DEVELOPMENT AND CONSTRUCTION OF A SMALL-SCALE WIND TUNNEL

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A report submitted in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering

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DECLARATION

I declare that this project report entitled "Development and Construction of Small-Scale Wind Tunnel" is the result of my own work except as cited in the references.

Signature : ....

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Date : 14 August 2020

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....

Name of Supervisor : DR FADHILAH BINTI SHIKH ANUAR

Date : 04/09/2020

ABSTRACT

The aim of this study is to develop and construct a small-scale wind tunnel for research and education purpose. Buying the wind tunnel might be a simpler solution but it is very costly. Thus, fabricating one in-house is a better solution. The study was started with several stages such as development and designing stages, flow analyses and fabrication processes. It is important to note that, the focus of this study is to present the appropriate stages in developing and constructing a small- scale wind tunnel. Specifically, the small-scale wind tunnel has a test section with size of 100 mm (height) x 100 mm (width). For a blown-type wind tunnel, the flow velocity in the wind tunnel depends on the blower performance. In this study, the air flow inside the test section should be less than 40 m/s (or Mach number is below 0.4), based on the 3.0 kW High Pressure Ring Blower that has been used as the incoming flow sources. Every main component of the wind tunnel such as nozzle, diffuser and test section were designed using CATIA V5R21 based on some calculation as suggested in the past literature. The file from CATIA was exported to CFD Fluent software to conduct further analysis on the flow development in the test section prior to the fabrication processes. The material of the wind tunnel was carefully selected to ease in-house fabrication and flow visualization studies in the future. Future improvement on the wind tunnel characterization and flow validation have been suggested at the end of this report.

ABSTRAK

Tujuan penyelidikan ini adalah untuk membangun dan membina terowong angin berskala kecil untuk tujuan penyelidikan dan pendidikan. Membeli satu dari pasaran mungkin merupakan penyelesaian yang lebih mudah tetapi sangat mahal. Oleh itu, membina sendiri adalah penyelesaian yang lebih baik. Proses penyelidikan ini melibatkan beberapa peringkat seperti reka bentuk dan pembangunan terowong angin, analisis pada aliran, dan proses fabrikasi. Adalah penting untuk mengetahui bahawa fokus projek ini adalah untuk mempersembahkan peringkat pembinaan terowong angin yang sepatutnya dan membina satu terowong angin bersaiz kecil. Secara khususnya, terowong angin kecil yang berukuran 100 mm tinggi dan lebar 100 mm untuk bahagian ujikaji. Untuk terowong angin jenis tiup, kelajuan angin di dalam terowong bergantunng kepada keupayan penghembus udara. Untuk kajian ini, halaju udara dalam bahagian ujikaji adalah kurang daripada 40 m/s (atau nombor Mach di bawah 0.4) berdasarkan penghembus udara tekanan tinggi yang mempunyai 3.0 kW kuasa dan digunakan sebagai punca aliran udara masuk. Setiap bahagian penting terowong angin tersebut seperti muncung, peresap dan bahagian ujikaji direkabentuk menggunakan CATIA V5R21 berdasarkan pengiraan yang dicadangkan dari kajian lepas. Fail CATIA dieksport masuk ke dalam perisian CFD Fluent untuk analisis lanjut ke atas pembangunan aliran di dalam bahagian ujikaji sebelum melakukan fabrikasi. Bahan-bahan yang dipilih untuk membina terowong angin hendaklah memudahkan proses fabrikasi dan membolehkan kajian visualisasi ke atas aliran dilaksanakan. Cadangan penambahbaikan ke atas pencirian terowong angin dan pengesahan aliran turut dibincangkan di akhir laporan ini.

