wjert, 2020, Vol. 6, Issue 5 39-56. *Original Article* **ISSN 2454-695X**

World Journal of Engineering Research and Technology

WJERT

www.wjert.org **SJIF Impact Factor: 5.924**

INVESTIGATION OF DRAG & LIFT FORCES FOR A HOLLOW PROJECTILE AND ITS NUMERICAL VALIDATION

MD Rafiqur Rahman*

Department of Mechanical Engineering, Military Institute of Science And Technology, Mirpur Cantonment, Dhaka, Bangladesh.

Article Received on 29/06/2020 **Article Revised on 19/07/2020** **Article Accepted on 09/08/2020**

***Corresponding Author**
MD Rafiqur Rahman
Department of Mechanical Engineering, Military Institute of Science And Technology, Mirpur Cantonment, Dhaka, Bangladesh.

ABSTRACT

Accurate experimental methods for determining the drag and lift forces of the projectile is very important. The trajectory of a projectile through the air is affected both by gravity and by aerodynamic forces. The aerodynamic forces can conveniently be ignored in many situations, even when they are comparatively large. In this paper 37 mm hollow projectile is considered since it shows good performance characteristics and easy to handle. Here main emphasis was given to determine pressure coefficient, Drag coefficients, lift coefficient of the hollow projectiles at different angle of attack. To study the aerodynamic characteristics of the projectiles the experiment was conducted in an open circuit subsonic wind tunnel where uniform flow velocity is maintained across the flow direction. For the experiment varied angles of the attack mostly between 30° to 50° is considered with an interval of 5°. Here inclined manometer was used to find out the surface static pressure and then the pressure coefficient was determined from that. Finally, for the numerical scheme, the ANSYS Software was used to simulate the experiment. In this study, it was found that the drag and lift forces acting on the projectiles, both increases when the angle of attack increases.

1. INTRODUCTION

The trajectory of a projectile is strongly affected by the drag and the lift forces. Accurate experimental methods for determining the drag and lift force of the projectile is very important. The trajectory of a projectile through the air is affected both by gravity and by aerodynamic forces. The aerodynamic forces can conveniently be ignored in many situations, even when they are comparatively large. When a projectile is launched it experiences a drag force which is more than the gravitational force. In the same way drag and lift coefficients play a vital role in projectile flight. These coefficients depend on the angles of attack, the nose shape of the projectile, velocity, and surface smoothness. However, the drag experienced by a single projectile will be different from the drag force experienced by two projectiles flying side by side since the disturbance created in the flow field by one projectile will affect the other one. Drag is the prime reason for reducing projectile velocity and accuracy. Thus it is necessary to determine and minimize the effect of drag to improve the range of projectiles. Since projectiles like different ammunition shells operate at a different speed (subsonic and supersonic) this breakdown will aid the designer to find potential areas for drag reduction and achieve the desired increase in range.

Study on hollow projectile has increased now a days for its good performance characteristics like superior target penetration, inexpensive manufacturing, low recoil, and easy handling. Both experimental and numerical studies are done on this type of projectile. Good agreements between numerical results and experimental observations are obtained where the coefficient of drag and lift are obtained at different Mach numbers. In recent years the three dimensional hollow projectile research development became very important for small calibers artillery projectile. The circular duct along with the longitudinal axis of hollow projectile which causes high muzzle velocity and low drag makes it performance characteristics greatly improved.

NOMENCLATURE

C_P	*Pressure Coefficient (Unit less)*
C_D	*Drag Coefficient (Unit less)*
C_L	*Lift Coefficient (Unit less)*
L_D	*Drag Force (N)*
L_L	*Lift Force (N)*
P	*Static Pressure On the Projectile (Pa)*
$P\infty$	*Ambient Pressure (Pa)*
Δl_k	*Manometer Height Difference (m)*
F	*Total Force (N)*
ρ_k	*Density of Manometer Fluid* (Kg/m^3)
ρ_{air}	*Density of Air* (Kg/m^3)
U_∞	*Air Velocity (m/s)*
α	*The Angle of Attack (AOA) (°)*
g	*Gravitational Acceleration* (m/s^2)

