Design and Fabrication of
Portable Smoke Tunnel for Flow Visualization

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(AP Dr. Hussain H. Ja'afer Al-Kayiem)

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.

NURHAFIZAH BT ABDULLAH

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ABSTRACT

A smoke tunnel design and fabrication is one of the improvement efforts to facilitate the flow visualization for the transparent fluid such as air and water to be visible. The field study of fluid kinematics such as the investigation over immersed model at different Reynolds Numbers and the complexity of flow characteristic when moving or static bodies or structure through a moving fluid also will be takes into consideration. However, wind tunnel and smoke generator which are available in UTP Fluid Mechanics laboratory are not exactly practical to visualizing the air flow pattern appropriately. The methodology of designing and fabricating of the smoke tunnel has been made based on the literature review on previous works or studies. The feasibility study also has been performed for selecting materials which are available in market with cost effective and effortless for construction. The smoke tunnel has been designed based on analysis on air blower characteristics followed by the diffuser length, the test-section cross section area, the contraction cone length, the setting chamber radius inlet, and smoke generator's tubing. The total length of this tunnel is about 1.6 meters with square test section 0.12 x 0.12 m providing maximum free stream velocity of 23 m/s. The details drawing of the smoke tunnel will be provided through CATIA software for two dimension and three dimension outlines. The design criteria will try to create a good matching between the smoke and the surrounding air flow field by minimizing the difference in the two fluids velocities.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Flow Visualization is a process of making the physics of fluid flow visible. Most fluids (air, water, etc.) are transparent, thus their flow patterns are invisible to us without some special methods to make them visible [2]. Flows can be visualized by three methods: surface flow visualization, particle tracer methods, and optical methods. Surface flow visualization reveals the flow streamlines in the limit as a solid surface is approached. Colored oil applied to the surface of a wind tunnel model provides one example (the oil responds to the surface shear stress and forms a pattern). Particles, such as smoke, can be added to a flow to trace the fluid motion [2]. We can illuminate the particles with a sheet of laser light in order to visualize a slice of a complicated fluid flow pattern. Assuming that the particles faithfully follow the streamlines of the flow, we can not only visualize the flow but also measure its velocity using a method known as particle image velocimetry. Finally, some flows reveal their patterns by way of changes in their optical refractive index. These are visualized by optical methods known as the shadowgraph, schlieren photography, and interferometry [2].

The observation of fluid motion using smoke has been carried out for many years. Smoke Tunnel is a particle trace method for flow visualization of air flow pattern to aerodynamic bodies [3]. The most commonly used tunnel in flow visualization is a non-return or in draft suction type where air is drawn through a large settling chamber consisting of a honeycomb and several screen followed by a large contraction before the air enters the test-section as shown in Figure 1[2]. Base on this design, the smoke can be exhausted to the outside of the building. The purpose of honeycomb is to break up the large-scale air turbulence entering the tunnel. Before entering the contraction section, the level of turbulence will be further reduced by using several of screens. The screens should be arranged in order to decreasing mesh size and optimal the result. The function of contraction section is to ensure the velocity profile at the entrance of the test-section is uniform.

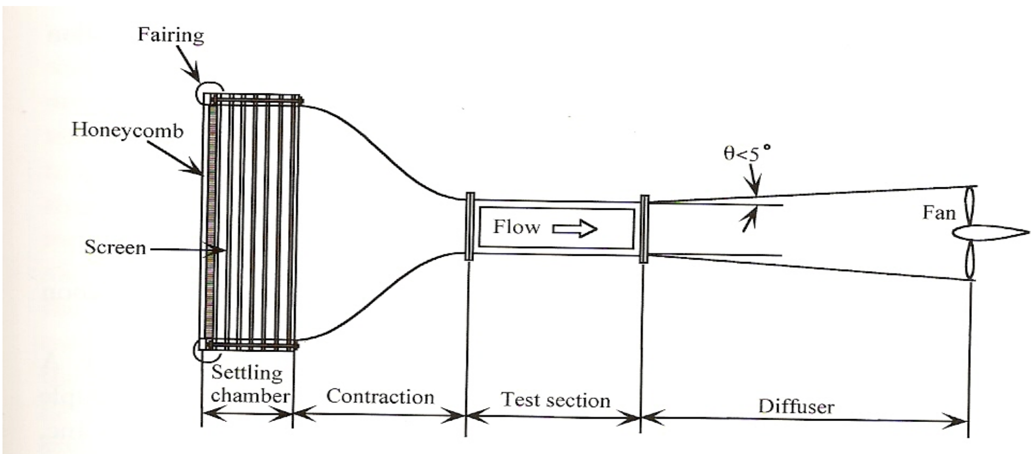

Figure 1: Schematic of a typical wind tunnel setup [2].

1.2 Problem Statement

Currently, Fluid Dynamic studies are lacking a proper visualization technique which is a powerful research tool in studies of flow behaviour on immersed bodies in air. To enhance the fluid dynamic investigation, a smoke tunnel will play a good role for resolve this matter. However, the recent subsonic wind tunnel in UTP Fluid Mechanics laboratory which has been connected to smoke generator was not convenience and applicable due to smoke detector alarm present. To resolve this problem, it is necessary to conduct an outdoor experiment. In order to achieve that, we need to have a portable unit of wind tunnel which is can easily connected to smoke generator and other elements on flexible trolley. Thus, we can have good visualization and measurement of results from the outdoor test.

1.3 Objective

The objectives of this project are:-

- To design and fabricate a smoke tunnel for flow visualization.
- To conduct experimentation over immersed model at different Reynolds Numbers.

1.4 Scope of Study

The flow visualization of fluid behaviour using smoke tunnel technique is an important tool to investigate and understand the physics of complex three-dimensional eddying motion and turbulence [3]. To be able successful interpret the flow pattern, it is requires the understanding of pathlines, streaklines and streamlines in steady and unsteady flow and a formal classification method to unambiguously describe the flow filed [3]. The Reynolds Number is very significant in determining the characteristic of air flow in smoke tunnel experimental [3]. By using this tunnel, we can straightforwardly observe the streamline of the air flow to a body with present of smoke particle in the air.

1.5 Significant of the Work

The smoke tunnel will facilitating the proper flow visualization of air flow to a static and dynamic bodies which are important to investigate and understand the characteristic and behaviour of air flow may be in form of two-dimensional or three-dimensional flow, steady or unsteady flow and laminar or turbulent flow. It is significantly improvise Fluid Mechanics Engineering technology of visualizing the flow pattern of aerodynamic bodies or structure studies. Therefore, we can make further investigation and exploration in the Reynolds Number studies.

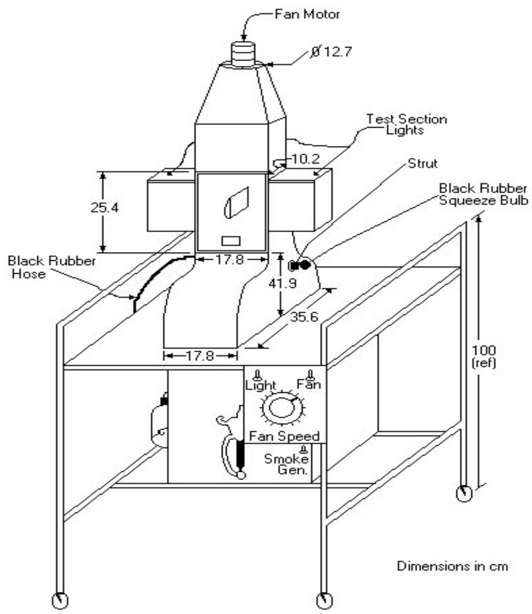

Figure 2: Smoke Tunnel [3].

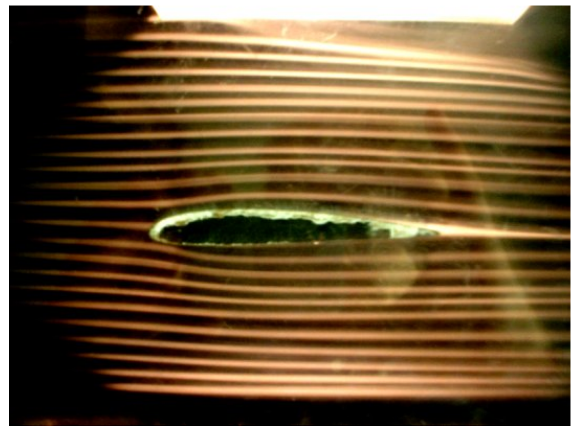

Figure 3: Sample of flow visualization by smoke tunnel method [3].

CHAPTER 2

LITERATURE REVIEW

2.1 Flow Visualization

Flow visualization is one of the most effective tools in flow analysis to improving our understanding of complex fluid flows. Prof. Brown from University of Notre Dame wrote that “A man is not a dog to smell out each individual track, he is a man to see, and seeing, to analyses. He is a sight tracker with each of the other senses in adjunctive roles. Further, man is a scanner, not a mere looker. A single point has little meaning unless taken with other points at different times are little better. He needs the whole field, the wide view” [2]. Thus, there are many experimental works have been done to proven the statement. Osborne Reynolds in 1883 has been carried out an experiment which dye injection method was used to show the transition from laminar flow to turbulent flow in a pipe [2]. In the era of Leonardo d Vinci, the observation of fluid motion using smoke and dye have been used as the oldest visualization technique in fluid mechanics due to inexpensive and easy to implement [2]. There was also has many studies and analysis in flow visualization in order to facilitate the investigation of flow behavior in fluid mechanics field.

