Design and fabrication of an Airflow tunnel for testing and analysis of NACA 23012 aerofoil

Ashwini N. Huddar[1]
Graduate Student,
Dept. of Mechanical Engineering
MMM's College of Engineering

Jayashri M. Gornale[2]
Graduate Student,
Dept. of Mechanical Engineering
MMM's College of Engineering

Ankita B. Alandikar[3]
Graduate Student,
Dept. of Mechanical Engineering
MMM's College of Engineering

Tejashree L. Deokar[4]
Graduate Student,
Dept. of Mechanical Engineering
MMM's College of Engineering

Prof. Shrikant N. Belsare[5]
Assistant Professor,
Dept. of Mechanical Engineering
MMM's College of Engineering

Abstract

In this paper we are discussing about the low speed airflow tunnel. In which a low speed airflow tunnel was design and fabricated. The project covered the process of design and fabrication of the small airflow tunnel. In completing this project, a computer aided drawing (CAD) tool called CATIA V5 is used to design the airflow tunnel and aerofoil. The airflow tunnel is used in aerodynamic research to study the effects of air moving past to the solid objects. An airflow tunnel consists of a tubular passage with the object under test mounted in the test section. With the help of efficient fan system or by a blower we can make the air move past the artifact.

In the testing we use the anemometer, manometer and solid artifact (NACA 23012 aerofoil). Experiments are conducted to find the lift and drag coefficient of NACA 23012 at different angle. An impression of fluid field flow around aerofoil is using smoke.

Keywords: Low speed airflow tunnel, NACA 23012 aerofoil, lift force, lift coefficient, drag force, drag coefficient.

Introduction

There are several types of airflow tunnel for different applications as no single tunnel fits for all purposes. Airflow tunnels can be classified based on wind speed in test section or based on the design. Open-typed airflow tunnel and close-typed airflow tunnel are airflow tunnels based on design while airflow tunnels are also based on speed that are low speed, high speed, subsonic, transonic, supersonic and hypersonic type of tunnels.

Low speed airflow tunnel testing has evolved over the last century and the objects have become a prominent in the development of aero field. An airflow tunnel testing is used to support many major development processes one of them is aerodynamics. An airflow tunnel is used in aerodynamic research to study the effects of air moving past solid objects. An airflow tunnel consists of a tubular passage with the object mounted in test section of the tunnel. We have designed an open low speed airflow tunnel in which air is drawn from the surrounding and is expelled to the same by means of powerful fan system. The test object is mounted in the test section and the air is allowed to pass over it and measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics.

Objective

- Airflow tunnel is a testing setup used to study the behavior of the fluid (air is the fluid which we have used).
- To calculate the drag and lift coefficient of the artifact to be tested, the tests are conducted in the test section of the airflow tunnel.
- To get an impression of fluid flow around a scale miniature of the real artifact.

Principle of airflow tunnel

Aerodynamics

Aerodynamics is the way fluid moves around the things. The rules of aerodynamics explain how an object (like airplane, rocket, helicopter etc.) is able to fly and in case of the automobile, how the speed varies depending on the behavior of the air passing the auto. Anything that moves through fluid reacts to aerodynamics.

What are the four forces?

The four forces are weight, lift, thrust and drag. These forces make an object move down or up, and faster or slower.

- . **Weight**

Every object has its own weight. This force comes from gravity, pulling down towards the earth's surface.

- **Lift**

Lift is the force that is used to raise the object to a higher level. It is the force that is the opposite of weight. Lift is mostly associated with the fixed wing of the aircrafts.

- **Drag**

Drag is a force that tries to resist the motion of the object. It slows down the object speed.

- **Thrust**

The force opposite of drag is thrust. Thrust is used to move any object in forward direction.

