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Design And Fabrication Of Low Cost Open Circuit Subsonic Wind Tunnel

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Abstract— **A subsonic wind tunnel is a device used to create a fast stream of air through a test area in which an object is kept. This paper will focus primarily on the fabrication process of small scale subsonic wind tunnel, flow visualization analysis on an object and calculation of lift and drag coefficient of an object through experiment. In the present world of obtaining excellence with the most extreme cost sparing and almost all the aircrafts are composed utilizing CAD programming. These plans however should be checked and tried continuously which gives imperatives results in the full scale. The momentum research not just incorporates confirmation of withdrawal cone outline by looking at the speed of air at various segments got amid CFD investigation with the trial values at comparing forces. This design explains the whole method to plan an open circuit subsonic wind tunnel which will be utilized to concentrate on the wind impact on the diverse models of basic components. The plans were made and broke down, bringing about different examinations of various geometries, and giving the required information of course from the outlines. The profile includes a contraction cone area of side 750mm, square test area of side 500 mm, to suit the model and required instrumentation in it, for power and weight estimation. The test section has a dimension of 340mm x 360mm x 500mm which is companionable to the outlet and inlet of the nozzle and diffuser respectively with the mean velocity of 15 m/s. A straight portion before the test chamber is given to allow the yield of withdrawal zone to offset before it accomplishes the test section.**

Keywords— **Open Circuit Subsonic Wind Tunnel; Velocity Profile; Test Section; Fluid Flow; Aerodynamics; Tunnel Performance component; formatting; style; styling; insert (key words);**

I. INTRODUCTION

The wind tunnel is an instrument to study the flow around a body and the strength created by the liquid structure collaboration. A wind tunnel experiment gives the force and pressure values on the model furthermore, the stream visualization. It is a basic instrument in the quick and careful outline procedure of anything that includes fluid dynamics [1].

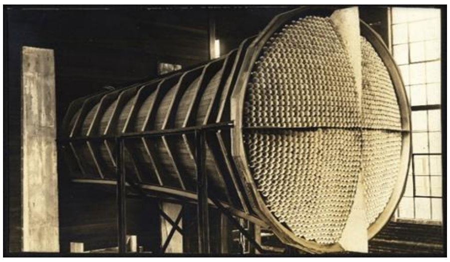

Fig 1. Old NASA Subsonic Wind Tunnel [Source:https://www.nasa.gov/multimedia/imagegallery/image_feature_1282.html]

Taking into account the tunnel circuit, the wind tunnel is of two types, open circuit and closed circuit. In open circuit, surrounding air enters from one side and exits to the air subsequent to streaming through the passage. In closed circuit wind tunnel (Refer figure 2), a consistent the principle objective of wind tunnel plan is to have uniform stream inside the test chamber. The design plan procedure begins by characterizing the test chamber dimensions and shape, after that the rest part of the wind tunnel is planned by keeping in view the measurements of the test chamber. Principle parts of an open circuit subsonic wind tunnel (Refer figure 1) are the test section, contraction cone, diffuser, settling chamber and driving unit (Heavy Duty Exhaust Fan). This paper manages the outline and design of an open circuit subsonic wind tunnel to have least development cost and the running expense.

The concept of wind tunnel was firstly introduced about four hundred years ago when Leonardo Da Vinci came to know that the air flow about the object was same as the Object moving through the air. The 1st Wind tunnel was constructed in Great Britain in year 1871 by Francis Wenham. After Great Britain many other countries like Russia, Austria and United States of America started building wind tunnels [2].

Based on speed range the most appropriate classification of wind tunnels is by the speed range they cover. The classification of wind tunnels based on the speed range includes: Low speed wind tunnel, the flow velocity in low subsonic wind tunnel is of the Mach number range of zero till 0.3. Viscous and inertial forces are dominant while compressibility effects are negligible [3].

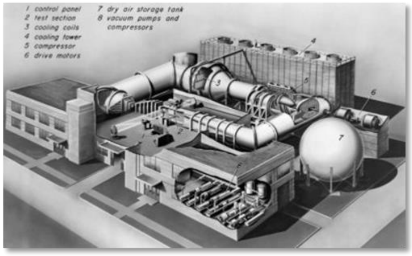

Fig 2. NASA's 1948 design for a supersonic closed circuit wind tunnel [Source: Explain That Stuff. 2017. Wind Tunnels. [ONLINE] Available at: http://www.explainthatstuff.com/windtunnel.html.]

