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Design and Fabrication of Cost-Effective Low-Speed Subsonic Open Type Wind Tunnel

Abdul Basit[1,*], Sufyan Ahmed[2], M. Hamza[2], Sarmad Ali Shah[2], Samar Iqbal[2], M. Hassan Razzaq[3] and Sheharyar Malik[4]

[1]Pakistan Institute of Nuclear Science & Technology, Islamabad, Pakistan.
[2]Mechanical Engineering Department, HITEC University Taxila, Pakistan.
[3]Mechanical Engineering Department, PIEAS, Islamabad, Pakistan.
[4]Abu Dhabi Polytechnic, Al Ain, UAE

*Corresponding author: Abdul Basit (abdulbasitpieas@gmail.com)

Abstract- **This paper presents the design and manufacturing of open circuit low-speed wind tunnel. The design of the contraction cone, test section and diffuser are finalized by the numerical analysis performed on ANSYS CFD software. A unique insight into the design of the contraction cone is presented. A fifth-order polynomial is used to model the contraction cone in PRO-E software. It allowed designing the test section with minimum turbulence and flow serration and a flow velocity profile of 20 m/s. The cross-sectional area of the test section and diffuser are selected after analytical calculations. The diffuser is designed as such to avoid pressure loss by incorporation changes in the rectangular cross-section. The initial study performed on the design helped us to select the fan with suitable power. Moreover, the intake of the contraction cone is equipped with the honeycomb structure of facilitating the laminar flow into the contraction cone. Following on to the initial numerical analysis, the fabrication of the wind tunnel is performed. Besides, a separate lift/drag measuring force system is also prepared; the intuitive design is cost-effective as well as accurate. The placement of anemometer helped us to directly measure the test section velocity, which is found to be 17 m/s.**

Index Terms-- **Contraction cone, Fifth order polynomials, Lift/drag system, Test section, wind tunnel.**

I. INTRODUCTION

Wind tunnels have revolutionized the field of fluid dynamics testing. They provide hands-on experience about the fluid flowing around the stationary object. Sensors fitted along the wind tunnel and on the test piece (body) can yield essential characteristics of the flow around the body. Thus, it is envisioned as a replica of the body moving in the flow and akin to flight conditions. The application of wind tunnel is not only limited to the field of aerospace; its application can be found in the field of automotive, biomedical, sports and fluid mechanics etc. Wind tunnel experimentation is of equal importance for research in academia and industry; it is extensively used to simulate the flow around an object. The researchers have used the wind tunnel experimentation to validate the control laws on the X-DIA prototype aircraft. In the research aero-elastic analysis was also carried out, and exciting modes of the wing were identified [1-2].

A wind tunnel is primarily divided into two groups: 1. Open circuit 2. Closed-circuit, while a closed circuit offers many advantages as listed in [3], few drawbacks are also associated with it like pressure loss and energy loss, both open and closed-circuit wind tunnel has some similarities like both of them has inlet section, contraction cone, test section, diffuser and fan is used to drive the air inside the wind tunnel. Knowing its advantage, researches have focused on several aspects to improve its performance that includes minimum turbulence in the test section, laminar flow and minimum pressure loss. One critical factor in the design of the wind tunnel is its size, and its size mainly depends on the size of contraction cone where a converging duct can be devised for the incoming flow by reducing its length and changing its cross-section sharply. The design of contraction care is well illustrated in [4], a 5th order polynomial equation is recommended for the cross-sectional shape of the contraction cone, and it plays a crucial role in the selection of the overall length of the contraction cone and the wind tunnel. Although fabrication of a contraction cone based on higher-order polynomials is a daunting task, it is preferred because it reduces the length of contraction cone significantly without the flow separation. Several studies have also been performed on the cross-section size, shape and length of the test section and diffuser. The impact of Reynolds's number and laminar flow on the flow properties is illustrated in [5]; it also helps to design the wind tunnel. Several designs are also proposed to enhance the speed of the test section velocity [6-7]. In one such effort, a parallel combination of nine fans is proposed where the test section velocity can significantly be enhanced [3, 8-13].

This paper presents the:

1. Analytical design of the diffuser and the test section.
2. Design of an open circuit wind tunnel which is numerically designed to produce the velocity of 20 m/s in the test section.
3. Low cost fabrication of the wind tunnel.

