DESIGN OF SUBSONIC WIND TUNNEL AND DETERMINATION OF AERODYNAMIC COEFFICIENT

By
MD RAFIQUR RAHMAN

DEPARTMENT OF MECHANICAL ENGINEERING , MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY, MIRPUR CANTONMENT, DHAKA, BANGLADESH

ABSTRACT
Open circuit subsonic wind tunnel is an experimental set up which is widely used in the field of Aerodynamic research. With the help of wind tunnel we can determine Aerodynamic coefficient of any solid object which is moving through air. This paper deals with a study of small scale open circuit wind tunnel design and test. In this paper low velocity wind tunnel was designed and fabricated to reduce the drag and lift forces. A typical open circuit wind tunnel consists of motor, fan unit, settling chamber, honey comb, contraction cone, diffuser and a test section. The main work of a wind tunnel is to improve the design according the aerodynamic shapes. It is vital to obtains reliable aerodynamic characteristics estimation to carry out a good design of any solid moving object. In this paper with the help of wind tunnel we will determine the aerodynamic coefficient of different types of projectiles used in military. Here a set of hollow projectile is considered to study aerodynamic characteristics of projectile in an open circuit subsonic wind tunnel where uniform flow velocity is maintained across the flow direction. Here we have used the inclined manometer to find out surface static pressure and then the pressure coefficient was determined.
Keywords: *Aerodynamic parameter, open circuit wind tunnel, Ansys software, Projectile, Numerical validation.*

1. Introduction

Wind tunnel is a tool used in aerodynamic investigation to evaluate influence of air travelling past solid object, wind tunnel testing facility is an aerodynamic test facility used to study wind flow pattern around bodies and measure aerodynamic forces on them. With the help of wind tunnel we can determine Aerodynamic coefficient of any solid object which is moving through air. This paper deals with a study of small scale open circuit wind tunnel design and test. In this paper low velocity wind tunnel was designed and fabricated to reduce the drag and lift forces. A typical open circuit wind tunnel consists of motor, fan unit, settling chamber, honey comb, contraction cone, diffuser and a test section.

The main work of a wind tunnel is to improve the design according to the aerodynamic shapes. It is vital to obtains reliable aerodynamic characteristics estimation to carry out a good design of any solid moving object. In this paper with the help of wind tunnel we will determine the aerodynamic coefficient of different types of projectiles used in military. Here a set of hollow projectile is considered to study aerodynamic characteristics of projectile in an open circuit subsonic wind tunnel where uniform flow velocity in maintained across the flow direction. Here we have used the inclined manometer to find out surface static pressure and then the pressure coefficient was determined. In this investigation, the static measurements of coefficients and gradient of aerodynamic force and moments depending on Mach number and angle of attack in the subsonic wind tunnel are done on the symmetric projectile. Optimization of the structural design and micro correction projectile aerodynamic shape is investigated.

2. Background History

In the field of aviation and many other sectors open circuit wind tunnel is used to determine the aerodynamic coefficients. Sir George Cayley (1773–1857) investigated the drag and lift of various airfoils by using the whirling arm. The dimension of whirling arm was 5 feet (1.5 m) long and achieved top speed between 10 and 20 feet per second. The steady flow of air impacting the test shape at the normal incidence was not produced by the whirling arm. Francis Herbert Wenham (1824–1908) evaluated these problems by fabricating and operating the first enclosed wind tunnel in 1871. Wenham and Browning investigated the dimensions of l/d ratios, and the exposure of the beneficial effects of a high aspect ratio. The world's largest wind tunnel was manufactured in 1932-1934, situated at Chalais-Meudon in France. The US built the largest wind tunnels in 1941 situated at Wright Field in Dayton, Ohio. German scientists faced the problems related with spreading the valuable choice of large wind tunnels. The large natural caves which were enhanced in size by pit and then closed to stock large volumes of air can be routed through these tunnels. This advanced methodology had permitted the lab research in high-speed regimes and had enhanced the advancement of aeronautical engineering. Three different supersonic wind tunnels of Mach No 4.4 were developed in Germany. The supersonic flow analysis was performed for the airflows near or above the speed of sound. United States scientist have conducted several experiments and fabricated new wind tunnels at universities and at military sites.

3. Aerodynamic Parameters

An Aerodynamic force is a force exerted on a body by the air in which the body is immersed and is due to the relative motion between the body and the air. Few aerodynamic parameters are discussed here.

3.1 Drag Force

In fluid dynamics, drag (sometimes called air resistance, a type of friction, or fluid resistance, another type of friction or fluid friction) is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. This can exist between two fluid layers (or surfaces) or a fluid and a solid surface.

3.2 Drag Coefficient

In fluid dynamics, the drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment, such as air or water. It is used in the drag equation in which a lower drag coefficient indicates the object will have a less aerodynamic or hydrodynamic drag.

The drag coefficient C_d is defined as

$$C_d = \frac{2L_d}{\rho_\infty \mathbf{U}_\infty^2 A}$$

Where F_d is the drag force, which is by definition the force component in the direction of the flow velocity,

where

ρ_∞ = Mass density of the fluid,

$U\infty$ = Flow speed of the object relative to the fluid,

A = Reference area.