High speed wind tunnel, the designation high speed usually includes high subsonic, transonic and low supersonic regimes, so that the range of the flow velocity for high speed wind tunnel is of Mach number between 0.3 and 1.4. Here, in principle, compressibility effects are of dominant importance. However, viscous effects also play an important part in particular when shock boundary layer intersection leads to flow separation. Subsonic (Refer figure 3), wherein the flow in the test section is limited to speeds below Mach 0.8. They can be further classified as low subsonic/low speed wind tunnel for flows below Mach 0.3, and high subsonic, for flows up to Mach 0.8. Transonic, in these tunnels, test section flow is in the transonic regime, i.e., between Mach 0.8 and Mach 1.2. Transonic flows are generally very complex to analyse, and as a result, it is difficult to design transonic wind tunnels, and there are not as many transonic wind tunnels as subsonic or supersonic wind tunnels. Supersonic wind tunnel, the flow velocity in supersonic wind tunnel is the range of Mach number of 1.4 till 5.0. Compressibility effects are dominant. The pressure disturbance raises in the flow field propagating downstream.

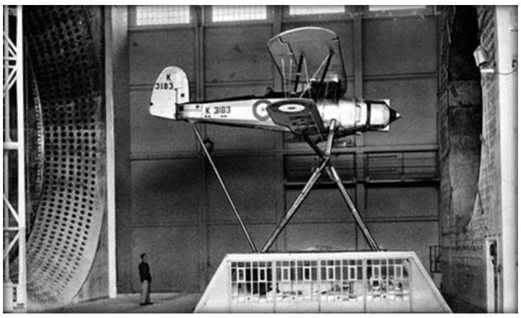

Fig 3. Farnborough wind tunnel [Source: fnewsmagazine. 2017. The Sound of Flight and Fight. [ONLINE] Available at: http://fnewsmagazine.com/2014/07/the-sound-of-flight-and-fight/.]

Engineers at NASA's Langley Research Center in Virginia are trying the model to see how the rocket may perform amid profound space missions. This test is especially centered around seeing how the load rendition of the substantial lift Block 1B SLS rocket, equipped for lifting 105 metric tons, will act at velocities just underneath supersonic [4].

NASA and many other's uses wind tunnels to test spacecraft and rockets. The Spacecraft's are been made to work in outer space, they do not have atmosphere and these rockets have to travel through the atmosphere to space. Wind tunnels are very use full in making new technology Ares rockets and Orion Spacecraft's. Ares and Orion are new vehicles that will take astronauts into space. NASA engineers tested ideas for the design of Ares in wind tunnels. Wind tunnel tests have helped NASA change the space shuttle to make it safer. Wind tunnels will keep helping make all spacecraft and rockets better. Spacecraft designs and parachutes are tested in wind tunnels set up to be like the Martian atmosphere [5]. Toward the finish of 1901, the Wright brothers (Refer figure 4) were disappointed by the flight trial of their 1900 and 1901 lightweight planes. The air ship were flown as often as possible up to 300 feet in a solitary coast. However, neither one of the aircrafts executed and additionally anticipated utilizing the outline techniques accessible to the brothers. So the wright brothers chosen to assemble a wind passage to create a more controlled condition. They would look at the outcomes they found in the wind passage to the execution they had measured amid their kite and lightweight plane flights [6].

The main purpose of the wind tunnels is obtaining information from which the aeronautical designers can develop a new type of airplane, because of the complexity of the modern era high performance airplanes, many varieties of data is required before making a perfect design. In most instances it is impossible or at least very uneconomical to obtain accurate design information from airplanes in flight, thus making it highly desirable to be able to obtain data by other methods than flight testing. For this reason, wind tunnels have been developed. With the development on the one hand of airplanes of very large size, and on the other of airplanes with extremely high speeds, it has become necessary to build wind tunnels of greater and greater complexity in order to enable the testing of models under conditions which correspond closely to those met by the full-size airplane.

