International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 10, October- 2014

The Study of Close Loop Wind Tunnel & Design & Construction of Table Mounted One

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Abstract—**A subsonic close loop wind tunnel facility has been designed and constructed in the Military Institute of Science and Technology campus to facilitate the study of flow for educational purpose. The wind tunnel is specially designed to make the best use of limited area available at the Applied Aerodynamics Laboratory. A comparatively unconventional bench mounting technique is utilized in this effort. This facility is designed such that students could use the tunnel and record data by themselves.**

The tunnel has a 15 cm x 15 cm square test section with a capability to produce flow velocity of 0 to 22m/s (Reynolds number 5×10^5). With this velocity range the wind tunnel is used to carry out experiments both for laminar and turbulent flow situations. The wind tunnel is powered by three similar co-rotating axial flow fans. The air velocity in the wind tunnel can be varied by varying the speed of the fans. The wind tunnel consists of a test section, bell mouth nozzle, bends, guide vanes, vibration insulators, silencer, diffuser, settling assembly and fan unit. Incorporation of vibration isolator and silencer reduce the vibration and sound to the minimum level. The instrumentation systems include pitot tube and manometer. The flow in this tunnel reaches steady state condition within a very short time and flow is free from any disturbances from the surrounding.

Keywords— ***Wind tunnel, subsonic flow, pitot tube***

I. Introduction

Wind tunnel is a basic experimental tool to carry out aerodynamic research to study the effects of air moving past various aerodynamic bodies and aid in design process. In our concerned field of aeronautical engineering it is used to test models of proposed aircraft. In the tunnel various flow conditions (which affect forces on the aircraft) are achieved to simulate various flight conditions and by making careful measurements of the forces on the model, the forces on the full scale aircraft can be predicted. And by using special diagnostic techniques, the performance of the aircraft can be improved and understood in more efficient manner.

In a wind tunnel air is drawn, or blown over a stationary body, by mechanical means in order to achieve a specified speed and predetermined flow pattern The flow so achieved can be observed from outside the wind tunnel through transparent windows that enclose the test section and flow characteristics and forces exerted by the flow on the body are measurable using specialized instruments.

II. Theory Of Operation

Wind tunnels were first proposed as a means of studying vehicles (primarily airplanes) in free flight. The wind tunnel was envisioned as a means of reversing the usual paradigm: instead of the air's standing still and the aircraft moving at speed through it, the same effect would be obtained if the aircraft stood still and the air moved at speed past it. In that way a stationary observer could study the aircraft in action, and could measure the aerodynamic forces being imposed on the aircraft.

Dimensional analysis is utilized in wind tunnel testing which gives the same force coefficients for similar flows. Two different flows are dynamically similar if (1) the bodies are geometrically similar, (2) the kinematics are dynamically similar, and (3) the dimensionless numbers are the same for both flows.

III. Wind Tunnel Layout

Wind tunnels are an arrangement of different parts or sections, joining all together to produce a requisite stream of flow over the test specimen in the test section. Number of parts or sections is more in a closed loop wind tunnel than the open one. This wind tunnel comprises of total 15 different types of parts:

A. Test Section

Test section is the most essential part of a wind tunnel. It is used to carry out the experiment. It consists of pitot tubes, different types of sensors etc.

B. Fan Section:

Aim of the fan unit is to produce air stream through the wind tunnel in an axial direction. Electrically driven axial fans are comparatively of low cost and appropriate in creating high wind speed at small pressure head which is essential for this wind tunnel. Again, air speeds can be controlled either by regulating the rotational speed or the pitch of the blades or by both.

C. Nozzle Guide Vane

The guide vane deflects the release air velocity of the previous fan to an angle which would be tangential to the inlet of next later fan. This will lessen both loss and generation of sound and offer stable flow.

