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Review of Design and Construction of an Open Circuit Low Speed Wind Tunnel

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Due to their ability to combine both types of data i.e quantitative data and visualization, wind tunnels are a critical instrument in the quick and thorough design process of anything that involves fluid dynamics. In addition to gaining a further understanding of aerodynamics and the importance of wind tunnels, the main objective of our project is to help us learn the process that engineers go through to research, test, analyze and ultimately rectify scientific and mathematical problems in our society.

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Review of Design and Construction of an Open Circuit Low Speed Wind Tunnel

Mansi Singh ^α, Neha Singh ^σ & Sunil Kumar Yadav ^ρ

Abstract - A wind tunnel is a tube like apparatus or tunnel with varying cross-sections that has man-made wind which is made to blow through it at a certain speed. Scientists and engineers put a model of an airplane in the tunnel and then study the way air moves around the model. By looking at the way this smaller model acts in the wind tunnel, they get a pretty good idea of how a real life-sized airplane of the same design will probably fly. It is a lot easier, cheaper, and safer to build and test a model than to build and fly a real airplane. This report will focus primarily on the design and operation of an open circuit low speed wind tunnels. The components involved in the construction of a typical wind tunnel will be presented and accompanied by brief commentary on the underlying physical processes most influential in determining optimal construction of each component.

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These small scale wind tunnels make excellent visual aids for communicating ideas with coworkers or customers. In addition, prototypes can be used for design testing. A summary overview of fluid dynamic principles concerning incompressible flow in tubes will include discussion on laminar and turbulent flow, fluid viscosity, Reynolds number criteria, and boundary layer formation. We will also be presenting data obtained from experimental research in the form of velocity profiles for the wind tunnel we constructed.

Wind-tunnel designing is a complex field involving many fluid mechanics and engineering aspects and it is impossible to cover them all in just one paper. Some books and articles have been written about this topic and e.g. Rae & Pope (1984), Bradshaw & Pankhurst (1964) are useful references when designing and constructing low-speed wind-tunnels. See also the comprehensive report on the German-Dutch Wind-tunnel edited by Seidel (1982). The first wind-tunnel at the Royal Institute of Technology was completed in the summer of 1932 at a newly constructed laboratory for aeronautical sciences. It had a closed circuit and an open jet test section, i.e. the test section had no walls. The test section was cylindrical in shape with a diameter of about 1.6 m and a

similar length. It was primarily used for measuring forces on aircraft models and airfoils. It had an axial fan and corners with simple guide-vanes made of bent plates in the shape of 14 - circles. The contraction ratio was about 5 and the maximum speed in the test section about 50 m/s, see Malmer (1933). It was later modified with, among other things e.g. a closed test section, and was in use until only a few years ago.

- For this paper, extensive literature survey has been carried out. The working of the model has been displayed after the design and construction. The analysis of the working has given us the propounding results.
- The observation of the turbulent flow and the calculations for the drag and lift forces have been done using this model.
- The construction for various parts after dimensioning has given us several experiences of practical aspects.
- The applications of the concepts of the fluid mechanics has been considered and worked upon.
- It is a cheap and efficient way of analysis.

Keywords : wind tunnel, prototype, model, fluid dynamics, turbulent.

1. INTRODUCTION

One of the most important parts of a wind tunnel is the flow visualization it provides. Sure lift, drag and efficiency can all be calculated with complex equations. However, it is the visual aspect of a wind tunnel and the controllable environment it provides that allows you to physically see what will happen in multiple real life situations. You can create an environment where you can see how a plane will react when it is taking off, cruising and landing all in the confines of a test lab. Then, with the same machine, you can see how air flows over the body of a race car when it is zooming around a track to maximize its efficiency. The versatility and tangibility of a wind tunnel is what makes it such an important part of aerodynamic research.

Being such an important part of aerodynamic research, it is important to continue to promote wind tunnel testing. In this project, the ultimate goal is to research, design, build and test objects in a real wind tunnel in order to more fully understand basic concepts of aerodynamics and recognize the capabilities and importance of wind tunnels in solving practical engineering problems.

In either case, there are 5 main components to the wind tunnel. There's the settling chamber, the contraction cone, the test section, the diffuser and the drive section. The settling chamber usually contains a

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honeycomb material to straighten airflow. The spinning fan creates a swirling motion in the air that produces an undesirable effect in the test section. The honeycomb eliminates this uneven air flow. The contraction cone increases the velocity of the air in the test section without creating turbulence in the airflow. The test section is where objects are placed and analyzed. The diffuser connects the test section to the fan and slows the airflow down, again without disturbing airflow. The drive section is the source of the wind and is chosen to produce the desired velocity in the test section.

Without knowing much about aerodynamics, we would experiment with design aspects when making different planes in an attempt to change flight characteristics or to see if the planes would even fly at all. Through building a wind tunnel we hope to learn more about aerodynamics, and, more generally, about the process that engineers go through in the real world to test hypotheses and solve problems. A common interest in fluid dynamics and aerodynamics has led both of us to this project where we plan to explore the complex field of aeronautical engineering and have some fun in the process, ultimately preparing us for future studies, jobs and real-life situations.

For our project, we will be constructing an open loop low speed wind tunnel, for its ease and cost of construction. In this type of wind tunnel, it will be easier to manipulate variables since we are designing the tunnel ourselves and it will be a trial and error type of process.

II. DESCRIPTION

a) Nomenclature

Nomenclature is the defined parameters on the basis of the following:-

1. α : angle-of-attack
2. CA : axial force coefficient
3. CN : normal force coefficient

Engineers for verifying their calculations when a model is prepared, carry out the aerodynamic tests that start from wind tunnel and end to ambient conditions. Forces and moments measurement is the most purpose of test in the wind tunnels. The subsonic wind tunnel is an intermittent blow down tunnel, which operates by high- pressure air flowing from storage to either vacuum or atmosphere conditions. Mach numbers less than 1 (<1) are obtained by using a controllable diffuser. Downstream of the test section is a hydraulically controlled pitch sector that provides the capability of testing angles-of-attack ranging from -2 to $+12$ degrees during each run. The diffuser section has movable floor and ceiling panels, which are the primary means of

controlling the subsonic Mach numbers. As an intermittent blow down-type tunnel, experiences large starting and stopping loads. This, along with the high dynamic pressures encountered through the Mach range, requires models that can stand up to these loads

b) Objectives

The main objectives that we want to achieve through this working model are:-

1. To design the wind tunnel using various parameters.
2. Study the velocity profile using the air/smoke on airfoil.
3. Calculate lift and drag coefficient for different velocities.

c) Working Principle

Wind tunnels work on the idea that a stationary model with air moving around it behaves the same way a real, full-scale airplane moving through stationary air does. Sometimes only a part of an airplane, like a wing or an engine, is tested in a wind tunnel. Here we are using an airfoil. The models, usually made out of steel or aluminum that is tested are loaded with many instruments and sensors that report back to the computers in the control room. It's there that scientists, engineers, and technicians can begin to understand how the airplane is performing.

d) Types of Wind Tunnel

1. Wind Tunnel can be classified on the basis of construction as-
 1. Open Loop
 2. Closed Loop
 - i. Open Circuit

In an open loop wind tunnel, there is an intake and an exhaust. There is no use for corners and long diffusers but the power needed to drive the wind-tunnel is high because of the loss of energy in the out- flowing air. The open circuit wind tunnel is the simplest and most affordable to build. In these tunnels air is expelled directly into the laboratory and typically reingested after circulating through the lab, though some tunnels utilize instead a compressed gas source. In addition to their low costs, open circuit tunnels are also advantageous because they have are relatively immune to temperature fluctuations and large disturbances in return flow, provided that the volume of the laboratory is much greater than that of the tunnel.

There are two basic types of open circuit tunnels-

- a. Suckdown
- b. Blower

The two are most easily differentiated by the location of the fan. Blower tunnels are the most flexible because the fan is at the inlet of the tunnel, so the test section can be easily interchanged or modified without seriously disrupting flow. These tunnels are so forgiving

that exit diffusers can often be completely omitted to allow easier access to test samples and instruments, though the omission often results in a noticeable power loss. Suckdown tunnels are typically more susceptible to low frequency unsteadiness in the return flow than blowers, though some claims have been made that intake swirl is less problematic in these tunnels because it does not pass through the fan before entering the test section.

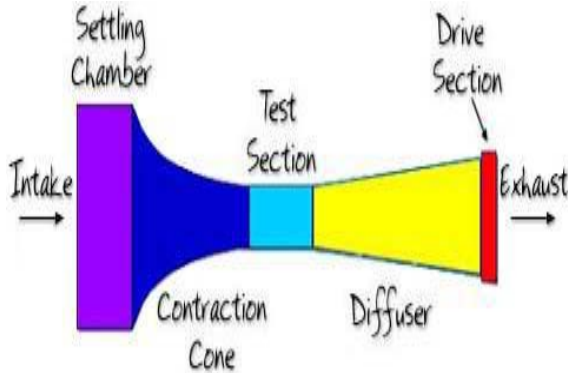


Figure 1 : Open Circuit Wind Tunnel Layout

ii. Closed Circuit

As the name implies, closed circuit tunnels (also called closed return) form an enclosed loop in which exhaust flow is directly returned to the tunnel inlet. In a closed loop wind tunnel, the air is recirculated to improve efficiency for high speed testing. These tunnels are usually larger and more difficult to build. They must be carefully designed in order to maximize uniformity in the return flow. These tunnels are powered by axial fan(s) upstream of the test section and sometime include multistage compressors, which are often necessary to create trans-sonic and supersonic air speeds.

Closed circuit wind-tunnels recirculate the air and thus normally need less power to achieve a given low speed, and, above all, facilitate the achievement of well controlled low conditions in the test section. The present, and most low-speed tunnels used for research, are of the closed circuit type.

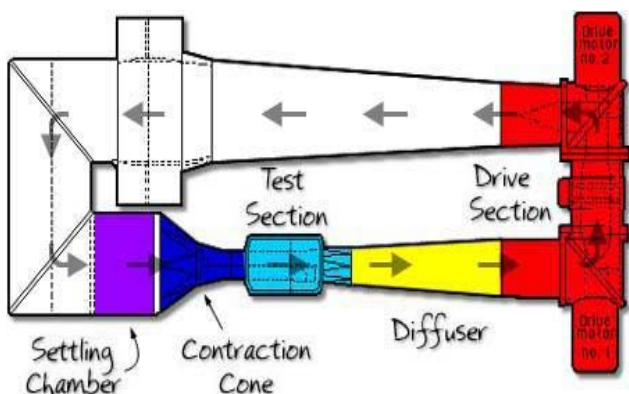


Figure 2 : Closed Circuit Wind Tunnel Layout

II. Wind-Tunnels can be classified on the basis of **flow speed** dividing them into four groups-

1. **Subsonic or low-speed wind-tunnels-** Subsonic or low-speed wind-tunnels are the most common type and the wind tunnel described in this paper is of this type.
2. **Transonic wind-tunnels-** Transonic wind-tunnels are common in the aircraft industry since most commercial aircraft operate in this regime.
3. **Supersonic wind-tunnels-** Supersonic wind-tunnels can be used to investigate the behavior of jet engines and military aircraft.
4. **Hypersonic wind-tunnels-** Hypersonic wind-tunnels find their applications in rockets and space vehicles.

