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THE DEVELOPMENT OF A MULTI-PURPOSE WIND TUNNEL

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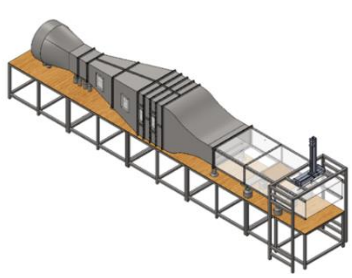
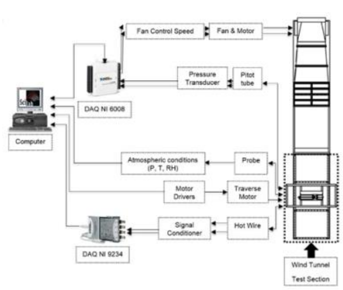
Graphical abstract





Abstract

This manuscript contains the development stages of a multi-purpose wind tunnel built at the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia. The fully automated wind tunnel is named Pangkor after an island in Perak, Malaysia. The development of the wind tunnel consists of three stages namely the design, fabrication and testing & commissioning. The computational fluids dynamic (CFD) approach was employed to ascertain the main geometries to optimize space utilization. Calculations are made based on typical wind tunnel design guidelines. Pitot tubes-pressure transducer, hotwire anemometry, temperature, room humidity and barometric sensors were used to verify actual flow of our construction. A traverse installed at the wind tunnel is capable of a two dimensional movements. The 15 kW axial fan used is especially selected because of space limitation. A variable frequency drive (VFD) connected to fan's motor allows velocity control from a computer. All devices are connected a computer with one single controlling software; Scilab – ensuring ease of operation. The project shows that, with a limited budget, a wind tunnel with full functionalities could be constructed.

Keywords: Wind tunnel; boundary layer

Abstrak

Manuskrip ini mengandungi dokumentasi peringkat-peringkat pembangunan sebuah cerowong angin pelbagai guna yang dibina di Fakulti Kejuruteraan dan Alam Bina, Universiti Kebangsaan Malaysia. Cerowong angin automatik sepenuhnya ini dinamakan Pangkor, iaitu nama sebuah pulau di Perak, Malaysia. Terdapat tiga bahagian utama di dalam pembangunan cerowong angin ini iaitu reka bentuk, pembinaan dan pengujian & pentauliahan. Kaedah dinamik bendalir komputeran digunakan untuk memastikan geometri utama dan pengoptimuman penggunaan ruang. Pengiraan dibuat berdasarkan garis panduan pembinaan cerowong angin. Tiub Pitot-transduser tekanan, anemometri dawai panas, penderia-penderia suhu, kelembapan bilik, jangka-tekanan (barometer) digunakan untuk memastikan aliran angin sebenar pembinaan ini. Sebuah terabas (traverse) dipasang di cerowong angin boleh digunakan untuk pergerakan dua dimensi. Kipas paksi 15 kW digunakan atas faktor keluasan yang terhad. Pacuan frekuensi bolehubah (VFD) bersambung kepada kipas membolehkan kawalan kelajuan angin dibuat dari komputer. Semua peranti bersambung kepada sebuah komputer dengan satu perisian untuk pengawalan; Scilab – memastikan operasi yang senang. Projek ini menunjukkan walaupun dengan kedudukan dana yang rendah, sebuah cerowong angin dengan fungsi menyeluruh boleh dibina.

Kata kunci: Cerowong angin; lapisan layer

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1.0 INTRODUCTION

Wind tunnels are widely used to measure aerodynamic behaviour of solid objects. These facilities provide actual drags, lift and other aerodynamic properties important for aircraft operations, car aerodynamic features such as side mirror, bicycle helmet and etc. Having wind tunnel facilities was considered of strategic importance during the Cold War; the development of supersonic aircraft as well as missiles gave upper hands advantages in the war. Early studies of wind tunnel were recorded in 1742 and 1759, simulated by Robins [1] and Smeaton [2], where both studies used rotational object on an arm to create the air flow. Wind tunnel are widely used to study aerodynamic properties of flow past an object/s e.g. in the automotive industries [3] or simply flow properties on the wall i.e. boundary layer studies [4].