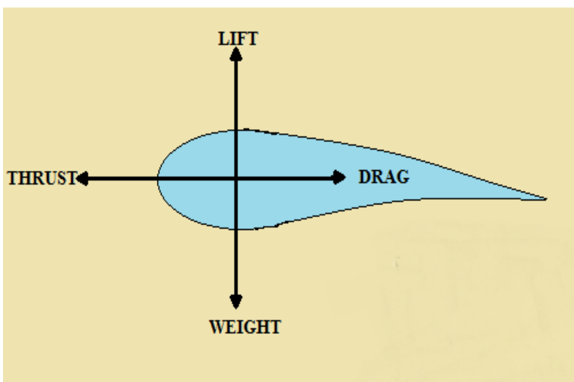


Fig 1: Aerodynamic Forces Acting on Aerofoil

Boundary layer

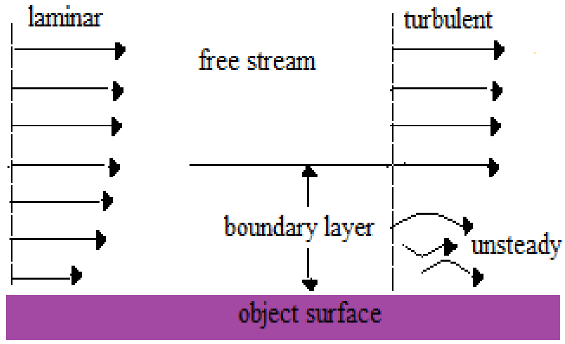


Fig 2: No slip condition (surface velocity zero)

Boundary layer is the region of fluid situated right to immersed artifact or wall within the flow velocities are governed by viscous forces. Boundary layer initiates as very thin region of laminar flow that gradually thickens with increasing Reynolds number and then towards turbulent layer flow through transition layer flow. Flow external of the boundary layer is independent of Reynolds number criteria.

Design parameters of airflow tunnel

- **Reynolds number and Mach number**

The ratio of inertial forces to viscous forces is defined as Reynolds number .The important parameter in the sizing of a low- speed airflow tunnel will be the achievable Reynolds number for the object that can be accommodated. Considering sea level standard atmospheric conditions, the maximum velocity for the designed tunnel will be 10 m/s, and the Reynolds number will be 10^5.

- **Airflow tunnel component energy losses**

The case of airflow tunnel flow is considered to be the case of flow through pipes. Since, at the boundaries there are number of losses that take place due to friction. Iteration is required to determine the friction factor. For smooth pipes friction factor is minimum but not equivalent to zero because of no slip condition and it increments with roughness, hence the Colebrook Equation reduces to Prandtl Equation and represented as,

$\mathbf{f = (2 \log_{10} Re \sqrt{f} - 0.8)^{-2}}$ **(**This equation is valid for turbulent flows where $4000 < Re < 10^8$**)**

Head of loss (h_L) = k $\frac{v2}{2g}$

Where,

k: coefficient of resistance (0.0192 at 34˚C)

v: velocity of the air (10m/s)

g: acceleration due to gravity (9.81m/s)

Design of the components of an airflow tunnel

- **Inlet Settling Chamber**

  The purpose of the inlet settling chamber is to align and uniform the air flow before it enters the contraction chamber. This is achieved by using paper wood honeycomb which assist to reduce transverse air fluctuation and knock down the large scale turbulent eddies. The dimension of the settling chamber is 228.75*228.75*457.5(mm).

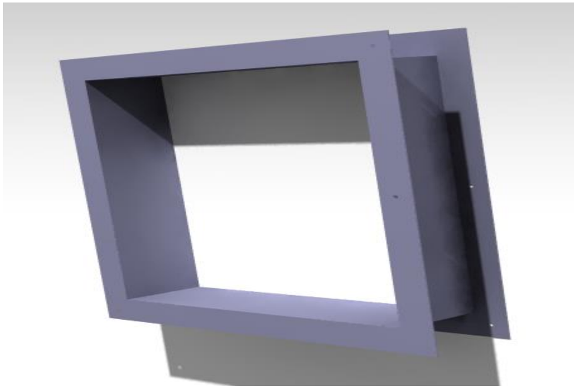


Fig 3: Inlet settling chamber

- **Honeycomb**

The honeycomb is generally the first component with which the fluid confronts in an open circuit, suck through tunnel. Its purpose is to remove twist from the incoming air and reduces large scale turbulent eddies. Honeycombs are known as the flow straightener, which makes the fluid flow laminar. The hexagonal honeycombs give the best result, the empty spaces are less and the frictional and pressure loss is less compared to rectangular and cylindrical structure, which reduces the pressure loss and gives best output. The loss coefficient for hexagonal honey comb Bradshaw and Mehta suggested that honeycombs with shorter axial lengths are better.