III. FLUID DYNAMICS

a) Ideal/Real Fluid

An ideal fluid is a fluid that that experiences no viscous forces. This property of inviscid fluids allows them to flow along walls without an velocity decay due to skin friction, and also eliminates drag on adjacent lamina due to velocity gradients. This in turn means that ideal fluids do not form turbulent vortices as these flow past obstructions. Ideal fluids can be thought of as body of tiny frictionless particles, capable of supporting pressures at normal incidence but unaffected by shearing stresses. Ideal fluids are strictly a theoretical conception, but are sometime useful in modeling real-world situations where viscous forces can be neglected to a reasonable approximation.

Viscous fluids more commonly found in practical situation are called real fluids, and though their analysis is a great deal more complex due to the addition of viscous forces, they are use in a far broader range of applications.

b) Laminar/Turbulent Flow

Laminar flow is the movement of fluid in thin parallel layers who slide one over the other much like sheets of paper. Each layer experiences strong viscous forces from adjacent layers and these forces have a damping effect on disruptions in the flow so that flow downstream of an obstacle quickly returns to its undisturbed state.

Turbulent flow is the highly random and chaotic flow that occurs at high Reynolds numbers characterized by the formation of eddies and vortices of various sizes. Unlike laminar flow, in which fluid behavior is determined primarily by viscous forces, flow behavior in turbulent flow is determined by inertial forces.

Calculating fluid behavior in turbulent flow is often very difficult, as the Navier-Stokes equations that must be used are very complex. These equations relate the pressure, density, temperature and velocity of a fluid through the use of rate of stress and strain tensors, and the result is a set of five coupled differential equations

(an additional equation of state is also needed in order to find a solution). In all but the simplest of cases, these equations are extremely difficult to solve analytically, and most solutions must be found through approximations and the use of high speed computers.

c) Fluid Viscosity

Viscosity is often defined as a measure of how resistive a fluid is to flow or deformation. Viscosity can be likened somewhat to friction experienced by solid objects, but unlike the frictional forces between solids, viscous forces are independent of pressure. Viscosity is ultimately caused by cohesive intermolecular forces, and can be expressed mathematically as the ratio of shearing stress on a fluid to its velocity gradient. Viscosity can be observed in a number of common liquids. For example, maple syrup has a higher viscosity than water and so flows more slowly. Gases also experience viscous forces and these forces increase as the temperature of the gas increases. This is due to the fact that as temperature increases, so does the kinetic energy of the molecules and so there is an increase in rate of intermolecular collisions. To a good approximation, the viscosity of a gas goes as the square root of its temperature.

d) Skin Friction Drag

Skin friction drag is the component of the total drag, also called parasitic or profile drag, experienced by a body in a fluid flow due directly to frictional forces between the fluid and the surface of the body. Assuming no boundary layer separation occurs, skin friction is the sole source of friction.

e) Reynolds Number

Osborne Reynolds first introduced the dimensionless constant that bears his name in his 1883, in a paper he published in the Philosophical Transactions of the Royal Society.

Using an apparatus that allowed him to inject a small stream of dye into fluid flowing through a glass tube and using a manometer to determine flow velocities, Reynolds noticed that at lower flow velocities, the stream of dye remained intact but at higher velocities the coherent stream began to diffuse. He also noted that the diffused dye could be reformed into a stream if the velocity was decreased. Reynolds found that there was a critical velocity, which he termed the upper critical velocity, at which the turbulent flow developed and a lower critical velocity at which turbulent flow became laminar. Velocities located between these two points were classified as lying in the transition region.

The Reynolds number itself is a dimensionless constant used to distinguish laminar from turbulent flow in a pipe or channel or sometime around an immersed object, with lower values corresponding to laminar flow and higher ones to turbulent flow. The Reynolds number

is calculated using mean velocity, pipe diameter, density, and viscosity, and is valid for any fluid. The Reynolds number is also dependent upon the geometry of the pipe, as well as the roughness of the walls. Analysis of the Reynolds number using the dimensionless forms of the Navier Stokes equations reveals that the Reynolds number is really a ratio of inertial forces to viscous forces. As of yet, no successful analytic methods for determining Reynolds numbers have been developed due largely to the difficulty associated with predicting turbulent flow, and so Reynolds numbers for flow through pipes or around immersed objects must be determined experimentally. Reynolds no. is given as: -

$$Re = \rho v d / \mu$$

Where,

Re, Reynold's No.

ρ , density of the working fluid

v, velocity of the fluid

d, diameter of the section

μ , kinematic viscosity of the fluid

f) Boundary Layers

Boundary layers are regions of fluid located immediately adjacent to an immersed object or wall in which flow velocities are governed by viscous forces. Drag forces and most of the heat exchange experienced by the object are due to fluid in this region. Boundary layers typically begin as a very thin region of laminar flow that thickens with increasing Reynolds numbers and then gradually transitions to a turbulent layer flowing over a viscous sub-layer. Flow outside of the boundary layer is independent of Reynolds number criteria.

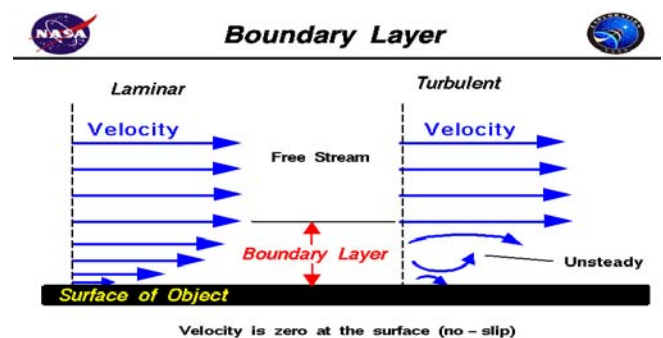


Figure 3 : Velocity Profile for Boundary Layers along a Wall

g) Mach Number

In fluid mechanics, Mach number (Ma or M) sometimes is a dimensionless quantity representing the speed of an object moving through air or other fluid divided by the local speed of sound. It is commonly used to represent the speed of an object when it is traveling close to or above the speed of sound.

$$M = \frac{V}{a}$$

Where, M is the Mach number, V is the velocity of the source relative to the medium and a is the speed of sound in the medium. In our project the Mach Number is according to the subsonic regime- $5.7/20000 < < 1$.

Mach number varies by the composition of the surrounding medium and also by local conditions, especially temperature and pressure. The Mach number can be used to determine if a flow can be treated as an incompressible flow.

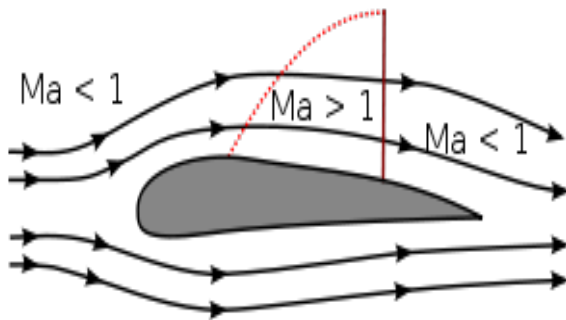


Figure 4 : Mach number variation

IV. COMPONENTS OF THE WIND TUNNEL

Following are the components of the wind tunnel:-

a) Settling Chamber

The settling chamber is located between the fan or wide angle diffuser and the contraction and contains the honeycombs and screens used to moderate longitudinal variations in the flow. Screens in the chamber should be spaced at 0.2 cm diameters apart so that flow disturbed by the first screen can settle before it encounters the second.

b) Screens

Screens are typically located just downstream of the honeycomb and sometime at the inlet of the test section. Screens create a static pressure drop and serve to reduce boundary layer size and increase flow uniformity. A screen is characterized by its open-area ratio, which is defined in the equation below where D_s is the wire mesh diameter and L_s is the length of the screen. At least one screen in the settling chamber (ideally the last) should have an open-area ratio of $\beta < 0.57$, as screens with lower ratios are known to produced non-uniformities in the flow. This is presumable due to the formation of small vortices created by the random coalescence of tiny jets emitted from the screen. The pressure drop across a screen depends upon the open-area ratio of the screen and the density, kinematic viscosity, and mean velocity of the fluid.

$$\beta = \left(1 - \frac{d}{L}\right)^2$$

c) Honeycombs

Honeycombs are located in the settling chamber and are used to reduce non-uniformities in the flow. For optimum benefit, honeycombs should be 6-8 cell diameters thick and cell size should be on the order of about 150 cells per settling chamber diameter.

d) Contraction Section

Contractions sections are located between the settling chamber and the test sections and serve to both increase mean velocities at the test section inlet and moderate inconsistencies in the uniformity of the flow. Large contraction ratios and short contraction lengths are generally more desirable as they reduce the power loss across the screens and the thickness of boundary layers. Small tunnels typically have contraction ratios between 4 and 9.

e) Airfoil

An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. Subsonic flight airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with asymmetric camber. Foils of similar function designed with water as the working fluid are called hydrofoils. Various types of the airfoils are shown in the picture below and the preferred is propeller blade.

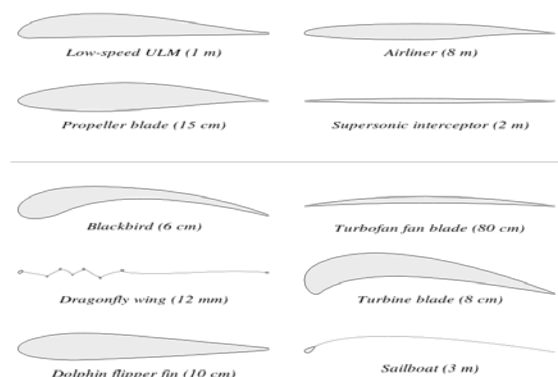


Figure 5 : Various Airfoil Designs and Profiles

f) Test Section

The test section is the chamber in which measurements and observations are made and its shape and size are largely determined by the testing requirements. The test section should be long enough that flow disturbances resulting from a contraction or screens are sufficiently damped before the reaching the test object. However, care should be taken not to make this section too long as this will lead to detrimental

boundary layer growth which can separate when it enters the exit diffuser and create a power loss. This can be prevented by slightly enlarging the tunnel or by partially obstructing the exit end of the tunnel to create an overpressure which allows the use of small vents to control boundary layer growth.

g) *Velocimeters /Observation Devices*

A wide variety of velocity-measuring devices exist, and for the sake of brevity I will only touch on a few of the most popular. Pitot tubes are used to measure differences in pressure, usually with the aid of a manometer. In modern experimentation, it is common to utilize a device that combines a pitot tube with a static pressure measurement device so that both static pressure and stagnation pressure (total pressure) can be measured simultaneously. These devices are called pitot-static tubes, and can measure the different in total and static pressure, from which velocities can be calculated using the relation between dynamic pressure and fluid velocity. (Total pressure is simply the sum of static and dynamic pressures.) When using pitot tubes, care must be taken with regard to proper orientation of the tube, as a difference of only a few degrees from parallel to the flow lines could alter readings.

h) *Diffusers*

Diffusers are chambers that slowly expand along their length, allowing fluid pressure to increase and decreasing fluid velocity. Angles slightly larger than 5 degrees do increase pressure recovery, but can also lead to boundary layer separation and thus flow unsteadiness. Exit diffusers are located downstream of the test section and are used to recover pressure flow. Wide angle diffusers are located between the fan and the settling chamber and are necessary in order to facilitate the use of a beneficial contraction section, but the wide angle leads to boundary layer separation which must be controlled with the use of screens.

i) *Fan*

Axial fans are popular in open circuit tunnels, and are almost always found in closed circuit tunnels. In larger tunnels, pre-rotation vanes called stators are commonly positioned upstream of the fan, substantially decreasing swirl in the exit flow. Axial fans have a relatively limited effective operating range as the reduction in pressure increase through the fan as the blades approach stall speeds is far more abrupt than in centrifugal blowers. Care must also be given to choosing the proper blade size, shape and spacing in order to prevent shock wave production, stalling, and backflow.

