Low Cost Laboratory Built Wind Tunnel

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Abstract: Laboratory wind tunnel made it possible to observe from a stationary position and measure the aerodynamic forces and associated parameters in a controlled environment the behaviour of objects that would normally be moving through the air. A conventional non-return type wind tunnel with one closed working section was designed, constructed and calibrated for wind speed up to 16 m/s. Test results indicated that the boundary layer effects on the air flow within the wind tunnel penetrated the velocity profile to a depth of approximately 60 mm over the test range 3 m/s to 16 m/s. The cost of construction totaled US$1354 which is a fraction of the cost for purchasing an off the shelf laboratory testing wind tunnel of comparative size.

Keywords — *Wind tunnel, open-circuit wind tunnel, low-speed wind tunnel, low-cost wind tunnel.*

I. INTRODUCTION

The need for developing wind tunnel for research was recognized as early as the 19th century to aid in the understanding and development of aeronautics. Wind tunnel design and use was propelled by research in the development of heavier-than-air flying machines. The wind tunnel made it possible to observe in a controlled laboratory environment the behaviour of objects that would normally be moving through the air. The wind tunnel concept was based on reversing the normal mode of the air standing still and an object moving at speed through it by recognizing that the same effect would be obtained if the object stood still and the air moved at speed past it [1]. In that way a stationary observer could study the behaviour of an object in action and could measure the aerodynamic forces and associated parameters being imposed on it.

II. BACKGROUND

Most wind tunnels used in the aeronautics industry and aero space industry were designed for high velocity testing. Also, the automotive industry with the high competition saw the need for aerodynamic wind tunnel testing of vehicles. This generated the need for wind tunnels with medium range wind velocity. The relatively recent thrust in the use of wind energy as a source of renewable energy for electrical power generation has hastened the need for low speed wind tunnel testing facilities under 16 m/s wind velocity [2]. However, the cost of a fully instrumented laboratory wind tunnel is usually beyond the reach of most universities.

To fill this need at The University of the West Indies, St. Augustine Campus, Trinidad, a low cost wind tunnel apparatus was designed, constructed and tested to facilitate research within the range of up to 16 m/s wind speed.

III. WIND TUNNEL DESIGN

The wind tunnel designed was an open-circuit suction wind tunnel in which the airflow was completely contained within the laboratory area. Fig. 1 shows a schematic of the low velocity wind tunnel design.
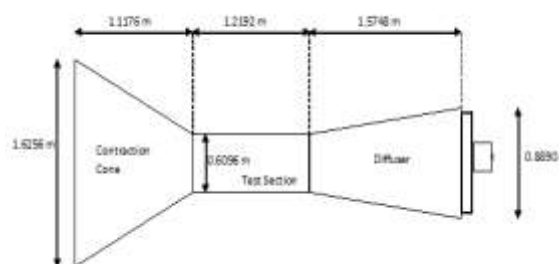

Fig. 1 Schematic of the low velocity wind tunnel design.

The air entered the wind tunnel through a filter and screen exited the wind tunnel into the open laboratory space. The wind tunnel was the conventional non-return type with one closed working section and was constructed using 9.50 mm thick plywood. The dimensions of the wind tunnel were 3.91 m in overall length, 1.63 m wide and 1.63 m high at the mouth [3].

Wind speed through the tunnel was controlled by a variable speed WEG 3.00 hp motor drive unit with a WEG CFW 08 vector inverter and a motor speed control unit. The fan size and motor speed range was designed to provide wind speeds between 3 m/s to 16 m/s in the wind tunnel over the test section. A hot-wire anemometer positioned 2.18 m upwind from the wind-tunnel exit was used to measure wind velocity.

A. Test Section Assembly

The test section was built from 6.35 mm thick transparent Plexiglas and attached together with silicone and L-Brackets. The dimensions of the test

section assembly were 61 cm x 61 cm and 122 cm in length. Fig. 2 shows the completed test section chamber into which samples can be mounted for observation.