3.3 Lift Force

Lift is the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is the component of the force parallel to the flow direction. Lift conventionally acts in an upward direction to counter the force of gravity, but it can act in any direction at right angles to the flow.

3.4 Lift coefficient

The lift coefficient (C_L) is a dimensionless coefficient that relates the lift generated by a lifting body to the fluid density around the body, the fluid velocity, and an associated reference area.

$$C_L = \frac{2L}{\rho u^2 S}$$

If the value of C_L for a wing at a specified angle of attack is given, then the lift produced for specific flow conditions can be determined:

where

L = Lift force

ρ = Air Density

U = Velocity or true airspeed

S= Projected wing area

C_L = Lift coefficient at the desired angle of attack, Mach number, and Reynolds number

3.5 Angle of attack

The angle of attack is the angle between the chord line of an airfoil and the oncoming airflow. A symmetrical airfoil will generate zero lift at zero angle of attack.

3.6 Pressure coefficient

A pressure coefficient is a dimensionless number that describes the relative pressures throughout a flow field in fluid dynamics. The pressure coefficient is used in aerodynamics and hydrodynamics.

$$C_P = \frac{P - P_\propto}{\frac{1}{2}\rho_\propto V_\propto^2}$$

where
'P' is the pressure at the point at which pressure coefficient is being evaluated
$P_\propto$ is the pressure in the freestream (i.e. remote from any disturbance)
$\rho_\propto$ is the freestream fluid density (Air at sea level and 15 °C is 1.225 kg/m3kg/m3)
$V_\propto$ is the freestream velocity of the fluid

4. Design of Wind Tunnel

Main focus of this study is to design and fabricate open circuit wind tunnel. A typical open circuit wind tunnel consist of various section i.e. Settling chamber, honey comb, contraction cone, diffuser and a test chamber. These Components are strictly necessary in order to correctly run the experiments.

4.1 Settling Chamber

Settling chamber is used for maintaining uniform wind velocity inside the wind tunnel. Manufacturing of honeycomb section is very difficult. In this work honeycomb section was created with the cutting and gluing of aluminium piece. Two settling chamber was fabricated. First we cut the four piece of plywood. Each four piece was assemble and form a cube like structure with the help of nail and fevicol. Manufacturing of honeycomb section is quite difficult with the help of large no of circular pipes with high strength of bond between two circular pipes. In honeycomb aluminium pipes was used due to low weight and high strength. The bond between two circular pipes with the help of adhesive glue makes stronger bond. Theses bond sustain a high velocity of wind striking on the aluminium pipes with high pressure. These pipes convert swirl winds, in a uniform wind. Settling chamber with honey comb shown in figure 1.

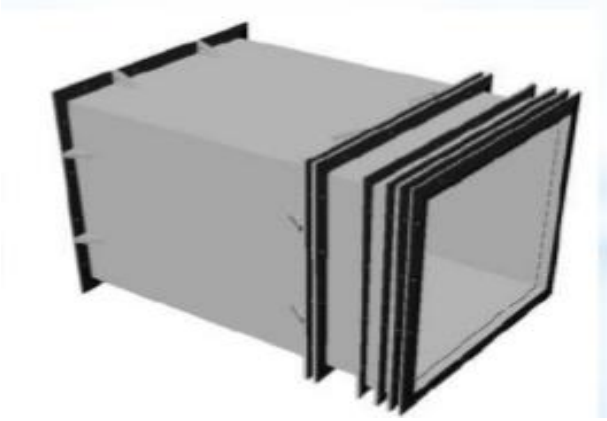

Figure 1: Settling chamber.

4.2 Contraction Cone

The contraction section aims to accelerate the flow to the test chamber generating, at the same time, a uniform flow velocity profile. This wind tunnel section is the most difficult to design because the flow uniformity in the test chamber depends on this section design. The nozzle design starts from its cross-section which has the same shape and dimensions of the testing chamber. In order to design the contraction inlet cross-section, it is necessary to define the nozzle area ratio. This parameter should be as large as possible to have the maximum flow acceleration and low total pressure losses in the upstream sections. Contraction section is shown in figure 2.

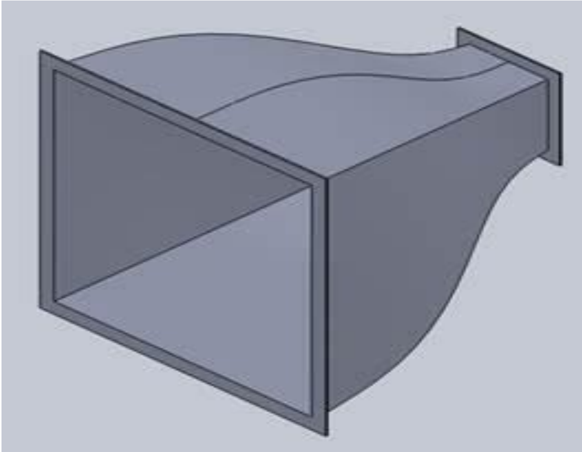

Figure 2: Contraction cone.