Centrifugal blowers, sometimes called squirrel cage blowers are most often in blower type open circuit tunnels, though they can be used in closed return tunnels if mounted in a corner. Centrifugal blowers have

a much larger operating range than axial fans with acceptable levels of unsteadiness.

j) *Corner Vanes*

Corner vanes are thin curved blades usually made from sheet metal that are placed in the corner of the wind tunnel typically along the return circuit in a closed type wind tunnel. Their purpose is to redirect the flow while minimizing pressure loss and boundary layer separation.

k) *Base*

The base for the wind tunnels was built off of an old six foot lab table. The drawers were removed and two ten foot lengths of two by six framing lumber were bolted to the sides of the table just under the lip of the table top. The carriage bolts used to attach the two-by-sixes were also run through vertical pieces of two-by-four. Three foot lengths of quarter inch threaded rod were bolted to the vertical two-by-fours so that they supported both the top and bottom of the tunnel.

l) *Smoke chamber*

The smoke chamber is the section which can be incorporated outside or along with the wind tunnel. The smoke is produced in it and then projected over the airfoil in the test section. Velocity profile is thus studied through it.

V. DESIGNING OF WIND TUNNEL PARTS

After basic research the early development of our wind tunnel seems to break down into five major components. These consist of the settling chamber, contraction cone, test section, diffuser, and power source or fan. Most sources indicate that the test section is the most important part of the wind tunnel and should be designed first, based on specific needs and Reynolds numbers, so that the rest of the wind tunnel can be constructed accordingly to meet the specifications determined by the test section.

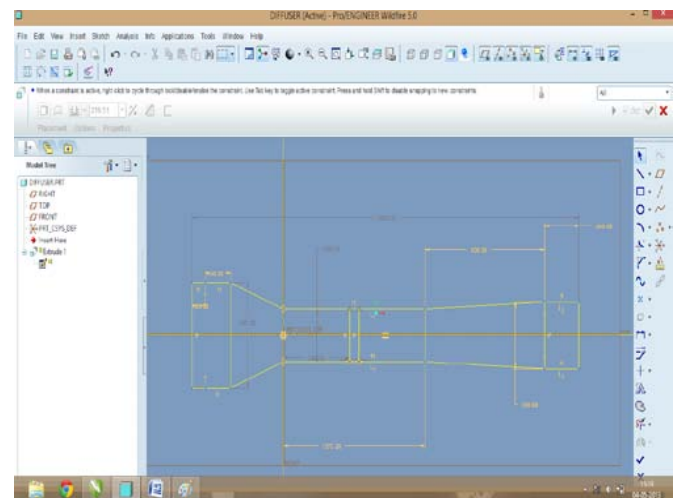


Figure 6 : Design of Tunnel Layout

a) *Airfoil (unsymmetrical)*

According to the data available from the NASA site we got the details of the airfoil with the co-ordinates for the foil. On plotting the point we got the design for the dimensions as-

Length: - 20cm

Width: - 30cm

The airfoil with the NACA 63-215, was selected with the details been discussed below. The co-ordinates of the airfoil will be-

NACA 63-215 AIRFOIL 26. 26.

0.000000 0.000000
 0.003990 0.012500
 0.006370 0.015280
 0.011200 0.019800
 0.023480 0.027920
 0.048290 0.039600
 0.073230 0.048470
 0.098230 0.055690
 0.148340 0.066820
 0.198520 0.074870
 0.248750 0.080490
 0.299000 0.083920
 0.349260 0.085300
 0.399520 0.084570
 0.449770 0.081940
 0.500000 0.077680
 0.550190 0.072030
 0.600350 0.065240
 0.650470 0.057510
 0.700530 0.049060
 0.750550 0.040140
 0.800510 0.031050
 0.850430 0.022130
 0.900300 0.013680
 0.950140 0.006160
 1.000000 0.000000
 0.000000 0.000000
 0.006010 -0.011500
 0.008630 -0.013880
 0.013800 -0.017660
 0.026520 -0.024200
 0.051710 -0.033280
 0.076770 -0.039990
 0.101770 -0.045350
 0.151660 -0.053360
 0.201480 -0.058950
 0.251250 -0.062590
 0.301000 -0.064480
 0.350740 -0.064700
 0.400480 -0.063150
 0.450230 -0.060040
 0.500000 -0.055620
 0.549810 -0.050130
 0.599650 -0.043820

0.649530 -0.036910
 0.699470 -0.029620
 0.749450 -0.022240
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 1.000000 0.000000

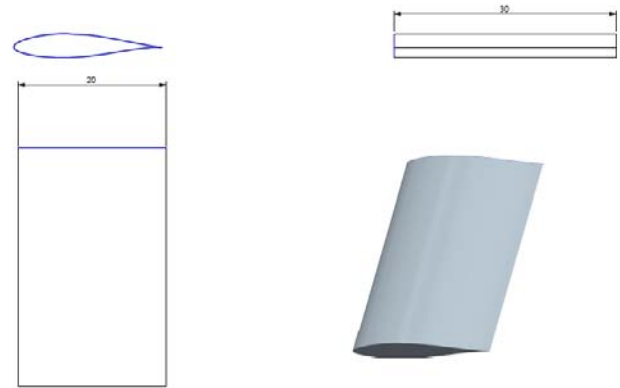


Figure 7 : Design of Airfoil

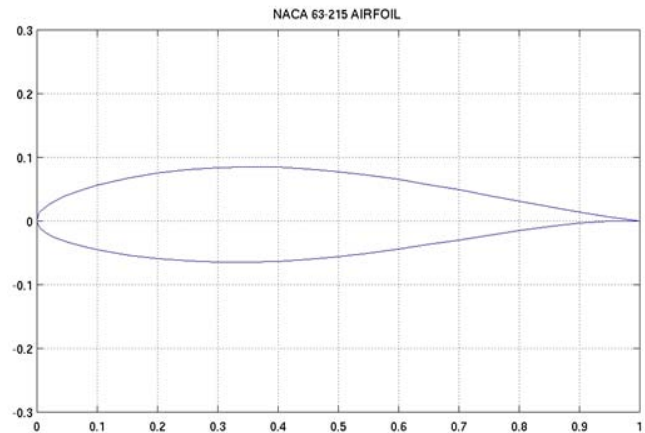


Figure 8 : Plotting of Airfoil

b) *Test section*

To accommodate the chosen airfoil dimensions the test section dimensions are chosen as-
 Cross-section:- $30 \times 30 \text{ cm}^2$

Since the length to the diameter (d) of the test section should be more than 1.5 thus the length is taken as-

$$\begin{aligned} \text{Length} &= \text{diameter (d)} \times 1.5 \\ &= 30 \times 1.5 \\ &= 45 \text{ cm} \end{aligned}$$

Hence the data taken is greater than 45 cm,
 Length: - 50 cm

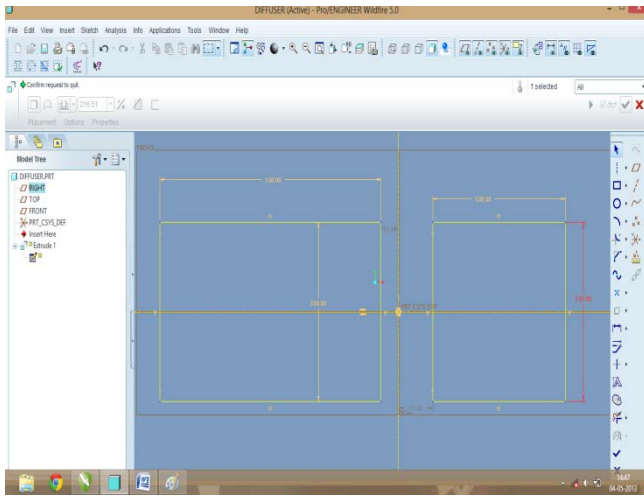


Figure 9 : Design of Test Section

c) Contraction cone

The contraction cone ratio can vary from 4-9 for a low speed wind tunnel thus according to the length of the contraction cone and contraction ratio with respect to the test section the dimensions of the cone were chosen as-

$$\text{Contraction ratio} = (60 \times 60) / (30 \times 30) = 4$$

$$\text{Cross-section:- } 60 \times 60 \text{ cm}^2 \text{ (for outer end)} \\ 30 \times 30 \text{ cm}^2 \text{ (for inner end)}$$

Length will be according to the similar ratio of $L/D = 1.5$

$$\text{Length} = 60 \times 1.5 = 90 \text{ cm}$$

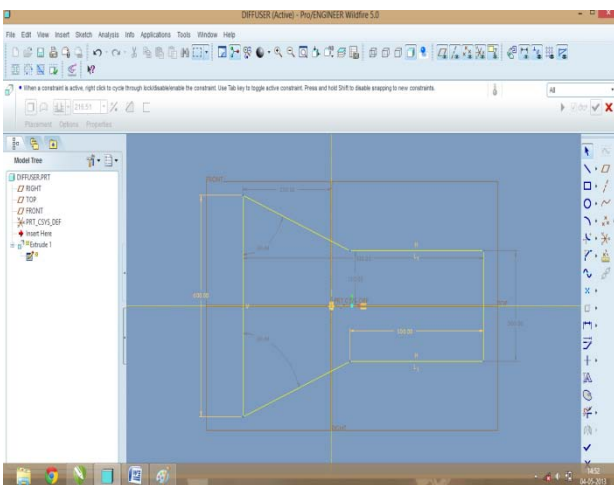


Figure 10 : Design of Contraction Cone

d) Honeycomb

The honeycomb follows the dimensions of the cross-section of the contraction cone's initial end. Thus,

$$\text{Cross-section:- } 60 \times 60 \text{ cm}^2$$

Thickness of the honey comb should be minimum of 2.5 inches i.e. approx. 6.4 cm. so, in order to minimize turbulence we considered the thickness as- Thickness: - 10cm (approx.)