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CFD	Computational Fluid Dynamics
PIV	Particle Image Velocimetry
CATIA	Computer-Aided Three-Dimensional Interactive Application
ANSYS	ANalysis SYStem
CAD	Computer Aided Design
PSM	Projek Sarjana Muda

LIST OF SYMBOLS

v	=	Velocity
$W_{d,i}$	=	Inlet diameter
β_s	=	Screen porosity
A_{flow}	=	Flow area
A_{total}	=	Total area
n_w	=	Generic wire number in the mesh
d_w	=	Wire diameter
l_{honey}	=	Length of honeycomb
β_h	=	Honeycomb porosity
H_i	=	Contraction height at inlet
H_e	=	Contraction height at outlet
L	=	Contraction length
X'	=	Ratio of length of X over total length
d_{honey}	=	Cell size

CHAPTER 1

INTRODUCTION

1.1 Background

In 1871, the first enclosed wind tunnel was invented, by Francis Herbert Wenham who was a Council Member of the Aeronautical Society of Great Britain (Ge, 2015). Then, in 1914, Eiffel, a French engineer who built an open-return (open circuit) wind tunnel which had been improvised from the previous wind tunnels, particularly in term of efficiency, and it is known as Eiffel-type wind tunnel (Ge, 2015).

Nowadays, there are two common types of wind tunnels, which are closed circuit and open circuit wind tunnels. Apart from its design, the wind tunnels can be also categorized based on its speed limits in the test section, where Mach number (M) which is a ratio of fluid velocity to the velocity of sound in that fluid is used. Six wind tunnels have been categorized based on different speed or flow velocity ranges, and it is typically presented according to Mach Number as listed in **Table 1.1** (Ge, 2015).

Table 1.1 Wind tunnel type (Ge, 2015)

Wind tunnel type	Mach number, M
Low speed	M < 0.4
Subsonic speed	0.4<M<0.8
Transonic speed	0.8<M<1.4
Supersonic speed	1.4<M<5.0
Hypersonic speed	5.0<M<10
High enthalpy hypersonic speed	M>10

The characterization of a wind tunnel usually started with CFD (Computation Fluid Dynamics) simulation. It is important to ensure a desired specification of wind tunnel can be constructed. Nowadays, with high-technology tools, most of aerodynamic studies could be done using CFD software, for example ANSYS CFD FLUENT and OpenFOAM software to obtain a good flow uniformity in the test section of the wind tunnel. The CFD simulation is used as the first designing stage or to verify and/or validate experimental studies using established models. Once validated, further designing works can be done faster through the simulation instead of relying on the experimental tasks that usually consume more energy and costs. However, it is important to note that experimental studies using a wind tunnel is also important for verification and/or final tweaking of the design models, especially for a new and complicated design as some of the features could be missing from the simulation software. The experimental studies may capture all the flow phenomenon especially the presence of any secondary flows. However, reliable measuring tools such as Particle Image Velocimetry (PIV), laser Doppler anemometry (LDA), or conventional tool like Pitot Tube is a must to collect the information on the flow dynamics.

Nowadays, the low-speed wind tunnel that introduce low speed velocity, lower than 135 m/s or $M < 0.4$ is widely used in educational institutions, research centre and industries. The flow in this kind of wind tunnel is assumed incompressible. This low speed wind tunnel required only low power consumption to maintain the speed limits, with a relative power less than 2000 kW, while in term of size, the cross sectional area of the test section can be up to 3 or 4 meters (Ge, 2015).

1.2 Problem Statement

To conduct a study on flow dynamics of a small-scale model, an acceptable flow uniformity in a test section of the wind tunnel is required. Thus, wind tunnel characterization must be conducted so that a reliable result can be produced. It is important to undergo every stages of wind tunnel development such as dimension estimation based on the blower specification, CAD design, flow analysis, material selection, fabrication and assembly process, as well as wind tunnel characterization and testing. However, as the desired wind tunnel is for the researches and educational purposes, it should be designed to ease the assembly and cleaning processes. It should also lightweight so that it can be easily reassembled and moved from one laboratory to another laboratory when needed.

1.3 Objective

The objectives of this study are stated as follow: -

- To design a small-scale wind tunnel using CAD software.
- To simulate the flow inside the test section based on a specific airflow velocity.
- To select suitable material and fabricate each of wind tunnel components.

1.4 Scope of Project

The scopes of this project are listed as below;

- Focusing only on a low-speed open-circuit wind tunnel.
- Using suitable fabrication processes within affordable budget and laboratories facilities.
- Utilizing air velocity of 40 m/s from the blower as the source of incoming air into the wind tunnel.
- Developing a small size of test section (100 mm x 100 mm) with high purity glass to suit flow visualization studies using thermographic camera, Particle Image Velocimetry (PIV) or any other laser diagnostic equipment in the future.
- Designing holes at the bottom side of the test section to suit future studies involving heat exchange process.