4.3 Diffuser

Diffuser is the most important part of wind tunnel which increases the speed of wind in test section. Diffuser create vacuum inside the test tube. Due to the vacuum creation inside the test tube the restriction decrease and increase the velocity of wind inside the tube. Diffuser for wind tunnel was fabricated by using plywood, fevicol and nail. We add damper in wind tunnel they absorb the vibration of diffuser and also no leakage of air at assemble joint. We add damper then they absorb the vibration of diffuser produce by the high velocity wind flow inside the diffuser. Vibration is absorb then the wind flow in uniform and minimum turbulence of wind stream. Figure no-3 is the diffuser of wind tunnel.

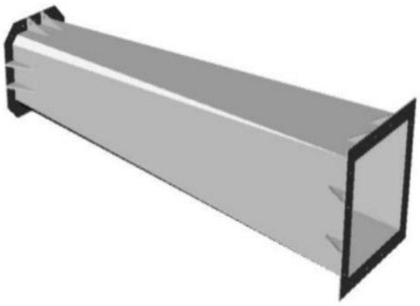

Figure 3: Diffuser.

4.4 Flow fan

Axial flow fan shown in figure no-4 can be fitted either at the inlet or outlet of wind tunnel. It can suck the air from the test chamber or push the air in test chamber.

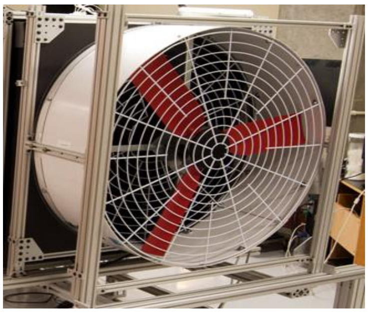

Figure 4: Flow fan.

The number of fans required depends on the basis of various factors like area of wind tunnel, length of wind tunnel, air velocity required in the test chamber, diameter of fan, number of blades etc. Normally large capacity, heavy duty fans were selected where high speed air velocity is required.

4.5 Assembly of Wind Tunnel

Assembly of different parts of wind tunnel was complicated along the line of alignment. There were several parts of wind tunnel viz., fan, settling chamber, contraction cone, test section and diffuser. For heavy motor and fan was fixed at a single position. A foundation was made for the driven unit then fan was fitted with settling chamber. A damper was fitted with the foundation to damped induced vibration from the prime mover. Motor and fan unit come a right position on the foundation. The contraction cone was assembled with the settling chamber with the help of damper, nuts and bolts. The test section was assembled with contraction cone and test section was assembled with the diffuser. Constructed wind tunnel is shown in figure no-5.

Figure 5: Open circuit subsonic wind tunnel.

4.6 Test section

The test section design influence the whole wind tunnel components design. The dimensions of the test chamber have a great impact on the wind tunnel. The reading was taken at the exit end of the wind tunnel in the open air as shown in Figure 6. The projectiles were placed with a stand at the same level as the wind tunnel at the exit end. In the middle of the hollow projectile, it was made groove and connected with a plastic tube. Either side of the plastic tube is connected with an inclined multi-manometer. Each circular projectile was equally spaced and made a total of 30 grooves for 125 mm projectiles, 16 groves for 57 mm, and 10 groves for 37 mm anti-aircraft artillery projectile. Each manometer is made with 30 tubes and connected with projectile grooves. 30 scales were fixed along the 30 tubes in the manometer to take the reading.

Since the top and bottom of the extended part of the wind tunnel was open; as v such no correction for the blockage was done in the analysis. The projectiles were placed very close to the exit end of the wind tunnel so that the approach velocity of a projectile was approximately identical as that in the exit end of the wind tunnel. The projectiles were placed at the exit end of the wind tunnel first line at 30 degree angle of elevation. Then it was gradually elevated at the interval of 5 degree each and data is recorded. In this way, projectiles were elevated up to 50 degree and necessary data was recorded and subsequently, calculations are carried out.

Figure 6: Test section with hollow projectile.

4.7 Measuring Equipment

The wind velocity across the test section of the wind tunnel was measured with the help of a digital anemometer shown in figure no-7. A pitot tube was also used to measure the velocity to cross-check. The pitot tube was connected to an inclined manometer and the limb of which contained manometer fluid. The surface static pressures were measured with the help of an inclined manometer. The inclination of the manometer was sufficient to record the pressure with reasonable accuracy.

Figure 7: Measuring equipment of test section.

5. Experiment

After design and constructing the wind tunnel now we will determine the aerodynamic coefficients of different types of projectiles. The experiment was conducted in the wind tunnel where the hollow projectile individually and side by side was placed at the exit end of the wind tunnel. A set of hollow shape projectiles (37 mm, 57 mm, and a 125 mm) was considered for the experiment. The dimensions are collected from the commonly used shell in an anti-aircraft gun and also from a medium tank. At different angles of attack (less than 60^o), the static pressure measurement will be made. The speed of the tunnel will be maintained at maximum to simulate the actual flow experienced by anti-aircraft gun projectiles. From the static pressure distributions, using numerical computations, the drag and lift coefficients will be measured and compared for a different size and flow configuration. For the numerical scheme, the ANSYS software will be used to simulate the experiment.