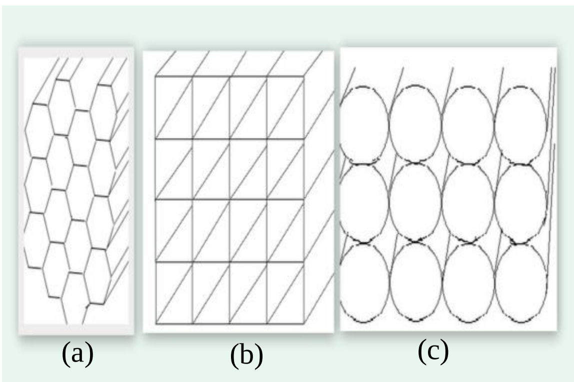


Fig 4: Different honeycomb structures

Fig 5: Hexagonal honeycomb

(a) Hexagonal structure
(b) Quadra structure
(c) Circular structure

- **Contraction Section**

The purpose of the contraction section is to smoothly accelerate the air departing the inlet settling chamber and direct it into the test section. The test section depends on the contraction section as in the process; turbulence intensity is further reduced, as the overall mean velocity rises. The contraction section is designed in the way that the turbulence and the twists in the fluid further reduce in the test section. The ratio of inlet cross-section to outlet cross section (must be in the range of 4:1~9:1) is 5:1.

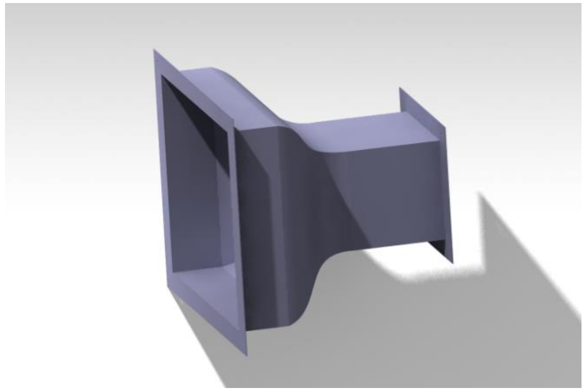


Fig 6: Contraction section

- **Test Section**

The test section is the lowest turbulence section of the airflow tunnel where all the tests are conducted. The test section drives the size of the airflow tunnel based on the type of testing desired. The test section is designed so that the component mounted is visible from each side. The window of the test section is designed in the manner the loss of air velocity is minimum. It is the main component of airflow tunnel, as the design of tunnel is based on the test section.

Fig 7: Test section

- **Diffuser**

The objective of the diffuser is to let the air exiting the test section to expand and decelerate, thus reducing the dynamic pressure (kinetic energy) and increasing the static pressure. This result in the reduction of the current drawn by the fan motor which increases the efficiency i.e. higher speed can be achieved with same motor size. The air exists the tunnel should not create any vibrations and expel smoothly, the criteria on which diffuser depends upon are equivalent angle and ratio of area. The equivalent angle for efficient divergence is 5˚~ 6 ˚, which is given by,

$$\alpha_e = \tan^{-1}\left(\frac{R1-R2}{L}\right)$$

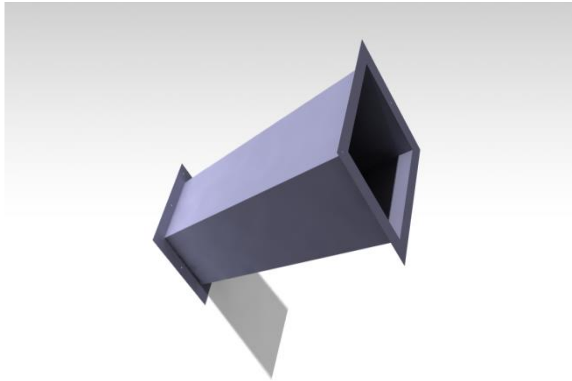


Fig 8: Diffuser

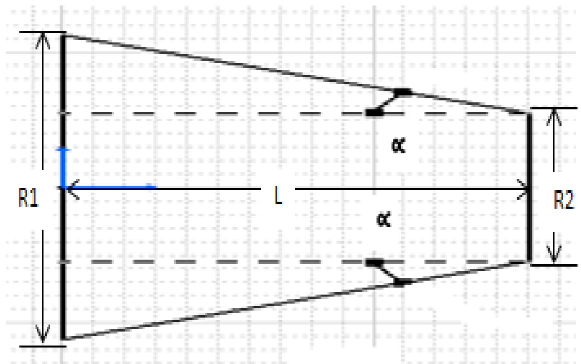


Fig 9: Geometric parameters of diffuser

- **Fan and motor description**

The fan is located at the mouth of inlet settling chamber attached to motor. The motor delivers 0.5HP of power, being a single phase induction type rated for 2880 rpm , which is mounted behind the fan. The fan is of axial type of which diameter is 12” and the hub diameter is 2”. The fan has four blades with an angle of attack of 60˚. With this angle of attack and an empty test section the fan efficiency is close to its maximum value of 65%.

