Design and Analysis of Wind Tunnel Testing Rig

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Abstract

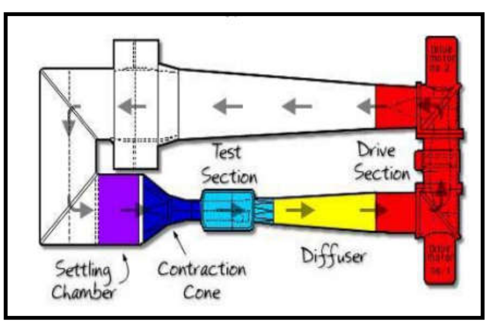
A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. Even though it predicts accurate results and flow parameter it comes with the disadvantage of high cost, large space utilization, noise problem. Hence the productivity and use of wind tunnel are limited. The existing wind tunnel model is much complicated to compute and to obtain necessary results. Also, this wind tunnel is not portable and generally manufactured for the large industrial testing purpose. Power required to test a small aerodynamic model is large in such wind tunnel. Hence, to test any small-scale graduate level project become unaffordable due to the cost of testing.

This project describes the design and analysis of the open circuit, small size, economical wind tunnel used for testing of the Aerodynamic model. This project uses computational fluid dynamics to determine the theoretical values for wind tunnel which will be statistically compared to actual values of fluid flow. An overall analysis and simulation of flow will also be performed. Aerodynamics of any high-speed car or airplane can be studied by using a scale model of an actual model by this apparatus.

Keywords: Mechanical engineering, Aerodynamics, Design, Wind tunnel, Fluid dynamics, Analysis, Simulation, scale model, Testing.

1. Introduction

Wind tunnels are one of the important tool for aerodynamics studies wind tunnel are used to similitude the actual flow condition of a prototype on a scale model by facilitating the actual flow conditions of a prototype on a scale mode one can study the aerodynamic property experienced by the prototype on the scale model with reasonable accuracy. It is a device in which air of uniform property are produced past the model. Basically, it a tubular passage for air or any other gases which are forced to produce a flow of uniform properties in the test section. The model which has to undergo for aerodynamic studies are mounted in the test section with suitable instrumentation for measuring the forces, pressure distribution and other aerodynamic characteristics.



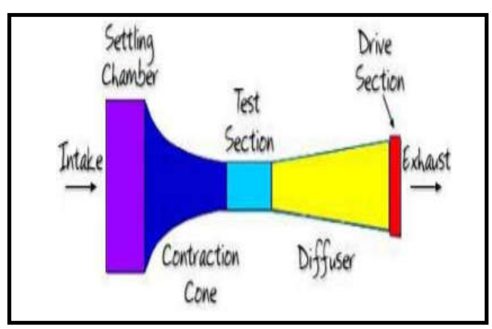


Figure 1. Closed circuit wind tunnel **Figure 2. open circuit wind tunnel**

2. Objectives

The following objectives of the project are as

a. To design the wind tunnel using various parameters.
b. To Study the velocity profile using the air/smoke on air foil.
c. Calculate lift, drag and moment coefficient for different velocities.
d. To obtain the considerable results of scale aerodynamic model for graduate project study purpose.
e. To minimize the required power for wind tunnel.
f. To study actual Dynamic behaviour of aerodynamic model in wind tunnel test.

3. Literature Review

P.Karava,T. Stathopoulous and A.K. Athienitis, [2016] [1] this paper reviews considerable variation with discharge coefficient with opening porosity configuration, wind angle and Reynolds number. Comparison of various study indicates significance differences in wind driven cross ventilation.

Mansi Singh, et al, [2013] [5] have concluded that models suitable for an aero foil should have weight less than 0.15 kg in a small sized subsonic wind tunnel. And velocity profiles can be studied for design of car and aero plane using this model. Due to their ability to combine both types of data i.e. quantitative data and visualization, tunnel is a critical instrument in the quick and thorough design process of anything that involves fluid dynamics.

Robert Howell, Ning Qin, et al, [2010] [9] have carried out research of small model on VAWT turbine was been manufactured and tested over a range of operating condition. Computational prediction of the performance coefficient of this turbine where carried out and a 3D simulation was shown to be in reasonable good agreement with the experimental measurement, considering errors and uncertainties in both CFD simulation and the wind tunnel measurement.