6. Mathematical Model

In this chapter, from the wind tunnel pressure tap, static pressure at the upstream of the test section was measured for calculating the lift and drag force. The inclined manometer was used to measure the static pressure on the projectile surface. A constant Wind Velocity of the Wind tunnel was chosen which was 4.7 m /s, measured directly with an anemometer which is later used to calculate the drag, lift, and pressure coefficient.

The wooden projectiles were prepared with the help of the original dummy projectiles. The projectiles were made with seasoned teak wood to avoid any kind of shape deformation. A lathe machine was used to make the projectile and holes are made to insert a small tube to measure static pressure on the projectile surface.

The pressure coefficient is a dimensionless number which describes the relative pressures throughout a flow field in fluid dynamics. The pressure is measured at the tapping by using Equation 1.

$$P = \Delta l_k \rho_k g \qquad (1)$$

Where

P = Static Pressure

Δl_k = Manometer reading

ρ_k = Density of Kerosene

g= Gravitational Acceleration

Now the pressure coefficient can be determine from the following equation:

$$C_p = \frac{\Delta P}{0.5 * \rho_{air} U_\infty^2}$$

Where, $\Delta P = P - P_\propto$

P = Static pressure on the surface of the projectile

$P_\propto$ = The ambient pressure

ρ_{air} = the density of the air

U_∞ = the free stream velocity

In our experiment ΔP can be obtained from the manometer reading.

Drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object. The drag coefficient (C_D) is defined as

$$C_D = \frac{2 * L_D}{S_{Total} * \rho_k * U_\infty^2}$$

Where:

L_D = is the drag force.
ρ_k = is the mass density of the fluid,
U_∞ = is the flow speed of the object relative to the fluid,
S_{Total} = is the reference area

Here the acting force on a single segment (assuming segment 1) is calculated from Equation 2.

$$F_1 = P * S_{Projected\ 1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (2)$$

Then the Total Force acting on the Projectile will be

$$F = F_1 + F_2 + F_{3+} \dots\dots\dots\dots\dots\dots\dots.. + F_n \dots\dots\dots\dots\dots (3)$$

As the air is coming at an angle, therefore, the Total forces will be divided into Horizontal and Vertical direction. If the Angle of Attack is 'α' then the drag and lift force is calculated from Equation 4 and 5.

$$L_D = F \cos\alpha \dots\dots\dots\dots\dots\dots\dots. (4)$$

$$L_L = F \sin\alpha \dots\dots\dots\dots\dots\dots\dots. (5)$$

Now with the help of Drag and Lift forces , Drag and Lift Coefficient can be determined.
Lift coefficient is a dimensionless coefficient that relates the lift generated by a lifting body. The lift coefficient is defined (C_L) by

$$C_L = \frac{2 * L_L}{S_{Total} * \rho_k * U_\infty^2}$$

Where,

S_{Total} = Total Active Projected Area ($S_1+S_2+S_3+\dots\dots\dots+S_n$)

7. Results

With the help of wind tunnel we get the experimental data for different types of hollow projectiles. Here the results of the experimental and numerical investigation regarding the surface static pressure coefficients, drag, and lift coefficients are discussed. Initially, the static pressure on the surface of the projectiles at various angles of attack was taken into consideration. Then the distribution of the static pressure coefficients on the surface of the projectile is compared with the numerical study. The calculated drag and lift coefficients for the group of projectiles are also compared in the same way.

There are some assumptions made that may not be accurate, such as, room temperature and humidity is considered as constant. In reality the density of the air changes due to the temperature and humidity. Another such assumption was the density of the manometer fluid and theoretical value was considered for the calculations.

7.1 Drag and lift coefficient

For the experimental data from wind tunnel and also for numerical simulation it was found the drag and lift forces found to be the function of the angle of attack. As the angle of attack increases the drag and lift forces increases as well. The drag forces are almost constant if the angle of attack is low. In this investigation, the rate of increasing the lift forces is more than the drag forces. It is found that a large size projectile may have large drag but due to large surface area and angle of attack, the lift force increases as well. Angle of attack vs drag force and lift forces shown in figure 8 and 9 respectively.