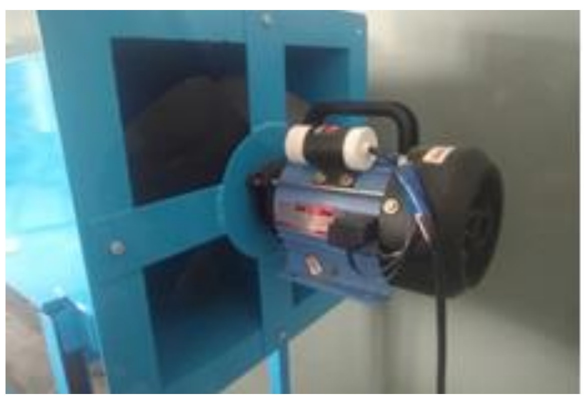


Fig 10: Fan and motor

Manometer

Pressure is defined as a force per unit, to measure unknown pressure U-tube manometer is on the devices. The u-tube is filled with suitable liquid with the equal column height. Both the port of the manometer is used to measure the pressure if one port is open to the atmosphere and other connected to the point where pressure is to be measured then the manometer act as gauge pressure device, and if both the ports connected to the pressure points then it act as differential pressure device.

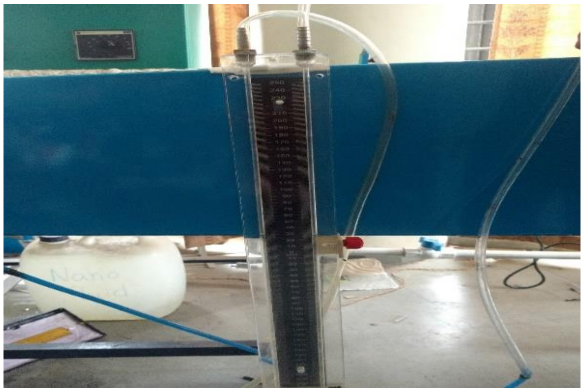


Fig 11: U-tube manometer

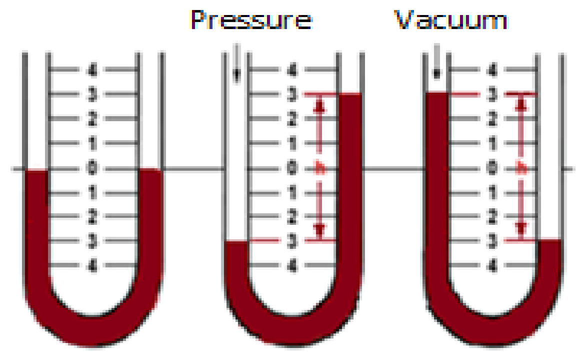


Fig 12: Manometric head

Manufacturing process

- **Manufacturing flow chart**

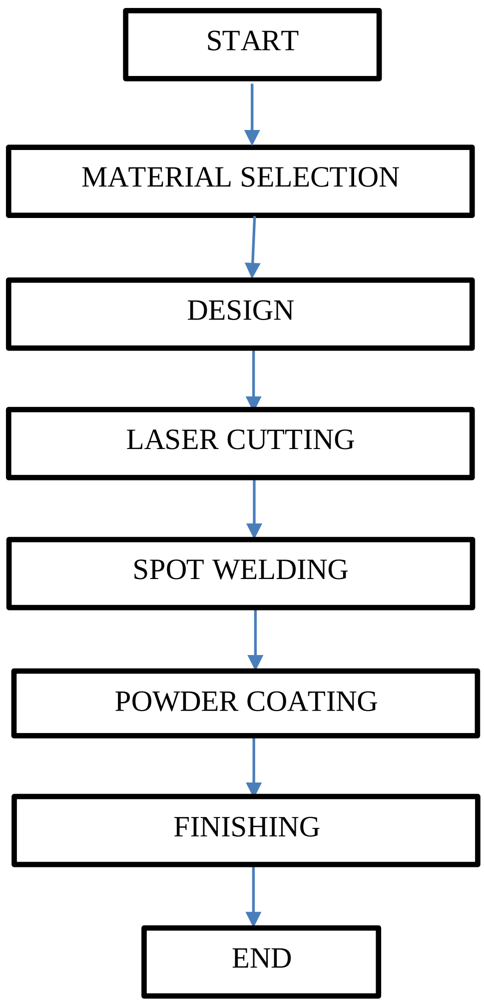


Fig 13: Airflow tunnel during manufacturing

- **Description**

The material selection was based on the number of factors; damping factor which should be high and creates less vibration, good strength, good welding property and within the budget. Mild steel is selected on the basis of the requirement. The manufacturing process involved was laser cutting, spot welding and powder coating.

- **Design and manufacturing of NACA 23012 aerofoil:**

NACA (National Advisory Committee for Aeronautics) have introduced many aerofoil series based on the requirement of the application. For the analysis of the aerofoil shape for this project we have selected NACA 5^{th} digit series i.e. NACA 23012. The parameters of the aerofoil are described by the numerical digits followed by the word NACA. The aerofoil was successfully modeled in industrial software CATIA V5 where the coordinates were plotted individually. The aerofoil was manufactured using sheet metal according to the size, and the holes were engraved at the certain distances from where the results need to obtain.