Moreover, the design parameters are implemented in the Computer-Aided Drawing (CAD), and numerical analysis is performed. In the end, the Wind Tunnel is fabricated by following the known design parameters.

The following section presents the design of the wind tunnel, followed by the numerical flow analysis of the wind tunnel test section in Section II. The fabrication process of the section is presented in Section III, in the end, the detail is also added to elaborate the lift/drag force measuring system

II. DESIGN OF THE WIND TUNNEL

The complete process is divided into two phases. Phase one consists of the analytical calculations of the different sections. In contrast, the manufacturing of various parts of wind tunnellike Settling Chamber, Contraction Cone, Test Section, Diffuser, and stand for the wind tunnel was completed in phase two. It also includes the development of Honeycomb screens. Moreover, after the fabrication of the aforementioned sections, parts were then assembled together; electrical wiring was provided for the van axial fan and the attachment for the test model device. The following subsection outlines the design of each section of the wind tunnel.

A. TEST SECTION DESIGN

The construction design starts with the selection of the test section while considering the accessibility and space for setting up the test objects as well as various instrumentation. As reported, the desired length must range 0.5 to 3 times the hydraulic diameter [6]. Figure 1 shows the desired chamber that was intended to analyze the scaled objects having the maximum cross-section of (20 cm x 20 cm) and a length of 25 cm. With an increase in the length of the test section, pressure loss coefficient (COL) increases. Therefore the selection of the desired section length ought to be as less as possible. The targeted maximum airflow speed within the test section is 20 m/s.

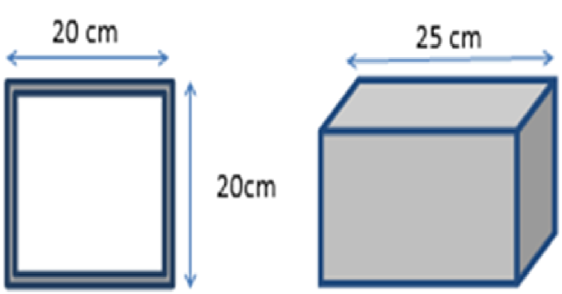
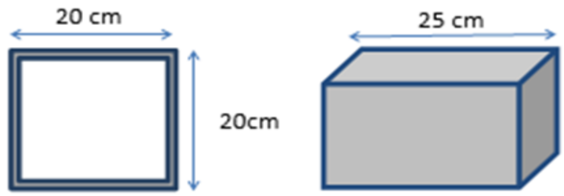


FIGURE 1: Schematic of a Test Section

Calculation of the test chamber loss coefficient can be made using (1), [8].

$$K_{ts} = \frac{(f)(L_{ts})}{(2)(R.h_{ts})} \quad (1)$$

Where;



B. SETTLING CHAMBER DESIGN

Wind tunnels are shaped as such so that the intake can eliminate the turbulence in the airflow entering the wind tunnel. To accomplish this task settling chamber is developed, it contains honeycomb as well as screens to make the flow laminar as it approaches the contraction cone. Settling cross-sectional chamber area was following the inlet of contraction cone, i.e. 500 mm x 500 mm having length up to 60 cm was selected [9].

C. CONTRACTION CONE DESIGN

The design of the contraction cone is the most significant and critical part of the structure. It directly dictates the dimensions of the complete wind tunnel and the flow quality. The accelerated air within the test chamber also depends upon the contraction section design. In contraction cone, with a decrease in the flow area, the flow velocity increase. Wall profile of the contraction cone is shown in Fig. 2. Following are the essential parameters for the creation of a contraction cone:

- Contraction Ratio (C. R)
- Contraction Length (C. L)
- Contraction Shape.