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Recently, Kerenyi, 1999 stated that the advances in physical modelling instrumentation have facilitated flow visualization to support research. Flow visualization is now performed using the hydrogen bubble technique whereby a platinum wire is mounted vertically upstream of bridge structure in the test flume. A graphite rod is used as an anode. The hydrogen bubble produced a small enough (d<0.025mm) that their buoyancy may be ignored within the visualization area. By employing pulsed time lime markers with a specially built hydrogen bubble generator, it is possible to visualize the phase speed of the diving current formed at the face of structure. The diving current is usually responsible for bridge scour. As the result, the flow visualization using hydrogen bubble technique gives better insight into flow patterns caused by obstruction. It also can give quick feedback for flow alteration idea and can reduce experiment time to get a good result.

According to Fichtelman, 2001, the principles of fluid dynamics such as lift and drag forces are exactly influence the performance of sports balls such as knuckle-ball, cricket ball, tennis ball and golf ball. This has been proven by using flow visualization studies using smoke to spot flow separation points as related to surface features of sports balls. Utilizing a Jet Stream Wind Tunnel (Ref 1) which measures lift and drag and several aerodynamic principles also came into play while testing was performed. Bernoulli's theorem explained the production of side and lift forces on sports balls consequent to their surface features. Aerodynamics of sports balls is strongly dependent on the development and behaviour of the boundary layer on the ball's surface. The critical Reynolds number is the speed at which flow becomes turbulent where by increasing the surface roughness will decreases the critical Reynolds number. Wind visualization studies were accomplished using dry ice. A cooler containing dry ice was connected to the air intake chamber of the Jet Stream wind tunnel by hose and soda straws. Six straws were used to create two horizontal rows. This was used to straighten and direct the smoke for photographic purpose. Dry ice was placed in a two and a half gallon cooler using thick gloves and goggles. Hot water was placed on the dry ice to create smoke. A cooper funnel covered the cooler and connected to the straws by a plastic tube, and a small florescent strip over the test chamber provided the only light. The principles of fluid mechanics and Newtonian physics determine the performance of all sports balls. The surface features of sports balls affect boundary layer separation, lift drag and their pattern of flight. By understanding these principles, the development of performance of sports balls can be improved to provide enjoyment of the individual sport.

Azar & Rodgers, 2001 have carried out flow visualization of air flow in electronic systems. Many misconceptions in understanding the behaviour of fluid flow can be cleared up by flow visualization and also to use logically as the first approach to studying a new flow situation. To understand the convective heat transfer process in electronic systems, it is vital that the dependence of heat dissipation on such phenomena be examined. However, to use the technique most suitable to a given problem need to take the consideration where laminar, transitional and turbulent flows need a different approach for visualization. Therefore, flow visualization methods can be grouped into two categories, 1) those suitable to investigate the complexity of the streamline just above a surface, and 2) those suitable to characterize the surface heat transfer properties. The combination of analyses can provide a detailed description of flow phenomena and their effects on the heat transfer processes. Smoke-tube method makes use of large quantities of smoke and is used to produce a limited number of streaks that are rather thick. Instead of smoke-wire method can produce very thin smoke streaks. Therefore, flow visualization techniques applicable to air flow in electronic system.

Referring to W.J Devenport & W. L Hartwell, 2006 flow visualization is an experimental means of examining the flow pattern around a body or over its surface. The flow is visualized by introducing dye, smoke or pigment to the flow in the area under investigation. The primary advantage of such a method is the ability to provide a description of a flow over a model without complicated data reduction and analysis. Smoke flow visualization involves the injection of streams of vapour into the flow. Generating a flow in a wind tunnel that accurately models the flow over a real vehicle or vehicle component can be a lot harder than just having a model the right shape. The Reynolds number effect and Blockage effect has been investigated in this small smoke tunnel study. The important properties of air are density and viscosity. The density of air can be determined by using equation of state. By using Sutherland's relation to find the dynamic viscosity and using dynamic viscosity and density relation to determined the kinematic viscosity of air. The smoke which is vaporized kerosene is produced using Preston-Sweeting mist generator. The vapour is piped via a black rubber hose into a strut located directly upstream from the test section. A series of equally spaced holes in the trailing edge of the smoke strut introduce smoke filament into flow. During the operation of the smoke tunnel it may be necessary to give a sharp squeeze to the black rubber bulb attached to the end of the strut. This will clear anything that may be blocking the smoke holes. Thus, the black rubber hose connecting the smoke generator to the strut be drained periodically or whenever the vapour flow is poor.

Lok Kin Lee, 2006 flow visualization of air underneath the paper in a printer while printing is important to understand how the air flows in between two layers of surface. Various phenomena can be identified from the flow visualization such as the motion of the fluid flow and the interference between two air flows. In the experiment, two air-flows are coming out from the two holes simultaneously and interference with each other and going to all directions. A stagnation line, which is due to interference of the two air-flows, is then formed in between the air-flows. In order to visualize the air flow, a Silver Rain Lighting Manufactory fogger machine is used to generate fog for the flow visualization process. To get sufficient light, two sets of high-powered halogen lamps are used to illuminate the environment beside room light. The visualization clearly shows the behaviour of a very laminar air flow, in which cannot be see normally in dry air. The combination of white fog with black background highly enhanced the visualization of the air flow. In further development, more different combination of air flow can be done and investigate the different behaviour.

2.2 Smoke Tunnel

Previously, the wind tunnel is a research tool developed to assist with studying the effects of air moving over or around solid objects. Because the air is transparent it is difficult to directly observe the air movement itself. Thus, a smoke particulate or a fine mist of liquid is injected into the tunnel just ahead of the device being tested. The investigation by Head and Bandyophadyay in 1981 which smoke injection method was used to show the existence of hairpin or Λ-shaped vortices in a turbulent boundary layer. This technique also has been used in NASA in aerodynamics studies [9].

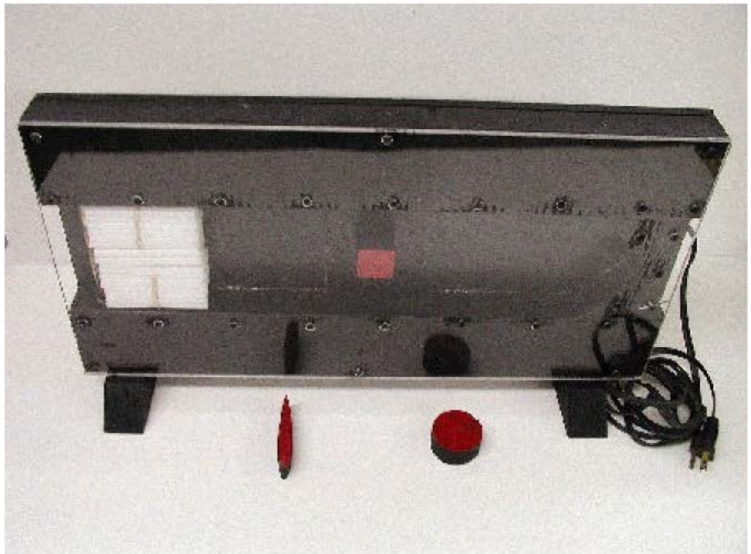


Figure 4: Smoky Wind Tunnel by NASA Glenn Research Centre [9].

The research has been done by Shojiro Shindo & Otto Brask, 1969 on a smoke generator for low speed wind tunnels shows the flow visualization has been a nebulous observation simply because air is invisible. Many substances were introduced to attempt flow visualization such as saw dust, tufts, fluorescent dye, laser beam and smoke. Although, all these methods required rather complex set up of equipment for the reason of either safety or health. Therefore, the substance introduced into the tunnel should be non-corrosive, non-toxic, and the equipment must be safe to handle which is in this case the Fog Juice has been used. There are three variable parameters that need to be considered to obtain a good smoke. 1) Temperature – hot oil produced tips instead of smoke because of low temperature. 2) Pressure – the smoke pulsates due to low pressure. 3) Voltage – to maintain the temperature. The principle of the device is to force oil through small diameter tubing which is heated by electric current. The oil vaporized in the tubing and quickly condenses to form a visible smoke at the open end. The probe can be fixed or hand held at any location. The smoke produced by passing Fog Juice through a heated long hypodermic needle is non-corrosive, non-toxic, and has a pleasant odour. It also dense, while and cool the smoke stream applicable for high and low air speed. By proper adjustment of the element voltage, the amount of fuel flow and pressure can produce a continuous white dense smoke suitable for observation or photographs.

R.D. Mehta and P. Bradshaw, 1979 have been developed the design rules for small low speed wind tunnel for the main components of a small wind tunnel which are the fan, wide-angle diffuser, corner vanes, settling chamber, contraction and exit diffuser. The strong effect of free-stream turbulence on shear layers became apparent, and emphasis has been laid on wind tunnel with low levels of turbulence and unsteadiness. It is possible to achieve high performance from an open-circuit tunnel thus saving space and construction cost. Open-circuit tunnel requires enough free room around it so that the quality of the return flow is not affected significantly.

John Cipolla, 1999 from AeroRocket has been designed a subsonic wind tunnel with a suction powered by a two speed 1/3 horsepower fan. The test section is 7 inches wide x 10 inches x 16 inches long. A quality pitot tube is used to measure the difference between static pressure and dynamic pressure in the wind tunnel. An analogue velocity meter is used to convert the resulting pressure differential between static and dynamic pressure to determine test section flow velocity in feet per minute. The aluminium honeycomb material has been inserted before and after the test section in a significant of increasing the accuracy of lift and drag coefficients measurement by decreasing flow turbulence by several orders of magnitudes. The flow visualization using probe-mounted yarn filament or smokes which are indicate areas of reverse flow and vertical motion corresponding to lift. The characteristics of wind flow can be measure and visualize using AeroRocket Subsonic wind tunnel which is connected with smoke generator where the smoke particle has been injected into the test section parallel with wind direction.