F_1	*Force Acting on Projected Area '1' (N)*
S_{Total}	*Total Active Projected Area (m^2)*

A. Necessity of Study

In the aerodynamics property there are two basic parameters, namely, lift and drag which are very important for the design of an artillery projectile. There are many methods available for the simulation, however, to achieve more reliable results, wind tunnel test is usually recommended. The study is performed to develop a computational fluid dynamics (CFD) based method to predict longitudinal and lateral-directional aerodynamic Coefficients of projectiles. As aerodynamic characteristics are strictly related and will affect the stability of the projectile thus it is vital to obtain reliable aerodynamic characteristic estimation to carry out a good design of projectile. Again within the field of artillery lots of steps have been taken to increase the range and accuracy of the guns. The increase of the range can be achieved either by gun improvement, the increased gas pressure in the barrel or by the improvements of projectile performance. Projectile performance largely depends on the aerodynamic characteristics.

In light of the above, the aerodynamics forces will have a direct impact on projectile stability, accuracy, and range. Thus the study is conducted and presented the result obtained from wind tunnel test experiments on 37 mm hollow projectiles at different angles of attack.

B. Objective of this Study

Experimental investigations will be carried out in the wind tunnel with the hollow shape dummy 37 mm projectile. Specific objectives are as follows:

1. Determine the drag and lift forces of projectiles at various angles of attack.
2. Determine the drag and lift coefficient of projectiles along with its pressure coefficient at various angles of attack.
3. Numerical modeling of the results for necessary validation.

2. Aerodynamic Forces

A. Drag

In fluid dynamics, drag 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 a fluid and a solid surface. Unlike other resistive forces, such as dry friction, which are nearly independent of velocity, drag forces depend on velocity. Drag force is proportional to the velocity for a laminar flow and the squared velocity for a turbulent flow. Even though the ultimate cause of a drag is viscous friction, the turbulent drag is independent of viscosity. Types of drag are generally divided into the following categories:

1. **Form drag (Pressure drag)** Form drag known also as pressure drag arises because of the shape and size of the object. The pressure drag is proportional to the difference between the pressures acting on the front and back of the immersed body, and the frontal area.
2. **Skin friction drag** Skin friction drag is a component of profile drag, which is a resistant force exerted on an object moving in a fluid. Skin friction drag is caused by the viscosity of fluids and is developed from laminar drag to turbulent drag.
3. **Base drag** Drag which is generated in an object moving through fluid from the shape of its rear side.

B. 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. The drag coefficient is always associated with a particular surface area.

C. Lift Force

A fluid flowing around the surface of an object exerts a force on it. 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.

D. Lift coefficient

The lift coefficient 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. Lift coefficient is a function of the angle of the body to the flow, its Reynolds number, and its Mach number. The lift coefficient refers to the dynamic lift characteristics of a two-dimensional foil section, with the reference area replaced by the foil chord.

3. REVIEW OF LITERATURE

It is necessary to determine the effects of the aerodynamic forces i.e drag & lift forces and its coefficient on the projectile. Many studies and researches are performed at the past to study drag and lift coefficients for various types of projectiles. All those researches are essential as any findings will help in the overall projectiles aerodynamic characteristics and its performances. Mahfouz et al.[1] in their study applied computational fluid dynamics (CFD) to simulate a 2-D hollow projectile with optimal geometry at different Mach numbers at $1 < M_a < 1.8$ and different angles of attack to investigate the shock wave structures and drag characteristics. Damir et al.[7] shows in this paper the research of aerodynamic characteristics of classic symmetric projectile. On the basis of constructed parameters and dynamic characteristics of 40 mm projectile model it calculates aerodynamic coefficients and their derivatives. Kiran et al.[3] Investigated in their research the aerodynamic properties of a standard M549, 155mm projectile. The detailed study was done and validated to reduce drag and to see its effect on the projectile design for both transonic and supersonic speeds.

Besides the above-mentioned research, there had been unfathomable work and study on the aerodynamic characteristics of projectiles done by many researchers worldwide. Here I have highlighted only a few for the present study. In the above-mentioned research work, a study on drag and lift forces was done only for a single type projectile.