Future scope of work in the wind tunnels are Analysis on complete wind tunnel including all sections could be carried out, Complete propulsion system design can be carried out, Model tolerances for the tunnel can also be calculated and different geometries analyzed in order to get the required result. Vanes for turning sections also can be designed, with the flow straightener system. Instrumentation system can be designed in order to get the measurements and readings from the wind tunnels. Install pressure taps at the inlet and exit of each duct and find the pressure loss coefficients experimentally [7].

Fig 4. Wright Brothers 1901 Wind Tunnel [Source: Wright Brothers Aero plane Co. 2017. THE 1901 WRIGHT WIND TUNNEL. [ONLINE] Available at: http://www.wright-brothers.org/Adventure_Wing/Hangar/1901_Wind_Tunnel/1901_Wind_Tunnel.htm]

II. LITERATURE REVIEW

Md. Arifuzzaman and Mohammad Mashud in their paper on Design Construction and Performance Test of a Low Cost Subsonic Wind Tunnel focuses their primary investigation to decrease the cost of development and to erect it in a research facility room [8]. The cross-sectional design area of the wind tunnel is of square sort with measurement 0.90 m × 0.90 m and the span/length of the section was 1.35 m. The general length of the passage is around 7.35 m which can be raised in a research center room. In the wake of testing the execution of the passage it was found that the most extreme twist speed inside the wind tunnel test segment is around 28 m/s and the speed profile along the height and width of the test segment is practically straight in nature. Hence the barring is roughly 12% and recompenses on four side dividers where boundary layer if formed.

A streamlined/aerodynamic research to break down the conduct of streams under fluctuating conditions, both inside channels and over strong surfaces was done by [9] H Ifeanyichukwu U. Onyenanu, Ijeoma H. Ezeonuegbu and Ifunanya M. Mobi and is described in their paper on Design and Fabrication of a Subsonic Wind Tunnel testing Machine. The machine was intended to create wind stream of different speeds through its test segment. The stream of air in the wind passage/tunnel is thought to be relentless and incompressible, along these lines administered by the progression condition and condition for the preservation of vitality. In a project by [10] Nelton Koo Chwee Yang, he covered the process of design and fabrication of the small wind tunnel. He opted for a computer aided drawing called Solid Work to design the wind tunnel. The drag force on a sphere in an air stream was measured at various free stream velocities below 100 m/s. This was done in a low speed wind tunnel using an integral balance system to measure the drag force and a Pitot tube and to measure the velocity. Method of analysis the flow in test section was shown by using strings and the experimental results are compared to published results over the range tested.

A Paper on the Designing, Constructing, and Testing a Low – Speed Open – Jet Wind Tunnel by [11] Nguyen Quoc Y describes on the design and fabrication of a low-speed wind burrow/tunnel. The wind passage designed in this wind tunnel is an open-stream sort with the spout zone of 1m x 1m and the greatest wind twist speed of 14 m/s. To assess nature of the wind stream made by the passage, speed dispersion and turbulence power of wind stream were measured at the spout by a warm couple anemometer. The estimations demonstrated that the turbulence power was under two percent while the consistency of wind twist speed over the spout is more than ninety-five percent.

While doing a change on the drive arrangement of the passage, [12] Todd David Walker, B.S.M.E in his paper Re-design of a Drive System for a Low – Speed Wind Tunnel describes that the normal test area speed would increase and produce of a 2 ft. distance across fan and in addition a few changes to the passage. The outcomes were a 21% expansion in the effectiveness of the drive framework and a 19 mph increment in the test segment speed. However, the plan technique by [13] J. H. Ringer and R. D. Mehta on their paper on Contraction Design for Small Low-Speed Wind Tunnel has been created for a few dimensional withdrawals introduced on little, low-speed wind burrows/tunnels. The strategy comprises of initially figuring the potential stream field and henceforth the weight dispersions along the dividers of a withdrawal of given size and shape utilizing a three-dimensional numerical board technique. The weight or speed conveyances are then nourished into two-dimensional limit layer codes to foresee the conduct of the limit layers along the dividers. This theory was affirmed by looking at the anticipated limit layer information at the withdrawal exit with measured information in existing wind burrows. The deliberate limit layer force thicknesses at the exit of four existing withdrawals, two of which were 3-D, were found to exist in 10% of the anticipated qualities, with the anticipated values for the most part lower. From the compression divider shapes examined, the one in view of a fifth-arrange polynomial was chosen for establishment on a recently outlined blending layer wind burrow/tunnel. An open circuit wind tunnel was designed and manufactured for the usage of magnetic suspension system by [14] Milan Vlajnac in his paper Design Construction and Evaluation of a Subsonic Wind Tunnel. The papers main aim was to make a low cost, high efficient with different application methods for reducing the turbulence in test section. The test section turbulence was less than 0.26% for the Reynolds number below 1.9 x 106 per foot and velocity was 300 feet per second with motor speed of 3000rpm.