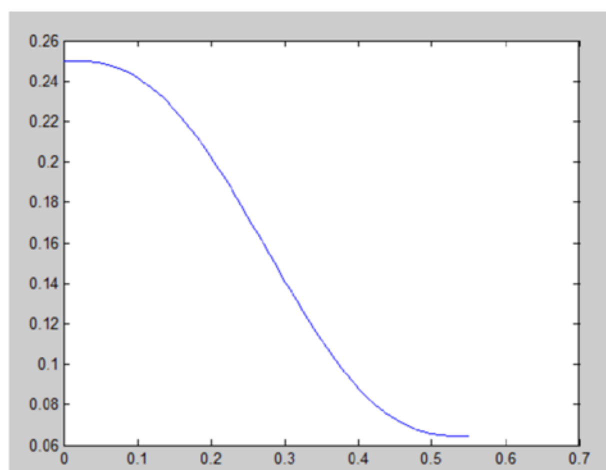


FIGURE 2: Wall Profile of the Contraction Cone

To avoid the flow separation within the contraction wall, the parameters given above should be computed carefully. The C.R range for the smaller wind tunnel lies from 6 to 12. Above this range, the values of pressure drop coefficient persist declining with an increase in C.R. Therefore the utmost permissible C.R is chosen for the current study. To minimize the flow separation, C.L of 600 mm is employed. A fifth-order polynomial was adapted to obtain the wall profile (2) and roof profile (3) of the contraction cone. [4]. Figure 2, shows the wall profile of the contraction cone that is used in the current study.

$$h = (-10\zeta^3+15\zeta^4-6\zeta^5)\,(hi-ho)+hi \qquad (2)$$

$$h=[(-10\zeta^3+15\zeta^4+6\zeta^5)\,(hi^{0.705}-ho^{0.705})+hi^{0.705}]^{1.418} \qquad (3)$$

Where, $\zeta = x / L$.

D. DIFFUSER DESIGN

The diffuser is the primary source of pressure losses in the wind tunnel. Significant pressure losses are present in the closed type wind tunnel. However, as the proposed design is open type wind tunnel, so, this doesn't pose a significant issue for our design. The design of the diffuser is based on the following parameters.

- A constant expansion angle of (6°)
- Area Ratio of (2:1)

While reducing the flow velocity, the above-mentioned parameter range should reduce the pressure loss and avoid the boundary layer separation as well. The efficient expansion angle for many of the structure designs is (5°) – extra savings in expansion angle less than (5°) causes additional frictional area losses [8]. While taking the assumption that the friction factor of material remains the same, the calculation of the frictional loss coefficient can be made using (4).

$$L.C_f = \left(1-\frac{1}{A_{rd}^2}\right)\left(\frac{f}{8\sin\theta}\right) \qquad (4)$$

Where (for Diffuser)

$L.C_f$ = Frictional Loss Coefficient
A_{rd} = Area Ratio
θ = Expansion Angle
f = Friction Factor

To reduce the losses and the flow separation, various reported literature suggested the least length of diffuser should be around the hydraulic diameter of the settling chamber [8]. The minimum diffuser length can be calculated by using the following (5).

$$L_d = R_i\left(\frac{A_r^{1/2}-1}{\tan(\theta_d)}\right) \qquad (5)$$

Where

Ld = Minimum Diffuser Length
Ar = Area Ratio
Ri = Inlet Hydraulic Radius
θd = Expansion Angle of Diffuser

III. CAD MODEL & CFD ANALYSIS

The most prominent feature of the study is this that the analytical model was numerically analyzed as well. The CAD model was created on Pro-E Software [7], and then using this CAD model, analysis was performed on ANSYS. The numerical results validated the findings of analytical results. The analysis also paved the way for the optimization in the analytical design and allowed the readjustment in the design parameters. Figure 3, shows the CAD model of the subsonic wind tunnel. Figure 4, depicts the velocity profile of the designed wind tunnel. The result shows that maximum air flow velocity in the test section with the aero foil at the 0-degree angle of attack can be achieved up to 17.46 m/sec as shown in red color. Figure 5, shows the close view of the velocity profile at the surface of the aero foil with a 0 degree angle of attack.