Keisuke NISUGI, et al, [2004] [13] have developed a flow analysis system, Namely the Hybrid wind tunnel, which integrates the experimental measurement with a wind tunnel and the corresponding numerical simulation with a computer. A specific feature of the hybrid wind tunnel is existence of the feedback signal to compensate the error in the pressure on the side wall of the cylinder and the feed forward signal to adjust the upstream velocity boundary condition.

4. Problem Definition

After carrying out several searches we found the following problem associated to existing wind tunnel are as follow

a. The primary problem associated with wind tunnel is high cost.
b. The Existing Wind tunnel are not portable and consume large space.
c. This Model consumes high power to test even small sized aerodynamic model.
d. Also, this wind tunnel is generally manufactured for industrial testing purpose this led to lack of study about wind tunnel testing.
e. Wind tunnel wall influence the flow boundary layer and some sort of clogging.
f. Maintenance time is high.

All the above mention will be overcome by designing this wind tunnel to test aerodynamic model based on various design parameter while considering the cost parameter as criteria which is to be minimized but also maintaining the efficiency of wind tunnel.

5. Methodology

5.1. Designing of Wind Tunnel

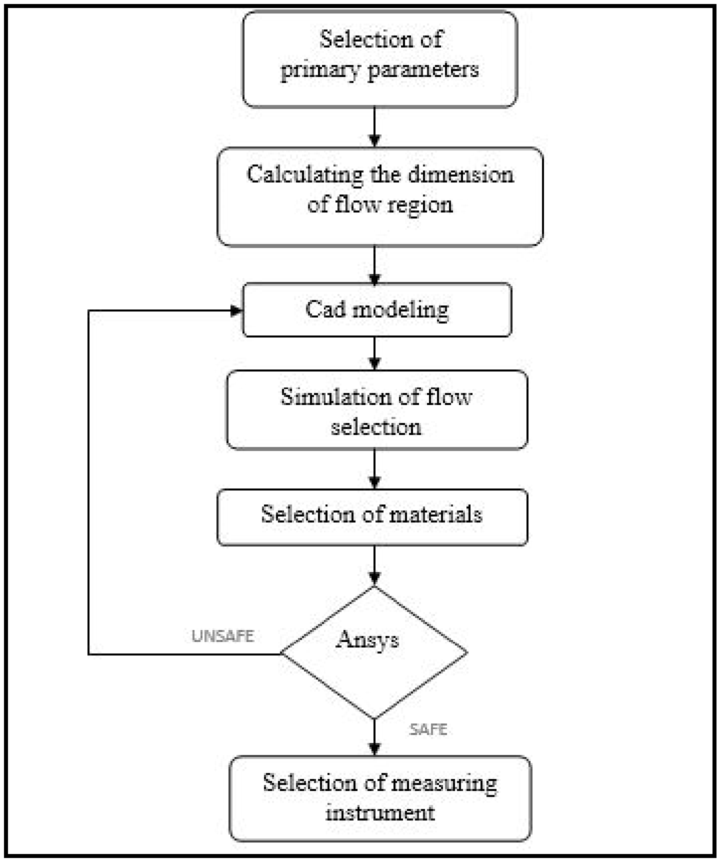


Figure 3. Design Procedure for Wind Tunnel Test Rig

5.1.1. Selection of Primary Parameters

1. Test Section

According to the initial assumption the test section was considered to be cylindrical cross-section, the airspeed to be 20 m/s and air mass flow rate around 5000 – 5200 CMH the value of the diameter of the cylinder for test section was calculated as below.

Since, Mass flow rate (Q) = Cross section area (A) x velocity (V)

(5100/3600) = A x 20

A = 0.0703 m2

A = π/4x d2

Diameter (d) = 0.299 m

Assuming, Diameter of cylindrical cross section to be 30 cm

2. Axial Fan

According to the above calculation and assumption of the airspeed & mass flow rate, the axial fan was selected to best suit the configuration. As the axial fan was to rotate on variable RPM so the 3-

phase motor was choosing over which a variable frequency drive was connected to vary the RPM of the motor.

