Laboratory development of low speed wind tunnel for educational purposes

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Abstract. In this paper presents the design and development of wind tunnel for educational purposes. The wind tunnel is designed as an open-type, low speed, able to provide wind speeds up to 20 m/s and maximum turbulent intensity is 5%. A 70 cm tube axial fan is driven by a 3 hp motor using a variable frequency drive to allow continuously variable wind speeds. The size of testing chamber is about 40 cm by 40 cm, large enough to conduct experiments such as drag coefficient, airfoil and wing. Preliminary test of air flow in testing chamber shows that wind tunnel is particularly suitable not only for education but also for aerodynamic researches.

1. Introduction

Research with the application of wind tunnels as a very intense tool used in aeronautics and has been so solid in terms of reliability in that field over the last few decades. Parameters such as pressure variation, number of Mach, density and temperature distribution, noise and acoustics have been the concern of many researchers. The most important performance measure in a wind tunnel depends on its turbulence, the rate of fluctuation in the unstable velocity of the average flow rate [1]. Wind tunnel designers seek to improve the flow quality of wind tunnels by using the best design rules and some optimization to improve the role of wind tunnels in industrial design. Currently wind tunnel testing is in the first stage in design for all aircraft [2]. This acceptance is so widespread that people are tempted to use the tunnel to study other airborne phenomena not encountered in the field of aeronautics. The analysis of contraction wall shapes has been published in designing of the open-type and low-speed wind tunnel using a variety of analytical and numerical techniques [3-5]. By using CFD software, flexibility in designing the expanded generally to the contractions of arbitrary cross-section and wall profile [6-7]. There are many types of different wind tunnel designs available for variety applications. Based on wind tunnel wind velocity there are wind tunnel for subsonic, transonic, supersonic and hypersonic speed. An advanced commercial wind tunnel sold commercially is considered very expensive. Since the knowledge of aerodynamics has become the basis for undergraduate students, some universities have built their own wind tunnels [9-10]. This paper aims to design and develop open-type wind tunnel at affordable prices capable of conducting experiments for educational purpose as well as aerodynamic researches.
2. Design Concept

2.1 Contraction ratio

The wind tunnels is designed for laboratory purposes with the primary consideration of having an inexpensive middle size, capable of performing aerodynamic force and moment testing as well as drag coefficients. The main objective is for teaching as an effort to increase theoretical knowledge. To accommodate these requirements, the wind tunnel is designed with modular, open-type construction and has components that can be easily modified for experimental work. The main modules of open-type of wind tunnel are contraction cone, testing chamber and diffuser. The dimensions of the wind tunnel are referred to literature data. The work of Mehta et.al [3-5] in analyzing the contraction ratio inspired the current design. As mention in their paper, the adequate contraction ratios of wind tunnel is about 6 to 10 for small and low-speed wind tunnels that suitable to the current requirement. For the present design the 7.5 ratio contractions is selected and this dimension is very close to the dimensions of C-wind tunnel as shown in Table 1. The wall contour contraction of the current design, E-wind tunnel, are inserted into J.H Bell and Mehta [4] result and re-produced as presented in Fig. 1.

The complete dimension of the current design can be seen in Fig. 2.

2.2 Wind Tunnel Development

A steel plate of 5 mm thick is used to form the contraction cone and diffuser modules. The plate is carefully bent to develop the appropriate shape. To form contraction contour is the most challenging job, starting forming the mold up to welded the plate (see Fig. 3). The diffuser module utilized 3-blade axial fan with a diameter of 70 cm to suck air that belt driven by a 3 hp motor as shown in Fig. 4(a). The speed of the motor is controlled by an inverter that can be adjusted ranging from 0 to 50 Hz. The current setting provides the airspeed range from 4 to 20 m/s. The test chamber module (40 cm x 40 cm x 60 cm) is designed with transparent windows. The completed wind tunnel is presented in Fig. 4(c).

The total production cost of the machine is about Rp. 10 million (US$750). The highest cost contributors are development of contraction cone, diffuser, fan, controllers and motor while frame and machining is relatively inexpensive due to the precision works is not so high.