III. DESIGN METHODOLOGY, PART DESIGN AND MATERIAL SELECTION

Phase 1 involved the making of initial layout of the subsonic wind tunnel model, drawing and construction of Test Section, Diffuser, and Contraction Cone. It also includes the construction of fence, Aluminum Honeycomb Core, Cutting and Joining of Plexi-glass Sheet and Plywood Board. Phase 2 involved drilling holes and Electrical Wiring for attaching the Heavy Duty Exhaust Fan with dimmer, attaching the lights, attaching model airfoil, Small fan with DC Motor, Voltmeter and the Sensors like Dual Range Force Sensors DFS-DTA and many more.

Materials Used are, Dual Range force Sensor with Lab Quest 2, the Dual-Range Force Sensor is a general-purpose device for measuring pushing and pulling forces. It can be used as a replacement for a hand-held spring scale or mounted on a ring stand. Voltmeter, a voltmeter, also known as a voltage meter, is an instrument used for measuring the potential difference, or voltage, between two points in an electrical or electronic circuit. Some voltmeters are intended for use in direct current (DC) circuits; others are designed for alternating current (AC) circuits. Specialized voltmeters can measure radio frequency (RF) voltage. Plexi-glass, Poly (methyl methacrylate), also known as acrylic, is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass. The same material can be utilized as a casting resin, in inks and coatings, and has many other uses. Paper Honeycomb Core, Honeycomb structures are natural or man-made structures that have the geometry of a honeycomb to allow the minimization of the amount of used material to reach minimal weight and minimal material cost. Plywood Boards, Plywood is a sheet material manufactured from thin layers of wood veneer that are glued together with adjacent layers having their wood grain rotated up to 90 degrees to one another with 48 x 96 inches.

Heavy Duty Exhaust Fan, An exhaust hood, extractor hood, or range hood is a device containing a mechanical fan that hangs above the stove or cooktop in the kitchen. It removes airborne grease, combustion products, fumes, smoke, odors, heat, and steam from the air by evacuation of the air and filtration with maximum flow rate is 60000 cubic meters per hour at 1400 rpm. Small DC Motor with Small Plastic Fan, a DC motor is any of a class of electrical machines that converts direct current electrical power into mechanical power. The most common types rely on the forces produced by magnetic fields. Dimmer, a device for varying the Speed and brightness of an electric light or fan. Electrical wiring material, rubber gasket striping, small L-brackets with two screw holes, drawer handles, springs

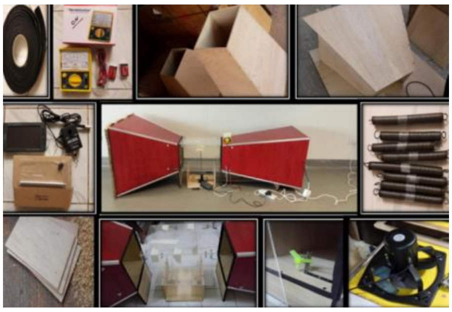

Fig 5. Collection of Wind Tunnel Construction Picture

A. Design of Test Section

The wind tunnel design starts with deciding the test section keeping an eye on the accessibility and installation of the test model and instrumentation. The test chamber length has to be in the range of 0.5-3 times its hydraulic diameter. The test chamber is being designed to test the scaled model of a silo with length 250 mm and minimum L/D ratio one. In order to have a blockage ratio less than 10% a square test chamber of 500 mm side. The test will be carried out at a flow speed of 15 m/s. The pressure loss coefficient goes on increasing with increase in the test section. So the length of test section should be as small as possible [8].