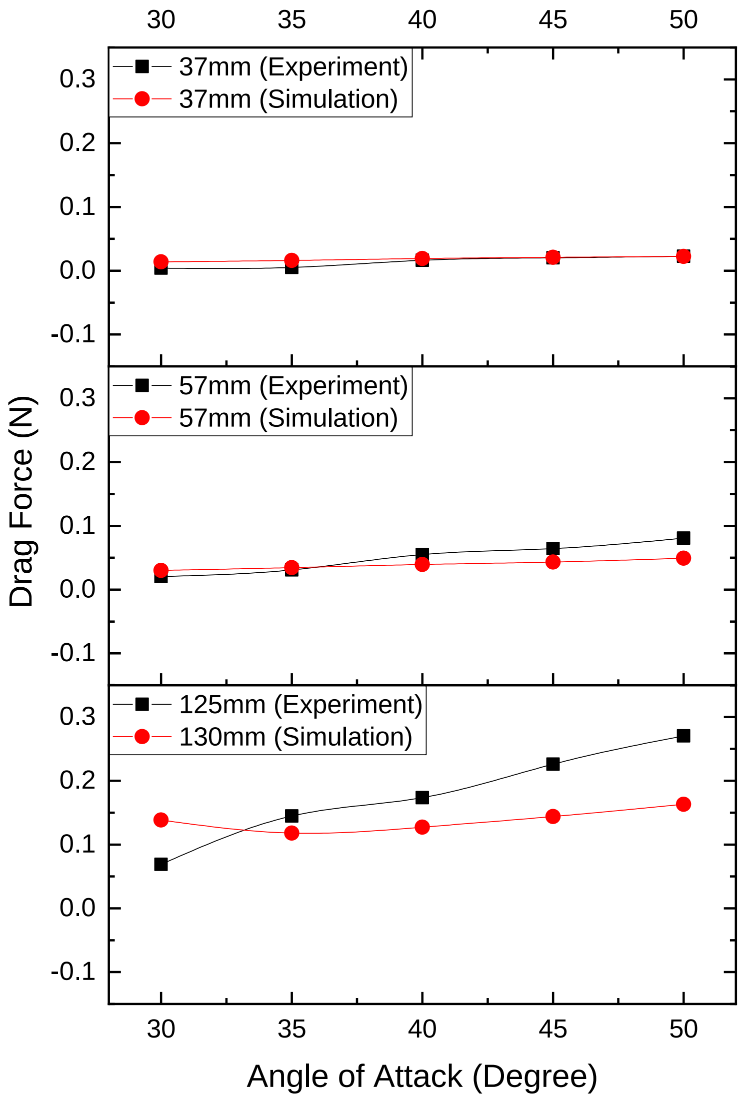

Figure 8 : Angle of Attack Vs Drag Force.

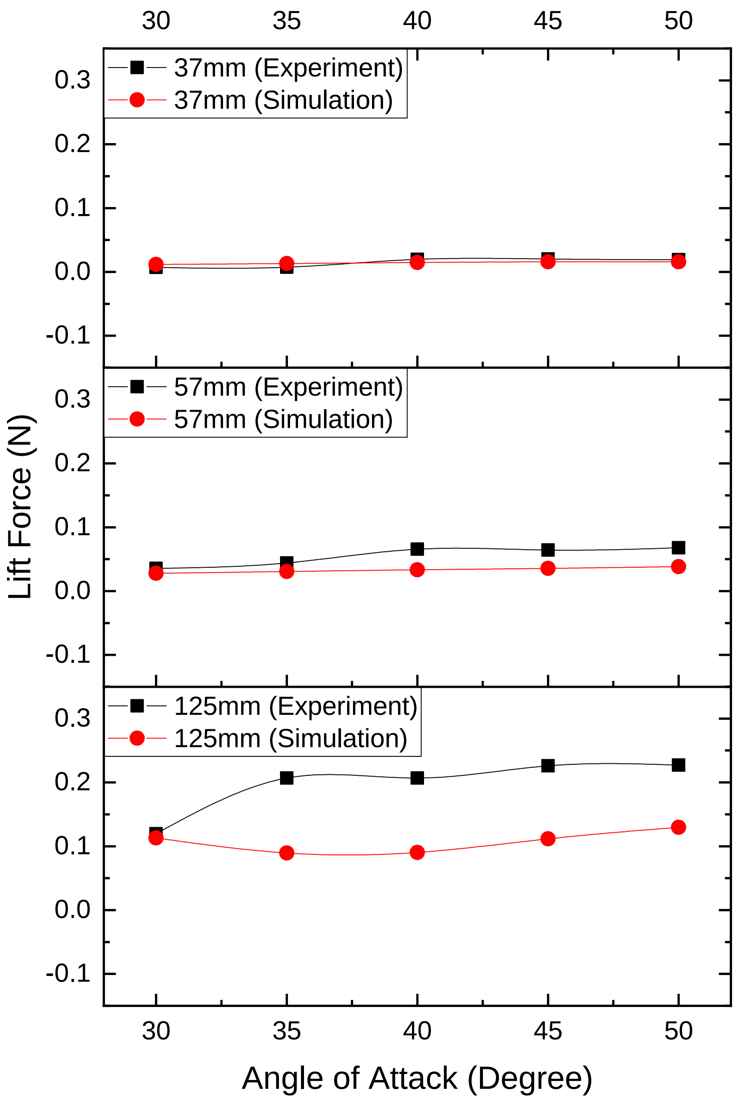

Figure 9 : Angle of Attack vs Lift Force.

The simulated and experimental drag and lift coefficients are plotted in Figures 19 and 20. The overall experimental drag coefficients are higher than simulated drag coefficients except for 37 mm projectile where the experimental drag coefficients slightly lower than the simulation. Angle of attack vs drag coefficient and lift coefficients are shown in figure 10 and 11 respectively.