CHAPTER 2

LITERATURE REVIEW

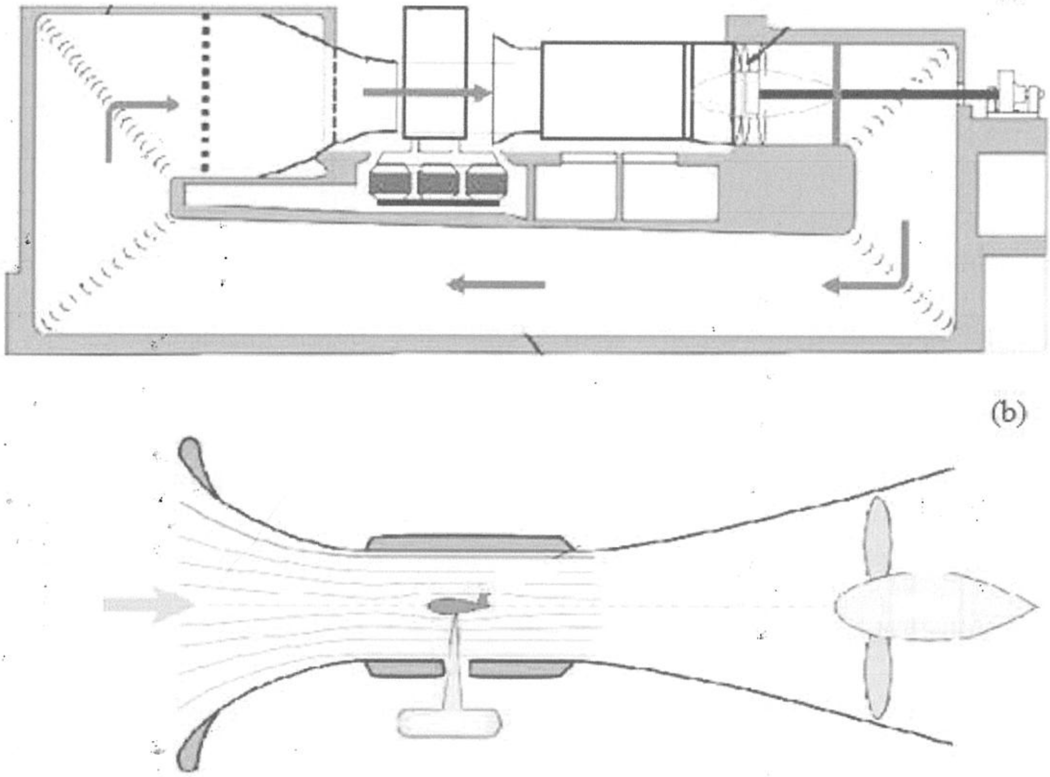
2.1 Introduction

Wind tunnels are mostly designed and constructed according to the test section size and what tests will be conducted. Small size wind tunnels have been used widely for research and educational purposes (Barlow, Rae, Jr., & Pope, 1999). Thus, an extensive review of past literatures regarding wind tunnel design and its subsequent operation is needed. The review will cover the classification of wind tunnel, information on computational fluid dynamics (CFD) analyses in designing a small-scale wind tunnel and guidelines for wind tunnel construction.

2.2 Classification of Wind Tunnel

There are two types of wind tunnel which are open circuit and closed circuit as shown in Figure 2.1. Both have their own advantages and disadvantages. The most obvious advantages and disadvantages are the capital investment and type of fans used. The open circuit has much lower capital investment, but it requires larger and more powerful fans while closed circuit requires a larger capital investment, but using less powerful fans (Boudreau III, 2009).

(a)



(b)

Figure 2.1: Two types of wind tunnel (a) Close circuit and (b) Open circuit (Boudreau III, 2009)

2.2.1 Open circuit wind tunnel

Most of the small wind tunnels are open circuit type, because of low construction cost (Barlow et. al., 1999). This type of wind tunnel does not have loop feedback to its contraction. For this type, the main sections of the wind tunnel are (1) contraction, (2) test section, (3) diffuser, and (4) fan as shown in Figure 2.1 (b). This type of wind tunnel then can be divided into two further types which are a suck-down wind tunnel and a blown type wind tunnel, where the air is sucked down and blown throughout the wind tunnel by a fan, respectively (Dalal, 2013). Normally, the fan of suck-down wind tunnel is located at the downstream of the wind tunnel while blown type is located at the upstream.

