Smoke tunnel is an apparatus for studying the interaction between a solid body and an airstream. Normally smoke tunnel is used to visualize flow trajectory occurred on the vehicle model. A smoke tunnel simulates the conditions of a vehicle in moving by causing a high-speed stream of air to flow past a model of the vehicle being tested. Applications of smoke tunnel research range from testing of airframes (the structures of aircraft and spacecraft) to research on the boundary layer, turbulence, drag, and lift. Measurements of air pressure and other characteristics at many points on the model yield information about how the total wind load is distributed. This can be done by injecting thin streams of smoke into the tunnel to render the airflow visible. A mixture of lampblack and kerosene painted on the model shows the surface streamlines. A suspension of talcum powder and a detergent in water is also used. Pressures on the model surface are measured through small flush openings in its surface. Forces exerted on the model may be determined from measurement of the airflow upstream and downstream of the model. In many instances, smoke tunnels have been rendered obsolete by computer modeling. Figure 2.7 shows an example of smoke tunnel in marketplace.

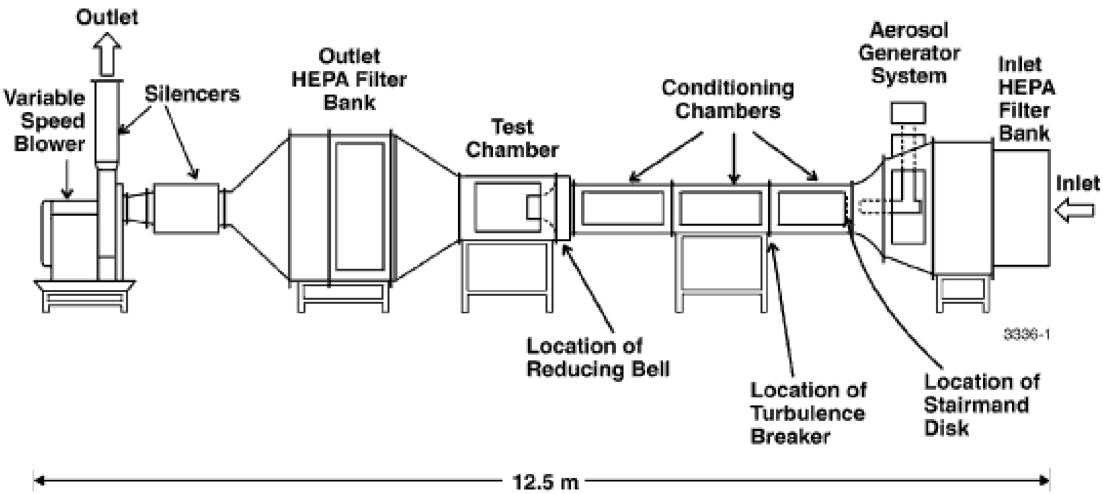


Figure 2.7: Schematic diagram of the Lovelace aerosol wind tunnel (smoke tunnel). (Source: www.inhalation.net/wind_tunnel.htm)