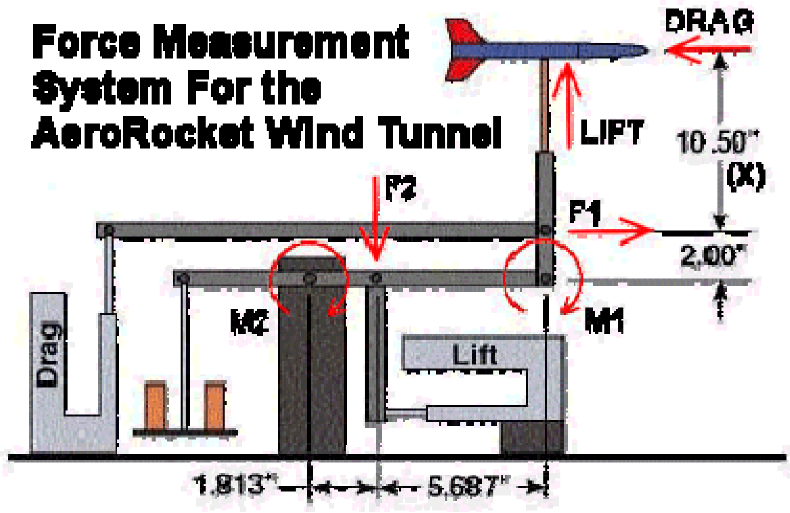


Figure 5: Force measurement system for AeroRocket Wind Tunnel [9].

CHAPTER 3

THEORETICAL WORKS

3.1 Conceptual of Flow Visualization Using Smoke

As the objective of this project to design a smoke tunnel, the smoke generator will be connected to the subsonic wind tunnel to inject the smoke particle into test section through a cylindrical probe with number of holes. Therefore, there are some of smokes characteristics that we need to consider. Thus, the smoke particle can visualizing the fluid flow without disturbance or causes any failure to the system. The requirements toward smoke's characteristics are non-corrosive, non-toxic and has pleasant odour [4]. It also need dense, while and cool the smoke stream applicable for low air speed. As the smoke generator is applicable in UTP Fluid Mechanics Laboratory which is can producing the dense white smoke and also it is not flammable. This smoke generated from Fog Juice where the fog liquid heated by electrical coil (heater). When the liquid vaporized, it will pass through the tubing (probe with holes) into the test section. As a result, the smoke particle will be combining with the air streamline where the speed of smoke can be controlled to approach the speed of air and thus visualizing the flow.

3.2 Aerodynamic Concept

Aerodynamics is a study of the air motion or flow, particularly when it interacts with a moving object such as aircraft and rocket [5]. Understanding the motion of air around an object enables the calculation of forces and moments acting on the object [5]. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. Aerodynamic can be classified into two groups which are:-

a) *External aerodynamic* – the study of flow around solid objects of various shapes, such as 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 [5].

b) *Internal aerodynamic* – the study of flow through passages in solid objects such as study of the airflow through a jet engine or through an air conditioning pipe [5].

Eventually, Reynolds number and Mach number were play significant role in investigating the characteristic of fluid flow as well as lift and drag forces.

3.3 Reynolds Number (Re)

Reynolds number is a dimensionless number that gives a measure of the ratio of inertial forces ($\mathrm{V}\rho$) to viscous forces (μ / L).

$$\mathrm{Re}_L = \frac{\rho \mathrm{V} L}{\mu} = \frac{\mathrm{V} L}{\nu}$$

where:

- V is the mean fluid velocity in (SI units: m/s)
- L is the *characteristic length* (m)
- μ is the dynamic viscosity of the fluid (Pa·s or N·s/m)
- ν is the *kinematic* viscosity (defined as $\nu = \mu / \rho$) (m^2/s)
- ρ is the density of the fluid (kg/m^3)

The significant of this number is to differentiating flow regimes, such as laminar, transition, or turbulent flow where:-

Re $\leq$ 2000	Laminar flow
2000 $\leq$ Re $\leq$ 4000	Transitional flow
Re $\geq$ 4000	Turbulent flow

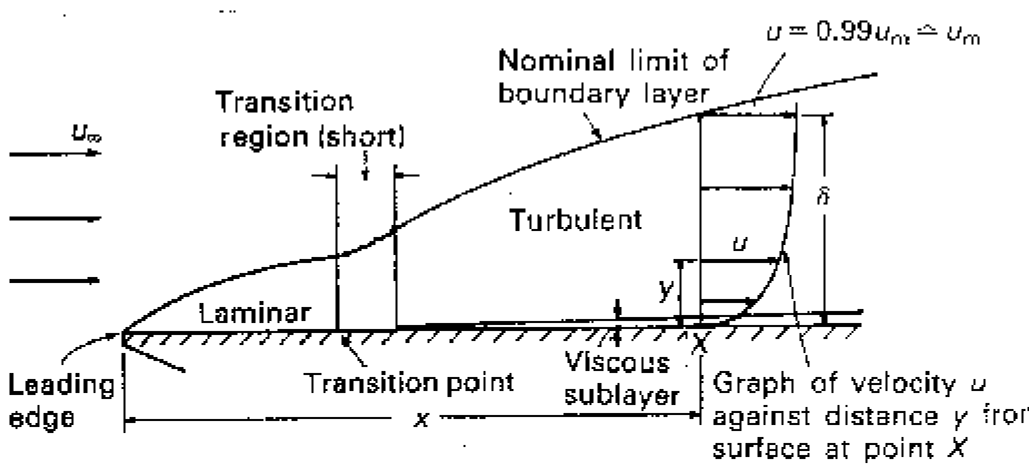


Figure 6: Boundary layer on flat plate [3].

3.4 Conceptual of Wind Tunnel

Basic concept of wind tunnel design as introduced by Orville Wright and Wilbur Wright in the year of 1902 was described as shown in Figure 6. Initially, this configuration has been used to investigate the flow field of airplane model in flight condition.

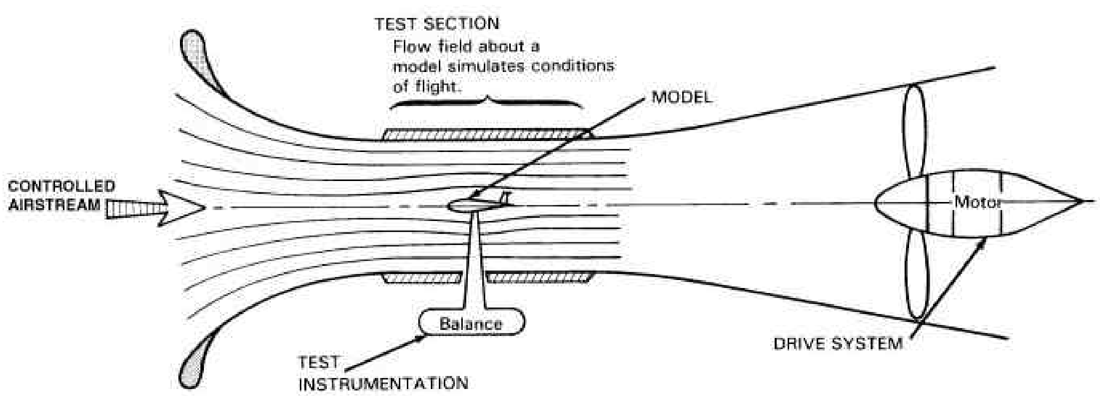


Figure 7: Basic concept of wind tunnel.

Nowadays with diversified technology of Fluid Mechanic field, the wind tunnel can be found in various types of configurations. For this project, as the study of flow visualization we only use the subsonic or low speed of wind tunnel where the maximum theoretical speed of air flow that can be produced by the blower (fan) is about 100 m/s as the Mach number is 0.3 and the speed of sound is 340 m/s. The configuration of subsonic wind tunnel as shown in Figure 7 where the wind tunnel consists of five main components which are settling chamber, contraction cone, test section, diffuser and drive section (blower).

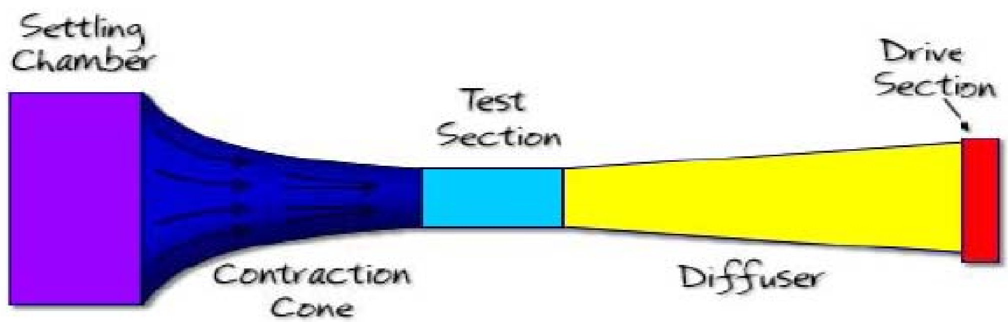


Figure 8: Wind tunnel main components [11].

a. Blower Design Concept

The design of wind tunnel prior to the blower design because this section will be driving the tunnel system where the speed of air flow will be controlled. As mention above, the maximum theoretical speed of air flow that will be required for this subsonic wind tunnel will be 100 m/s. These speed and flow rates highly depend on the fan and power that can be produced. The blower or fan will be selected from availability in market. The smaller size of fan with higher speed of power will be the prior consideration. This will lead to the diffuser and test section designs.

b. Test section Design Concept

The Conservation of mass or Continuity Equation can be applied to design the test section base on the maximum speed and cross sectional area of blower.

$$m = \rho \times v \times A$$ where, m = mass flow rate
ρ= density
v= velocity
A= cross sectional area

As the subsonic classified as incompressible flow, the density of fluid remain constant. Therefore the equation becomes flow rate, Q instead of mass flow rate.

$$Q = A \times v$$

The flow rate of air enter the test section is equal with the flow rate of air exit from the test section as well as the flow rate of air exit from diffuser. Figure 8 shows the inlet and outlet flow rate through the test section and diffuser.