Table 1. Axial fan Specification

Motor supply	3- Phase
Motor Power	1000 watt
Numbers of Blades	6 (six)
Air flow	6000 CMH
speed	1440 rpm
Impeller Diameter	20 nch

5.1.2. Calculating the Dimension of Flow Region

1. **Contraction Cone**

The contraction cone ration 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

Contraction ratio = (90*90) / (30*30) = 9
90*90 cm2 (for outer end)
30*30 cm2 (for inner end)
Length will be according to the similar ratio of L/D = 0.77
Length = 90*0.77
Length of Contraction cone was calculated to be 70 cm.
The Head loss was calculated as below
Hl = K x (V/2g) K: Resistance of Coefficient
Hl: Head loss V: Average velocity
K = (1.2 + 160/Re) ((d1/d2)4 - 1) x (sin (theta/2))
K = 160 x (sin (theta/2))
K = 100
Hl = 100 x (12/2 x 9.81)
(Head loss) Hl = 61.16 (approx.)

2. **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 11^0. Thus we have considered
Angle of diffusion as φ/2 = 5.7o
Thus the outer diameter of the diffuser will be calculated as
Do = Di + (2 x (Ld x tan φ/2))
Do = 300 + (2 x (1000 x tan5.71))
Outer Diameter of Diffuser (Do) was calculated to be 50 cm.

5.1.3. CAD Modelling

As far as the Designing is concern which is the most important step in every project journey after complicated calculation and try and error. We finally design the CAD model as shown below one by one according to the calculation and considering manufacturing aspect by using the CAD software known as "Solid works 2016."