The lists of advantages and disadvantages of this type of tunnel, are stated as follows (Zehhrung, 2011):

Advantages:

- Low construction cost.
- If one intent to run internal combustion engines or conducting flow visualization study using smoke, there is no purging problem as both inlet and exhaust are open to the atmosphere.

Disadvantages:

- If located in a room, depending on the size of the tunnel to the room size, it may require extensive screening at the inlet to obtain high-quality flow. The same may be true if the inlet and/or exhaust is open to the atmosphere, where wind and cold weather can affect operation.
- For a given size and speed, the tunnel will require more energy to run. This is usually a factor only if it is used for a developmental testing where the tunnel has a high utilization rate.
- In general, a wind tunnel is noisy. For larger tunnels (test sections of approximately 6 m^2 and more) noise can cause environmental problems and limits on hours of operation due to safety and health reasons.

2.2.2 Closed circuit wind tunnel

The closed-circuit wind tunnel has a continuous loop from the diffuser section back to the contraction section. It also has two more additional sections compare to the open circuit wind tunnel; corner vanes and return ducts (the loop). Mostly, larger size wind tunnels use this design as it produce high quality flow and have low pressure drop (Dalal, 2013). This type of tunnel then can be divided into two subcategories which are "The Open Test

Section" in which air is blown from the contraction cone to an open space between the contraction area and the diffuser, and "The Closed Test Section" in which air is blown from the contraction cone to a closed wall test section (Dalal, 2013).

The advantages and disadvantages of the closed circuit wind tunnel are listed as follows (Zehhrung, 2011):

Advantages:

- The quality of the flow can be easily controlled using corner turning vanes and possibly screens.
- For a given size and speed, the tunnel will require less energy to run. This is usually a factor only if using for a development testing where the tunnel has a high utilization rate.
- Less noise when operating.

Disadvantages:

- Higher initial cost due to additional components like return ducts and corner vanes.
- A solution to purge tunnel if used extensively using smoke or running of internal combustion engines.
- It should have an air exchanger or some other method of cooling.

2.3 Wind Tunnel Design

This section is divided into four (4) subsections which each focuses on different components for a small-scale open-loop wind tunnel.

2.3.1 Drive system

Fan and compressor are the two primary drive systems for a wind tunnel. A compressor can be used to provide pressurize air from storage tank to drive air through the wind tunnel. Besides compressor, a fan also can be used to drive air through by blowing or sucking air from surrounding into the test section. For the fan, axial or centrifugal fan as shown in Figure 2.2 and Figure 2.3 can be used alternatively. However, fans hold an advantage over compressor in ability to provide air continuously to the test section. This is because the compressor is restricted by the capacity of a storage tank that will affect the operation duration (Ramrukheea, 2017).

There are several studies that state the centrifugal fan can provide more steady and efficient operation compared to the axial fan (Mehta, 1977). Moreover, the outflow from the centrifugal fan is far from uniform as the span of the rotor being only half of the width of the volute casing, it affects the flow uniformity (Ramrukheea, 2017)However, the use of screens and flow straightener can eliminate the non-uniformities and provide low-turbulence flow within the test section (Ramrukheea, 2017).