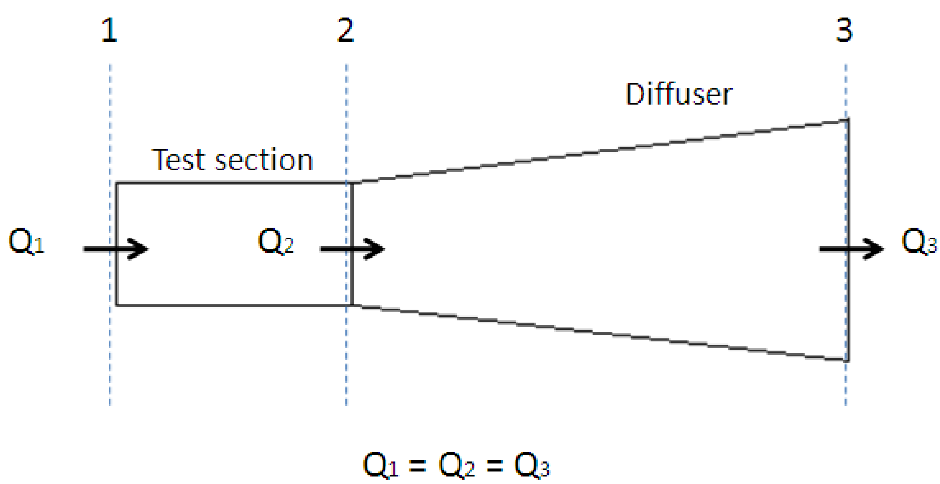


Figure 9: Air flow rate enter and exit the test section and diffuser.

The dimension of test section will be manipulative so that we can determine the most suitable speed of air flow that would be required to run this wind tunnel.

c. Diffuser Design Concept

Basically, to determining the dimension of cross sectional area of test section and diffuser mouth, we can calculate the length of diffuser required by using the ratio of cross sectional area of the end diffuser to the cross sectional area of the diffuser mouth. The angle of the diffuser should be setup at 5 degree to avoid flow separation [11]. But in order to minimize the diffuser's length, the angle will be slightly bigger. So, the separation can be avoided only by using boundary layer control methods such as suction, blowing, insertion mesh screen and splitters [12].

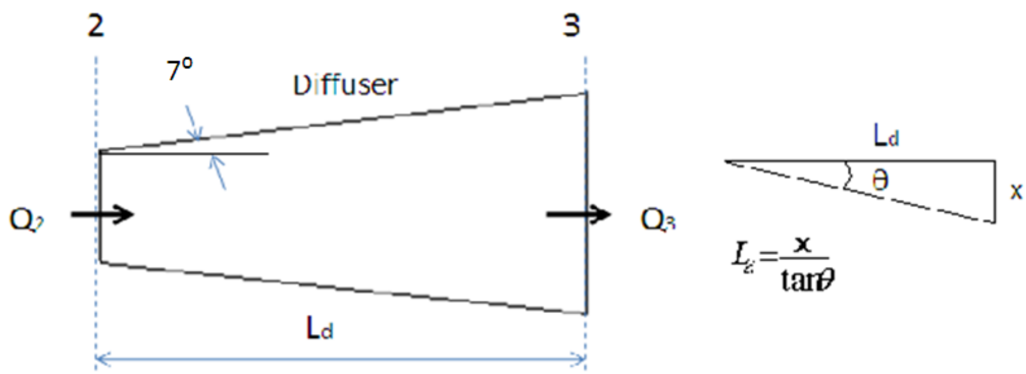


Figure 10: Method of calculating diffuser length.

d. Contraction Cone Design Concept

The design of contraction is using similar approach of conservation of flow rate to determine length and cross sectional area. Contraction ratio is between 6 and 9 are normally used at least for the smaller tunnel [10]. The principle of contraction cone is to take a large volume of low velocity air will be reduces to small volume of high velocity air without creating turbulence [11].

e. Settling Chamber Design Concept

The purpose of the settling chamber is to straighten the air flow as the subsonic wind tunnel draws air in from the surrounding air. Therefore, the honeycomb which is in series of tubes laid lengthwise in the air stream to straightening the flow [11]. Thus, it allows the air to only enter in one direction, parallel to air flow and laminar.

f. Honeycomb

According to Prandtl, a honeycomb is a guiding device through which the individual air filaments are rendered parallel. The design parameters for honeycomb are the ratio of streamwise length, L_h to single-cell hydraulic diameter, D_h and the porosity or solid defined as for screens [12]. The length to cell diameter ratios are in range of 6-8 and that about 150 cells per settling chamber diameter or about 25 000 total cells [10].

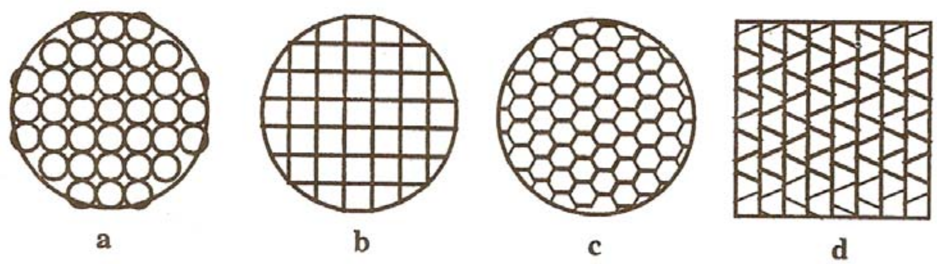


Figure 11: Type of honeycomb cell shape [12].

g. Screens

For the purpose of avoiding pressure drops completely independent and turbulent reduction, it has been found that a screen combination with spacing equivalent to about 0.2 settling chamber diameter will performs successfully [10]. The optimum distance between the last screen and the contraction entry has also been found to be about 0.2 cross-section diameters [10].

h. Smoke Generator

This component is meant for creating the stream-lined denser white smoke in the direction of air flow, and across the model. This component is available in the Fluid Mechanics laboratory.

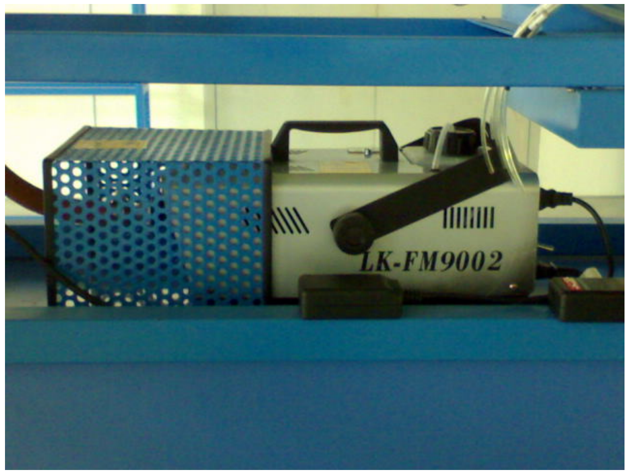


Figure 12: Some generator unit.

CHAPTER 4

METHODOLOGY

4.1 Technique of Analysis

4.1.1 Research Methodology

a. Information Resources Centre (IRC)

Many books, journals and paper works that have been referred to facilitate in understanding the concept of designing and fabricating a small wind tunnel and also flow visualization techniques.

b. Internet

The fastest and easiest way to collect the case study and previous people works in order to enhance knowledge in the new techniques, attempts and also to make wide review to the current works that have been established in the engineering fluid mechanics field.

c. Expertises

Besides, my supervisor AP Dr. Hussain Al-Kayiem and also the Fluid Mechanics laboratory technician Mr. Zailan also give a lot of guidance, opinion and though which are very helpful.

4.1.2 Designing

The smoke tunnel equipped with a smoke generator, smoke probe, variable speed blower (fan) and transparency test-section. Initially, the transparency test-section, smoke probe and air blower will be design and modelled using Auto CAD software in three-dimension layout with specific dimension.

Design Assumption and Calculation

a. Fan Analysis

Previously, the fan selection was based on priority to avoid the flow separation and turbulence flow in the diffuser. However, with the principle of wide-angle diffuser by Barlow [12], it had been helpful to minimize the length of diffuser. By increasing the angle of diffuser to 7°, thus the greater mass flow rate would be possible. The flow separation can be avoided by using boundary layer control method where a splitter will be inserted in the diffuser horizontally.

Table 1: Fan selection process.

Model	diameter, d	Diamension		Flow rate, Q
	M	L	w	m^3/sec
FV-20AUM3	0.2	0.3	0.3	0.15
FV-25AUM3	0.25	0.35	0.35	0.25
FV-30AUM3	0.308	0.4	0.4	0.335

Therefore, FV-30AUM3 model has been selected for this project which is the maximum mass flow rate is 0.335 m^3/s.

b. Test Section Analysis

Due to the previous fan selection, the test section analysis has been made where the mass flow rate was 0.25 m^3/s and the maximum velocity in the test section was 17 m/s.

Calculation for test section area is when the maximum velocity is 17 m/s.

$$A_{TS}V = Q$$
$$A_{TS} = \frac{Q}{V} = \frac{0.25}{17} = 0.0147m^2$$

The length of test section edge is,

$$H_{TS} = \sqrt{A_{TS}} = \sqrt{0.0147} = 0.121 \approx 0.12m$$

The length of test section,

$$L_{TS} = \frac{\mathrm{Re}_{cr}\,\mu_{air}}{\rho_{air}V} = \frac{500000 \times 1.849 \times 10^{-5}}{1.184 \times 17} = 0.45m$$

The blockage effect of model to the air flow in test section,

$$A_m = \frac{20}{100} \times A_{TS} = \frac{20}{100} \times (0.0144) = 2.88 \times 10^{-3} m^2$$

However, the previous fan selection is no longer reliable for this tunnel design because the current fan produced more mass flow rate. Still the cross-sectional area and length of test section has been decided to remain. Though, the velocity analysis needs to be modified base on the current fan selection. The calculation is based on the principle of Conservation of mass and the result as followed.