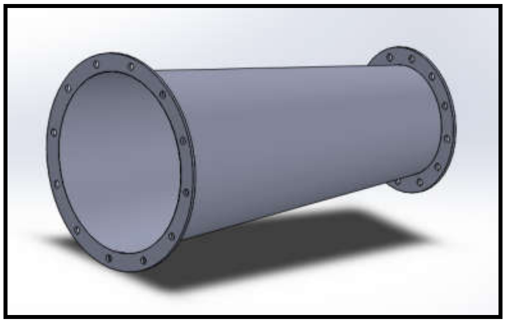


Figure 4. Diffuser

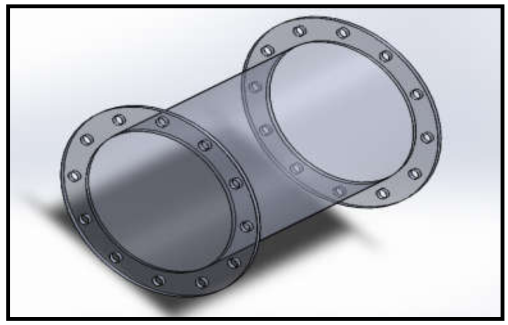


Figure 5. Test Section

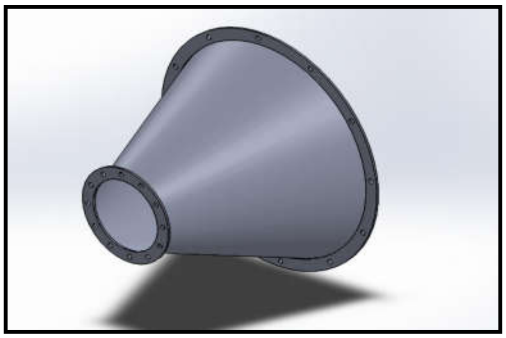


Figure 6. Contraction cone

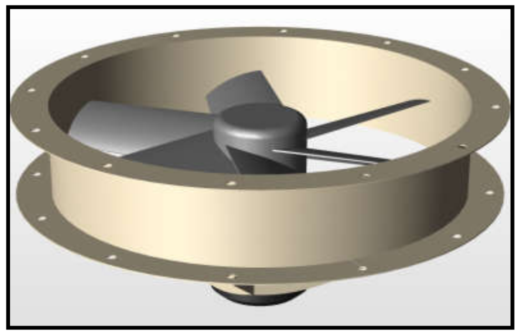


Figure 7. Axial Fan

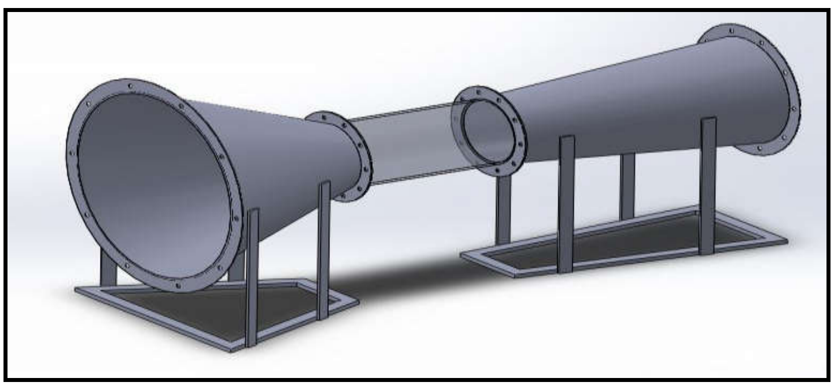
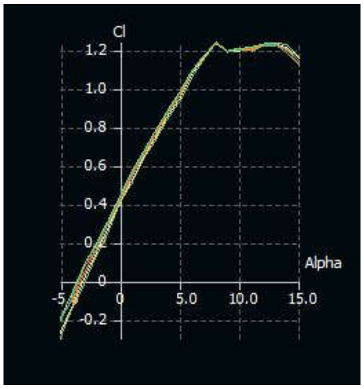
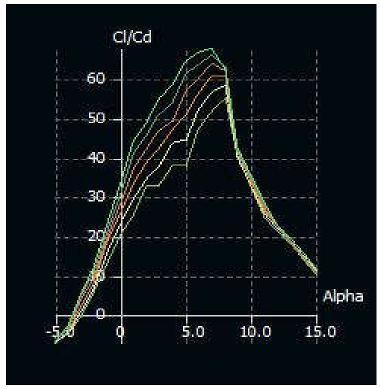


Figure 8. Wind Tunnel Assembly

5.1.4. Analysis of Specimen

For actual experimentation many aero foils were selected like NACA 4412, following results would be verified by experimentation the following graphs were plotted by using the software name known as "XFLR 5".





5.1.5. Selection of Measuring Instrument

1. **Load Cell**

A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured. This load cell can be used to calculated values of lift force, drag force and moment.

Table 2. Load cell configuration

Number of Load cell	6 (Six)
Load cell Type	cantilevered type
Material	Aluminum
Maximum load	3000 g

2. **Analog to digital Circuit for load cell**

As the load cell is the only load sensor which can sense the weight induced over it accordingly. To calibrate and digitalize the load cell to show the varying load inducing over it a circuit as to build which can convert analog reading to digital values by mean of HX711 module as shown below in figures.

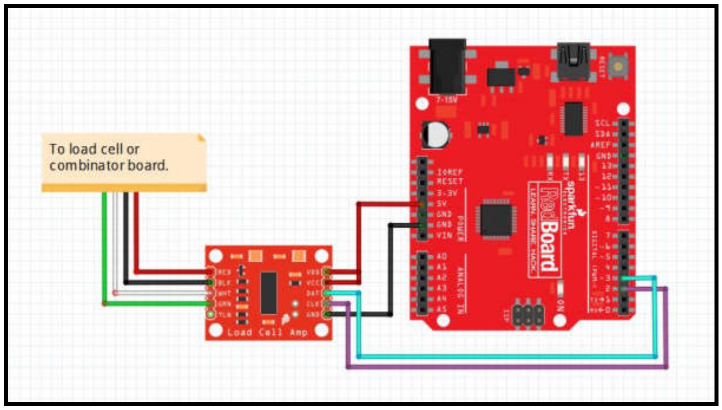


Figure 9. Load cell analog to digital converter circuit

6. Results and Discussion

The following result were obtained by using analysis software for different condition as shown below.

6.1. Analysis for Pressure Region

we can observe minimum pressure drop is at 'Test section' which is 100499.03Pa (Pascal). We can also observe that minimum pressure is almost equal to atmospheric pressure.