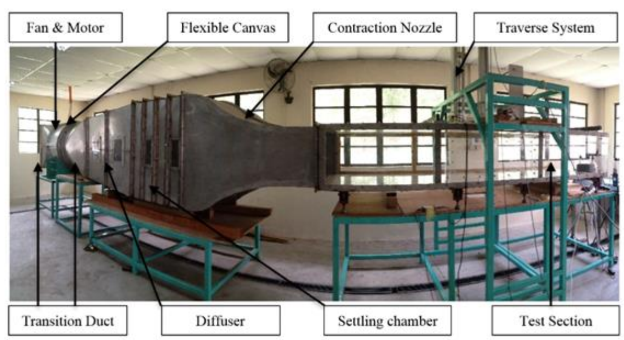
Wind tunnel experiments also provide the necessary information for much larger atmospheric-scale boundary layer studies. The wind tunnels results are compared with bigger facilities for especially flow similarities [4], [5]. The features of natural wind in the atmospheric boundary layer were only properly simulated in 1950s [6], [8]. Since then, extensive research have been conducted to improve the wind characteristics in the wind tunnel, notably by placing flow-adjustment devices and the advancements in data-acquisition systems [9], [10]. Wind tunnel permits an exploration of atmospheric boundary layer effects on building structures, pollutant dispersion, wind-induced vibration and weather prediction [11], [15]. Investigation of simulated natural wind characteristics on small-scale models in boundary-layer wind tunnel (BLWT) contributed to enhancement of scope and accuracy in both research and design.

Even with recent and updated technologies, materialising a functional wind tunnel proved to be a challenge, particularly with restricted funding. This article describes the development of low-cost, multi-purpose and automated close-circuit wind tunnel. The paramount requirement is to have a proper simulation of the characteristics of a controlled flow using local material, in-house fabrication and self-assembly. Even working with limitations, attentions were paid to the foregoing requirements of surface roughness, flow structure, pressure gradient and sufficient upwind fetch.

2.0 DESIGN

2.1 Planning

Prior to starting detailed design works, the team deliberated a few main criteria which were (a) the type of wind tunnel to be constructed, (b) available funds, (c) space in laboratory and (d) benchmarks. The first three items are inter-related; the wind tunnel designs should be tailored to meet the specific research goal and is subject to budget and facility limitations. We decided that the wind tunnel should be used to study the flow characteristics/aerodynamic of objects, boundary layer as well as for the use of particle image velocimetry (PIV). With the space available at Makmal Kejuruteraan Air dan Pantai (The Laboratory of Water and Beach Engineering), Department of Civil and Structure, Faculty of Engineering and Built Environment, UKM, a space of about 12 m long, 4 m wide and 3 m height allows for the use of wind tunnel facility. The place was only use for laboratory works either for undergraduates or for research works. Noise, vibrations and potential hazards from the operations of a wind tunnel will unlikely affect existing use of the laboratory which currently holds typical undergraduate laboratory works.



(a) Snap-shot

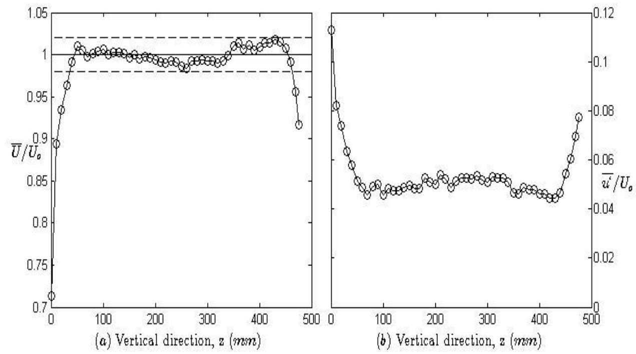


Figure 6 Diagram of connectivity of all devices to a computer using Scilab

Figure 6 shows the diagram of all connectivity. Starting from the motor, a National Instrument (NI) data acquisition (DAQ) system is used to send signal to the VFD. The fan speed was controlled through an output voltage signal produced by the NI DAQ 6008 module under request of Scilab. The rest of connectivity for all sensors, stepper motors and other devices are listed in the diagram. We have to leave the details and readers are encouraged to visit www.ukm.my/zambri/consult/WT.htm for Scilab programming codes and the connection methods.

3.0 FLOW QUALITY AND COMMISSIONING

Prior to hotwire and pitot tube measurements, the wind tunnel has been run continuously for eight hours for different fan frequency to test fan general working performance including speeds and temperature. No abnormalities were observed except for insufficiency current.

Flow qualities are the only analysis presented here. Figure 7(a) shows the velocity profile at the centerline of the wind tunnel, 1700 mm from the start of the test section. The measurements uses hotwire anemometry, set at 20 KHz, measurement period of 10 s, platinum wire of 5 µm, and sensor length of approximately 1.5 mm and overheat ratio of 1.7. The horizontal axis in the plot is the entire extent of test section height i.e. 500 mm. The speed in this measurement is set at approximately 22 m/s or at the highest frequency sent to the controller's VFD. Each measurement point is separated by 10 mm, therefore there are 49 points in this measurement. The solid line indicates mean velocity taken 50 mm from each bottom and top surfaces i.e. four points from each surfaces are omitted from the mean velocity calculation. The dashed-lines indicate 2% deviation from the mean velocities. With all points lie within the 2% deviation, the centerline at 1700 mm is ready for aerodynamic measurement. Note that this is also the location where slot for traverse and infrastructure for rotating table have been allocated.