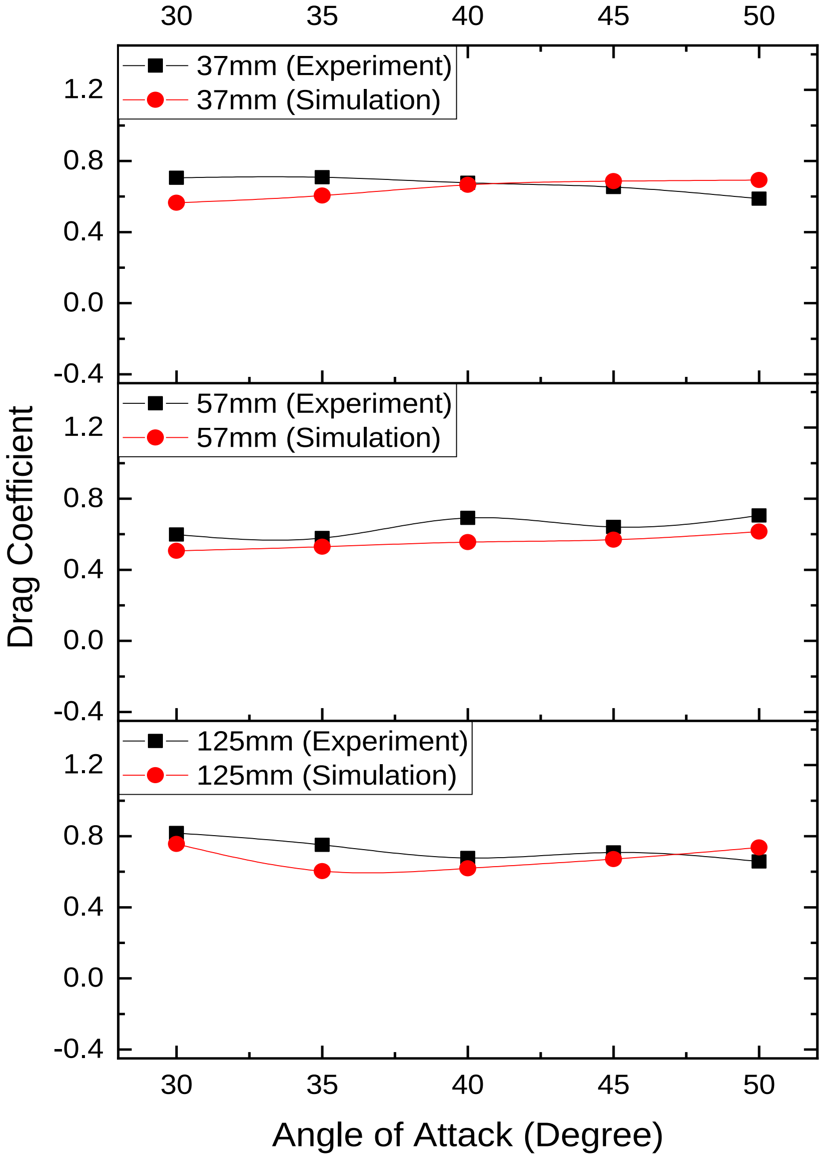

Figure 10 : Angle of Attack vs Drag Coefficients.