4. Experiment

For the study of aerodynamic characteristics of the projectiles, it requires the use of variety of theoretical, experimental and numerical method. The experiment will be conducted in an open circuit subsonic wind tunnel. The wind tunnel has a bell mouth entry, a flow Straightener, diverging section, and two axial flow fans. The hollow projectile individually and side by side will be placed at the exit end of the wind tunnel. A set of hollow shape 37 mm projectiles will be considered for the experiment. The dimensions are collected from the commonly used shell. At different angles of attack (30^o to 50^o) the static pressure measurement will be made. The speed of the tunnel (4.7 m/s) will be maintained at maximum to simulate the actual flow experienced by projectile. From the static pressure distributions, using numerical computations, the drag and lift coefficients will be measured and compared for different size and flow configuration. For numerical scheme the ANSYS software will be used to simulate the experiment.

A. Preparation of the Projectiles

Projectiles of existing 37 mm was used for the preparation of the model. A solid works model of 37 mm projectile is shown in Figure 1. We have prepared the dummy model by wood instead of metal because with the metal the dummy model will be heavier and will be difficult to use during the experiment. So each of the models was made of seasoned teak wood to avoid bucking and expansion due to the change in weather. Wooden dummy model is shown in Figure 2 . The diameter of the 37 mm projectiles shown in Figure 3. Dummy projectile contained 10 tapping point. The distance between the consecutive tapping points was equal as shown in the figure. Inner Diameter of each tapping point is 1 mm.

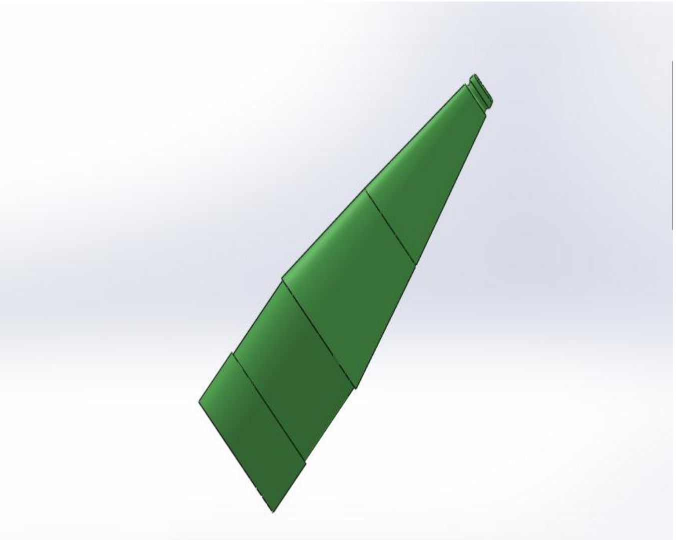


Figure 1: 3D model of the 37 mm projectile.

Figure 2: 37 mm Dummy Model.

The tapings were made along the circular-section of the projectiles. Since the velocity was two-dimensional flow, this would not make any effect on the experimental result. Keeping the outside of the projectiles intact the inside of the projectiles was made hollow through which the plastic tubes were allowed to pass.

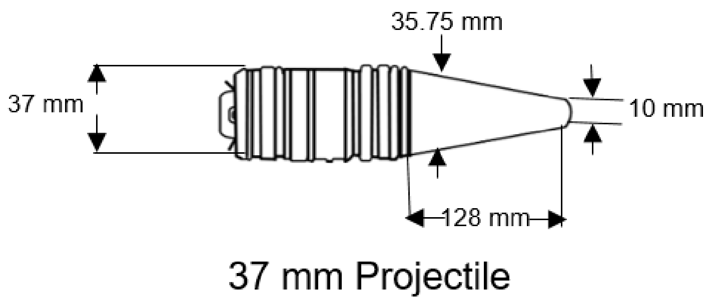


Figure 3: 37 mm Dummy Projectile.