D. Silencer

Silencer is a device which reduces the amount of noise

E. Vibration Isolator

It reflects and absorbs waves of oscillatory energy, extending from a piece of working machinery or electrical equipment

F. Round to square Section & Square to round section

A round-to-square section is used to direct the flow from round silencer to the square shaped diffuser. It works as a low efficient nozzle also. Whereas, square-to-round section is used to direct the flow from square shape bend to the round shaped vibration isolator. It also works as a low efficient diffuser also

G. Diffuser

The diffuser is where the air coming out of the high speed flow unit slows down prior to exhausting or recirculating. The air decelerates due to the shape of the diffuser according to the Bernoulli's equation, and the flow pressure increases.

H. Bell Mouth Entry

The bell mouth nozzle is used at delivery side of the bend section. The reduction of sectional flow area is achieved by creating a parabolic profile for maximum flow speed of the wind tunnel.

I. Flow straightener

Usually smooth pipes are used to make a honeycomb like configuration to remove the swirls and produce low turbulence flow condition.

J. Inlet section & Delivery section :

These sections are used for the entry and exit of flow to and from the test section. These are usually free ducts for the flow to enter or exit the test section without any troubles.

K. Bend section

Air passing through the corners of these bends is prone to major flow energy losses due to change flow direction and differential flow velocity. As a consequence, guided vanes are unavoidable to direct the flow smoothly and evenly distributing the flow over whole sectional area.

L. Flange

It is used to connect the components. It holds the component each other via screws & glues.

M. Settling Assembly

Setting assembly is used to slow down the flow velocity and stabilize the flow.

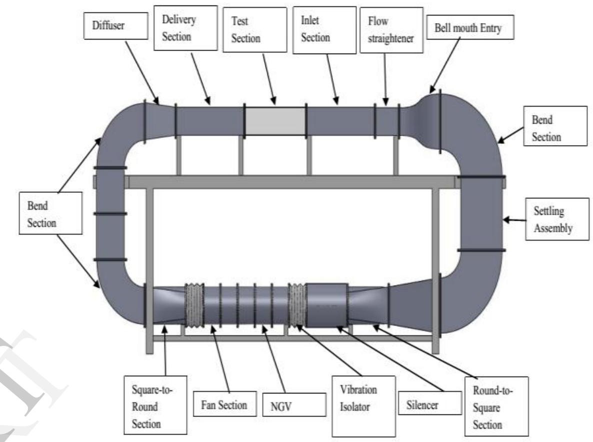

Fig.1. The wind tunnel

IV. INSTRUMENTATION

A. Pitot tube

Pitot tubes are differential pressure flow meters. Pitot tubes are mostly used to detect due to pressure flow velocity of fluids. It is extensively used to determine the airspeed of an aircraft and to measure air and gas velocities in industrial applications. The pitot tube is used to measure the local velocity at a given point in the flow stream and not the average velocity in the pipe or conduit. However, Bernoulli's equation states that it can be calculated:

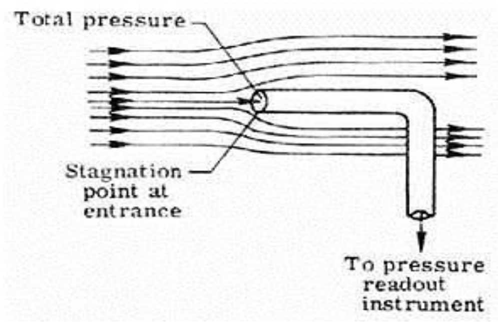

Fig.2. Pitot tube

Stagnation pressure = static pressure + dynamic pressure

This can also be written

$$P_t = P_s + (\frac{\rho V2}{2})$$

Solving that for velocity we get:

$$V = \sqrt{\frac{2(Pt - Ps)}{\rho}}$$

Note: The above equation applicable only to incompressible fluid.
Where,

- V is fluid velocity;
- P_t is stagnation or total pressure;
- P_s is static pressure;
- P is fluid density.

B. Manometer

In low speed wind tunnel, a method of measuring the pressure difference $P_1 - P_2$, hence measuring V_2 via equation$V_2 = \sqrt{\frac{2(Pt - Ps)}{\rho(1-(\frac{A2}{A1})2)}}$,is by mean of a manometer.