Fig. 2 Transparent test section chamber

B. The Diffuser and Fan Assembly

This section housed the fan, electrical wiring and fan controller. The diffuser assembly was fabricated using 9.5 mm plywood. The fan assembly consisted of a direct drive 77.5 cm diameter fan and with a 90.2 cm x 90.2 cm aluminium fan housing as shown in Fig. 3. The area of the Drive Section (the large end of the Diffuser) was designed in accordance with the findings Cockrell and Markland [4] which indicated that best results were achieved for a ratio of 2:1 between the drive and test section cross sectional area. The Drive Section area was 0.790 m^2 which was 2.127 times the area of the end of the Test Section (the area of the small end of the Diffuser). The dimension of the diffuser body was 0.790 m^2 tapered to 0.403 m^2 over a length of 1.575 m.

Fig. 3 Fan assembly attached to drive section

C. Contraction Cone Assembly and Settling Chamber

The contraction section was located between the settling chamber and the test sections and served to both increase mean velocities at the test section inlet and moderate inconsistencies in the uniformity of the flow [5]. This assembly was at the forward end of the tunnel into which the air flowed as it was drawn in by the fan at the back. This assembly consisted of the Contraction Cone and the Settling

Chamber. The body of the contraction cone was constructed with 9.5 mm plywood, fastened together and sealed with silicone (Fig.4). The settling chamber was construed with two honeycomb mesh and one screen in the large end of the Contraction Cone. This served to reduce turbulence to a minimum and improves airflow quality (Fig. 5).

Fig. 4 The contraction cone assembly.

Fig. 5 The settling chamber.

IV. CALIBRATION OF THE WIND TUNNEL

Experimental measurements were conducted to calibrate the laboratory built wind tunnel. Calibration measurements included, the boundary layer velocity profile and the wind velocity verses milliamps, in the working section, in terms of the differential pressure values in the contraction cone [6]. A calibrated hotwire anemometer (Amprobe TMA20HW) was used to measure the velocity profile across the test section of the wind tunnel.

This anemometer measured wind velocity with an accuracy of 0.1% over the wind velocity range 0.3 m/s to 30.0 m/s. Wind velocity measurements with the hotwire anemometer indicated that the laboratory built Open Wind Tunnel achieved wind velocity up to 16 m/s.

A. Differential Pressure Sensor Calibration

The Setra Model M264 Differential Pressure Transmitter was chosen for this wind tunnel as it provided accurate readings over a small pressure differential range. This low-air pressure transmitter was capable of sensing differential pressure in both negative and positive ranges. The Model M264 incorporates a tensioned stainless steel diaphragm to form a variable capacitor that produced variation in the output signal between 4mA to 20 mA.

The free-stream speed within the test section was set by measuring the pressure drop across the 6.55:1 contraction [7]. The pressure drop was calibrated against the hot wire anemometer positioned in the mid-span of the test section. The contraction pressure drop was monitored by the Setra Model M264 Differential Pressure Transmitter. This data was used to develop a calibration curve of the wind velocity versus contraction pressure drop expressed in terms of milliamps [7]. Fig. 6 shows a graphical representation of the calibration results.
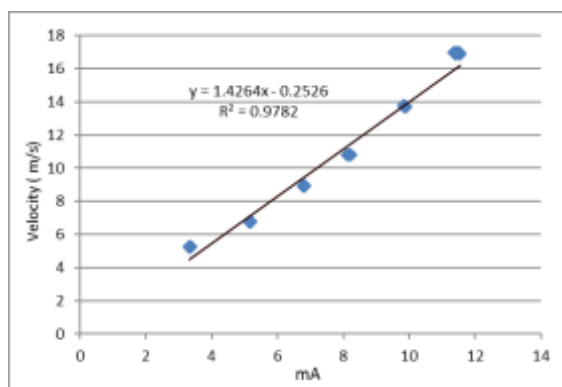