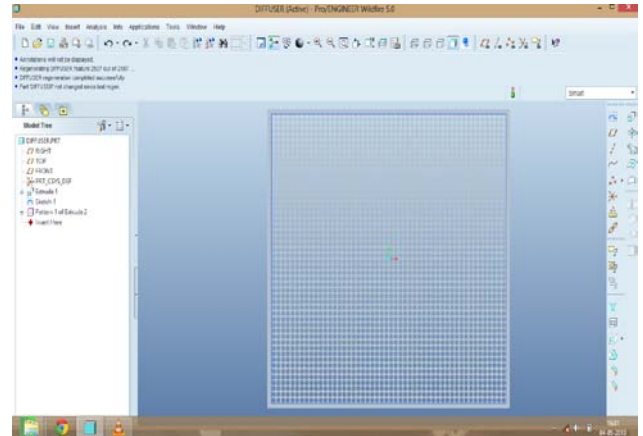


Figure 11 : Design of Honeycomb

e) Settling chamber

As the honeycomb follows the dimensions of the contraction cone's initial end the same way settling chamber follows the dimensions of the honeycomb thus it has the same cross-section as that of the honeycomb. Cross-section:- $60 \times 60 \text{ cm}^2$ (for all the screens)

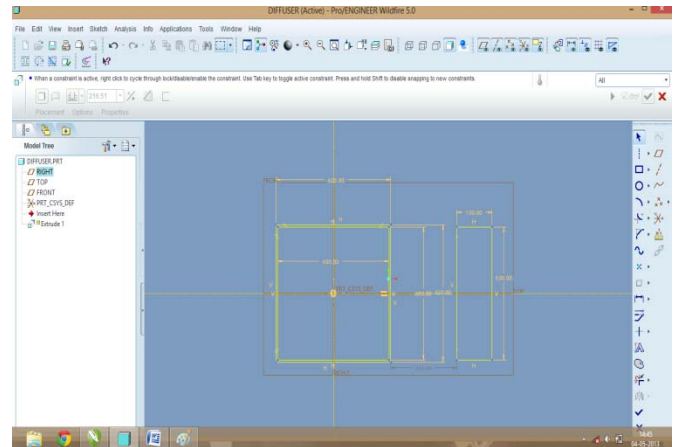


Figure 12 : Design of Settling Chamber

f) Diffuser

The diffuser is designed according to the diffuser angle of the diffuser cone. It is designed such that the angle of diffusion (ϕ) should be around 5° . Thus we have considered-

$$\text{Angle of diffusion as:- } \phi/2 = 2.54$$

Thus the outer diameter (D_o) of the diffuser will be calculated as:-

$$D_o = D_i + \{ 2 * (L_d * \tan \phi/2) \}$$

Where,

D_i – inner diameter of the diffuser = diameter of the test-section = 30cm

L_d – length of the diffuser = 90 cm

Therefore,

$$\begin{aligned} D_o &= 30 + \{2 * 90 * \tan 2.54\} \\ &= 30 + 7.984 \\ &= 38 \text{ cm (approx.)} \end{aligned}$$

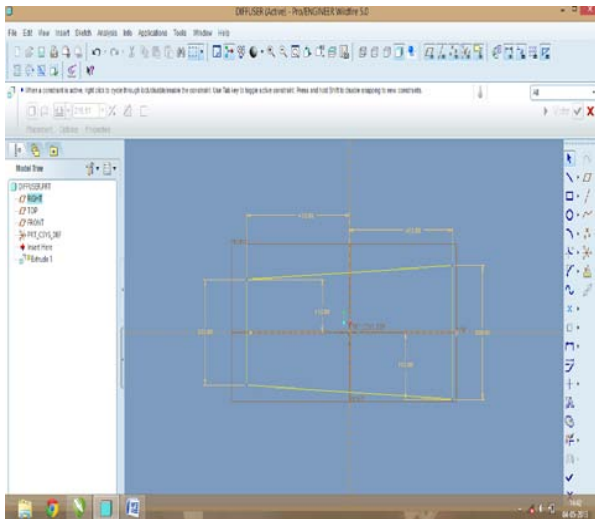


Figure 13 : Design of Diffuser

g) Fan

Since the wind tunnel we are constructing has the diffuser at the extreme end thus instead of an axial fan we have made use of the exhaust fan of $\frac{1}{2}$ H.P.

With the finalizing of the fan and other parts of the tunnel, we moved forward to the fabrication part. Since the designing was itself a hectic and a time taking procedure thus we had taken some time to rest for further working in the project.

VI. FABRICATION PROCEDURE

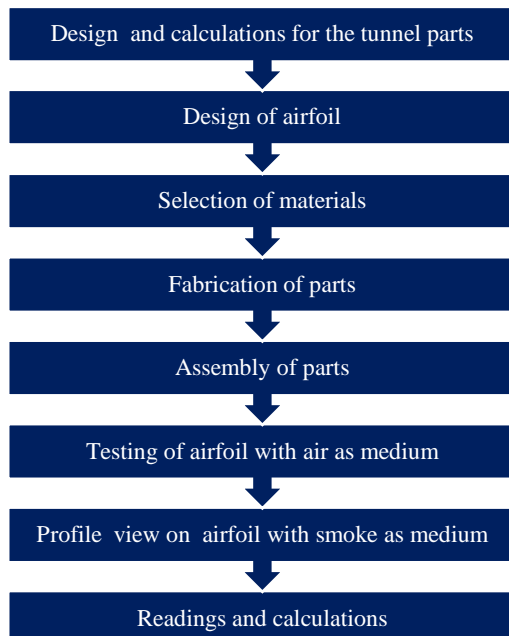
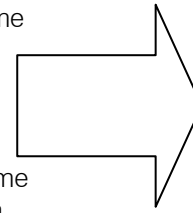


Figure 14 : Fabrication Procedure Overview

a) Materials used

Settling chamber frame
Honeycomb frame
Test section frame
2cm thickness
Diffuser frame
Contraction cone frame
Support frame for fan



wood ply with

Screen material:- mild steel wire sieves with different cross-sections (M).

Honey comb:- straws with circular cross-section and diameter of 4mm, FRP for circular holes of diameter 10mm.

Contraction cone body:- G.I sheet of 28 gauge.

Test section:- Plexiglas sheet (polycarbonate transparent sheet) 2mm thick.

Diffuser:- G.I sheet of 28 gauge.

Fan- Domestic Cooler Exhaust of $\frac{1}{2}$ H.P

Pitot tubes

Manometer

Incense sticks for smoke.

Mica and Electricity tapes for sealing.

Rubber stoppers for tube arrangements.

After selection of material and bringing it to the project fabrication area the dimensions finalized were-

b) Dimensions

Overall length – 10ft

Test Section Length – 50 cm

Test Section Diameter – 30cm

Settling Chamber Diameter – 60cm

Contraction Ratio – 4

Honeycomb Thickness/Cell Size/Cell Count – 10cm

Max Mean Air Velocity – 5.7 m/s

Max Mean output- 4.024 m/s

Diffuser angle- 2.54°

Now the fabrication work was initiated so as to complete the project in time. To avoid any kind of confusion and errors we started the work from one end of the wind tunnel .The first part we started with was settling chamber.

VII. PHASES OF THE FABRICATION

• Stage I-

A second critical component for the wind tunnel is the settling chamber, most often the placed at the entrance of the contraction cone. This piece of the wind tunnel is best described on the 'Flight of Inspiration' website. "The settling chamber straightens the airflow. Uneven turbulent flows can cause unpredictable forces to be experienced and measured in the test section. The less turbulence there is, the better the wind tunnel will simulate actual flying conditions. The settling chamber usually includes a honeycomb flow straightener and wire

mesh smoothing screens that produce a smooth airflow". The honeycomb material they discuss can be made of hexagonal cells, like normal honeycomb, but it can also be circular or square cells. Not much of this aspect as been thought through in the design process yet. However, one idea is to use a square fluorescent light diffuser section to straighten the airflow. Research shows that the length should 6-8 times the cell diameter. Stacking the diffuser panels could meet this requirement. So far this seems to be the best low cost solution for honeycomb, and a good alternative to the real hexagonal cells; which are shown to be slightly better at reducing turbulent air.

The next component following the air through the tunnel is the contraction, most often referred to as the contraction cone. The purpose of this section is to compress the air to form a higher velocity in the test section. As discussed above the settling chamber is normally placed at the very beginning of the wind tunnel; making up the front part of the contraction cone. This is because the honeycomb is more effective when the air is at a lower velocity. Because the contraction cone starts off as a large area it allows the honeycomb to be placed in an area where the air is more static, before contracting to the operating air velocity. The major design issue with this aspect of the wind tunnel is its unique wavy shape; commonly a cubic function or a combination of radiuses. On NASA's website, 'Wandering Wind tunnel', they discuss some of the issues they had regarding shape and material of this section. Most notably, they recommended the use of the cubic function and 14 gauge sheet metal as a material. Since 14 gauge sheet would not have been feasible to bend and also for clamping purpose thus we preferred the use of 28 gauge sheet metal for the sheet. With regard to these issues, scale paper models have been constructed to verify a few design ideas and confirm that it can be constructed from flat pieces of sheet metal. Although research has shown this specific shape to be important, it is also recognized that the specific shape of the curve is not as critical in the design of small wind tunnels. Also, for ease of construction, straight walls that form a trapezoid are being considered. Despite what all the references say about having a curved compressor, a flat one was chosen instead to allow for ease of construction. Because of this, a small settling chamber (circular honeycomb) will be added just in front of the test section to renormalize the flow".

Following the air through the test section the next large component required is the diffuser section. This connects the end of the test section with the fan and goes from a smaller area to a slightly bigger one. Research has noted that the angle of expansion should be approx. 5 degrees, which fits the degrees in the current design. The shape of this section is best when square is blended with a circle it is very difficult to construct. For something that is more easily built the

square attaches to 4 triangles, whose tips connect to the fan shroud. The gaps are filled in with curved sheet metal for a generally smooth shape to connect the fan to the test section.

The fan, or power source, is the final critical component in the design of our low speed wind tunnel. An industrial fan was selected, and acquired, to meet specifications made by the test section. With a 15 in. diameter and max rate of 0.5 H.P so that it can pull enough air to reach speeds in the test section of up to 10mps. A switch is being considering allowing for a free range of wind velocity.

- *Stage II-*

With over the two weeks of working, significant progress had been made in the design and construction of our wind tunnel. Each section of the wind tunnel has been planned out and finalized to some degree and some parts were under construction. The details of the plan, which will be discussed below, follow some original thoughts but also include some significant design changes to minimize cost and maximize performance. Although this is the most current design there is still some future planning required and thus it is always subject to change.

