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DESIGN, FABRICATION AND TESTING OF A SMALL SCALE LOW REYNOLDS NUMBER TABLE TOP WIND TUNNEL

Syed Shahrukh[1], Nithin Raj N[1], Jayaprakash BP[1], Premkumar Naik R[1], Dr. G Balakalyani [2], S. Srinivasan[2]

[1]Student, Department of Aerospace Engineering, RVCE, Bangolre-560059
[2]Assistant Professor, Department of Aerospace Engineering, RVCE, Bangolre-560059

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Abstract - Wind Tunnel forms the basis for any practical aerodynamic study. The experimental testing is inevitable to study the characteristics of aerodynamic behaviour of bodies. The wind tunnel setup provides a controlled environment, simulating the real flight conditions. The low Reynolds number tunnels are very much essential to understand the aerodynamic characteristics of UAV and *MAV's which flies at very low speed. A small scale open* circuit wind tunnel of 1.8m length is designed and fabricated in order to achieve flow velocity of approximately 8m/s with a test-section of square cross section. Numerical flow simulation is carried out in ANSYS workbench to understand the flow characteristics through the wind tunnel. The designed wind tunnel components are fabricated with Mild steel material and the calibration of test section is carried out by measuring the test section velocity using pitot static probe for various driving fan speeds [14].

Key words: Reynolds number, Wind tunnel, Pitot-static probe, laminar flow, Computational fluid dynamics.

1. INTRODUCTION

The Wind tunnel is an experimental set up for aerodynamic testing where air is either blown or sucked in through a varying area duct and its purpose is to simulate different airflow conditions as that of the flight environment. It provides a conditional environment to test aerodynamic bodies to extract many parameters that govern the flow. The wind tunnel experimentation is not only limited to aircrafts, they are also used for automobiles, helicopters, spacecraft re-entry, tall building and skyscraper designs. Wind tunnels can operate at all speeds ranging from subsonic ($M < 0.4$) to hypersonic ($M > 5$) [1].They are classified based on airflow direction, test section size and many more. Of which, Open circuit Wind tunnel is of keen interest in this study. Open Circuit employs surrounding air as the fluid medium. The major data cradles required for aerodynamic design of any vehicle is CFD, wind tunnel tests in addition to flight experiments, generally on simplified geometries [11]. The key method of research, which decides the success of aerodynamics as a science and its extensive applications in many turfs of technology, is its testing in wind tunnels. Based on literature review, basic equations and empirical relations for designing the various cross sections of Wind tunnel, fabrication methods and materials needed to be used are thoroughly studied and taken into consideration for design and development of the Wind tunnel.

1.1 Classification of Wind tunnels

The Wind tunnels are classified based on airflow direction. The basic types of wind tunnel are closed circuit and open circuit wind tunnels [14]. Hence the two basic test section configurations are closed and open test sections.

Figure 1.1 Classification of Wind tunnel

1.2 Open Circuit Wind Tunnel:

The air flow direction in open circuit wind tunnel shown in Figure 1.2 follows a fundamentally a straight way from the entrance through a Contraction to test section, finally to diffuser. Open circuit wind tunnels do not re-circulate air [14]. Reasonably, air is drawn in from the atmosphere, passed through the test section and returned from exhaust to atmosphere. These low speed wind tunnels can also be utilized for smoke flow visualization.

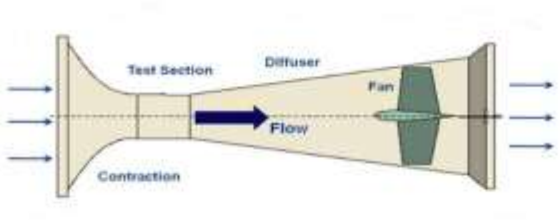

Figure 1.2 Schematic of Open Circuit Wind Tunnel

2. Design criteria

For subsonic flows velocity increases and pressure decreases by reducing the size of contraction cross section. Whenever there is an increase in cross section, pressure rises and velocity decreases [9]. On this principle maximum possible velocity can be achieved in the test section. For subsonic flows since the velocity is a function of cross sectional area, desired velocity can be achieved at the test section by using law of conservation of mass.

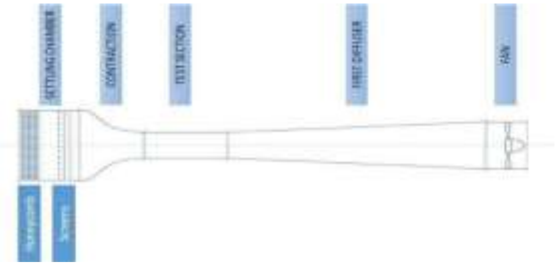

Figure 2.1: Open Circuit Wind Tunnel schematic [6]

An Open Circuit Wind tunnel consists of following main components as shown in the Figure 2.1.