The plastic tubes were connected with the copper capillary tubes at one side and the other side with the inclined multi-manometer. The tapings were made of copper tubes of 2 mm outside diameter. Each tapping was of 50 mm length approximately. From the end of the copper tube flexible plastic tube of 1.5 mm, inner diameter was press-fitted. The tapping positions on the cross-section of the projectiles are shown in Figure 4.

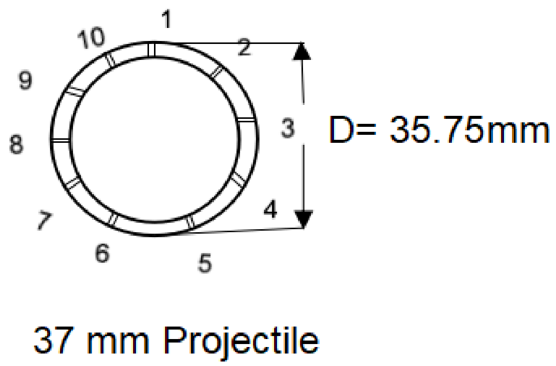


Figure 4: Tapping position shown on Projectile.

In the experimental investigation, 37 mm projectiles were used, where initial reading was taken placing the single projectile in front of the wind tunnel shown in Figure 5.

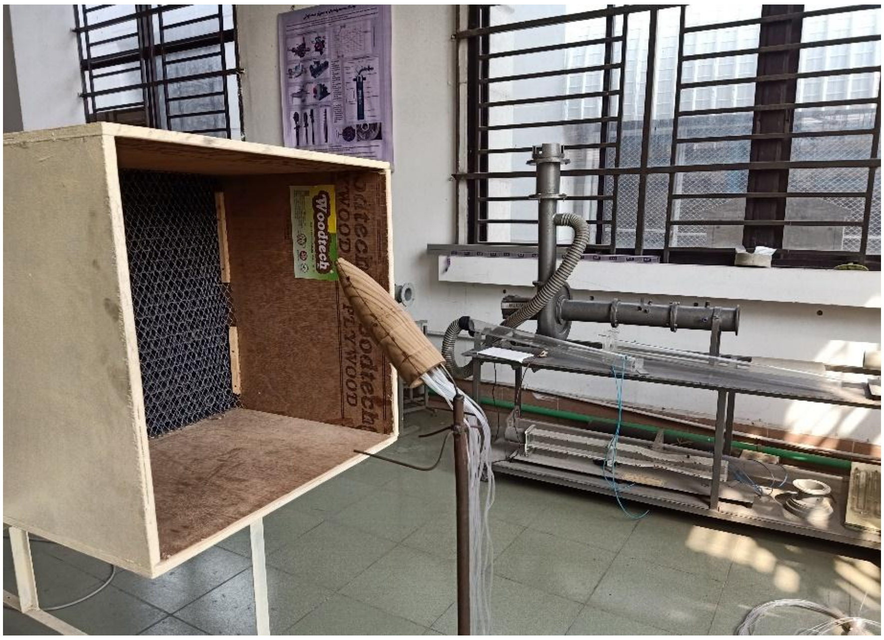


Figure 5: Experimental setup of 37 mm projectile for measuring static pressure.

B. Measuring Equipment

The wind velocity across the test section of the wind tunnel was measured with the help of a digital anemometer. 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.

C. Experimental Conditions

The static pressure was measured with a manometer and it had a minimum deflection of 1 mm. The experiment will be done having the angle of attack in between 30o to 50o with a interval of 5o. Air velocity in the wind tunnel test section will be 4.7 m/s. A Computational Fluid Dynamics (CFD) simulation was done with ANSYS software on similar conditions to compare the experimental and simulation results.

5. 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.

A. Determination of Pressure Coefficient

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.

$$P = \Delta l_k \rho_k g \quad \ldots\ldots(1)$$

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.

B. Determination of Drag and Lift Coefficient

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.

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

Then the Total Force acting on the Projectile will be

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

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.