Table 2: Test section's velocity analysis.

Model	diameter, d	Flow rate, Q	V_{ts}
	M	m^3/sec	m/s
FV-20AUM3	0.2	0.15	10.42
FV-25AUM3	0.25	0.25	17.36
FV-30AUM3	0.308	0.335	23.26

Therefore, the maximum velocity through the test section is 23.26 m/s.

c. Diffuser Length calculation

Base on the wide-angle diffuser, the angle can be up to 7^{o} [12]. With that the length of diffuser can be shorten as possible with insertion of splitter. The calculation of diffuser length has been calculated as follow.

$$\tan\theta = \frac{x}{l_d}, \qquad l_d = \frac{x}{\tan\theta} = \frac{(H_d - H_{TS})/2}{\tan 7^\circ}$$

$$= \frac{(0.31 - 0.12)/2}{\tan 5^\circ} = 0.7737 \approx 0.75m$$

Therefore, the length of diffuser will be 0.75 meters.

d. Contraction Cone area analysis

The inlet area of contraction analysis is base on the area of test section. Here the area ratio of 6 has been selected for designing small wind tunnel [10].

$$A_C = 6A_{TS} = 6 \times (0.12 \times 0.12) = 0.08m^2$$

The length of contraction cone edge is

$$H_C = \sqrt{A_C} = \sqrt{0.08} = 0.282 \approx 0.3m$$

The length of contraction cone is half of inlet of contraction edge

$$L_C = 0.5 \times H_C = 0.5 \times 0.3 = 0.15m$$

e. Settling Chamber Analysis

The cross section area of settling chamber is equal to the inlet area of contraction cone. The length of settling chamber is also half of inlet diameter which is the edge, $L_{SC} = 0.15m$ [12].

f. Honeycomb

It is necessary to setup 150 cells per settling chamber's length so that the total cells at the entrance will be about 25 000. Base on that requirement and the settling chamber length, the calculation of streamwise length, L_h and hydraulic diameter, D_h are as followed.

$$D_h = \frac{300}{150} = 2mm \qquad\qquad L_h = 6 \times 2mm = 12mm$$

However, it is difficult to fabricate this small size of honeycomb. The straws that will be used to make the cells are not available in the local market. Therefore, the regular straw with 5 mm diameter has been choosing as substitute and the streamwise length, L_h will be 30 mm.

4.1.3 Material Selection

Apparently, the selection of materials is base on material specification and requirement for this smoke tunnel. However, it also depends on the availability of particular material in market. Cost effectiveness also takes into consideration to maintain the feasibility of this tunnel to fabricate.

Material Selection for Main Components

a. Fan Selection

Basically, the design specification for fan (air blower) is as per analysis in the previous section, where the diameter of the fan is 0.31 m. The maximum flow rate is 0.335 m^3/s and the maximum velocity through the test section is 23.26 m/s. As result the FV-30AUM3 model will be selected and it is available in laboratory.

b. Diffuser

This part will be constructed from plywood with smooth surface to avoid the flow separation occurs and to reducing the construction cost.

c. Test Section, Contraction Cone and Settling Chamber

These components are a very crucial for this design because this is where the flow visualization works or testing will be conduct. Therefore the requirement of this component is to be transparent and sustainable for slightly high pressure, the Perspex or fibreglass material has been selected.

d. Screen and Honeycomb

The screen or meshes are usually made from nylon or metal wire. The honeycomb mainly will be made from Perspex for the frame and straws for the cells.

e. Trolley

This bottom part will be made from thick plywood for the table and angle bar for the legs

4.1.4 Fabricating

The component of smoke tunnel will be fabricated using selected materials which are sustainable for air load that would be applied in the experiment such as the test-section should be made up by a glass or high strength plastic. The smoke probe will be fabricated using a tube or small cylinder with several holes on it to projecting the smoke particle from smoke generator.

The speed controller for air and smoke particle will be installed to vary the Reynolds Number of the flow.

Fabrication Phases

Currently, the materials and design of the smoke tunnel already sent to the fabricator for construction process. It is almost 40% of the construction has been made which is including the settling chamber, contraction cone, test section and honeycomb frame. Next figures show the fabricated part of smoke tunnel.

Primary Stage of Fabrication

Figure 13: Contraction cone and test section

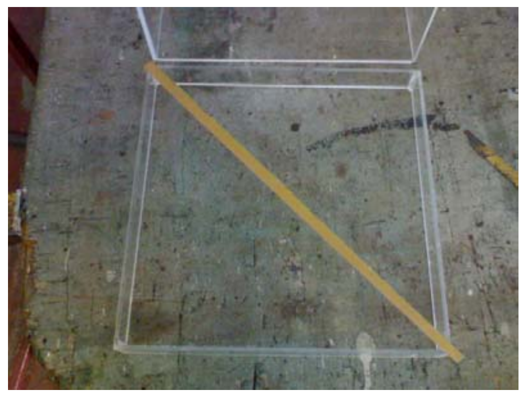


Figure 14: Honeycomb's frame

Figure 15: Assembled settling chamber, contraction cone and test section

Assembly Stage of Fabrication

Figure 16: Main components of smoke tunnel have been installed.

At the middle of fabrication process, some changes have been made in order to maintain the design in place such as the diffuser section has been designed to make from plywood instead of Perspex. But due to construction issues the fabricator decides to used Perspex rather than plywood. Of cause the cost of material would increase but the finished product that has been produced is attractive.

Completion Stage of Fabrication

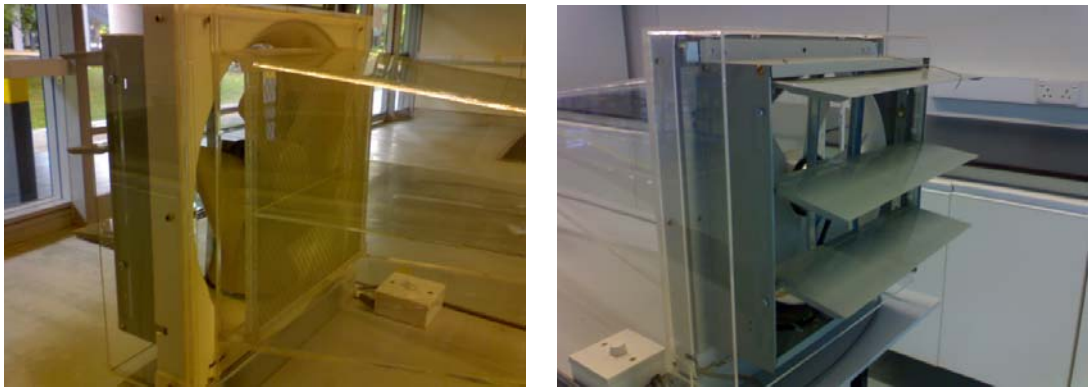


Figure 17: Drive section or fan completely installed.

Figure 18: Diffuser with splitter.

Figure 19: Test section.

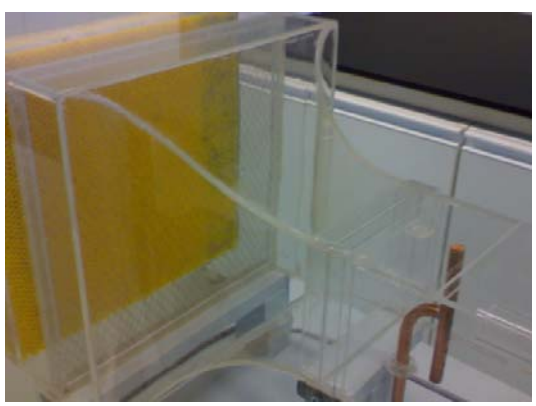


Figure 20: Contraction Cone.

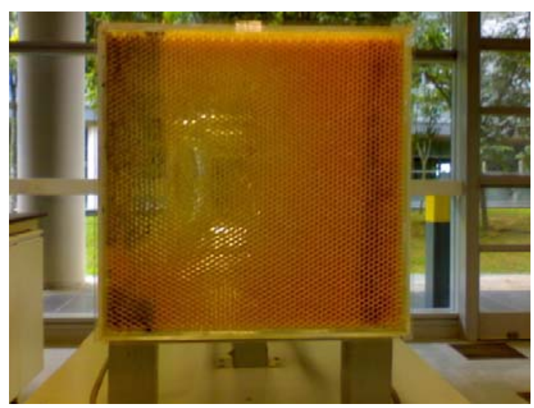


Figure 21: Settling chamber with honeycomb.

Figure 22: Probe with holes

Figure 23: Model stand with clamp.

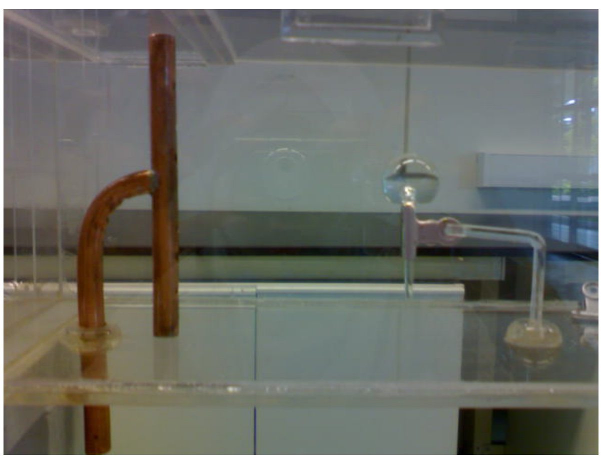


Figure 24: Probe and model stand in test section.