1. Test Section
2. Contraction Nozzle
3. Fan
4. Diffuser Section
5. Settling Chamber
6. Honeycomb
7. A Series of Screens

For the design procedure, the test section influences every component in the wind tunnel design [11]. Overall wind tunnel dimensions are dependent on test section size followed by design of Nozzle to have maximum acceleration with laminar flow. Selection of wind tunnel fan, the diffuser and settling chamber which consists of honeycomb structure and Screens are designed.

2.1 Test Section: Generally it is expected that the test section should have as large cross section as possible. Test section design process starts from the initial requirements like the test section shape, dimensions and the preferred velocity [10]. The dimensions of the test section are mentioned in the Table 1, which are used the design the model shown in Figure 2.2.

Material	Mild Steel
Dimensions	(33.2×15 ×15) cm
Thickness	3mm
Mirror	Acrylic

Table1: Dimensions of the Test Section

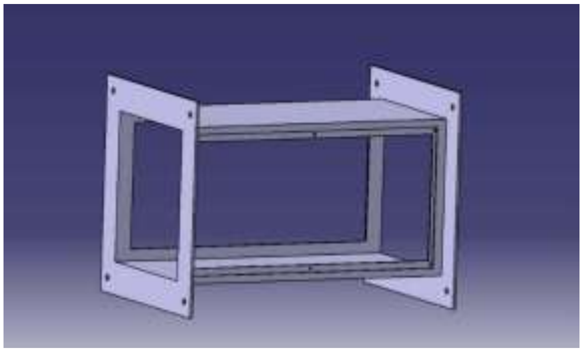

Figure 2.2 Isometric view of Test Section

2.2 Contraction Nozzle: The major aim of the Contraction Nozzle is to accelerate the low speed, high pressure fluid flow to high speed, low pressure flow in the test section. Flow uniformity in the test section is mainly dependent on the Contraction Nozzle design. Flow uniformity in the test section is mainly depended on the Contraction Nozzle and due to its complexity of the curve it is very difficult to design [11]. Using the formula for a contraction nozzle

$$r = \frac{r_0}{\sqrt{1 - \left[1 - \left(\frac{r_0}{r_i}\right)^2\right] \frac{(1 - 3z^2/a^2)^2}{(1 + 3z^2/a^2)^2}}}$$

Where ‘r’ is the radius of the nozzle cross section at a distance ‘z’ along the axis from the inlet. The inlet and outlet radii are denoted by r_i and r_o respectively. And the profile achieved is as follows in the Figure 2.3.

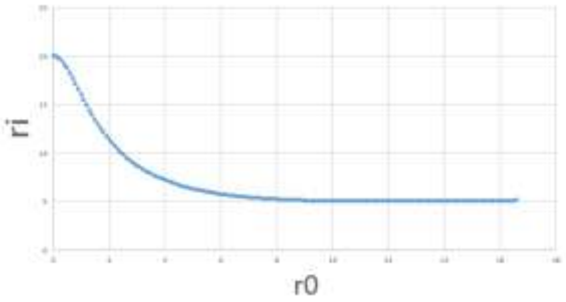

Figure 2.3: Contraction Nozzle Profile

2.3 Selection of Fan: The area ratio of fan and the test section is typically between 2:1 or 3:1. If the area ratio is designed larger, a poor velocity profile is achieved [12]. The power required by the fan is a function of the fan head, which is calculated from the aerodynamic design data for the tunnel, by considering the hydraulic losses as the air passes through it. Flow velocity is adjusted by altering the fan speed with provision of a continuously variable speed control to the fan motor. The design parameters of the fan are shown in the table 2.

Description	Value
Number of blades	3
Maximum speed	2400 rpm
Vloumetric flow	520CFM
Supply frequency	50 Hz
Dimensions	305x300x170 mm
Sweep	300 mm
Depth	150 mm
Weight	2.1 kg

Table 2: Fan parameters

2.4 Diffuser Design: In open-circuit wind tunnel a diffuser is necessary to avoid excessive friction due to high flow velocities which reduce the flow quality in the test section. The performance of diffuser is its capability of converting the kinetic energy into pressure energy which is mainly influenced by the magnitude and distribution of the velocity at its inlet, its divergence angle, and the expansion ratio. To determine the cross-sectional area of the fan from the equation the ratio between fan cross-section area and test section cross-section area (AR) should be imposed [12]. The area ratio has to be between 2 to 3 for best results,

$$2 \leq AR = \frac{\Omega_{fan}}{\Omega_{TS}} \leq 3$$

Values greater than 3 will result in irregular flow velocity at the final inlet section, while ratios less than 2 will tend to increase of the overall subsonic wind tunnel dimensions and price hence these should be avoided strictly. The best choice is a ratio equal to 2 which lead to a lower wind tunnel dimensions and also the construction costs with regular flow velocity at the fan inlet section.

