Design and Fabrication of an Open Circuit Subsonic Wind Tunnel for Educational Purposes

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Abstract - *The capability of any educational institution to study and perform experimentation in the field of fluid mechanics can be immensely increased by the availability of a wind tunnel. The major hindrance in procuring such an apparatus is the high costs associated with it. This paper holds a discussion regarding the design and fabrication of a low-cost wind tunnel that can be used for educational purposes. The aim was to construct a wind tunnel which can achieve a velocity of more than 10 m/s in the test section and inculcate factors such as compactness, ease of use and longevity in the design. Another aim was to perform a simulation analysis of the same and showcase the difference between numerical and experimental results. Previously constructed subsonic wind tunnels were referred and modifications were done in the design to improve the airflow and attain all our objectives.*

Key Words: wind tunnel, contraction cone, diffuser, test-section, CFM, anemometer.

1. INTRODUCTION

"I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is turbulent motion of fluids. And about the former, I am rather optimistic." These are the words of Horace Lamb, the person who coined the term "vorticity" in 1916. Even though major steeds have been made in the field of Turbulence over the last few decades there is still much to discover. Theoretical research and practical validation form the basis of any research. The wind tunnel is one such apparatus which proves imperative for the aforementioned validation. However, the high cost and limited accessibility of a wind tunnel cause a hindrance in research operations. The aim of this project is to construct a wind tunnel which can be used for experimentation purposes at a college level. Dimensional constraints, cost-effectiveness, and longevity were the primary factors considered while designing this wind tunnel.

2. LITERATURE REVIEW

In order to achieve flight man first began studying birds and thus the designs of all primitive flying machines were based on avian structures. Their consequent failure realized the need for a different approach. The flow of air over surfaces leading to lift and drag forces could not be studied without appropriate apparatus.

Early aeronauts began testing their models against relatively steady natural wind sources. This eventually led to the birth of the whirling arm apparatus wherein the momentum of a falling weight is used to rotate a centrifuge on which the model is mounted. Using this apparatus, Benjamin Robins (1707-1751) concluded that different shapes may have different air resistance irrespective of their frontal area to the airstream. [1] This proved that there existed a complex relationship between model shape and drag and further refuted a pre-existing theory by Newton. Up until the end of the nineteenth century, the whirling arm was considered to be the most systematic source for aerodynamic experimentation. However, there existed some inherent flaws in its design. As the models mounted on the arm underwent rotary motion, they created wakes which caused unnecessary turbulence during the subsequent revolution. Mounting of sensors on the high-speed arm was also a task. Hence there was a requirement for some better apparatus with minimum flaws and ease of use.

The inadequacies of the whirling arm are eradicated by the conception of Wind Tunnel by Frank H. Wenham (1824-1908) from the Aeronautical Society of Great Britain. He used a steam engine to run a blower that propelled air down the model. Wenham's research with the wind tunnel proved that the lift to drag ratios were quite high at low angles of incidence over long narrow wings. [1] This further provided impetus to the idea of a powered flight. Later, Osborne Reynolds (1842-1912) defined the Reynolds number and refuted any doubts regarding congruency of experimental results between a scaled model which is tested in the wind tunnel and the full-scale model. He specified that the behavior of air over the scaled and full-scale model will be the same as long as the Reynolds number is the same in both cases. [1] With this, the wind tunnel achieved the necessary backing to establish itself as an appropriate apparatus for airflow experimentation.

Further, Sir Hiram Maxim (1840-1916) constructed a wind tunnel which was 12 feet long and had a test section of 3ft X 3ft. He used two coaxial fans upstream to attain a velocity of 50mph in the test section. Using this wind tunnel Maxim was able to determine that cambered airfoils would provide the most lift and least drag. Next up, the Wright brothers made their own wind tunnel as they needed to make a new data handbook to determine the correlation between the inclination of the test surface and the lifting forces. Their test section had a vane type balance with the model to be tested on one side and a calibrated counter plate on another. While in operation, the balance would move to either side indicating the forces acting on the model. [2] In this manner, the Wright Brothers compared different models and found out the ideal design variables for their aircraft.