One of the larger and more critical aspects of the wind tunnel is the contraction cone. The most difficult part about this section is deciding what shape to make it. There were two main options we had. First, there was the more traditional approach of a curved contraction; a profile with an 'S' shape to it. The other option was to make flat walls in the shape of a trapezoid, which would serve the same purpose. The underlying goal of the contraction cone is to transfer from a larger area to the smaller area of the test section; in a sense a large square to a smaller square. The contraction cone serves many purposes in the overall scheme of the wind tunnel. The contraction cone increases the efficiency of the system by giving the fan a larger pool to pull air from it is easier to pull air through the tunnel. Also by starting off at a larger area the velocity of the air is much lower and more ideal for the use of screens and honeycomb to straighten the airflow. Problems that can occur in this section include separation of air and an increased boundary layer. All of these factors were considered in making the final design; however, it was ease of construction, and total cost that also played a large factor in the final decision.

A curved contraction cone would be much harder to construct, so the flat design was chosen for its ease of construction. The advantages of a curved contraction cone were not seen to be necessary and are compensated for elsewhere in the design. In our research, this flat design was found to cause a greater chance of separation and possible problems at the boundary layer. However, sources also show that by increasing the length of the contraction you can

minimize both of these issues. "It is also possible to avoid separation in the contraction by making it very long, but this results in an increase of tunnel length, cost, and exit boundary layer thickness". As stated, the trade offs are cost, size, and thickness of boundary layer; however these factors are far less significant for our specific wind tunnel. Since it was easier to make it longer than to make a curved shape, a length of 90 cm was chosen as it is 30% longer than the general recommended length.

The final aspect of this part of the wind tunnel is the contraction ratio or difference in areas. Although this ratio was not found to be very critical, sources showed that a minimum ratio of 5:1 is ideal. We had considered the ratio of 4:1. By making the opening a 60*60 cm square and contraction down to the test section with an area of 30*30 cm square we were able to achieve a nearby similar ratio while keeping the overall size reasonable. The only other aspect of this section is the settling chamber, which is normally placed at the beginning of the contraction cone.

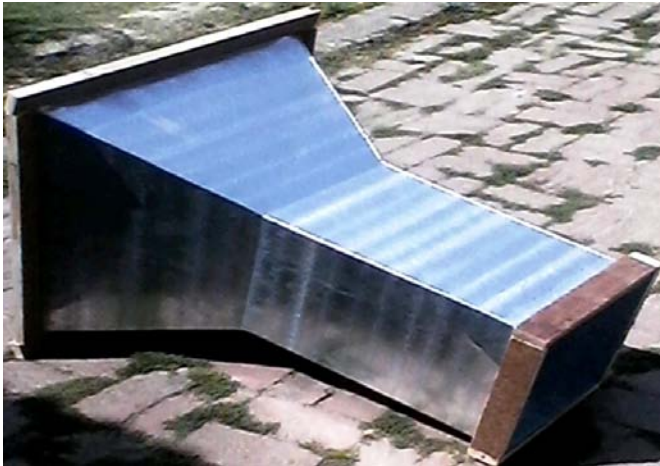


Figure 15 : Actual Contraction Cone (longitudinal view)

For the complete construction of the contraction cone we had first bought a G.I sheet of 28 gauge with the area of 8 ft*3ft. This area of sheet was sufficient enough to construct a contraction cone of the required data. Then across one edge of the width along the length we made the marking of 4*60cm length to get the leading end cross-section of the cone. Similarly for the trailing end we made marking 4*30cm. We had left extra 3cm on each side of the sheet as the tolerance while joining the sheet when folded for getting the cross-section. Then we removed the extra unnecessary portion of the sheet by cutting that portion with the help of snap. The major problem we faced was during joining the sheet edges since the G.I sheet cannot be welded through any welding, therefore we had to struggle a lot with the fixing of this issue. Then we got it pinned from the edges with the help of sheet metal shop workers. Finally we were done with the contraction cone fabrication. Finally the framing of the cone from both the

opening sides was to be done. For this we got the wood ply of the thickness 2cm. Then we got two plywood cuttings with 6 cm width and of 60 cm and two of 64 cm lengths for the leading end and two 30 cm and two 34 cm length cuttings of same width for the trailing end. Thus, after nailing it on the edges the finishing of the cone got accomplished finally.



Figure 16 : Actual Contraction Cone (cross-sectional view)

• Stage III-

Our research has proven that the use of honeycomb settling chamber as a flow straightener is most effective in areas of low velocity, and thus should be placed in the entrance of the contraction cone. It was also found that the reasoning for this was that the efficiency is drastically reduced when the honeycomb settling chamber is placed in an area of higher velocity. Efficiency, however, is not of utmost importance to us. Having found this, it is easier and more economical to place the honeycomb towards the end, right before the test section. After researching different honeycomb materials, the lowest cost honeycomb (commonly used in small low speed wind tunnels) was found to be plastic drinking straws. However, the problem becomes not only buying thousands of straws in bulk, but the complexity involved in cutting thousands of straws to the correct length and stacking them together. Because of the much larger area at the beginning of the wind tunnel, it would cause much more straws to be used and add to the overall complexity.

To reduce this issue without eliminating the necessary use of honeycomb the settling chamber (honeycomb) can be placed at the end of the contraction cone which is right before the test section. The advantage of this is that it is over a much smaller area and would cost less while being easier to construct. But the other major factor in this decision relates to the flat design of the contraction cone and the disadvantage in that design is that it makes the flow

more likely to separate, or in other words can create more turbulent air which is not required. Thus we placed the settling chamber before the contraction cone as we had decided earlier. Downsides to this design were found to reduce efficiency, possibly making the fan work harder. The last aspect of the settling chamber is screens, normally combined with honeycomb to reduce turbulence. The thinking was to place one screen in the very front and others where it is seen to be needed.

The flow straightener has been fairly difficult to construct being on such a low budget. If we would have had a high budget to work with, there is extruded aluminum honeycomb that we could have purchased to serve as our flow straightener. Being low-budget, we decided to go on a more unconventional route using straws to produce a normal airflow. However, this is not that farfetched because this method has been used before. The Myth Busters used it in their wind tunnel and straws were also used in an experimental wind tunnel at MIT (Maniet1). The main purpose of the honeycomb flow straightener is to reduce the swirling effect the fan has on the air. In order to simulate conditions close to those an airplane flying in the air would experience, the flow needs laminar to produce the effect of a wind traveling through the air as opposed to the air traveling over the wind as it is in all wind tunnels. The construction of this piece has been difficult to say the least.

After deciding to go with the straw method, we needed to calculate how many straws we would need and where we would get them. Each of these variables, though, depends on each other. The bigger the straw, the less you need. After doing hours of research on just where we could get straws, we got at it at a general store. After actually obtaining the 9260 straws, we needed to figure out a way to cut the straws into 9 cm sections and place them into a frame that would fit into the contraction cone. After cutting 10 cm strips of wood, we assembled the frame that the straws would go in by placing the wood pieces together in the cone to get the exact dimensions and then gluing the corners with wood glue. However, before we could attach the window screen to the top of the frame, we still needed to figure out how to cut the straws in bulk so we would not have to place each straw in the frame individually. There was a lot of trial and error in this process. Ultimately, we bundled the straws into circles and we cut the 9cm sections with a snap. In the end, there was a group of approximately 27800 straws.



Figure 17 : Actual Honeycomb (cross-sectional view)

After all this mind storming we started up with the construction. Firstly we got our plywood frame ready of the cross-sectional area 60*60 cm square. Then next was the cutting of the long straws into the size of the length of the honeycomb. After whole day cutting we could gather the straws of the appropriate size. Then we started placing them in the honeycomb section using the wood glue. It served the purpose but due to the diameter of the straws being very small it was very difficult to put the straws one by one properly aligned. On the second day of the construction of the honeycomb we found out an easy way of placing the straws in it. Thus the construction took a pace. Then after 3rd day of doing the same work we thought of placing a FRP sheet with the drilled hole of 1cm diameter in the left part and we did the same. At last the honey comb was ready.

A window screen was chosen because it is easy to use and was the most cost effective. We got the sieves of different M (holes / inch) factors. There were three sieves:-

1. Outermost sieve with $M = 1.5$
2. Mid sieve with $M = 9$
3. Innermost sieve with $M = 16$



Figure 18 : Actual Screen (cross-sectional view) M=9

We got the wire frames cut with the help of the snap. The sieves were then tucked in a frame of the 60*60 cm square cross-section. The cross-section of the settling chamber is same as that of the contraction cone thus the frame is of the same size as that of the leading end of the contraction cone. The sieves were then finally attached to the frames through the nails hence all the parts of the settling chamber were prepared.



Figure 19 : Actual Screen (cross-sectional view) M=16



Figure 20 : Actual Screen (cross-sectional view) M=1.5

• Stage IV

The next section of the wind tunnel is the test section. This mainly consists of two wooden frames connected by a clear material. A test section area of 30*30cm square was chosen because it allowed a wide range of wind velocities, and it was also convenient to the length of wood we had on hand. By cutting plywood of .5 cm thickness of cross-section 50*30 cm square we got the base of the test-section ready. The taper of 1° angle had been provided to avoid pressure drop through the section. The only other part of the test section is the Plexiglas or clear material needed to view the experiment. It is common to make all four sides of the square out of Plexiglas, however, we are now thinking about only using two or three sides of Plexiglas to minimize cost. No research or sources have indicated anything about this part of the test section, however, a few things are being considered in the decision. The only purpose of the Plexiglas is to view the object. However, other considerations such as the amount of light that will then get in or the background in viewing smoke needs to be looked into. Other low-cost clear materials are also being considered as a means of reducing cost; but no final decision has been made.



Figure 21 : Actual Test Section (Longitudinal view)

The pieces after the test section are somewhat less significant because the air is already through the test section; although separation of air is still an important factor. Then the Plexiglas sheet was cut by us into 3 equal rectangular pieces of area 50*30 cm square. We got the frame for fitting the sheets into by making an inverter table with base of plywood which we had already made. We place four legs at the four corners of the base in the upright direction and nailed

them. Thus our frame got ready. Thereafter, we made the drill holes on the sheet with the help of hand drill and drill bit of 10mm on the sheet sections to be placed front to front so as to put in the rod on which the airfoil will be mounted and also for making a pitot tube and manometer arrangement on the sheets to be kept perpendicular to each other. After that firstly we nailed the sheets on the frame which were to hold the airfoil and we placed airfoil with the aluminum rod passing through it and holding it across the section. Hence the test section was over after few days of working.

The test section is the latest sub-project we have worked on. We bought 1mm thick Plexiglas and made a rectangular prism out of it using the square frames we previously constructed. The One other thing we still have to do on the test section is to construct something to hold the test pieces in place. One idea we had is to drill a hole to allow an aluminium dowel to fit inside to mount airfoils. This has to be done very carefully so the Plexiglas does not crack. Also, flow visualization is going to be very important in the test section.