From fluid statics relation:

$$p_b + \rho g h_b = p_a + \rho g h_a$$

Or,

$$p_b = p_a - \rho g\ (h_b - h_a)$$

In which p_b is the body surface pressure, p_a the atmospheric pressure. The tops of the liquid in the tube connected to the body and open to the atmosphere with heights h_b and h_a respectively.

P_a,ρ and g are known, and $(h_b - h_a)$ is read from the tube, thus p_b can be measured.

C. Pressure tranducer

A pressure transducer measures pressure, typically of gases. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure transducer generates an electric signal, usually voltage, as a function of the pressure imposed on the element.

In this project, MPXV5050GP pressure sensor was used to measure pressure. This can measure pressure from 0 KPa to 50 KPa and it can withstand up to 200 kpa.

D. DAQ (Data Acqusition) system for Instrumentation

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

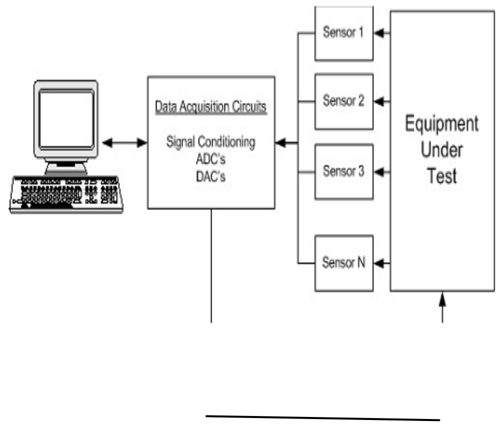

Fig.3. Data Acquisition System.

V. GOVERNING AERODYNAMIC EQUATIONS

A wind tunnel is a basic tool of measuring aerodynamic characteristics that uses many aerodynamic equations.

A. Continuity Equation

The continuity equation uses the conservation of mass and states as in equation (6.1)

$$\frac{\delta\Psi}{\delta t} + \nabla * (\rho V) = 0$$

Where,

$\delta\Psi$ = Change in Fluid Density
δt = Change in Time
∇ = Divergence
$*$ = Dot Product
ρ = Fluid Density
V = Fluid velocity vector

Incompressible Flow Assumption for Low-Speed Applications
For low speed applications, defined by Barlow as speed less than 0.3 Mach, the fluid is incompressible and simplifies the continuity equation. The assumption of incompressible flow can be safely assumed because Atmospheric Boundary Layer (ABL) wind tunnels are almost exclusively run at low wind speeds below Mach 0.3.

$$\frac{\delta\rho}{\delta t} = 0$$

$$\nabla \cdot V = 0$$

Where,

δρ = Change in Fluid Density
V = Fluid Velocity Vector
A = Cross Sectional Area

Simplify for Average Two Dimensional Flow Using Eulerian Perspective

$$Q_1 = Q_2$$

$$A_1V_1 = A_2V_2$$

Where,

V = Fluid velocity vector
Q = Mass Flow
A = Cross sectional area

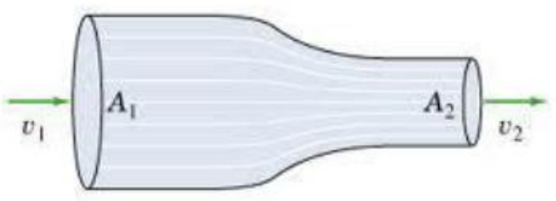

Fig.4. Continuity equation Figure

B. Bernoulli Equation

The Bernoulli Equation gives an estimate of the overall velocity pressure relationships throughout the low-speed wind tunnel system; by incorporating frictional and local losses into the Bernoulli Equation, it can give estimations of overall system performance and specific pressures can be conducted.

$$P_1 + \frac{1}{2}\rho V_1 + Z_1 = P_2 + \frac{1}{2}\rho V_2 + Z_2$$

Where:

p = Pressure
ρ= Fluid density
V = Average velocity of the fluid
Z = Elevation above datum
h_f = Sum of Frictional and Local Losses