Once the aircraft was invented, the primary purpose of a wind tunnel slightly changed. What was initially used to calculate forces on wings was being used to verify CFD algorithms, study hybrid flow and examine the behavior of different materials under the wind. [3] In 2016, Bert Celis and Harm H. Ubbens designed a wind tunnel to study the resistance offered by the wind to a cyclist. [5] Their dimensions were large enough to accommodate two cyclists in the test section. Similarly, in 2015, T H Young and SS Dol developed a low-cost wind tunnel which can be used to conduct small scale experiments for educational purposes. [4] Both of the wind tunnels mentioned above were made in adherence to the design guidelines specified by R.D. Mehta and P. Bradshaw in 1979. Due to the wide variety of requirements, strict rules cannot be laid to design a wind tunnel. [9] However, Mehta and Bradshaw have provided certain guidelines for designing the main components of a wind tunnel.

3. DESIGN METHODOLOGY AND CONSTRUCTION

The steps taken for designing individual modules of the wind tunnel are specified in chronological order below. Square sections were taken thorough the design to achieve symmetry and feasibility in construction.

3.1. Test Section

Since the main purpose of constructing this wind tunnel was to perform experiments on aerofoil models available in the college. These models generally consist of a frontal cross-sectional area lesser than 8 inch2 (5161.28 mm2). The maximum blockage factor for a model should only be 10% of the test section area [2]. Due to this the test section was designed to have a cross section of 9x9 inch (228.6 x 228.6 mm) which gives area of 81 inch2. The length was taken as 18 inches (457.2 mm) for ease of use. Acrylic was selected as the material of choice due to its workability.

3.2. Contraction Cone

The frontal dimensions of contraction cone were taken as 24x24 inch (609.6 x 609.6 mm) which give an area ratio of 7.1. This adheres with the range of typical area ratios (7 to 12) as specified by Barlow [5]. The material taken was plywood as it provided the best balance between cost and weight.

3.3. Diffuser

As per Barlow, the ratio of outlet area to inlet area must lie between 2 to 4[5]. Thus, a section of 16x16 inches (406.4 x 406.4 mm) was taken which gives area ratio of 3.16. Length of the diffuser was taken to be twice of the test section i.e. 36 inches (914.4 mm) [5]. Plywood of thickness 12mm was used for construction here in order to get better vibration dampening.

3.4. Fan

Selection of fan had two constraints, the maximum diameter must be 16 inches (406.4 mm) as per the available diffuser cross section and the speed of air in the test section must be at least 15m/s (49.21ft/s). As the test section is 9 x 9 inch i.e. 0.5625 sq. ft, the discharge required is calculated as follows Q = A x C (Assuming incompressibility of air due to low Mach No)

= (0.5625 sq. ft) x (49.21 ft/s)
= 27.68 cubic ft/s = 1660.8 CFM

Thus, a fan was selected with 16 inches diameter, 1440 rpm and 1910 CFM. This fan fulfilled all the requirements and the final air speed in the test section was calculated to be 17.25m/s.

3.5. Flow Conditioner

Traditionally, a honeycomb section sheet is used to improve airflow quality in the flow conditioner. However, in our case a cost-effective alternative of straws was used. Straws of 8mm diameter were attached in a square frame of 9 x 9 inch to make the flow conditioner. Length of the straws was taken as 64mm (2.5 inch) so that it satisfies the condition mentioned by Mehta and Bradshaw [6].

3.6. Mating Apparatus

Aluminum L-Channel flanges of 10 inches length and 0.75-inch-wide were screwed in place on the edges of every module. Holes on the subsequent flanges were matched and the wind tunnel was assembled together by use of screws, bolts and nuts.

3.7. Sealing Apparatus

One-inch wide double-sided tape was adhered in between the modules to attain an airtight seal. Care was taken that no excess tape protruded from the inner surface. All extra tape was sheared off from the outer surface. In regions where the inner edges of plywood showed misalignment, clay was used to smoothen the surface.