The diffuser, or part that connects the fan to the test section, has been designed based mostly on fixed dimensions such as the diameter of fan and cross section of the test section. Although research does not note on the length of this section, it has shown that a slope of 5-10 degrees is desirable, and at about 6 degrees meets our criteria. With the final dimensions set for both the diffuser and contraction cone, the plans have been sent out to be made from sheet metal; used for its light weight and low cost. The final aspect in our wind tunnel design and construction is the fan. As previously mentioned we have decided on and purchased an industrial strength fan that can push up to 8400 cubic feet per minute. However, most experiments require a wide range of wind velocities; so the need to control a wide range of speeds is very important. The idea is to use a dimmer switch to interrupt the power leg to the fan motor and thus control its speed.

However, after dissecting the electronics of the fan we found that a capacitor was wired into a 3 position switch; somehow making a high, low and off setting. After preliminary research, we found that using a classic style dimmer switch could not be used on an AC fan motor because the voltage required had to be at certain frequencies. Not fully convinced of this, we did small scale testing with a classic style one pole dimmer switch on a small inexpensive AC fan. Without replacing the existing high, low, off switch we wired the dimmer switch into the wire with power. This worked out very well and produced fine adjustments in the speed of the fan. More importantly, though, it produced no signs of damage to the motor or switch. Despite this promising small scale test, the potential risk to the large fan motor prevented us from dimming the real fan as of today. More research is being done to see the dangers, if any, of dimming an

AC motor. Other options, such as dimmers designed for AC motors (although more expensive) are also being considered.

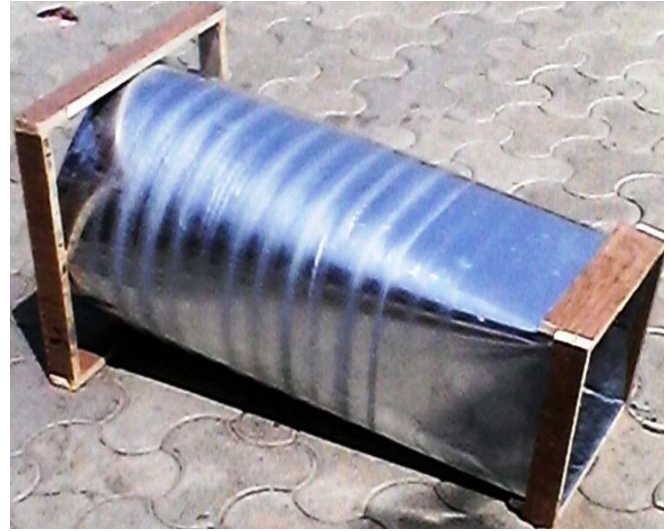


Figure 22 : Actual Diffuser (Longitudinal view)

The details discussed above are the most current and final designs although they are subject to change. One thing we have found through all the research is that for every design option, there are tradeoffs. Most often between cost, performance, and ease of construction; this current design balances these things to make a wind tunnel that is not only functional and low cost but also reasonable to build.

• Stage V

The biggest sections of the wind tunnel have recently been completed and are beginning to come together. There is finally some resemblance to a complete wind tunnel. Some of the major successes have included wiring the fan to be variable speed, building the contraction cone, diffuser and test section. However, there is still a fair amount of work that needs to be done to connect all of these pieces to make a functional wind tunnel.

After we designed the contraction cone and diffuser on the computer, we took the help of the carpentry shop people so as to put these pieces together for us. Although the pieces were not exactly constructed to our specifications, they should still be functional. The contraction cone goes from a 30 cm square to a circle 38 cm in diameter. Since we had already decided to straighten the airflow at the end contraction cone, the shape the contraction cone itself is not critical because if the air is somehow disturbed by this particular shape, it will be re-straightened by the honeycomb straightener which we are going to put right before the contraction cone as we discussed in the previous phase entry. As Flights of Inspiration stated, "The contraction cone's purpose is to take a large volume of low-velocity air and reduce it to a small

volume of high-velocity air". The contraction cone will serve this purpose just fine, again, considering we will be straightening the air flow just prior to the air entering the test section. The biggest problem that could arise from using this shape will be separation at the boundary layer but this will hopefully be renormalized by the straightener. The contraction ratio is the other important aspect of this section. The target contraction ratio was 4:1 and with our current section, it is approximately 4.1:1 which is very close to our target ratio.

The honeycomb straightened that we will use will be constructed of plastic drinking straws that are 3mm in diameter and approximately 9 cm long. They were placed together in a square frame and covered with screen door mesh to eliminate any eddies that may have formed in our obscurely shaped contraction cone. Even though we are trying to keep this project low-cost, many other small, low-speed wind tunnels use this straw method as well. A research project at MIT used it for many of the same reasons we chose to use this method.

"Accordingly, the honeycomb is constructed of approximately 130,000 plastic soda straws, 3/16 inches in diameter and 10 ½ inches in length, carefully stacked in a hexagonal close-packed configuration and held in place fore and aft by 18-mesh screening. The whole process results in seamless construction and clean-cut ends. The whole section proved to be quite inexpensive and relatively easy to construct."

Once the tunnel is done, we can experiment with the various methods that have been previously described in past journal entries. However, one of the methods would require a mounting setup right behind the test object. This method is the low-density string method that would show the vortices produced behind the airfoils. This would eventually need to be incorporated into the test section and/or airfoil. One of the shapes that will be interesting to test with this method is a triangular shaped wing because these wings have distinct vortices that are produced and should be easy to see with the low-density string method of flow visualization.

The diffuser we have was built exactly to the specifications of the plans. It is a square-to-round transition with a 38 cm diameter circle for the fan attachment and the square is 30 cm to fit the test section. This piece was less critical in the design because its main purpose is to connect the fan to the rest of the tunnel and since it is after the test section, boundary separation and turbulence becomes less important.

Over the course of constructing our wind tunnel concerns about the fan's electrical system have led to specific research in the field, small scale testing, and a few key design modifications. Although this is specific to our fan and wind tunnel design it is very relevant to anyone trying to have a variable speed

controller on an AC motor, and worth discussing individually due to the complexity involved.

The purpose of the main fan in all small open circuit wind tunnels is to provide the force that pulls the air through the wind tunnel. Although this seems like a relatively easy task there are a few critical components involved. The first is due to the nature of wind tunnel design and the several inefficiencies in air flow from flow straitening and screens. To overcome the severe pressure differences that can occur it is necessary to have a fairly powerful fan. Another important aspect of the fan and power system is to have fine control over the flow rate through the tunnel. Although this can be accomplished a few ways the most obvious and reasonable way to do so is to have the fan operate at variable speeds. Because it is important to test models at variable air speeds, and because we are unsure of what air speed would make the best for flow visualization it was deemed necessary to have a variable speed fan.

The fan used for this project is a domestic strength fan used to air in through the coolers. It came stock with a 3 position switch for high, low, and off and could push a maximum of 0.5 H.P. power through its 15 in diameter fan shroud. Although this fan had the right dimensions and power requirements there were several problems that required modifications, specifically to the electrical system. One was that we did not have any control panel to mount on the fan shroud making it possible to access with varying speeds once it was installed, and the other was that the fan had only had one speed and not the variable speed required. Originally both were seen to have easy solutions; however, further research caused some concerns about variable speed AC motors.

The original thought of wiring a common regulator switch into the circuit was something our research warned against. However, not fully convinced it would not work we purchased a single pole switch and did our own testing. Not wanting to risk damage to the fan we tested the dimmer switch on an old window fan that was far less expensive. More typical DC motors work with the electricity flowing in one direction. Because the motor would only do a half turn with this scenario a split ring commutator is used to reverse the direction of current every half turn. This results in keeping the motor spinning continuously in one direction. To alter the speed of a DC motor the only required change is the voltage which can be controlled easily through things like transformers. Unlike the simple process of DC current AC motors operate very differently. In alternating current the electricity is pushed forward and then pulled back continuously, in essence modeled by a sinusoidal function.

The complexity comes in when motors are designed to run off of AC current. Unlike DC motors who switch the direction of the current themselves AC motors

have the “advantage” of having the current switched for them, and thus do not have or need a split ring commutator. However, this does mean that every AC motor must be designed specifically to operate at a single given frequency of AC current.

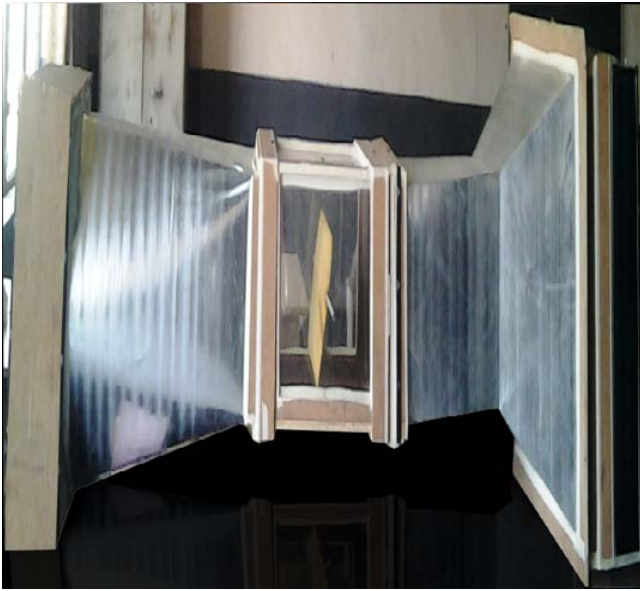


Figure 23 : Actual assembled wind tunnel (Longitudinal view)

As mentioned before, the fan has been wired so that it has a variable speed control which is a lot easier said than done. Having talked with our project guide, getting recommendations from an electrician, doing small scale testing and spending about 10 hours of time, we were finally able to get the desired results. We were now be able to run the wind tunnel at air speed of 0-20 m/s.

VIII. OBSERVATIONS AND CALCULATIONS

Loss of head due to an obstruction in a pipe

a = maximum cross-section of obstruction

A = cross-section of pipe

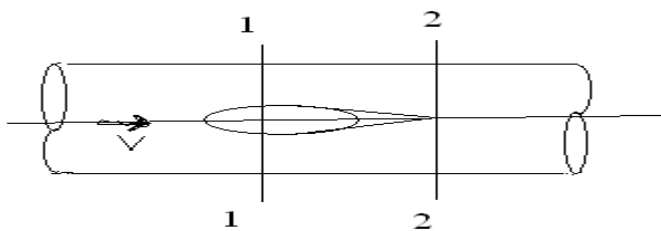


Figure 24 : A Pipe with an obstruction

V = velocity of fluid in pipe

$A-a$ = cross-section of fluid at section 1-1

At section 2-2, velocity of flow = v

V_c = velocity of liquid/ fluid at vena contracta

Then,

loss of head due to obstruction = head loss due to enlargement from vena contracta to section 2-2,

$$h_{ob} = (V_c - V)^2 / 2g$$

$$A_c V_c = AV$$

A_c = vena contracta cross-section

C_c = coefficient of contraction

C_c = vena contracta cross-section / cross-section of fluid at section 1-1,

$$C_c = a_c / (A-a)$$

$$A_c = C_c (A-a)$$

Substituting the value of A_c –

$$C_c (A-a) V_c = AV$$

$$\text{Or, } V_c = AV / C_c (A-a)$$

$$h_{ob} = [(AV / C_c (A-a)) - V]^2 / 2g$$

$$h_{ob} = V^2 * [\{ A / C_c (A-a) \} - 1]^2 / 2g$$

$$A = \pi D^2 / 4 \text{ (circular)}$$

$$a = \pi d^2 / 4 \text{ (if obstruction is circular)} \quad h_{ob} =$$

$$V^2 * [\{ (\pi D^2 / 4) / C_c (\pi D^2 / 4 - \pi d^2 / 4) \} - 1]^2 / 2g$$

$$h_{ob} = V^2 * [\{ D^2 / C_c (D^2 - d^2) \} - 1]^2 / 2g$$

Loss of fluid power –

$$P = mg h_{ob}$$

Calculating the value of h_{ob} we can get the value of the pressure. We had used an easy way out for the calculation of the h . We firstly observed and measured the value of difference in the liquid level in two arms of the manometer tube i.e. “ x ”. Then we calculated the value of h as-

$$h = x * [(\text{specific density of fluid in the manometer} / \text{specific density of working fluid}) - 1] \text{ m}$$

Hence, the velocity for different sections can be calculated corresponding to the different values of the x and h .

$$v = \sqrt{2gh} \text{ m/s}$$

Where, $\sqrt{}$ stands for the square root.