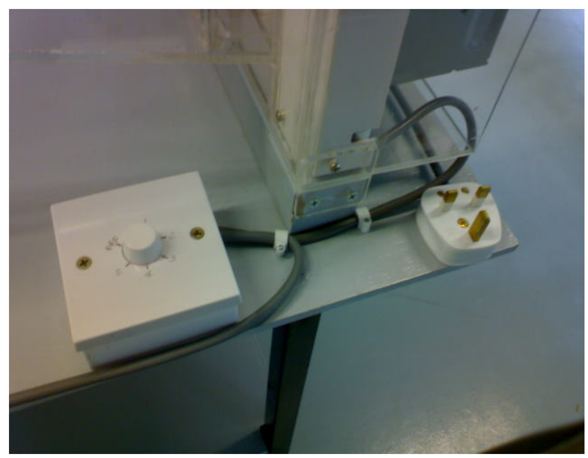


Figure 25: Switch and fan's speed controller.

Figure 26: Complete assembly of smoke tunnel.

The fabricated portable smoke tunnel has been allocated in the Wind Tunnel laboratory at Building 18. Further experiment and testing will be conduct to investigate the performance of the portable smoke tunnel.

4.1.5 Experimental

The fabricated smoke tunnel then will be tested to ensure the design and dimension are applicable and practicable for experimental of air flow visualization.

Smoke Tunnel Testing

Objective

1. To calibrate the portable smoke tunnel function.
2. To investigate the characteristic of air flow in test section without model and with spherical model.
3. To visualize the air flow using a smoke particle.

Apparatus

1. Portable Smoke Tunnel with smoke generator.
2. Pitot Static Tube and Manometer
3. Camera.

Procedure

1. Preparing the smoke using dry ice and hot water in the smoke generator.
2. Running the smoke tunnel at speed 2 without installing the model.
3. Open the smoke valve to release the smoke into test section through the probe.
4. Take a picture of air flow in the test section.
5. Measures the pressure difference in the test section using Pitot Static Tube and Electronic Manometer in unit of mmH_2O.
6. Repeat step (4) and (5) for speed 3, 4 and 5.
7. Turn off the smoke tunnel.

4.2 a) Milestone for FYP I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Selection of Project Topic - Propose Topic - Topic Approval															
2	Preliminary Research Work and literature review - List of references - Project Planning															
3	Submission of Preliminary Report															
4	Project Work - Theoretical works related - Design criteria selection											Mid-semester break				
5	Submission of Progress Report															
6	Seminar (compulsory)															
7	Project work continues - Design assumption - Calculation/Design analysis - Detailed design drawing - Material Selection and Requisition															
8	Submission of Interim Report Final Draft															
9	Oral Presentation															

Suggested milestone

Process

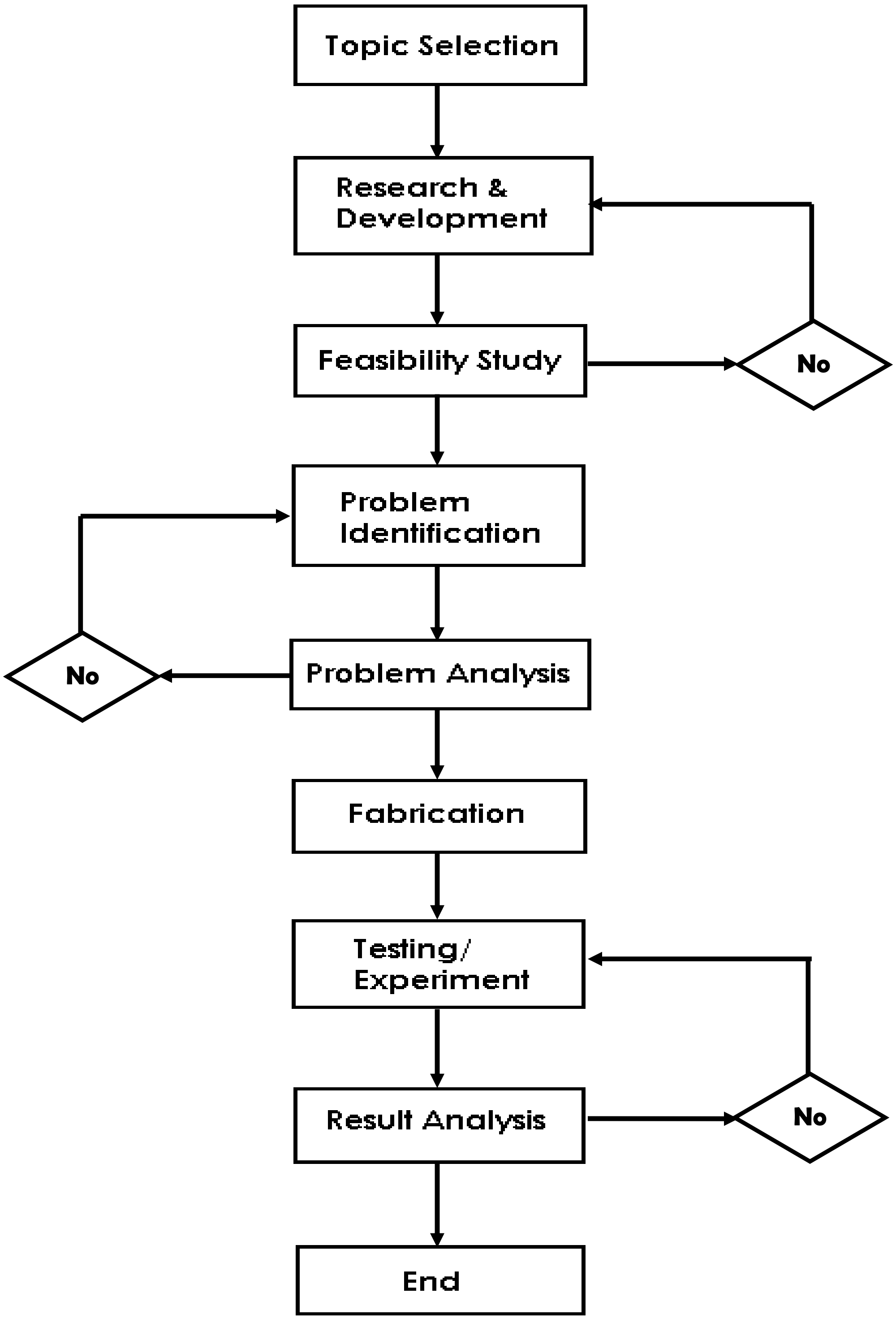
b) Milestone for FYP II

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Project Continuation - Design Review - Construction Drawing Preparation - Purchasing Material	■	■									Mid-semester break				
2	Submission of Progress Report 1			●												
3	Project Continuation - Material Preparation - Fabrication				■	■	■	■								
4	Submission of Progress Report 2								●							
5	Project Continuation - Fabrication - Laboratory works-testing								■	■	■		■	■	■	■
6	Submission of Dissertation Final Draft													●		
7	Oral Presentation														●	
8	Submission of Project Dissertation															●

● Suggested milestone

■ Process

4.3 Flow Chart of Execution



4.4 Tools and Software

4.4.1 Microsoft Office Manager

This application is very constructive and accommodating in dealing with documentation and reporting activities. Besides, drafting and design analysis also has been completed in this application for convenient purposes.

4.4.2 CATIA V5R14

This software used to designing detailed drawing of smoke tunnel and its components which are drive section, diffuser, test section, contraction cone, settling chamber, and smoke generator. The drawing is available in two-dimension (2D) and three-dimension (3D) as well. The detail drawing is applicable as per attachments in Chapter 5 and also Appendix.

CHAPTER 5

RESULT AND DISCUSSION

5.1 Smoke Tunnel Modelling

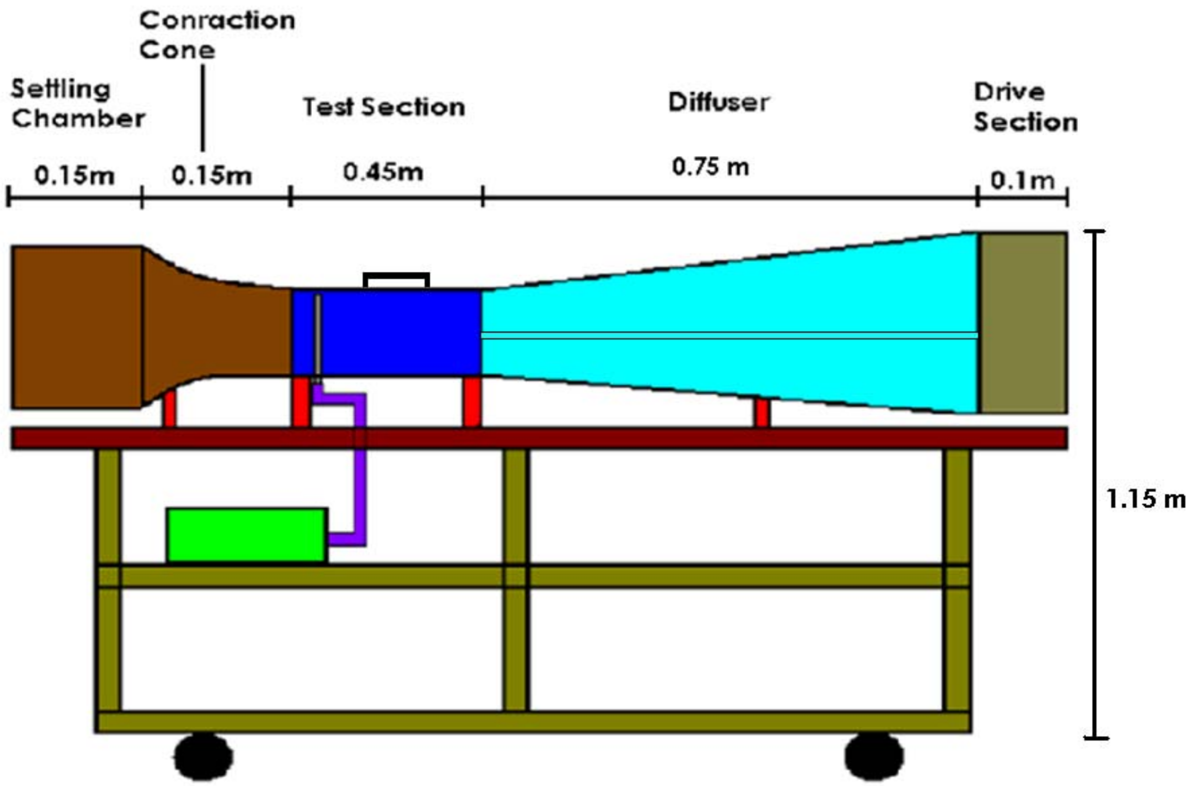


Figure 27: Smoke tunnel conceptual model.