Pressure Loss Equation Using a Loss Coefficient

. The total pressure loss is calculated by adding up all of the individual section pressure losses.

$$\Delta p = \frac{1}{2} k\rho V^2$$

Where,

Δp = Pressure loss
K = Loss Coefficient
ρ= Fluid density
V = Average velocity of the fluid

C. Circuit Energy Loss Equation

The circuit energy loss is the energy lost through the circuit through expansion, contraction and frictional losses. It is estimated using the total pressure loss in equation :

$$\Delta E_{circuit} = \frac{\frac{1}{2} K \rho V^2}{550hp}$$

Where:

$\Delta E_{circuit}$ = Circuit Energy Loss (hp)
Q = Flow Rate (cf/s)
ρ= Fluid density (slugs/ft^3)
V = Average velocity of the fluid (ft/s)
550 hp = horsepower conversion

VI. Scopes And Experimental Facilities

A. Lift and Drag Measurement

The Lift and Drag coefficients can be calculated by the linear displacement of the test object due to lift and drag and then send it to the computer through the DAQ (Data Acquisition). Lift coefficient C_l and drag coefficient C_d is given by the formula,

$$C_l = \frac{L}{\frac{1}{2}\rho V^2 S}$$

$$C_d = \frac{D}{\frac{1}{2}\rho V^2 S}$$

Where,

L = experimental lift
D = experimental drag
ρ = air density
V = free stream velocity in front of the test object
S = surface area of the object

B. Wall ShearStress Measurement

By measuring velocities at 2 different height of the field, wall shear stress (τ) can be measured by the formula,

$$\frac{u_{max} - u}{\sqrt{\frac{\tau}{\rho}}} = 5.75 \log_{10}\left(\frac{H}{y}\right)$$

Where,

U_{max} = Velocity at the center of the test section
u = Velocity at a distance 'y' from the wall
H = Height of the center point from the wall

ρ = Air density

C. Discharge Through The Test Section

As the boundary layer changes with the height from the wall, the flow velocity does not remain constant. So the average velocity (*U*) is calculated by the formula,

$$\frac{u - \bar{U}}{\sqrt{\frac{\tau}{\rho}}} = 5.75 \log_{10}\left(\frac{y}{H}\right) + 3.75$$

Where,

τ = Wall shearing stress calculated in section
u = Velocity at a distance 'y' from the wall
H = Height of the center point from the wall
ρ = Air density

Now, the discharge (Q) through the test section can be calculated by

$$Q = A \times \bar{U}$$

Where, A is the area of the test section and *U* is the average flow velocity.

D. Test Section Loss

Using the exact methods for computing the pressure losses in laminar flow, one can obtained with the following equation,

$$\frac{\Delta p}{\frac{1}{2}\rho V^2} = \lambda \frac{L}{D}$$

VII. Limitations And Scope Of Further Improvement

A. Limitation

- The wind tunnel has designed with three fans due to the required flow speed and design requirement. That's why the length was increased and also increases the guide vane stages. There also create some turbulence and flow disturbance in the tunnel.
- Also to ensure a uniform steady flow the wind tunnel also had to be built within extremely limited tolerances. Without the benefit of machine fabricated pieces that are usually found in wind tunnels additional time and effort was required to keep the dimensions and contraction shapes close to the calculated requirements.
- Another issue was to ensure uniform steady flow all of the surfaces and transitions had to flow smoothly. This caused a problem with using screws or bolts, which could penetrate the wind tunnel and lead to irregular flows around the protrusions. The solution to this was to use a combination of rivets, tape, and adhesive to attach the components without any protrusions.
- To measure the pressure of the flow, pitot tubes are required with the pressure sensors. So the effectiveness of the pitot tubes was of major importance. But, commercial pitot tubes are unavailable in our country. As such, homemade pitot tubes, rather than commercial pitot tubes, were used for measuring the pressure in the test section. These are obviously less efficient to sense air pressure and thus slight error was there in the pressure reading.
- High power fans are of a prime need in these sorts of wind tunnel projects. That is why the total power output of the fan section was the most important thing in this project. As the NGV had some losses and inefficient, so it actually required high power axial fan to increase the power output of the fan section. But high power axial fans of the required dimension and which was compatible with our designed wind tunnel are unavailable in our country.