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

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

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 ($S_1+S_2+S_3+\ldots\ldots\ldots+S_n$)

6. Computational Simulations

A. Geometrical setup

For the computational simulation, we need to prepare the geometry of the projectile. Here we have considered the dimensions of 37 mm projectiles. With the help of solid works, we have developed the geometry of the projectile. The Solid Works model was made for measuring the projected area which is used for simulation. Ansys software is used to analyse the CFD model. Numerical results are highly influenced by the dimensions of the geometrical domain. The projectile is considered as a solid domain and outside of it is considered as air domain.

The k-ε turbulence model is used for solving the problem. The inlet condition was 4.7 m/s air and outlet condition was atmospheric condition similar to experiment. The rest of the surface is considered a wall. Figure 6 shows the geometry of the 37 mm projectiles.

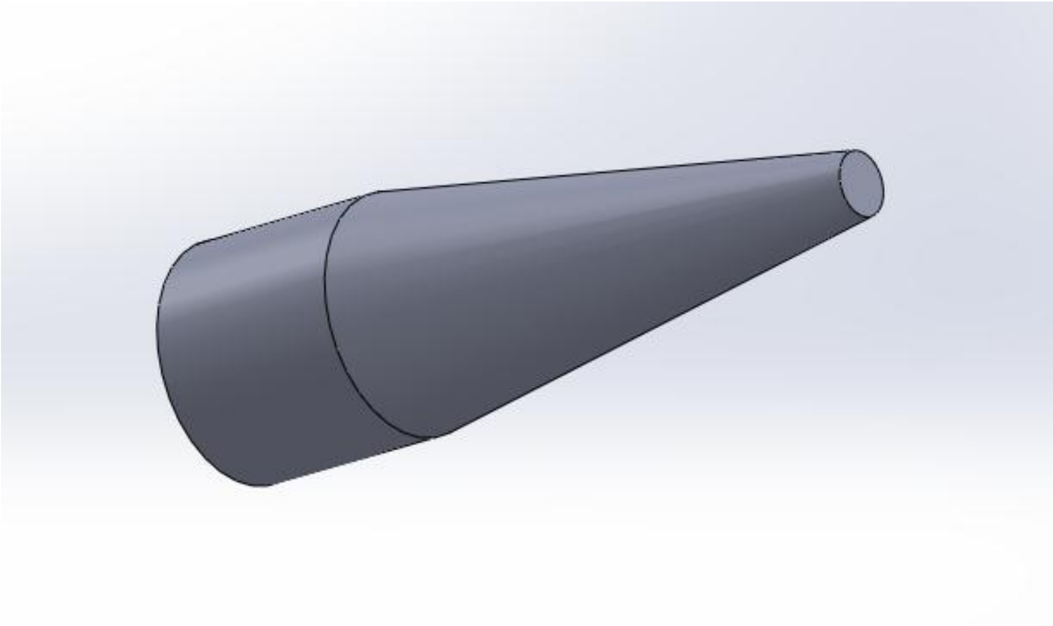
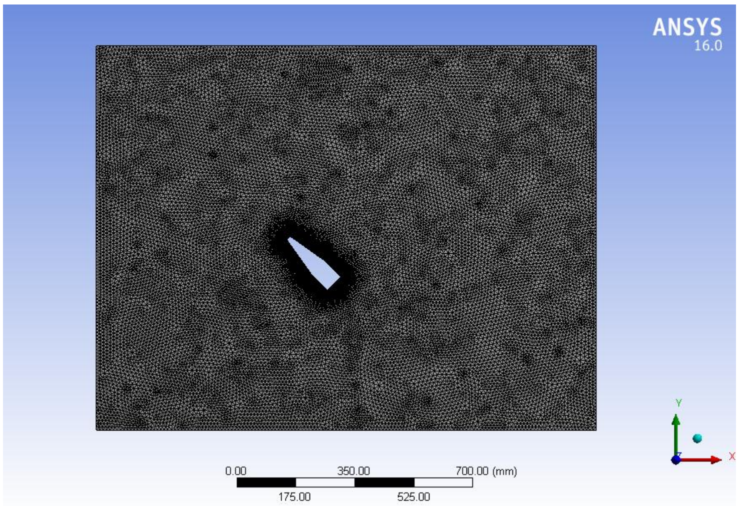