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Table -1: Dimensions of modules

Sr. No.	Module	Length (inch)	Inlet Area (inch^2)	Outlet Area (inch^2)	Material
1	Test section	18	9 X 9	9 X 9	Acrylic
2	Diffuser	36	9 X 9	16 X 16	Plywood
3	Contraction cone	12	24 X 24	9 X 9	Plywood
4	Flow Conditioner	6	9 X 9	9 X 9	Plywood + Paper Straws

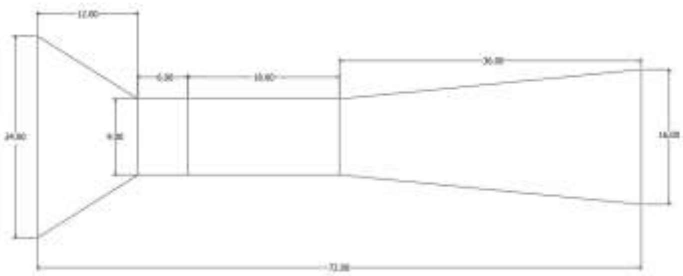

Fig -1: Schematic Diagram

4. EXPERIMENTATION

The velocity inside the wind tunnel was needed to be calculated in order to determine the working conditions in the test section. Due to its availability in the college, a simple anemometer was used to check the wind velocity. It's specifications were as follows.

Range 0.4 – 30.0 m/s

Resolution 0.1 m/s

Accuracy ± (2% + 1d)

The anemometer was placed as shown in the figure.

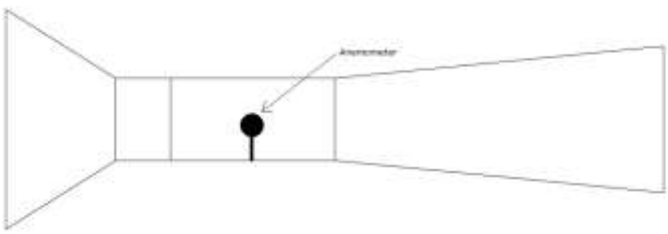

Fig -2: Schematic Diagram

Readings were taken at intervals of 10 seconds right after the fan was started over a time period of 5minutes.

5. RESULTS

5.1. Experimental Results

The values of velocity obtained from the anemometer at regular time intervals were as follows.

Table -2: Observation Table

Time (s)	Velocity (m/s)
10	12.7
20	13
30	13.1
40	12.7
50	12.5
60	13.1
70	12.8
80	12.9
90	13
100	12.5
110	13.2
120	13
130	12.9
140	12.7
150	12.9
160	12.6
170	12.8
180	13.1
190	12.7
200	12.9
210	13
220	12.9
230	12.9
240	13
250	13.1
260	13.2
270	13.2
280	12.9
290	12.9
300	13

Furthermore, the variation can be observed in a graphical format as follows.

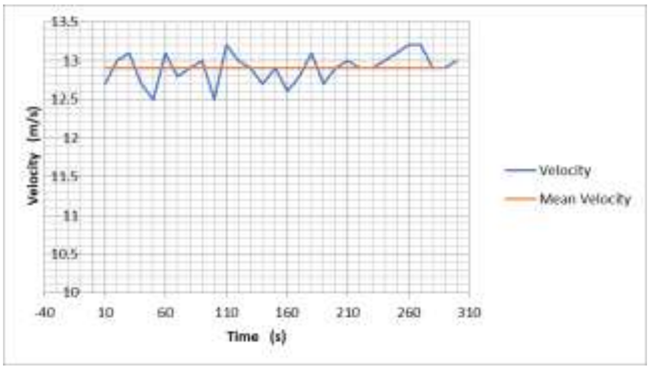

Chart -1: Velocity v/s Time

From the graph it is evident that the variations in velocity are within 1 m/s. The mean velocity obtained was 12.9 m/s

5.2. Simulation Results

CFD analysis was performed to check the velocity and pressure contours in the tunnel using ANSYS Fluent 2019 R1.