2.5 Settling Chamber: The main aim of the settling chamber is to reduce the turbulence of the flow before entering into Contraction. Design of settling chamber is related do the components it is connected to [13]. Settling chamber includes Honeycomb at the inlet for flow straightener and one set of removable screen to filter the air it is joined to inlet of settling chamber.

3. Numerical Analysis

The 2D axis symmetric wind tunnel is modelled with finite number of mesh elements as shown in figure 3.1. It is observed that about 98% mesh quality is obtained in Ansys Workbench. The 2D Axis symmetry model is used for most of the pre-processing analysis because it saves time and eases the entire analysis of model than complete model of wind tunnel. A simple Contraction curve was modelled in order to check the flow in the wind tunnel.

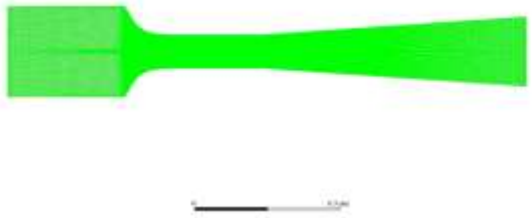

Figure 3.1: ANSYS workbench mesh

Fluent analysis of meshed model is performed for respective boundary conditions (table 3). Pressure inlet and outlet boundary conditions were used for analysis of wind tunnel by considering the following assumptions: -

Standard atmosphere pressure - 101325 pa,

Temperature -300k,

Density -1.225 kg/m^3.

Parameters	Conditions
Type of Symmetry	Axis symmetry
Type of Flow	Viscous-Laminar
Inlet Boundary	Pressure Inlet –1atm
Outlet Boundary	Pressure outlet-101281pa

Table3: Subsonic Wind Tunnel Boundary Conditions

An increase in velocity through contraction nozzle is observed from 0 to 8ms^{-1}, before the flow reaches the test section. From analysis it is observed that a constant velocity and constant pressure is maintained at different points in test section as shown in figure 3.2, 3.3.

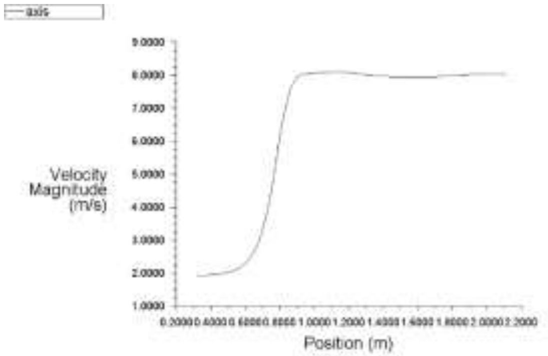

Figure 3.2 Plot of Velocity vs. Axial length

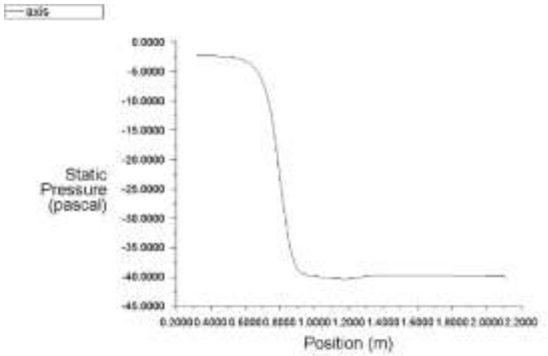

Figure 3.3 Plot of Static Pressure Vs Axial length

4. Fabrication of the Wind Tunnel

The test section is manufactured based on design criteria. The fabrication process involves with finalizing the design in every aspect after numerical validation. The pressure and velocity plot obtained at the end of simulation reinforces the fact that velocity remains constant in the test section, hence a major validation.

The materials employed for manufacturing are mild steel sheet metal and Acrylic glass. Sheet metal provides flexibility in forming curves and edge. The top and bottom of the test-section are made with mild steel of thickness 3mm and the side faces are made with Acrylic glass of thickness 4mm (figure 4.1). Acrylic glass is used only for side view panels because of its transparent property which aids in flow visualization. A circular hole of 8cm is drilled in the Acrylic glass using laser cutting and replaced with a piece of wood to mount the test specimen.

Figure 4.1: Fabricated test section

The components are covered with a layer of powder coating to prevent from corrosion and to further prolong the reliability of the system. The test section parameters are shown in table 4.