When the wind tunnel is run the value of x at different sections is observed using the same manometer and pitot tube arrangement at various sections. The major difficulty we had to go through was to carry the arrangement of manometer to the different sections and to fix it everytime. There were more chances of the manometer to be aligned and of the error in the readings. But somehow it was all managed well.

Then the calculations were made according to the readings observed in the sections as shown in the table below:

Specific density of fluid in the manometer = 1000 kg/m³ (water)
 Specific density of working fluid = 1.21 kg / m³ (air)
 Acceleration due to gravity, $g = 9.81 \text{ m/s}^2$

Readings obtained are

Sections	Settling Chamber	Test Section	Diffuser
x (mm)	0.8	2	1
h (m) calculated	0.66055	1.650892	0.825
v (m/s) calculated	3.599	5.69122	4.024

a) Calculations for the Drag and Lift Forces

Determination of the angle of attack according to the airfoil design-

For the angle of attack the value of the height of the foil after elevation should be < 15 %.

The blockage of the test section for the fluid is given as-

$$B = W \cdot H / (\text{cross-sectional area of the test-section})$$

Where,

B = blockage

W = width of the foil = 30cm

H = the height of the foil for the angle of attack

For the calculation of the value of H. We must have the value of the C that is the chord length. The chord length is determined from the airfoil as -

$$C = 20 \text{ cm}$$

Thus, the value of the H can be calculated using the value of the C from the formula, -

$$H = C \cdot \sin \alpha$$

Where, α = angle of attack preferred.

The angle of attack can vary from range 9° to 15°. Taking the value of the α as 12°.

Hence the calculation for the H is as-

$$\begin{aligned} H &= 20 \cdot \sin 12 \\ &= 4.158 \\ &= 4.2 \text{ cm (approx.)} \end{aligned}$$

The value of the blockage is as-

$$\begin{aligned} \% B &= [(30 \cdot 4.158) / (30 \cdot 30)] \cdot 100 \\ &= 13.86 \% \\ &= 14 \% \text{ (approx.)} \end{aligned}$$

The concept of the coefficient of lift and drag:-

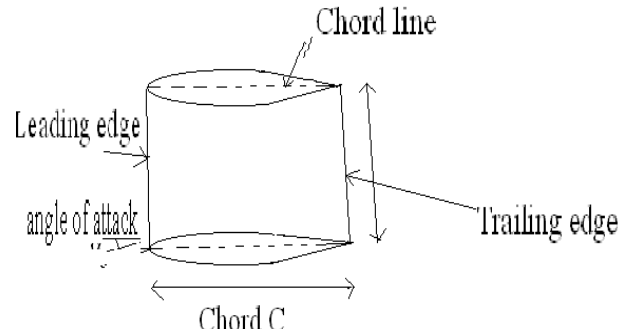


Figure 25 : Schematic Layout of an Airfoil

The aspect ratio is defined as;

$$A.R = L/C = \text{Span/Chord Length}$$

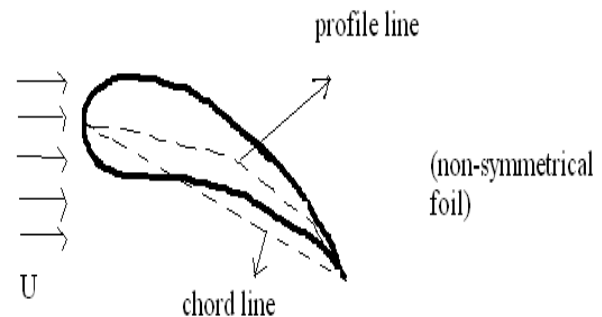


Figure 26 : Non-Symmetrical Airfoil

The figure shows the layout of a non-symmetrical airfoil which is exposed to a fluid of velocity U flowing across it.

Now, let,

$$T = \pi C U \sin \alpha$$

$$C = \text{chord}$$

$$U = \text{velocity of fluid on airfoil}$$

$$\alpha = \text{angle of attack}$$

Then, According to Kutta - Joukowski's Eqn. →

$$F_l = \rho U L T$$

$$= \rho U L \cdot \pi C U \cdot \sin \alpha$$

$$= \pi \rho C U^2 \cdot L \cdot \sin \alpha$$

$$F_l = C_l \cdot (A \rho U^2) / 2$$

Where,

C_l = coefficient of lift

$A = C \cdot L$, projected area

$$F_l = C_l \cdot (C \cdot L \cdot \rho \cdot U^2) / 2$$

$$\pi \rho C U^2 \cdot L \cdot \sin \alpha = C_l \cdot (C \cdot L \cdot \rho \cdot U^2) / 2$$

$$\pi \sin \alpha = C_l / 2$$

$$C_l = \pi \sin \alpha / 2$$

Similarly,

$$F_d = C_d \cdot (A \rho U^2) / 2$$

And,

$$C_d = \pi \cos \alpha / 2$$

Now,

For Coefficient of Lift- $\alpha = 12^\circ$

Area of cross-section- $A = 611.876 \text{ cm square (lower surface)}$

$= 616.926 \text{ cm square (upper surface)}$

Considering the lower surface area for the calculations :-

Coefficient of lift -

$$C_l = 1.30634$$

Force of lift -

$$F_l = 1.5711 \text{ N}$$

Coefficient of drag -

$$C_d = 6.14588$$

Force of drag -

$$F_d = 7.39184 \text{ N}$$

The minimum weight of the airfoil which can work normally against the force of lift been calculated is -

$$W_l = 1.5711 / 9.81 \text{ kg}$$

$$= 0.160152 \text{ kg}$$

$$W_l = 160.152 \text{ gms}$$

Since the weight of the airfoil being used by us is 420 gms i.e 0.42 kg, thus the maximum force it can sustain is given as -

$$F_l = 0.42 * 9.81 \text{ N}$$

$$F_l = 4.1202 \text{ N}$$

The maximum velocity it can sustain is determined as :-

$$V_l = 9.2304 \text{ m/s or } 10 \text{ m/s}$$

For Fan-

Since a fan of 6 H.P power gives out a velocity of 20m/s using air as medium. Thus the P.F used is calculated using the formula →

$$P.F = P / (A_p V_t^3 / 2)$$

$$P = 1.21 \text{ (for air)}$$

$$V_t = 20 \text{ m/s}$$

Hence,

$$P.F = 0.014 \text{ (power factor rating)}$$

$$P = 0.5 \text{ H.P. (power in horse power)}$$

Using the same power velocity relation as before given by the formula →

$$P.F = P / (A_p V_t^3 / 2)$$

Thus V_t is calculated as -

$$V_t = 8.68 \text{ m/s (theoretical)}$$

$$V_t = 5.7 \text{ m/s (experimental)}$$

$$\eta = [V_t (\text{experimental}) / V_t (\text{theoretical})] * 100$$

$$= 65.6\%$$

b) Power Loss Calculations

Equations for calculation →

$$P/A = \pi d / (\pi d^2 / 4)$$

Where,

P = perimeter of the cross-section.

A = area of cross-section.

For circular sections -

$$P/A = 4/d$$

For square sections-

$$P/A = 4/\text{side}$$

For Test Section-

Horizontal pipe → constant area of cross-section.

For a fully developed pipe flow → Bernoulli's eqn.

$$P_1 / \rho g + V_1^2 / 2g + Z_1 = P_2 / \rho g + V_2^2 / 2g + Z_2 + h_f$$

$$Z_1 = Z_2$$

$$V_1 = V_2$$

$$P_1 / \rho g = P_2 / \rho g + h_f$$

$$P_1 - P_2 / \rho g = h_f$$

$$\Delta P / \rho g = h_f$$

(1)

Frictional resistance → F_1

$$F_1 = f' \pi d L * V^2$$

$$= f' P L * V^2$$

Where, P = perimeter

Pressure force at entry → $P_1 A_1$

Pressure force at exit → $P_2 A_2$

Let,

$$A_1 = A_2 = A$$

$$P_1 A_1 - P_2 A_2 = F$$

$$F_1 = f' P L * V^2$$

$$P_1 - P_2 = f' P L * V^2 / A$$

(2)

$$P_1 - P_2 = \rho g h_f$$

$$\rho g h_f = f' P L * V^2 / A$$

$$h_f = (f' / \rho g) * P * L * V^2$$

Frictional head loss-

$$h_f = (f' / \rho g) * 4/d * L * V^2$$

$$= (f' / \rho g) * 4 L V^2 / d$$

$$f' / \rho g = f / 2 \quad (f \text{ is the coefficient of friction})$$

$$h_f = (4f/2g) * L V^2 / d \rightarrow \text{Darcy Weishbach Equation}$$

$$4f = f' = \text{friction factor}$$

Therefore, $\Delta P = f' * L / d * V^2 / 2 * \rho$

$$d = D_h = \text{hydraulic diameter}$$

Coefficient of Friction,

$$C_f = f(\text{Re, roughness})$$

$$= f(\text{Re}) \text{ for smooth wall}$$

$\text{Re} \rightarrow \text{Reynolds's number,}$

$$\text{Re} = \rho * V * d / \mu \quad (d = D_h)$$

$$1/f' = 2 \log (Re / f') - 0.8$$

From the equation (3), Re can be determined.

$$\text{For } f' = 0.013 \quad Re = 500,000$$

$$\text{For } f' = 0.010 \quad Re = 25,00,000$$

$$\text{For } f' = 0.007 \quad Re = 30 \times 10^6$$

And so on.