Figure 27 shows the full smoke tunnel modelling whereby the entire components are in lined on trolley which the length is 1.6 meters and the width is 0.5 meters. The detailed drawing and dimension of each component will be show as per attachment in Appendix.

5.2 Modelling Using CATIA

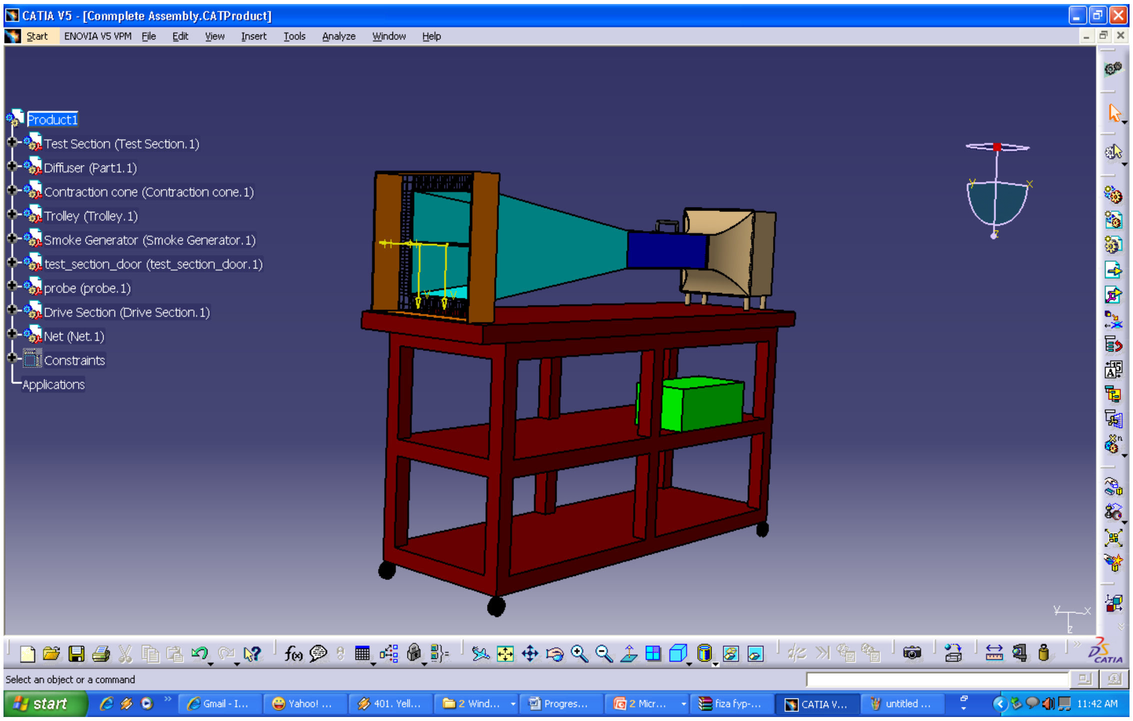


Figure 28: Assembly drawing of portable smoke tunnel.

5.3 Fabrication Result

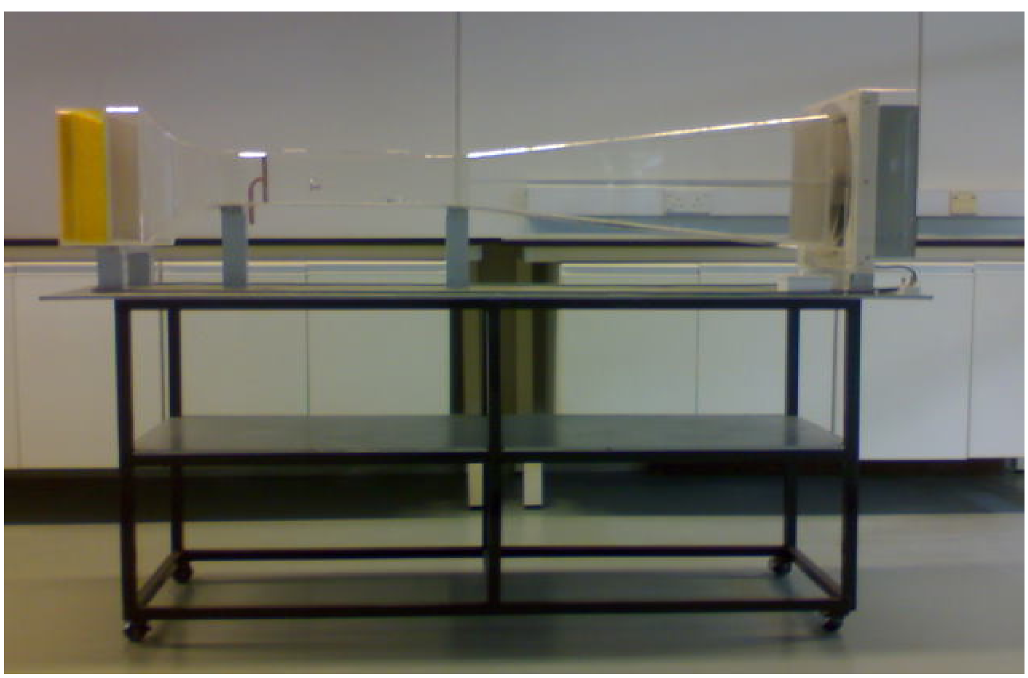


Figure 29: Complete assembly of smoke tunnel with table (trolley).

5.4 Materials and Fabrication Cost

Table 3: Total cost of fabricating the smoke tunnel and honeycomb.

Nu.	Material	Quantity	Cost / unit	Cost (RM)
1	Perspex sheet (t= 4mm)	1	200	200
2	Angle bar and plywood			100
3	Chlorofoam and glue			50
4	Wheels	4		30
5	Speed controller and wiring			40
6	Painting			100
7	Copper, sphere and tube (model)			30
8	Labour			800
9	Transportation			100
10	Straw	14 pkg	2.5	35
11	Glue	2	11	22
	Total			**1507**

Table 4: Total cost of fabricating smoke generator.

Nu.	Material	Quantity	Cost / unit	Cost (RM)
1	Cylindrical casing	1	5	5
2	PC fan	1	25	25
3	Open Valve	1	8	8
4	Piping			10
5	Dry ice			60
6	Labour			150
	Total			**258**

Therefore, the total cost of the project for fabricating smoke tunnel and smoke generator is RM 1765.00.

5.5 New Smoke Generator Design and Fabrication

Initially, this portable smoke tunnel will be operates with UTP's Smoke generator which is produce fruit base smoke. However, some problem has been encountered when the pump in the smoke generator is broken down. Since the UTP's smoke generator is not working and need to send off to the supplier for maintenance.

Nevertheless, this project is all about generating smoke particle to facilitate air flow visualization. Therefore, I have been deciding to design and fabricate new smoke generator using dry ice and hot water to ensure this project achieve the objectives.

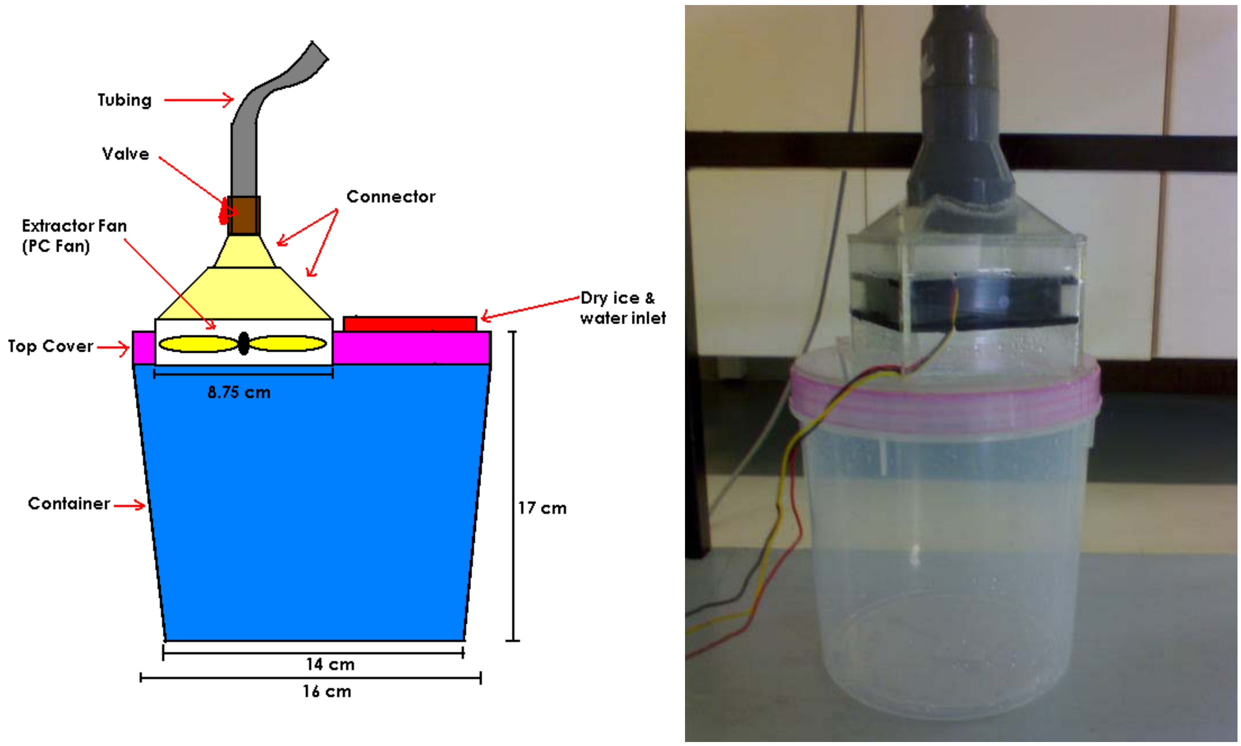


Figure 30: Design and fabricated smoke generator.