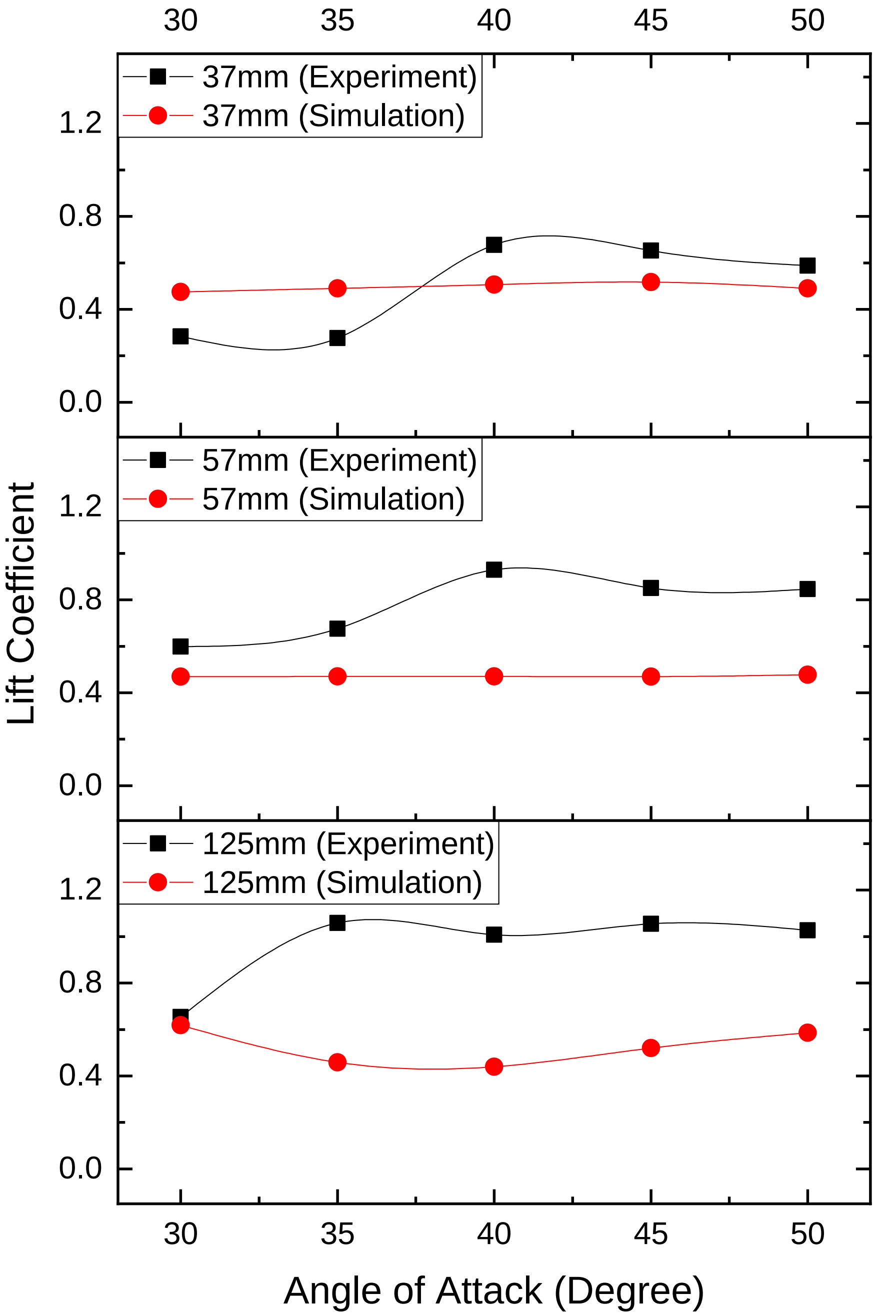

Figure 11 : Angle of Attack vs Lift Coefficients.

7.2 Pressure coefficient

The pressure coefficient is calculated and plotted against the tapping points on the projectiles. The pressure coefficients at the tapping points that are facing the air gradually decreasing and increasing. The measurement at the back of the projectile is very fluctuating as turbulence was observed in the back. Therefore, the pressure coefficients at the back of the projectile are not dependable. It was also observed that the turbulence felt at the back of the projectile is related to the size of the projectile. The turbulence decreased as the projectile size increased from 37 mm to 57 mm shown in Figure 12, Figure 13, and Figure 14.

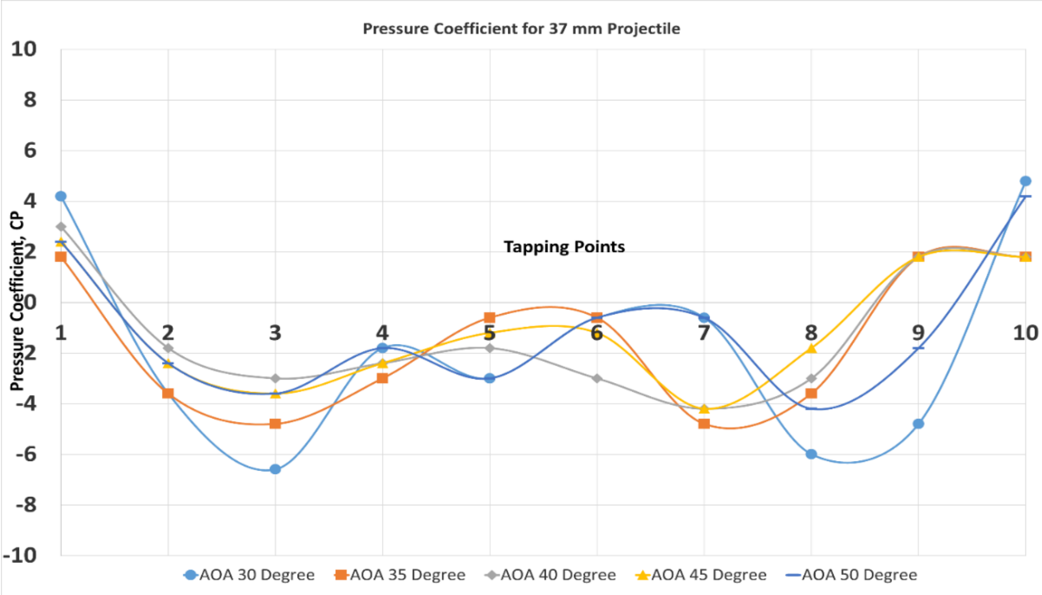

Figure 12 : Tapping Point Vs Pressure Coefficients for 37 mm Projectile.