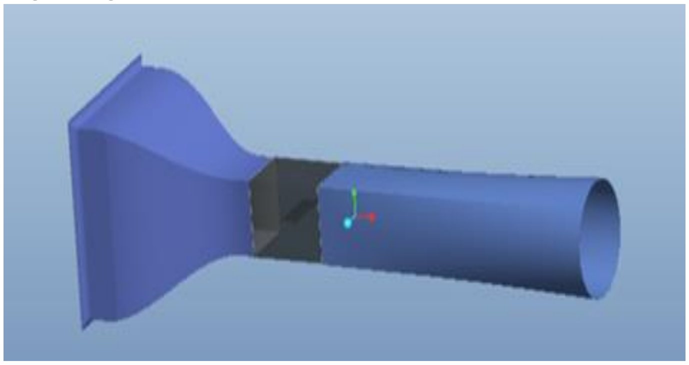


FIGURE 3: CAD Model of Designed Wind Tunnel

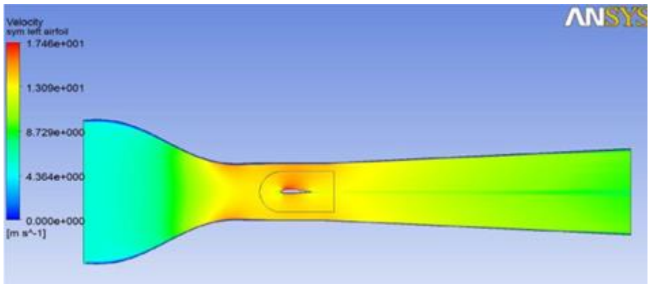


FIGURE 4: Maximum Velocity Profile Analysis of Designed Wind Tunnel

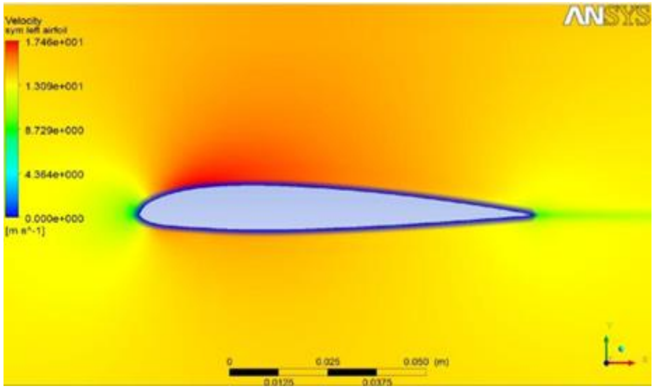


FIGURE 5: Maximum Velocity Profile Analysis

IV. FABRICATION OF COMPONENTS

A. TEST SECTION

The test section is fabricated by using the readily available acrylic sheet of 6mm thickness. It also facilitates the visualization in the test section. The test section incorporates a dimension of 20 cm x 20 cm cross-section and the length of 25 cm. It is fabricated in such a way to make it compatible with the inlet and the outlet of diffuser and contraction cone respectively. To optimize the space, a square cross-section was preferred. It was bolted with both ends and properly sealed to avoid the leakage of the air. The test section incorporated the space for placing the test objects and also for lift and drag measuring system.

B. CONTRACTION CONE

The most significant part of the structure was fabricated using G.I. sheets having a square cross-section, as shown in Fig. 6. The inlet of the test chamber connected its outlet section by incorporating the seal/gaskets to minimize the leakage of the air form the joints. Particular expertise is required to fabricate the fifth-order polynomial wall and roof profiles. Wall and roof profiles were manufactured separately and then riveted together to get the desired contraction cone shape. Fig. 6, shows the fabricated model of contraction cone.

FIGURE 6: Contraction Cone

C. HONEY COMB

This part was fabricated using plastic straws and by joining them in the array, structure to get the desired cross-section of the honeycomb, as shown in Fig. 7. Tangential velocity by the axial fan airflow ceases by the honeycomb. It conjointly minimizes the turbulence in the airflow by allowing it to flow through the guided path as streamlines

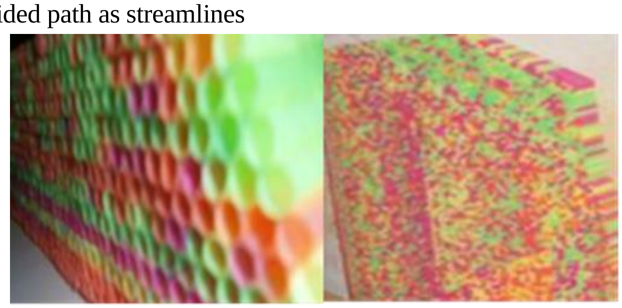


FIGURE 8: Honey Comb

D. MOTOR FAN ASSEMBLY

Mainly two types of fan are used in the wind tunnels.