Testing of an aerofoil in airflow tunnel

- **Procedure**

- Assemble the equipment in proper way.
- Mount the aerofoil in the test section properly.
- Motor drives required single phase, air speed can be smoothly controlled by varying the speed controlling knob.
- After preliminary preparation, switch on the 1 phase supply. For starting motor switch on the button.
- By varying the angle of attack the lift coefficient and drag coefficient can be calculated.
- While experimenting in the tunnel precaution should be taken that not keep any light thing that is unclamped in the tunnel.
- When the experiment on the model is not going on, lock of window (test section) perfectly.

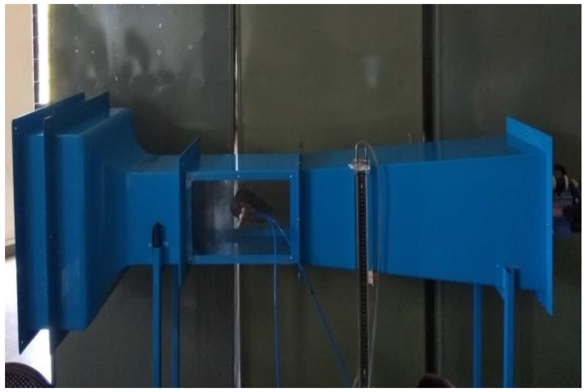


Fig 14: Testing in the airflow tunnel

- **Calculation**

- Pressure in Pa Pressure p= ρgh

  Where,

  - ρ=density of water (1000 kg/m^3) ,
  - g= acceleration due to gravity (9.81m/s^2)
  - h= manometeric height
- Theoretical Lift Force (F_L) = L x b x p x COSβ
- Coefficient of lift (C_L) = F_L /0.5 x A x ρ x u^2
- Theoretical Drag Force (F_D) = L x b x p x COSβ
- Coefficient of drag (C_D) = F_D /0.5 x A x ρ x u^2

  Where,

  - L= span length of the aerofoil (0.11m),
  - b= width of the aerofoil (0.15 m),
  - A=Projected area of aerofoil body (0.0165 m^2),
  - ρ=Density of air at 34^0C (1.16 kg/m^3),
  - u = Velocity of air (10 m/s),
  - β = angle of attack

Flow visualization in the airflow tunnel

Flow visualization is an experimental means of examining the flow patterns around the aerofoil, over its surface. The flow pattern is visualized by introducing smoke or dye. The flow around the aerofoil gives the conception to solve the aerodynamics problem. The flow can be visualized with the naked eyes or by the films recording the flow pattern.