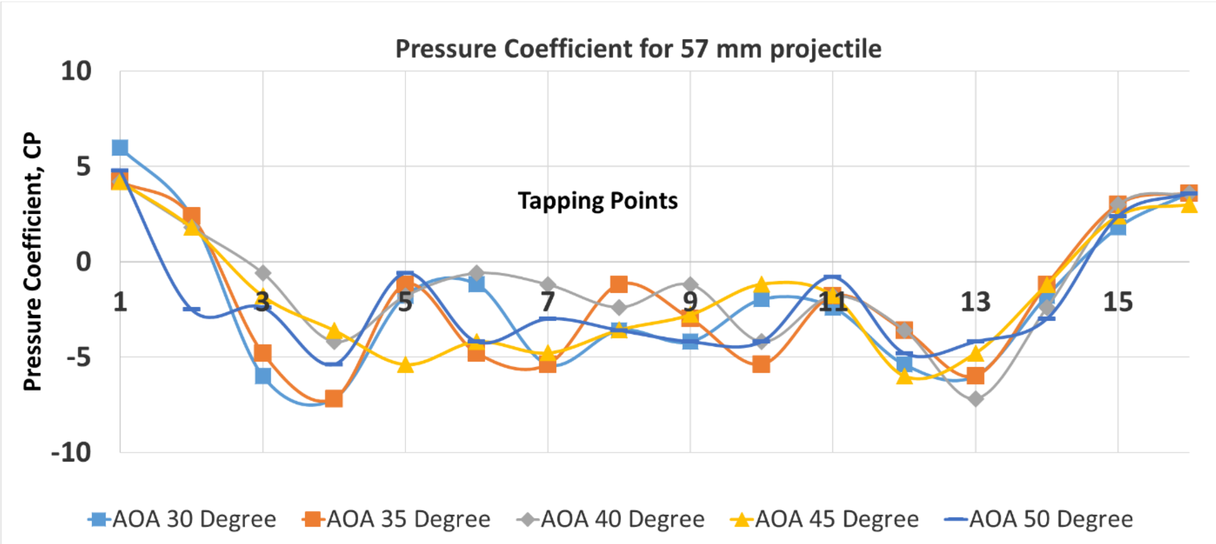

Figure 13 : Tapping Point Vs Pressure Coefficients for 57 mm Projectile.

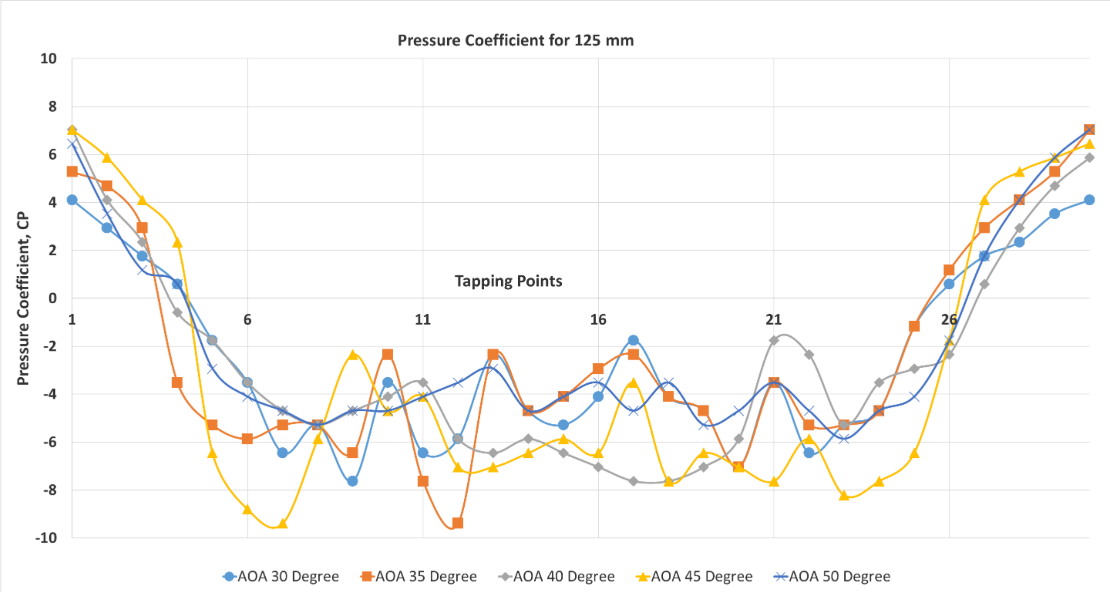

Figure 14 : Tapping Point Vs Pressure Coefficients for 125 mm Projectile.

8. Conclusion

In this study we have describe the design, fabrication of a open circuit subsonic wind tunnel. Finally we have tested the wind tunnel for determining aerodynamic coefficients of projectiles. It is very important to select the size, shape, material and manufacturing process for preparing the wind tunnel. The experiment was done on the projectiles model with a subsonic wind tunnel and similar experimental conditions were applied for numerical simulation to investigate further parameters that are not possible to measure or visualize in real-time.

Results from the experimental data and also from numerical valuation show a large size projectile may have large drag but due to size the lift forces increases too. It also shows lift & drag forces are function of angle of attack and lift & drag coefficients are related to its forces. Pressure coefficients are positive at some tapping points and tapping points move away from the centre. We have carried out the testing of the projectile in subsonic wind tunnel but the projectile moves in supersonic speed. For more accuracy these projectiles can be tested in supersonic wind tunnel. So for determining aerodynamic coefficients, open circuit subsonic wind tunnel is certainly a very suitable equipment.

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