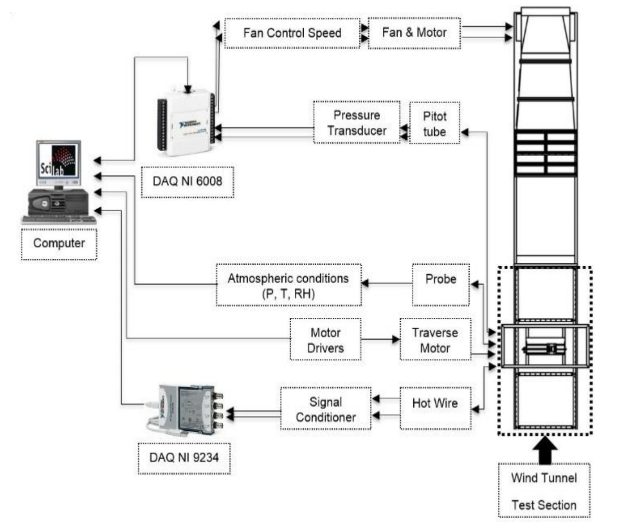
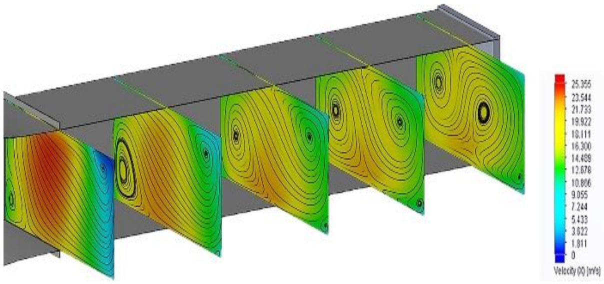


Figure 7 Flow profiles at centerline (y = 0 mm). (a) Velocity profile and (b) Turbulence intensities profile. Where U is the velocity, overbar lines indicate mean values, U_o is the bulk velocity and u' is the fluctuating velocities

Hotwire anemometry calibration has been carried out in-situ. Pitot tube pressure transducer pair has been used to measure flow velocity. Air density and kinematic viscosity have been calculated using the Comet ambience sensor device, therefore the speeds measured in the experiment are considered accurate. Figure 7(b) shows turbulence intensities profile. u', the standard deviation of the fluctuating velocities, scaled with the mean velocity, U_o. The profile suggests that the intensities are relatively large i.e. approximately 5%. The measured turbulence intensities are similar with the ones produced by the Wieghardt's formulation (Eq. 1) as in the results shown in Table 1 and subsequent Batchelor's formulation (Eq. 2). An improvement will have to be done further up in the wind tunnel if lower intensities are required. Currently honeycomb is being installed. From both profiles, the boundary layer thickness δ is approximated to be 50-60 mm i.e. within the expectation from the calculation.

(a) Velocity contour (cross-section) along the middle of the test section



(b) Velocity contour at different location of test section

Figure 8 Velocity flow distribution. (a) Velocity contour profile and (b) velocity contour at a different location. *U* is the velocity

In this section, we describe the flow uniformity by computational fluids dynamic (CFD). The velocity contours of the test section, shown in Figure 8(a), indicates that there is no two-directional flow along the middle section. The flow is from right to left. The flow accelerates towards the end of test section as the boundary layer thickens. Figure 8(b) indicates two low-speed centers which develop on the lower right and upper left of the flow. The centers are being pushed towards each corner as the flow moves towards the end of the test section. The results here are generated without the two layer screen feature. So the actual results which is shown Figure 7(a) might not be readily compared with Figure 8(b). The screens and honeycomb yet to be installed are expected to improve the flow quality.

4.0 CONCLUSION

We have constructed a wind tunnel made mostly from stainless steel body and acrylic body low speed wind tunnel for aerodynamic as well as boundary layer research. Pangkor is capable of 25 m/s speed research and could be run automatically for long period of time. This is possible since all controls are made from one single source - a computer and a software. The internally designed and built wind tunnel allows the turbulence team to go for much focused research. We have omitted computational fluid dynamics (CFD) analysis but only presented selected data for this article.

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- *AP-2012-010 for the VFD and other accessories*
- *GGPM-2012-092 for the construction of contraction chamber and diffuser sections*
- *FRGS/1/2013/TK01/UKM/02/3 for the installation of sections and fan*
- *PIP-2013-40 for particle image velocimetry (PIV) equipment.*

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