Material	Mild steel
Dimension of test section	(33.2x15x15) cm
Thickness of mild steel	3mm
Mirror	Acrylic
Thickness of Acrylic glass	4mm

Table 4 Specifications of Test Section

The Diffuser is fabricated using mild steel of thickness 3mm and bent according to the dimensions of the cross section and welded with a maximum angle of inclination of 50. The inlet of the diffuser is bolted to the test section and the outlet of the diffuser is mounted to a fan with the help of nuts and bolts (figure 4.2).

Figure 4.2: Fabricated Diffuser

The final assembly of the wind tunnel is achieved by securely mounting the parts to a table with help of bolts and nuts. The orders of parts are settling chamber, Contraction nozzle, test section and diffuser. A fan is installed at the outlet of the diffuser and all these are fixed to the table with the help of flanges. To provide electrical supply to the fan and to vary speed a regulatory controller is mounted to a wooden board firmly. The final assembly of the wind tunnel is shown in the Figure 4.3.

Figure 4.3: Final Assembly of Wind Tunnel

5. Calibration of the Wind tunnel

Fabrication process is followed by calibration. In order to ensure the wind tunnel parameters such and velocity and pressure profile, Calibration is must and should. The fabricated subsonic wind tunnel can be calibrated using many techniques like Pitot static probe, particle image velocimetry (PIV) etc. A pitot-static probe is chosen for its versatility and ease of operation.

The Numerical analysis resulted in constant velocity of 8m/s, obtained at test section and constant atmospheric pressure of 101325 Pascal (1bar) is obtained throughout the wind tunnel cross-section. These values serve as a reference base against which the experimental testing results are to be compared. During experimentation, a velocity of $4ms^{-1}$ is measured before the honeycomb structure is placed. Once the honeycomb is mounted which aids for laminar flow, it is found that an increase in velocity from $4ms^{-1}$ to $7ms^{-1}$ in test section for maximum speed of 2400rpm. The honeycomb acts as a flow straightener.

The visualization techniques like Smoke test visualization was used to determine the flow uniformity in the test section.

For different fan speeds, velocities and total pressures are tabulated, as mentioned below Table 5.

Fan speed	Velocity	Pressure	(R_e)
400	1.35	0.01	13,705
800	2.59	0.03	26,293
1200	3.79	0.08	38,475
1600	6.18	0.20	62,738
2000	6.87	0.24	69,743
2400	7.01	0.26	71,063

Table 5: Fan speed and Reynolds number comparison

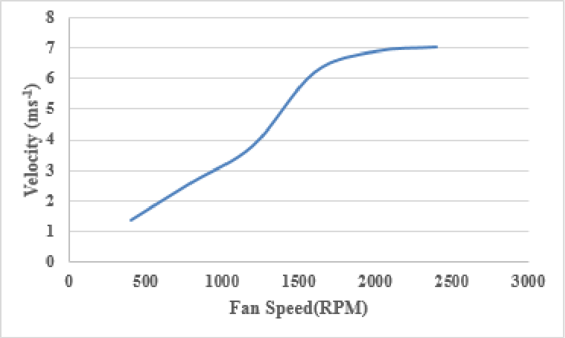

Fig 5.1 Velocity vs. Fan Speed

The figure 5.1 is graphical representation of obtained values of velocity for varying fan speed. Since paper straws are used, paraffin cannot be used for smoke flow visualization.

6. Conclusions

- The low speed wind tunnel components such as the Test section, Contraction nozzle, Diffuser, Settling chamber, Honeycomb structure and a series of screens are designed and modeled in CATIA V5 using suitable design procedures as per the literature survey to achieve the required maximum flow velocity of approximately $8ms^{-1}$ and a maximum Reynolds number of R_e=75,000.
- The designed Wind tunnel model is numerically simulated using ANSYS workbench to study the flow

characteristics throughout the tunnel. From numerical analysis it is observed that a velocity of 8ms^{-1} is achieved in test section.

- Considering the cost effectiveness and ease of manufacturing, the low speed wind tunnel is fabricated using Mild steel sheet of 3mm thickness. A transparent acrylic glass is used as the test section side panel to enable flow visualization.
- The developed wind tunnel setup test section is calibrated using pitot-static probe. Through the calibration and testing it is observed that a maximum velocity of 7ms^{-1} is achieved experimentally with a maximum Reynolds number of Re= 71,000 at maximum fan speed. Thus this tunnel can be used for very low speed wind tunnel testing in the range of Reynolds number 13,000 to 71,000.

7. Scope for future work

- Varying fan speed with variable frequency drive in diffuser outlet enables for easy test section air speed control.
- Up-gradation of measuring system for further aerodynamic testing. A full scale data acquisition system is critical in extracting pressure and velocity profiles, which has high accuracy and precision.

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