B. Design of Settling Chamber

The aim of a settling chamber containing honeycombs and screens is to reduce the flow turbulence, more uniform and make the flow become straight before it enters the cone. Its important components are honeycomb and screens.

A selection of honeycomb and screens for a wind tunnel is very much dependent on the test type to which the tunnel is intended. The settling chamber cross-sectional area matches the dimensions of contraction cone inlet i.e. 80 cm x 77 cm with a length equal to 70 cm is used [15].

C. Design of Contraction Cone

Contraction cone is the most important section in the wind tunnel because airflow's in the test section. As the flow area reduces, the flow speeds up through the contraction. Three main parameters of a contraction are contraction ratio, wall shape, and contraction length. They are computed carefully so that there is no flow separation inside the contraction. Thickness of the boundary layer at the outlet is minimized. For smaller tunnels the contraction ratio should be in between 6 to 9. The pressure drop coefficient values go on decreasing with increase in CR, so the maximum allowable contraction ratio 9 is chosen. To avoid flow separation, a contraction of length of 900 mm is used, which is 20% longer than the maximum recommended value. For easier and cheaper construction, a straight contraction shape is used instead of solving complex equations to get the wall shape [16].

D. Design of Diffuser

The diffuser connects the inlet section and the settling chamber. It is required that there is no flow separation inside this section. The area ratio between the inlet section and the outlet (of the settling chamber) of the diffuser is 2. It is suggested that the maximum diffuser angle suitable for that ratio to prevent flow separations is 200.

IV. FABRICATION OF SUBSONIC WIND TUNNEL COMPONENTS

The subsonic open circuit wind passage is made of a few different segments, the settling chamber, the contraction cone, the test section area, the diffuser and the heavy duty exhaust fan. A few contemplations' must be made keeping in mind the end goal to accomplish a wind passage with the needed properties.

E. Test Section

The test section was designed especially for the finding of lift and drag in the wind tunnel; which is the test model for the tunnel; it has a dimension of 340mm x 360mm x 500mm which is compatible to the outlet and inlet of the nozzle and diffuser respectively. It is made up of Acrylic sheet (Plexi-glass) is used in its construction to provide viewing of the model. A square cross section was chosen to optimize the available space inside the balance while at the same time providing plane surface on the walls to eliminate optical distortion of the model. The Acrylic sheet used was 6mm thickness. It has flanges attached to both ends where it is connected to both the contraction cone and diffuser.

Fig 6. Test Section

F. Contraction Section (Cone)

The contraction cone is made up of the ply wood. It has a square cross section of 10:1 contraction ratio. Firstly, we took a full sheet 12mm thickness ply wood and with the measurement of 800mm which contract up to 350mm, with the height of 700mm. The outlet section has a flange that was connected to the inlet test section flange. The inlet area was welded smoothly together with the stilling chamber. The nozzle (contraction section) where fitted to the test section with the aid of bolts and nuts, soft 2mm smooth paper gaskets were used in between the two flanges to prevent air leakage thereby sealing the joint. The unavailability of the small pieces of aluminum honeycomb core in the market restricted me and so I used the paper made honeycomb core, which is made in Finland. Honeycomb helps to cease tangential velocity of the airflow caused by the axial fan. It also reduces turbulence level of the airflow.

Fig 7. Contraction Cone

G. Paper Honeycomb Core

The unavailability of the small pieces of aluminum honeycomb core in the market restricted to the usage of paper made honeycomb core, which is made in Finland. Honeycomb helps to cease tangential velocity of the airflow caused by the axial fan. It also reduces turbulence level of the airflow.