Fig 15: Testing in the airflow tunnel

Results

Angle of attack	Lift force	Lift coefficient
-10	-0.3188	-0.333
-5	-0.1612	-0.1678
0	0.161	0.168
5	0.161	0.168
10	0.3188	0.333
15	0.4855	0.497
20	0.6084	0.635
25	0.733	0.766
30	0.84107	0.8788
35	0.663	0.6927

Table No.1: Results of lift coefficient

Angle of attack	Drag force	Drag coefficient
-10	0.1611	0.166
-5	0.160	0.164
0	-0.161	-0.168
5	0.332	0.333
10	0.159	0.166
15	0.156	0.163
20	0.07605	0.0794
25	0.733	0.0766
30	0.140	0.146
35	0.1325	0.138

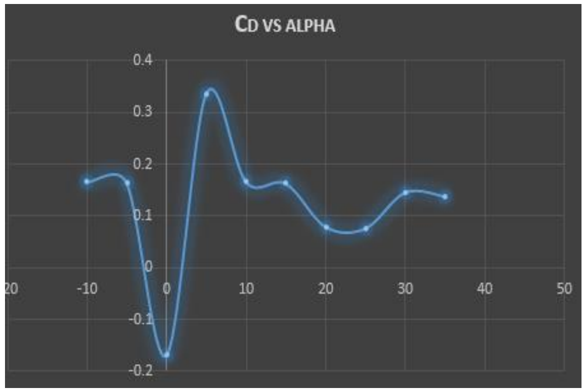
Table No.2: Results of lift coefficient

Coefficient of lift(C_L)	Coefficient of drag(C_D)	C_L/C_D
-0.333	0.166	-1.987
-0.1678	0.164	-1.0243
0.168	-0.168	-1
0.168	0.333	0.5286
0.333	0.166	2.006
0.497	0.163	3.051
0.635	0.0794	7.9974
0.766	0.0766	10.005
0.8788	0.146	6.01
0.6927	0.138	5.0195

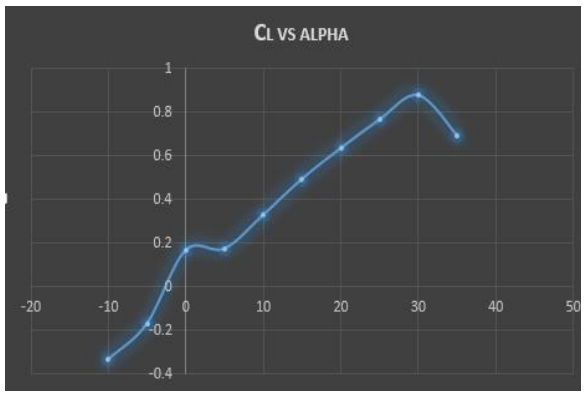
Table No.3: Results of Lift Coefficient to the Drag Coefficient

Graphical results

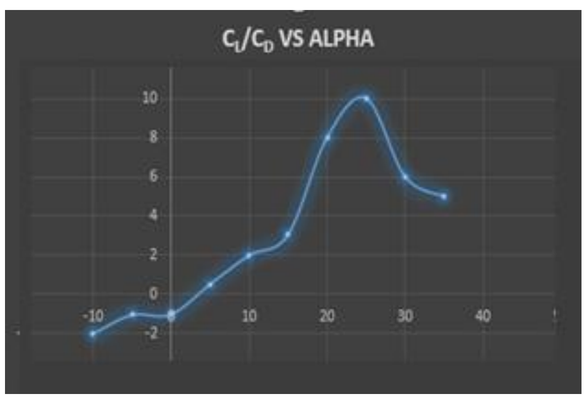
Experimental Graphs:



Experimental Graph of C_DVS Alpha



Experimental Graph of C_L VS Alpha



Experimental Graph of C_L/C_DVS Alpha

Advantages, disadvantages & applications

- **Advantages**
- Reliable and uniform airflow.
- Low turbulence.
- Capable of precise measurements.
- Reproducible conditions and results.

- **Disadvantages**
- Airflow tunnels are generally expensive and time consuming.
- If the object to be tested is oversized to fit in the tunnel itself, a very accurate scaled miniature must be produced, and Reynolds number must be accurately matched to the expected operating conditions. These miniatures can be prohibitively costly as well.

- **Applications**
- Drag and lift force measurement of aerodynamic bodies.
- Flow visualization (with smoke, dye, talcum etc.).
- Surface pressure distribution.
- Static stability of aircraft and missiles.
- Dynamic stability of aircraft.