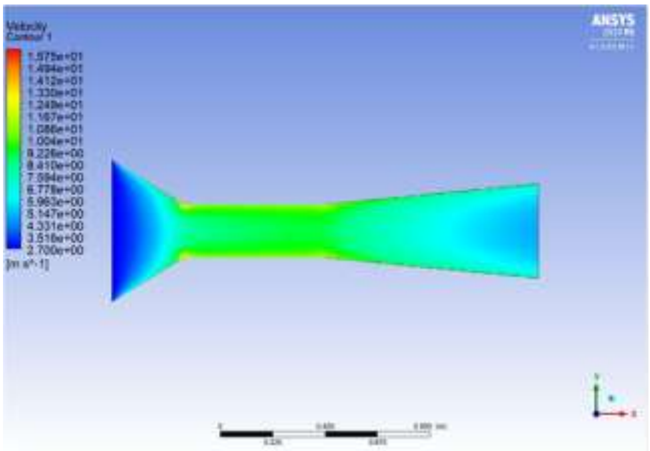

Fig -3: Velocity Contour

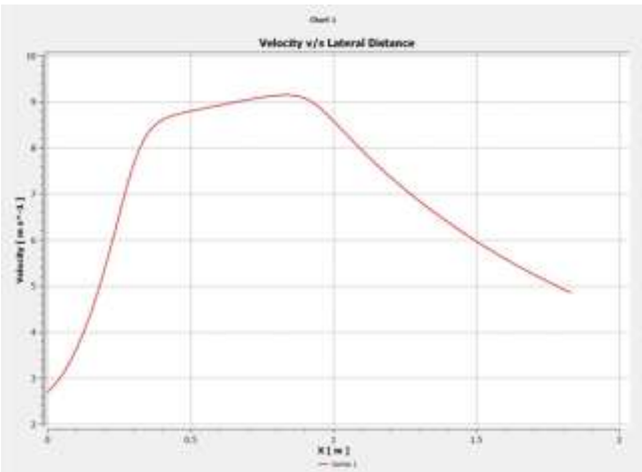

Fig -4: Velocity v/s Lateral Distance

It can be observed that the velocity in the test section peaks at 9.2 m/s. The wind speeds up in the contraction cone, achieves maximum velocity in the test section and then finally slows down to 4.8 m/s in the diffuser.

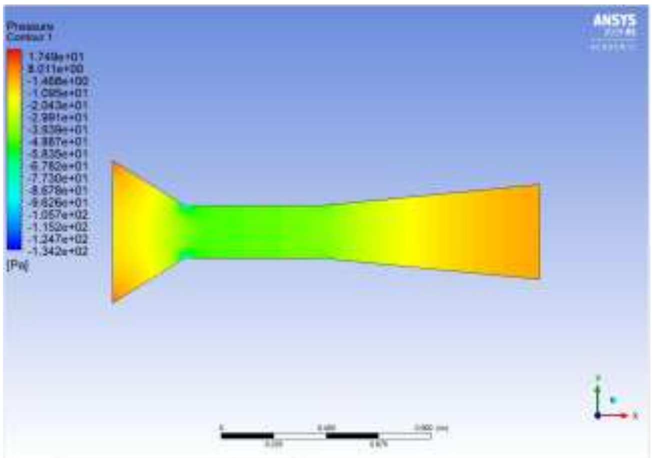

Fig -5: Pressure Contour

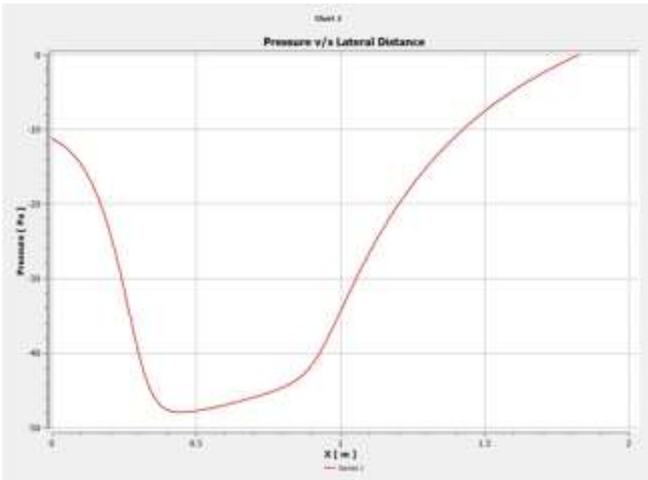

Fig -6: Pressure v/s Lateral Distance

6. CONCLUSION

The wind tunnel was successfully constructed within the given time frame and a minimal budget. Even though a difference was obtained between the simulation results and experimental results, the later value was higher which serves the purpose of the wind tunnel. The use of flanges and double-sided tape for mating and sealing respectively proved beneficial as the construction is sturdy and the entire tunnel can be disassembled within an hour. One side of the test section is kept removable so as to add any new instrumentation if deemed necessary in the future. By making a hole at the bottom of the test section and using a precision balance, students in the college have calculated the lift force generated by a NACA airfoil. Thus, the wind tunnel is proving to be of service in the Fluid Mechanics Lab as it was intended to be.

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