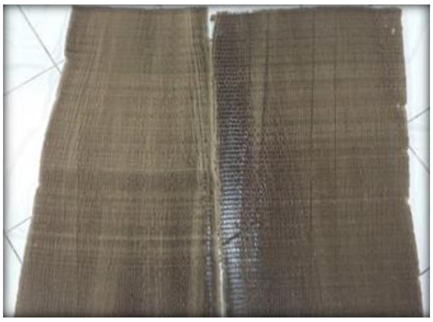

Fig 8. Paper Honeycomb Core

H. Fan and electric motor

Two types of fan can be used for wind tunnel: axial fans and centrifugal fans. At the same flow rate, a centrifugal fan is more expensive than an axial one. For this tunnel, an axial fan made by a

Pak Fan manufacturer was selected. The diameter of the fan is 12 inch. A single phase 1 H.P alternation current motor was selected to drive the axial fan with maximum flow rate is 60000 cubic meters per hour at 1400 rpm. The motor is also made in Pakistan. The maximum power of the motor is 11 kW. Speed of the fan is controlled by a converter.

Fig 9. Heavy Duty Exhaust Fan

I. Diffuser

The diffuser connects the inlet section and the settling chamber. The height of the diffuser is 100 cm. The angle of the diffuser increases from 35 cm x 35 cm to 65 cm x 62.5 cm. The area ratio between the inlet section and the outlet (i.e. of the settling chamber) of the diffuser is 2. It is suggested that the maximum diffuser angle suitable for that ratio to prevent flow separations is 200. The diffuser angle of our design is 140.

Fig 10. Exhaust fan kept in diffuser

Fig 11. Bottom Portion of the Diffuser

J. Inlet Section

The inlet is a square shape with a diameter of 1.28m which is slightly larger than the diameter of the fan. The mouth of the inlet section was square. A wood frame supports the inlet section.

The detailed specifications of the built wind passage are demonstrated as follows:

TABLE 1: SPECIFICATIONS OF NEWLY DESIGNED WIND TUNNEL

Parameters	Value
Type	Subsonic Open Circuit Wind Tunnel
Test section length	50 cm
Test section cross section	34 cm x 36 cm
Airfoil Shape	Symmetrical Airfoil
Mean air velocity range	15 m/s
Overall length	2.5 m
Sensors	Dual Range Force Sensors (DFS-BTA) • ± 10 N Range Resolution: 0.01 N • ± 50 N Range Resolution: 0.05 N
Honeycomb cell diameter, length	4mm thickness, 65 cm x 62.5 cm
Material Used	Malaysian Plywood
Mach Number	M < 1
Lift and Drag Generator	Lab Quest Mini - 2
Heavy Duty Exhaust Fan	60000 cubic meters per hour at 1400 rpm,11 kW, 4 blades

V. EXPERIMENTAL TEST ANALYSIS

The Reynolds (Re) number is an amount which engineers use to appraise if a liquid stream is laminar or turbulent and which is also computed using mean speed, pipe measurement, thickness, and consistency, and is substantial for any liquid.

The Reynolds number is calculated from:

$$Re = \frac{\rho v l}{\mu} = \frac{vl}{\nu} \qquad (1)$$

Where,
v = Velocity of the fluid
l = The characteristics length, the chord width of an airfoil
ρ =The density of the fluid
μ = The dynamic viscosity of the fluid
ν = The kinematic viscosity of the fluid

The lift coefficient (C_L) is a dimensionless coefficient that relates the lift created by a lifting body to the liquid thickness around the body, the liquid speed and a related reference range.

The Coefficient of lift is calculated from:

$$C_L = \frac{L}{\frac{1}{2}\rho u^2 S} \quad (2)$$

The drag coefficient (C_D) is a dimensionless amount that is utilized to evaluate the drag or resistance of a protest/object in a liquid situation.