Construction cost

Material	Quantity	Cost(in ₹)
Fan and motor	1	2500
Material cost (Mild steel with 1.6 mm thickness)	55 Kg	5000
Manufacturing cost	-	3500
Honeycomb structure	-	150
Acrylic sheet	2	750
Wheels	4	800
Powder coating	-	3500
Wheels	-	650
Connectors	10	300
Other cost	-	2500

Table No.4: Construction cost

Conclusion

- An airflow tunnel is a testing or analysis setup for solid objects, use to calculate the drag and lift coefficient of the designed object
- Fan speed, control airflow is vital parameter in airflow tunnel design.
- Reynolds number, Mach number and other parameters can be calculated.
- By changing the velocity and angle of attack, the behavior of the aerodynamics bodies can be studied.
- To get an impression of fluid flow around a scale miniature of a real object.

References

- Andrew R. Coggan, Ph.D. "The Coggan Low Speed Wind Tunnel: Design, Dimensions, and Operating Characteristics" Coggan LSWT-November 2011.
- Advanced Topics in Aerodynamics- Airflow Tunnel and Experimental Aerodynamics.
- Bradshaw, P and Pankhurst, R. C (1964). The Design of Low Speed Wind Tunnels. Progress in Aeronautical Science, v5
- Fluid dynamics - Equation of continuity and Bernoulli's principle. Lecture 4 Dr. Julia Bryant.
- G. Dimitriadis Wind Tunnel Tests on Road Vehicles Experimental Aerodynamic Fluid dynamics - Equation of continuity and Bernoulli's principle. Lecture 4 Dr Julia Bryant.
- **http://navier.stanford.edu/bradshaw/tunnel/index.html** this is Bradshaw and Mehta's (or Mehta and Bradshaw's) website, which contains much sufficient advice and discussion.
- **http://www.grc.nasa.gov/WWW/K-12/airplane/bgt.html**
- Ishan.M.Shah, S. A. Thakkar, K. H. Thakkar, Bhavesh A. Patel " Performance Analysis on Airfoil Model in Wind Tunnel Testing
- Jean-Luc Aider • Jean-Franc¸ois Beaudoin • Jose´ Eduardo Wesfreid "Drag and lift reduction of a 3D bluff-body using active vortex Generators" Published online: 16 October 2009! Springer-Verlag 2009 Exp Fluids (2010) 48:771–789 DOI 10.1007/s00348-009-0770-y
- J.B.Barlow ,W.H.Rae,A.Pope,Low Speed Wind Tunnel Testing,Third Ed,John wiley,New York,1999,P360,374
- Josue Njock Libii "Wind Tunnels in Engineering Education" Indiana University-Purdue University Fort Wayne USA
- Kalpesh Vaghela "Optimization of Roof fairing angle to reduce the Aerodynamic Drag of Heavy Duty Truck" (IJETCAS) ISSN (Print): 2279-0047 ISSN (Online): 2279-0055
- Machine (WTTM) "(IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013, pp.2094-2103
- Mansi Singh, Neha Singh & Sunil Kumar Yadav "Review of Design and Construction of an Open Circuit Low Speed Wind Tunnel" Volume 13 Issue 5 Version 1.0 Year 2013Online ISSN: 2249-4596 Print ISSN: 0975-5861 Publisher: Global Journals Inc. (USA).
- Md. Arifuzzaman, Mohammad Mashud "Design Construction and Performance Test of a Low Cost Subsonic Wind Tunnel" (IOSRJEN) e-ISSN: 2250-3021, p-ISSN: 2278-8719, www.iosrjen.org Volume 2, Issue 10 (October 2012), PP 83-92
- Nguyen Quoc Y "Designing, Constructing, And Testing A Low – Speed Open – Jet Wind Tunnel "www.ijera.com ISSN: 2248-9622, Vol. 4, Issue 1(Version 2), January 2014, pp.243-246
- P. Bradshaw and R. Pankhurst, "The Design of Low-speed Wind Tunnels," Progress in Aerospace Sciences 5, pp. 1-69, 1964.
- Ranjan Basak, Debojyoti Mitra, Asis Mazumdar "Design of Various Components of an Open Circuit Blower Tunnel without Exit Diffuser " International Journal of Advances in Science and Technology, Vol. 2, No.6, 2011
- Reference book-Khurmi gupta for duct design and fan selection.
- Reference book- unique publication, by Senjal Cimbala for aerofoil design.
- V.B Bhandari, Design of Machine Elements.