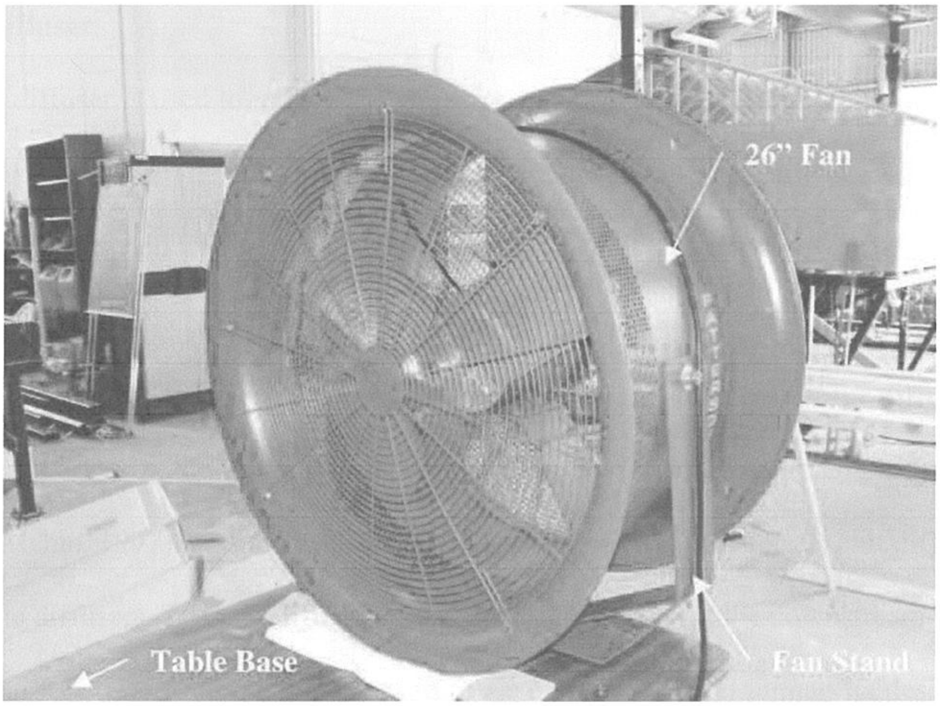


Figure 2.2: Example of axial fan (Boudreau III, 2009)

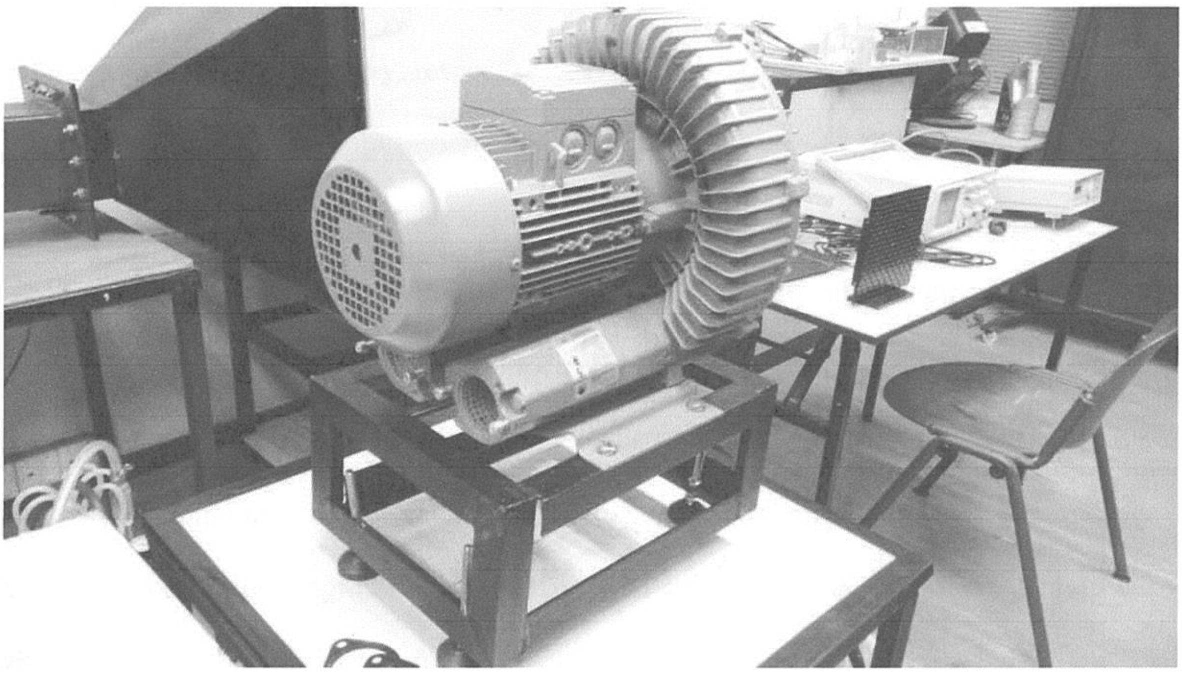


Figure 2.3: Example of centrifugal fan which is available at the Turbo Machinery Lab in FKM