Fig. 6 Calibration of wind velocity vs. mA

V. VELOCITY PROFILE

The velocity profiles across the test section was obtained with the fan kept at a constant setting and measurements taken at incremental distances from the wall [8]. The stem of the hot wire anemometer was calibrated in ten millimeter increments to measere the wind velocity incremetally from the wind tunnel wall. This procedure was repeated for various wind speeds and plotted. Fig. 7 shows the plot for a free stream velocity of 4.9 m/s and Fig. 8 shows the plot for a free stream velocity of 11.1 m/s.
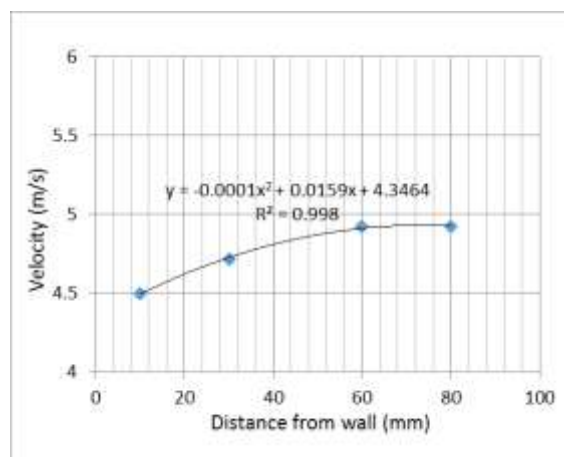

Fig.7 Plot of wind velocity variation with distance from wind tunnel wall at 4.9 m/s free stream.
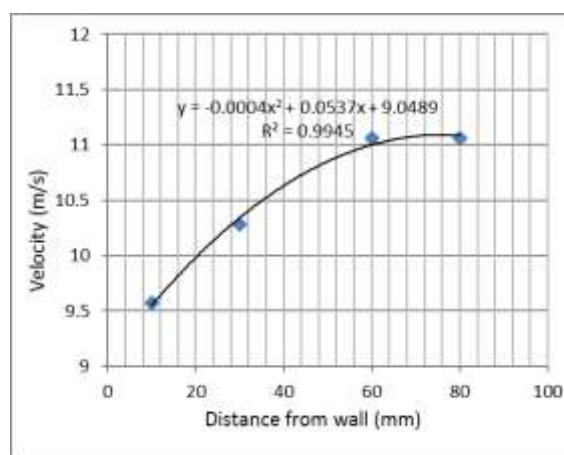

Fig.8 Plot of wind velocity variation with distance from wind tunnel wall at 11.1 m/s free stream.

VI. COST ANALYSIS

The wind tunnel was built inhouse at The University of the West Indies, Mechanical and Manufacturing Engineering laboratory. A breakdown of the cost of the materials for the wind tunnel is shown on Table 1. The overall cost excluded labour cost for construction. From the cost breakdown analysis an overall material and equipment cost was US$ 1354.00.

The price of laboratory testing wind tunnels that operate within the range up to 16 m/s wind velocity is above US$ 8000.00

TABLE 1

COST BREAKDOWN OF WIND TUNNEL MATERIAL

Item	Cost US$
4 sheets 9.5 mm plywood	100.00
1 sheet 6.35 mm thick transparent Plexiglas	185.00
Amprobe TMA20HW anemometer	294.00
Setra Model M264 Differential Pressure Transmitter	105.00
WEG CFW 08 vector inverter	450.00
WEG 3.00 hp motor drive fan	150.00
two honeycomb mesh	40.00
Auxiliary material (sealant, fasteners, nails, etc.)	30.00
TOTAL COST	**1354.00**

VII.   DISCUSSION AND CONCLUSIONS

The wind tunnel of the open-circuit design was simple enough to be constructed in the laboratory workshop with the existing resources. The calibration of the differential pressure drop as it relates to wind velocity was critical for the performance analysis of the wind tunnel design. From the calibration the free stream wind velocity can be predicted from the milliamp signal of the differential pressure transducer.

The plot of wind velocity variation with the distance from the wind tunnel wall indicated that the boundary layer effects on the air flow within the wind tunnel penetrated the velocity profile to a distance of approximately 60 mm. This was shown over the test range between 3 m/s to 16 m/s wind velocity. Figs. 7 and 8 are the plots at 4.9 m/s and 11.1 m/s, respectively, and is representative of the test results obtained at other test velocities. The dimension of the test section was 690 mm^2.

Therefore, the inner section of 489 mm^2 had free stream flow unaffected by the walls of the test section.

A cost breakdown of the material and equipment used in the construction of this laboratory built wind tunnel totaled US\$ 1354. This is a fraction of the cost for purchasing an off the shelf laboratory testing wind tunnel of comparative size.

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