3. Preliminary test result and discussion

In order to test the performance of wind tunnel, a simple test was performed with anemometer as the sole instrument. The constant motor speed is set to the fan so it is expected to suck air in the laminar stage in the testing chamber. The first test is to measure the turbulent intensity by using equation,

| No | Wind tunnel                              | Contraction ratio | Inlet height x width (cm) | Exit height x width (cm) | Contraction length (cm) | Length to height ratio | Wall contour shape |
|----|------------------------------------------|-------------------|---------------------------|--------------------------|-------------------------|------------------------|-------------------|
| A  | Shear layer tunnel (NASA Ames)            | 10                | 38 x 76                   | 7.6 x 38                 | 91                      | 1.2                    | “Eye” design      |
| B  | Mixing layer tunnel (NASA Ames)           | 7.7               | 91 x 137                  | 91 x 18                  | 244                     | 0.89                   | Fifth-order polynomial |
| C  | Boundary layer tunnel (NASA Ames)         | 7.5               | 120 x 100                 | 20 x 80                  | 120                     | 1.0                    | Fifth-order polynomial |
| D  | Boundary layer tunnel (Imperial College)  | 9                 | 114 x 76                  | 13 x 76                  | 122                     | 1.07                   | “Eye” design      |
| E  | Boundary layer tunnel (UMSU)              | 7.5               | 120 x 100                 | 40 x 40                  | 120                     | 1.0                    | “Eye” design      |
\[ T.I = \frac{u'}{U} \quad (1) \]

where \( u' \) is the root-mean-square of the turbulent velocity fluctuations and \( U \) is the mean velocity at the same location over same time period. Anemometer is placed and data is collected at the centre line for same time period. Figure 5 shows the results of wind velocity for time about 100 seconds with the mean velocity of about 10.52 m/s. By using Eq. 1, it was found that the turbulent intensity was 3.69 %. Based on this preliminary test data, the maximum turbulent intensity limit below 5% has been satisfied.

For the second tests, above the testing chamber, vertical and horizontal rail pits are made to observe the distribution of wind velocity. Data for each position in Fig. 6 are an average data of 10-15 seconds. It can be seen laminar stage occurred at the testing chamber.

\[ \text{Figure 1. Comparison of wall contour of six contractions.} \]
\( (L \) is the contraction length and \( H_i \) is the inlet height).
Figure 3. Construction of wind tunnel.

Figure 4. Completed development of UMSU wind tunnel.

Figure 5. Wind velocity vs. time on centre line of test section.
4. Conclusion

In this paper, the UMSU wind tunnel has been successfully designed and built as a modular, small scale, low-speed wind tunnel and has been evaluated for educational purposes. It will allow mechanical engineering students and faculty staff to have access to a local wind tunnel where a variety of testing and experimentation on aerodynamics field. With wind speeds of up to 20 m/s and a cross sectional area test chamber as large as 40 cm by 40 cm, it possible to use it for a variety experimental works.

References

[1] Frank M W 2006 *Viscous Fluid Flow* Third Ed. McGraw Hill.
[2] Douglas A J 2014 *Flying beyond the stall: the X-31 and the advent of supermaneuverability* National Aeronautics and Space Administration.
[3] James H B and Rabindra D M 1988 *Joint Institute for Aeronautics and Acoustics*, Stanford University.
[4] Bell J H and Mehta R D 1989 *American Institute of Aeronautics and Astronautics Journal* 27-3 372-374.
[5] Mehta R D and Bradshaw P 1979 *The aeronautical journal of the royal aeronautical society* 443-449.
[6] Sargison J E, Walker G J and Rossi R 2004 *Proc. 15th Australasian Fluid Mechanics Conference*.
[7] Ahmed D E and Eljack E M 2014 *Proc. 10th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics*.
[8] Mohod S W and Aware M V 2011 *Int. Journal of Engineering, Science and Technology* 3 (5) 73-82.
[9] Bunlung N, Somporn S, Somchai C 2007, *Int. Energy Journal* 8 21-28.
[10] Yong T H and Dol S S 2015 *IOP Conf. Series: Materials Science and Engineering* 78 012039.