B. Scope of Further Improvements

Due to the time shortage, material delay and unavailability of components, the performance and flow analysis with the designed wind tunnel is quite less than advanced full scaled wind tunnels. There are some certain improvements which can be made for better performance. These are listed below,

- The test section can be improved to contain a cascade of stationary or rotary blades to study the characteristics of turbine or compressor blade cascades.
- After the cascade is validated, the wake generator will be installed. The energy spectrum in the frequency domain will also be measured in the wake of the wake generator blades. Phase averaged velocity and pressure profiles will be acquired with the wake generator running to characterize the effects the wake generator has on them.
- The wake generator blades can be slightly modified to include more fasteners and an all-Aluminum body. The Aluminum body helped solve a warping problem the old blades were having.
- Several new designs can be created to accommodate measurements in the test section including a three axis traverse. The traverse has a specific travel range and it was specifically designed to make automated hot wire/film measurements in the test section.
- Heat exchanger can be equipped to transfer the heat from high temp zone to the low temp zone. Basically it is connected with the fan section.
- The whole wind tunnel can be insulated due to prevent the external thermal effects.
- To provide adjustability and the ability to "tune" the flow, tail boards and inlet bleeds were included in the test section design.
- It necessary to use innovative design ideas that could allow a large enough test section for research projects, such as high Reynolds number turbulent boundary layer

studies, into a small size wind-tunnel. There are some possibilities to reduce the overall size of a closed circuit wind-tunnel without making the test section smaller. One obvious way is to decrease the contraction ratio, CR, i.e. the ratio between the largest cross section area and smallest cross section area. Most large wind-tunnels already have quite small contraction ratios though, CR ≤ 6.

- The only option to measure pressure and velocity was kept in test section. But it can be further improved by installing facilities that would allow to measure pressure and velocity of air in other section, such as bend section, diffuser, bell mouth nozzle etc. The only requirement for this is adding pressure probes in those sections where the pressure and velocity are to be measured.
- The mass flow in the test section can be increased to be able to run tests at higher flow velocity on test objects. To do so, the flow rate can be increased by installing higher powered axial fans compatible with our designed wind tunnel by replacing existing fans.
- The blade angles of the nozzle guide vanes should be made as precise as possible to ensure maximum flow velocity output by the fans.

VIII. CONCLUSION

The wind tunnel was designed to study the flow characteristics, boundary layer formation with pressure and velocity distribution. The purpose of this report was to characterize and verify the performance of the wind tunnel through velocity and pressure measurements in the test section.

There are some important conclusions which can be summarized as the followings

- The design was made in accordance with the availability of the items and also compromising the delivery lead times.
- Several designs were made but the ultimate choice was made by taking the consideration of higher performance with available components.
- For studying aerodynamics and fluid mechanics this closed loop wind tunnel is of vital choice where flexibility, mobility and user friendly rugged operations are prerequisite.

IX. ACKNOWLEDGEMENT

We would like to express our heartiest gratefulness and indebtedness to Dr. M. A. Taher Ali, Professor, Mechanical Engineering Department, Bangladesh University of Engineering & Technology (BUET), for his deliberate encouragement, consistent support, valuable guidance and supervision on completing the project. We are also very much thankful to Group Captain Md. Abdus Salam, psc, Senior Instructor and Head of the Department, Department of Aeronautical Engineering, Military Institute of Science and Technology (MIST), for his consistent support and valuable time for the project.

We are very grateful to Aeronautical Engineering Department, MIST, for providing the financial support and other facilities throughout the whole project work.

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