Keeping the $L/D = 1.5$

i.e. for $L = 50\text{cm}$

$$D = 30\text{cm}$$

The loss coefficient \rightarrow

$$K_o = \Delta P / q_t$$

Where,

$q_t \rightarrow$ (mass flow rate) discharge through test-section.

$$q_t = \frac{1}{2} \rho V_t^2$$

$$K_o = (f' \cdot L / d \cdot V^2 / 2 \cdot \rho) / (\frac{1}{2} \rho V_t^2)$$

$$= f' \cdot L / d \cdot (V/V_t)^2 / 2$$

For the test-section, $V = V_t$

Therefore the loss coefficient for this section can will be

$$K_o = f' \cdot L / D_h$$

$$= f' \cdot L / d$$

The value of K_o should be $< 0.15 \rightarrow$

Thus, taking $f' = 0.06$

$$K_o = 0.06 \cdot 0.5 / 0.3$$

$$K_o = 0.10$$

Frictional head in test section-

$$h_f = f' \cdot \rho \cdot L V_t^2 / 2d$$

For $f' = 0.06$

$$L = 0.5\text{m}$$

$$V_t = 5.7 \text{ m/s}$$

$$D = 0.3\text{m}$$

$$\rho = 1.21 \text{ kg/m}^3$$

$$h_f = 1.965645 \text{ m}$$

Pressure difference

$$\Delta p = h_f \cdot \rho \cdot g$$

$$\Delta p = 23.332 \text{ N/m}^2$$

Efficiency of the duct

$$\eta = \Delta p / [(1/2 \cdot \rho \cdot V_t) \{1 - (A_1/A_2)^2\}]$$

$$= 13.5021\%$$

For Diffuser

For no losses in diffuser \rightarrow

$$d(V^2/2) + dp/\rho = 0$$

But it is not possible, therefore \rightarrow

Let $\eta_d \rightarrow$ Diffuser Efficiency, then \rightarrow

$$\eta_d d(V^2/2) + dp/\rho = 0$$

$$\eta_d = (P_1 - P_2) / [1/2 \cdot \rho \cdot (V_1^2 - V_2^2)]$$

(3) From continuity equation,

$$A_1 V_1 = A_2 V_2$$

$$\eta_d = (P_1 - P_2) / [1/2 \cdot \rho \cdot V_1^2 \{1 - (A_1/A_2)^2\}]$$

Where,

$$\Delta P = 23.332 \text{ N/m}^2$$

$$V_1 = 4.04 \text{ m/s}$$

$$A_1 = 30 \times 30 = 900 \text{ cm square}$$

$$A_2 = \pi d^2 / 4$$

$$d_2 = 38 \text{ cm}$$

$$A_2 = 1134.11494 \text{ cm square}$$

Therefore, the efficiency of the diffuser is \rightarrow

$$\eta_d = 6.381\%$$

$$= 6.4 \% \text{ (approx.)}$$

Therefore, loss of total head \rightarrow

$$\Delta H = 1/2 \cdot \rho \cdot V_1^2 - 1/2 \cdot \rho \cdot V_2^2 - (P_1 - P_2)$$

And,

$$K_o = \Delta H / q_o$$

$$K_o = (1 - \eta_d) [1 - (A_1/A_2)^2]$$

where, A_1 = test section area

Therefore, coefficient of loss \rightarrow

$$K_o = 0.3465$$

IX. RESULTS

The following are the results obtained out of the testing of the wind tunnel we have constructed:-

- Lift and drag coefficients calculated for the test section with velocity 5.7m/s has been calculated as-

$$C_l = 1.30634$$

$$C_d = 6.14588$$

- For a better view of what the air is actually doing, we have implemented a smoke system to see how the air moves around objects. As of now, we have 5 plausible methods of obtaining smoke. Strings, incense sticks, mineral oil, smoke-in-a-can, and dry ice. After doing numerous tests with each method, so far the dry ice seems to be the most successful. With the smoke, you can see the air flow over and around airfoils very well. We built a small airfoil section complete with remote controlled surfaces that demonstrate what is happening on an aircraft when air moves over a wing and the control surfaces.
- We can simulate flaps, spoilers and ailerons with the one wing section. One thing the smoke shows really well is a stalled wing section. As the air comes over the wing, it gets stuck on top the wing and creates turbulent air. This drastically reduces lift and can be very dangerous when flying a plane. The phenomenon seen is similar to the picture above, where the air begins to swirl over the airfoil.

- The graph is plotted for the velocity profile as horizontal distance Vs velocity.
- The graph is plotted for the velocity profile as vertical distance Vs velocity.

Also with the smoke, we can put various model cars in the tunnel and see how aerodynamic they are and how they react to doors being open or how drafting can improve efficiency, etc.

The velocity curves can be drawn for various speeds and distance at different sections

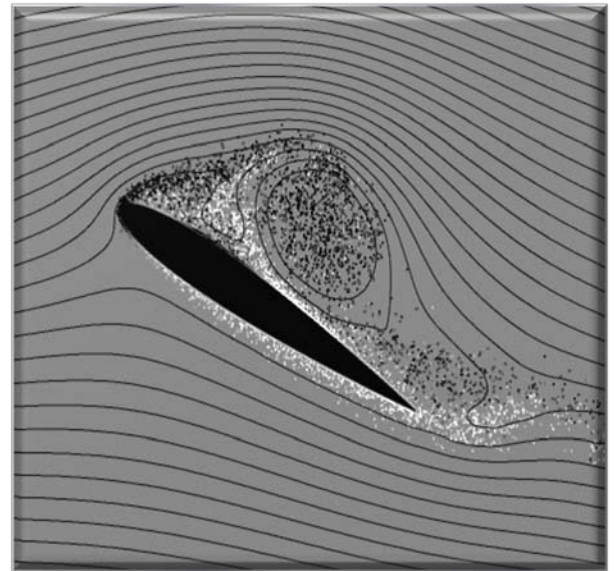
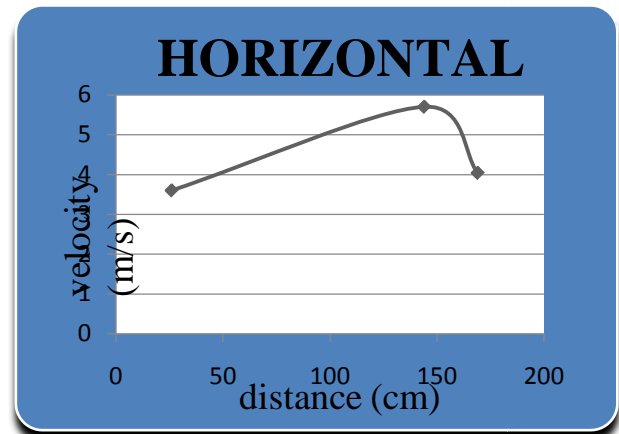


Figure 27 : Velocity Profile on the Airfoil

X. CONCLUSIONS

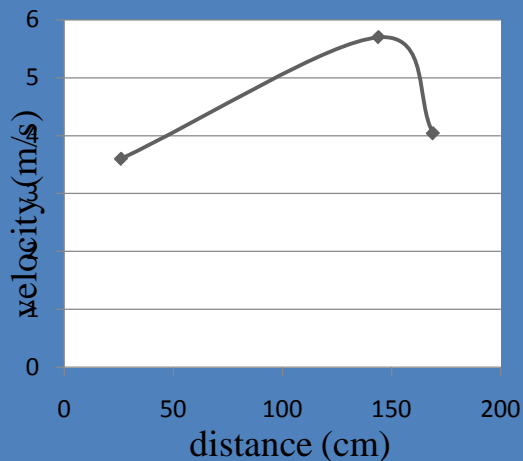
The following conclusions are derived from the results obtained after the model testing of our project. The designing and fabrication of the tunnel is done for a sub-sonic velocity of the fluid inside the tunnel of about 10 ft length.

- The velocity profile is depicted by the above displayed graphs. The profile shows that the fluid i.e. smoke flowing inside the tunnel has high turbulence.
- Lift and drag coefficients for the test section with velocity 5.7m/s has been calculated for the airfoil of the weight 0.42 kg.
- To show the effect of the velocity on the airfoil we need a velocity more than 10 m/s. Thus after achieving variant velocities by attaching a drive to the exhaust and obtaining a velocity above 10m/s we can show the effect of the variation in velocity on the airfoil inclination through this model.
- This model is suitable for an airfoil of weight less than 0.15 kg. And the study can be done using

HORIZONTAL

Distance (cm)	26	144	169
velocity (m/s)	3.6	5.7	4.04

HORIZONTAL



VERTICAL

Distance (cm)	66	35	45
velocity (m/s)	3.6	5.7	4.04

different airfoils with variant weights, materials and designs.

- By looking at the way this smaller model acts in the wind tunnel, we get an idea of how a real life-sized airplane of the same design will probably fly.
- Aerodynamics of any high speed car or airplane can be studied using this model.
- Velocity profile can be studied for the design of cars and air planes using this model.
- The testing of the airfoil, propeller blades and turbine blades can be done through this apparatus.

XI. APPLICATIONS

The following are the application of the project model fabricated -

1. Scientists and engineers use wind tunnels to study the pressures, forces, and air flow direction affecting an airplane.
2. Pressure is measured by small devices called pressure taps that are placed at various locations on the surface of the model.
3. Forces are recorded by sensors in the structures that support the model in the test section.
4. The direction that air flows around the model can be seen by the way tufts, small yarn-like strands attached to the model, flap around.
5. Smoke is blown into the test section to make it easier to see how the air is flowing. From these different kinds of measurements, a great deal can be learned about the model being tested.
6. Wind tunnels vary in size according to their function. Some of the smallest wind tunnels have test sections that are only a few inches large and therefore can only be used with tiny models.
7. The largest wind tunnel in the world is at the National Full-Scale Aerodynamics Complex at NASA Ames Research Center, in the United States. Its 80 foot by 120 foot test section can fit a life-sized Boeing 737 inside.
8. Wind tunnels aren't just used to test airplanes. Anything that has air blowing around or past it can be tested in a wind tunnel.
9. Some engineers have put models of spacecraft, cars, trucks, trains, even road signs, buildings, or entire cities in wind tunnels to see how to improve their designs.

Hence it is worth working on this project as it helps to explore new areas of study and learning through practical knowledge and understand the application of the various theoretical concepts, laws and equations.

XII. FUTURE ASPECTS

The following can be future amendments for different results to be obtained :-

- The drive with a variac can be attached to the fan or exhaust to vary the speeds and to get desired output inside the tunnel test-section.

- The fan with pointed and sleek twin and three blades can be preferred for higher speeds which should be placed on the leading end of the tunnel.
- High H.P motor exhaust can be applied to the tunnel for higher outputs in velocity.
- The modifications can be made in the design of airfoil i.e. the airfoil with different configurations can be tested for respective velocities and the profile.
- The material and the weight of the airfoil can also be varied for the observation of different lift and drag forces.
- The scaled models of the cars or other vehicles can be tested using this wind tunnel along with the airfoils.
- For studying the profile fluid different gases can be used such as dry NH_3 gas can also be used instead of incense sticks.
- Honeycomb can be placed just before the test section. Although it does not make much difference in reducing the turbulence, yet cheaper and less time consuming.
- Thus with these beneficial and profound aspects, this model leads to the effective learning and practical applications of the concepts studied by us.



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