The Coefficient of drag is calculated from:

$$C_D = \frac{F_D}{\frac{1}{2}\rho u^2 S} \quad (3)$$

The airfoil we have use in this wind passage is NACA 0010 which is a symmetric airfoil and we have computed the airfoils approach from 0 to 10 values, the Max C_L/C_D is the ratio of maximum lift coefficient and drag coefficient which is found as 44.4062, the Max C_L/C_D alpha is ratio of maximum lift coefficient and drag coefficient with respect to Angle of Attack which is found as 4.25, the Reynolds number is the proportion of speed of the liquid duplicated by characteristic length and which is separated by the dynamic thickness of the liquid, which was found as 211,164. The test estimations of the Coefficient of lift (C_L), Coefficient of Drag (C_D), Angle of Attack (alpha), C_L/C_D is specified in the beneath table 1:

TABLE 2. EXPERIMENTAL CALCULATIONS OF C_L, C_D, AND C_L/C_D

Airfoil		NACA 0010	
Reynolds number		211,164	
Max C_L/C_D		44.4062	
Max C_L/C_D alpha		4.25	
Alpha (AOA)	**C_L**	**C_D**	**C_L/C_D**
0	0	0.01	0
1	0.2491	0.00928	26.842
2	0.3373	0.00923	36.543
3	0.4281	0.01008	42.47
4	0.516	0.01162	44.406
5	0.5982	0.01456	41.085
6	0.6833	0.01759	38.845
7	0.7736	0.02129	36.336
8	0.8623	0.02622	32.887
9	0.9325	0.03436	27.139
10	0.9609	0.04628	20.762

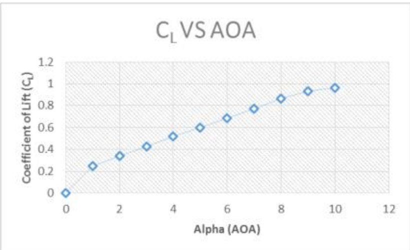

Fig 12. Coefficient of Lift vs Angle of Attack

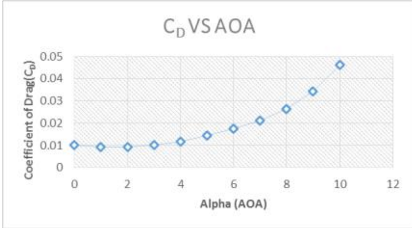

Fig 13. Coefficient of Drag vs Angle of Attack

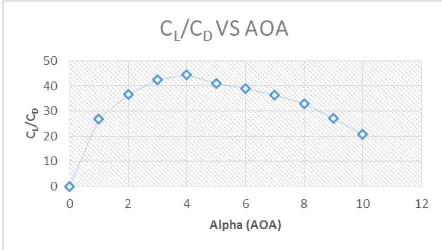

Fig 14. C_L/C_D vs Angle of Attack

The constructed wind tunnel values are a bit similar to the readings done in the NASA tunnel and the MIT tunnels in the USA. Although the test section is comparatively smaller than the normal test section of NASA and MIT [8], it does provide the factual readings as these are of experimental situation.

TABLE 3. COMPARISON OF NEWLY DESIGNED WIND TUNNEL WITH EXISTING TUNNELS

Parameters	**New Tunnel**	**NASA(Small) Tunnel**	**MIT (USA) Tunnel**
Test section	0.34 m x 0.36 m	0.9m x 0.9m	0.85m x 0.85m
Mean velocity	15 m/s	25 m/s	40 m/s
Test section length	50 cm	3m	2.8m
Overall length	2.5 m	13 m	11m

Estimations of the speed in the unfilled/empty wind tunnel demonstrated a uniform field which is basic for utilizing it for streamlined aerodynamic research.

VI. CONCLUSIONS

The reason for minor venture work was to design, build and execution trial of a little subsonic twist tunnel passage to confirm its ampleness for streamlined aerodynamic investigation applications and also to reproduce the speed profile at various position of the test area. The mean test segment speed of 15m/s is considered in a wind tunnel and the components are taken into consideration where it would be made as short as it can get under the situation. The length of the developed wind passage is around 2.5 m and a free stream speed is discovered roughly 15 m/s. From the correlation obviously the general length of recently composed wind passage is substantially shorter than the NASA wind tunnel and MIT wind tunnel. Other than this, the development cost of the wind passage is around $1000 which is a great deal not as much as the one accessible in the market of a similar size.

The results of the tests that was conducted on the low speed wind tunnel showed results that are nearly accurate to the NASA and MIT wind tunnel readings. When compared to the wind tunnels in NASA and MIT, which was fabricated in a much more sophisticated, large and tested in a controlled environment, the modification made on the wind tunnel gets the aerodynamic results as close as possible on any object.

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