1. Axial Fan
2. Centrifugal Fan

For the same flow rate, the use of the axial fan is least expensive than the centrifugal fan. Also, axial flow can accommodate a large mass flow rate as compared to the centrifugal fan. Fig. 8, shows the Van axial fan motor assembly having a diameter of 12 inches (30 cm) and manufactured by Pakistan used in this study. The motor fan assembly was connected at the outlet of the diffuser [9].

FIGURE 9: Van Axial Fan

E. DIFFUSER

The diffuser is also fabricated by using the G.I. sheet with one end having the square cross-section of 20 cm x 20 cm and other end having the circular cross-section of 30 cm diameter to incorporate the van axial fan. The length of the diffuser in this wind tunnel was 100 cm. Fig. 9, shows the fabricated model of diffuser for this wind tunnel.

FIGURE 10: Diffuser

After the completion of each of the sections, the parts were assembled to form a complete win tunnel, as shown in Fig. 10.

FIGURE 11: Complete Wind Tunnel Assembly

F. FORCE BALANCE APPARATUS

The novelty to this project was also added by the force apparatus system that was specifically designed to measure the lift and drag on the specimen in the test section. Figure 11 and 12, shows the specially designed and fabricated model of the force balance system, respectively. The force balance system is designed for measuring the two forces, i.e. Lift & Drag forces electronically.

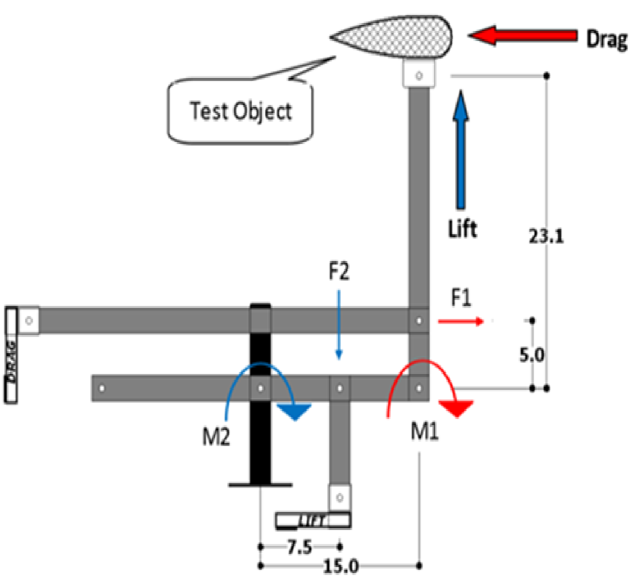


FIGURE 11: Design Model of Force Balance System

The system displays the value in gram/oz, which can be multiplied by the gravitational acceleration to get the F1 and F2 as shown in Fig. 11 both lift and drag forces separately. By resolving the forces F1& F2 as well as Moments M1 & M2, the actual values of Lift & Drag can be calculated.

The force balance system is also incorporated with the graduated protector to analyze the different objects at various angles of attack.

FIGURE 12: Fabricated Model of Force Balance System

V. RESULTS AND DISCUSSION

In the current research work, the cost-effective low-speed wind tunnel was successively designed, fabricated, and tested. It was concluded that the cost-effective wind tunnel for the research purpose could be built by optimizing the various parameters of different sections of the wind tunnel. The selection of material & fabrication process is essential for the fabrication of wind tunnels. Using cost-effective wind tunnel, the scale models of different sizes can be tested, which can provide and oversight of real-time behaviour at other flow parameters.

Conclusion: In this study, bell and Mehta 5th order polynomial contraction cone was successfully fabricated. The maximum speed achieved in the test section is 17m/sec exclusive of turbulence in the test section with 2 horsepower van axial fan. The results achieved are in good agreement with the computational analysis. The 5thorder polynomial contraction cone with large C.R. and short CL gives the most excellent product in terms of airflow velocity exclusive of boundary layer separation. However, extraordinarily hard work and skill are required to fabricate the bell and Mehta 5th order polynomial contraction cone. Proper designing of honeycomb to minimize the turbulence of the air, which can affect the necessary results and the angle of the diffuser, is also an essential and integral part of designing and fabrication of a subsonic wind tunnel.

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