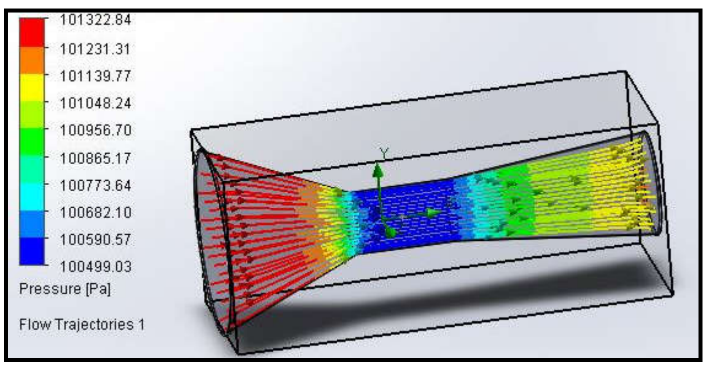


Figure 10. Analysis of pressure

6.2. Analysis for Velocity Region

we can observe maximum velocity was observed at test section which is around 22 m/s as shown in figure

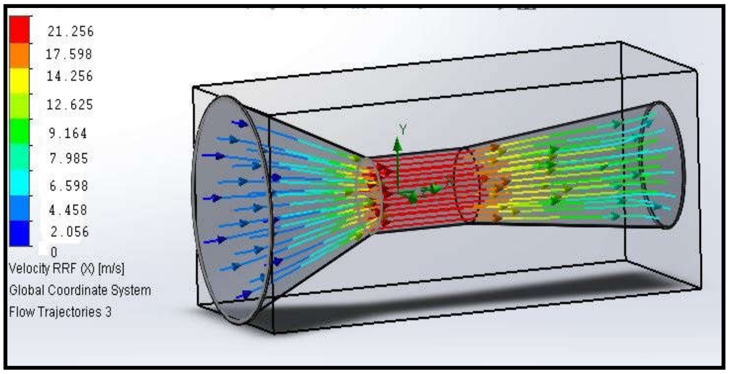


Figure 11. Analysis of velocity

6.3. Analysis for Thick Cylinder

For calculating the thickness of the cylinder and cone the following analysis was performed to confirm with theoretical value, following graph was plotted.

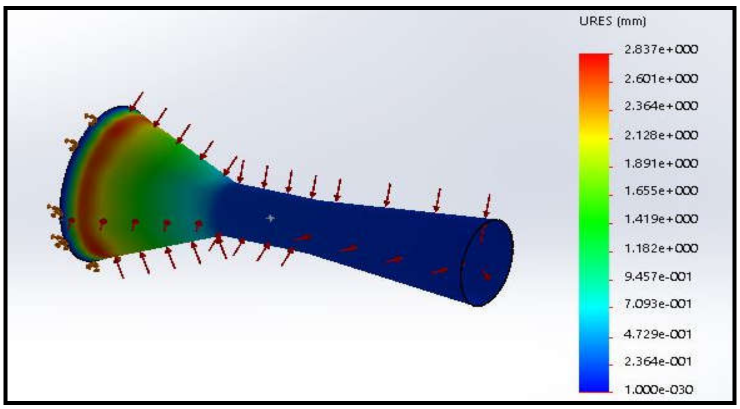


Figure 10. Analysis of thickness

7. Conclusion

The following conclusions would be derived from the above results after model testing for our project. The designing and fabrication of the wind tunnel is done for subsonic velocity of fluid inside the tunnel.

a. The velocity profile will be depicted by the graphs which will be plotted. The profile will show that the fluid i.e. smoke flowing inside the tunnel has high turbulence.
b. Lift and drag coefficients for the test section can be calculated for the aero foil.
c. This model is suitable for an aero foil of weight less than 0.15 kg. And the study can be done using different aero foils with variant weights, materials and designs.
d. By looking at the way the 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.
e. Aerodynamics of any high speed car or airplane can be studied using this model.
f. Velocity profile can be studied for the design of cars and air planes using this model.
g. The testing of the aero foil, propeller blades and turbine blades can be done through this apparatus.
h. Load cell apparatus was successfully coded and executed according to the requirement of the Wind tunnel testing rig for measurement of Lift, Drag and Weight.

i. 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.

8. Future Scope

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

a. 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.
b. High H.P motor exhaust can be applied to the tunnel for higher outputs in velocity.
c. The material and the weight of the aero foil can also be varied for the observation of different lift and drag forces.
d. For studying the profile fluid different gases can be used such as dry NH3 gas can also be used instead of incense sticks.
e. 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.
f. 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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