The fabrication cost of the new smoke generator is RM150.00 and the cost for the dry ice is RM60.00 per block. However, the dry ice was only enough for the testing because there is no appropriate freezer to keep it which is the temperature of dry ice is 73°C.

5.6 Experimental Data and Result

On 8th April 2009, the flow visualization testing has been conducted in objectives to calibrate the function of smoke tunnel and investigate the air flow behaviour. Below is the data that has been collected during the testing.

Table 5: Smoke tunnel testing data.

Fan Speed	Diameter (m)		ΔH_{mmH_2O}	ΔH_{mH_2O}	V (m/s)	Q (m^3/s)	Re
	No Model	Spherical					
2	0	0.02	0.25	0.00025	2.016376	0.029036	2660.512
3	0	0.02	1.01	0.00101	4.052866	0.058361	5347.562
4	0	0.02	1.94	0.00194	5.616974	0.080884	7411.328
5	0	0.02	2.23	0.00223	6.022183	0.086719	7945.982

The graph below shows the relationship between velocity and Reynolds Number.

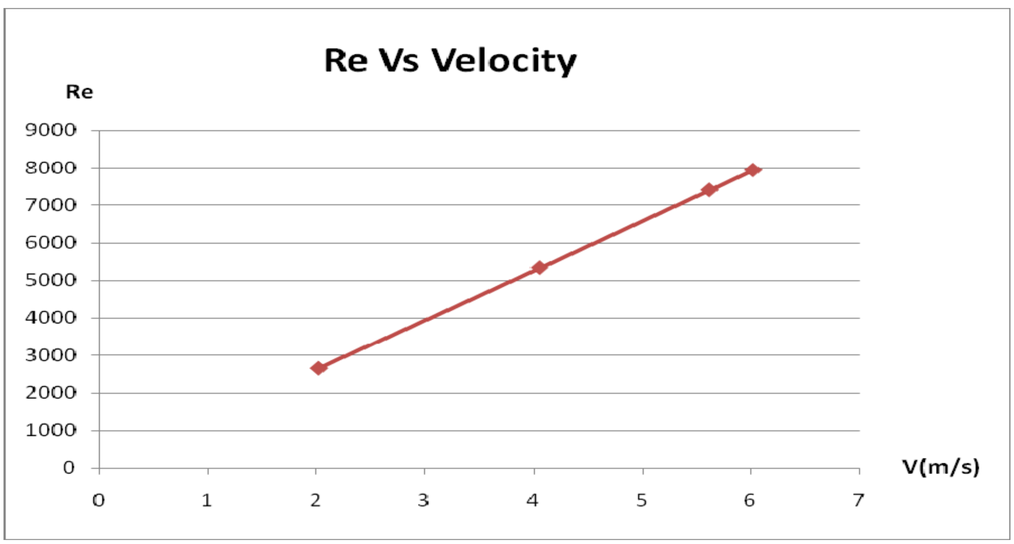


Figure 31: Graph Reynolds Number against velocity.

The pictures of air flow that have been visualised using smoke particle.

Without Model

Speed 2

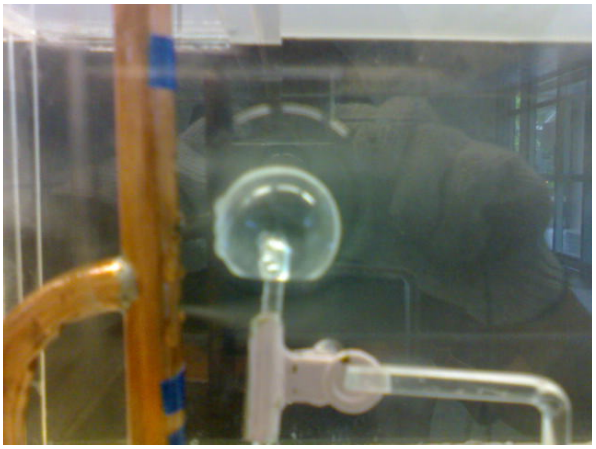
Speed 3

Speed 4

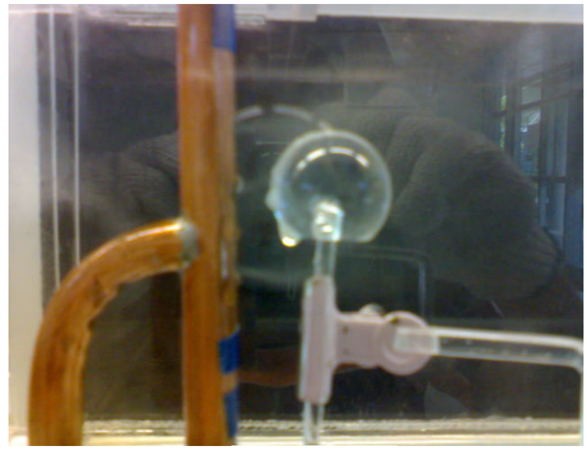
Speed 5

Figure 32: Pictures of air flow in test section without model.

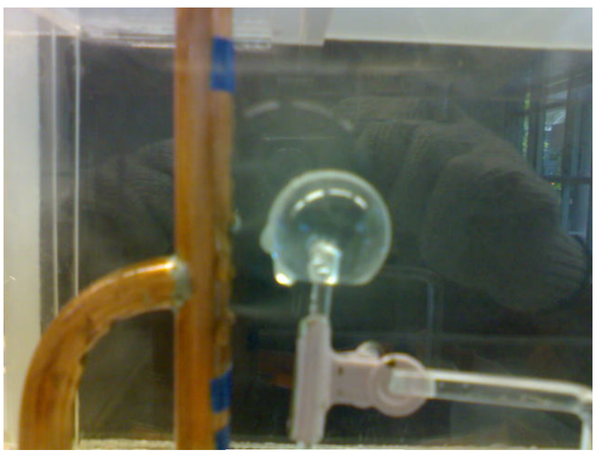
Spherical Model



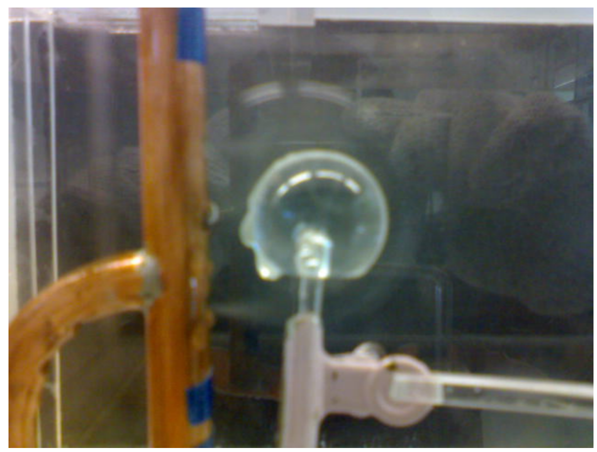
Speed 2



Speed 3



Speed 4



Speed 5

Figure 33: Pictures of air flow in test section with spherical model.

Based on these two techniques of testing 1) using pitot static tube; and 2) flow visualization, it shows that the air flow for speed 2 of fan is transition flow with Reynolds Number of 2660 and the other three speed 3, 4 and 5 are turbulent flow which the Reynolds Number are 5347, 7411 and 7945 respectively.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

As the conclusion, the flow visualization of fluid behaviour can be determined by using the smoke as a type of particle tracer to investigate and understand the studies of fluid mechanics flow. This experimental will be conduct conveniently and effectively with portable smoke tunnel which is consists of an air blower section, diffuser, contraction cone, settling chamber, and a transparency test-section. Thus, it will improvise and have variety in flow visualization technique.

6.2 Recommendations

Although the objective of designing and fabrication of portable smoke tunnel being achieved and enthusiastically used to help the investigation on fluid flow over body, however this new smoke tunnel still required further improvements in order to produce the best result.

1. Starting with the settling chamber section, whereby a screen is feasible to be slotted in front of the honeycomb, so that can reduce the turbulence of air flow which coming into the smoke tunnel.

2. The probe that has been used need to be modifies so that the holes size smaller and with tubes at end of the holes as shown in Figure 34.

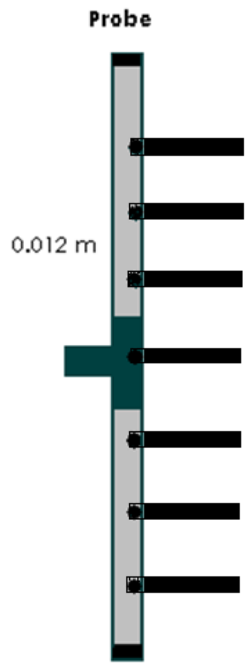


Figure 34: Modification on probe.

3. The smoke has been produced using dry ice and hot water requires some colouring or instead of dry ice, maybe there other material or fluid that can be used in order to help the flow visualization appropriately.

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