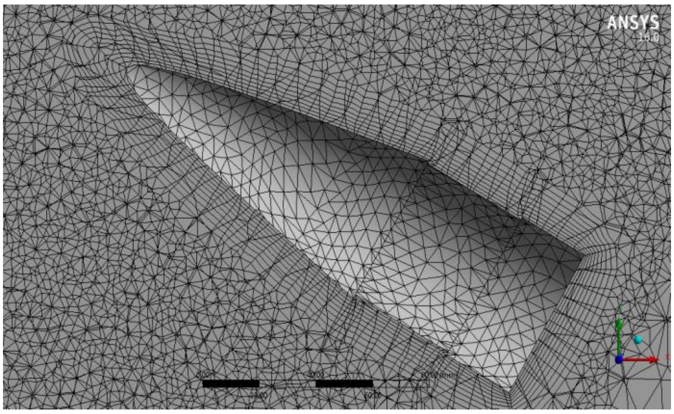
Figure 6: Geometry files for CFD simulation of 37 mm Projectiles.

B. Meshing and other Simulation of Projectile

An unstructured meshing of the projectile was done for rendering a computer screen and for physical simulation i.e for finite element analysis or CFD. It is a subdivision of a continuous geometric space into a discrete geometric cell. Here resolution of the meshing was greater in the regions where greater computational accuracy was needed. It is done at 45° having the boundary condition greater than the projectile. The mesh file for simulation is shown in Figure 7 and the simulation settings for the projectiles are shown in Figure 8.



(a)



(b)

Figure 7: Mesh of the CFD Simulation for (a) 37 mm, (b) 37 mm (zoomed) Projectiles

The geometry of the projectiles with the same dimension of was put forward to simulation with scale 1:1. The geometric model of the projectile is shown in Fig. No 6. The projectile model was sketched on Solid Works 2017 then imported to ANSYS Geometry. The boundary is C-type pattern with 10D at the upstream side and 15D at the downstream side from the surface of the model where D is the diameter of the projectile

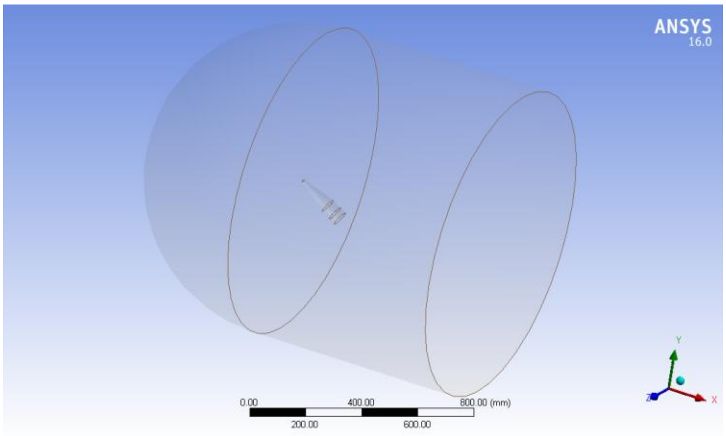


Figure 8: Ansys CFD Simulation setting for 37 mm Projectiles.

7. RESULTS AND DISCUSSION

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 projectiles are also compared in the same way.

The projectiles are not only different in sizes they are also unique in their shapes. Therefore, the possibility of drag forces and lift forces could be different as the drag force and Lift forces are a function of the shapes. The static pressure acting on the projectiles are calculated from the manometer reading, projected area, and the angle of attack. The friction of the projectile is not considered in the experimental and simulated evaluation. But the surface friction has a contribution to the drag force and lift forces. The total force acting on the projectile can be determined by combining the drag and lift forces acting on each segment of the projectiles. For the same angle of attack (say 50°), the drag forces for 37 mm projectile is 0.0224 N and the lift forces increase by 0.0159 N for 37 mm projectiles.

The drag and lift forces of hollow projectile found to be the function of the angle of attack as well. 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. Drag force and lift force Vs angle of attack is shown in Figure 9 & 10 respectively.

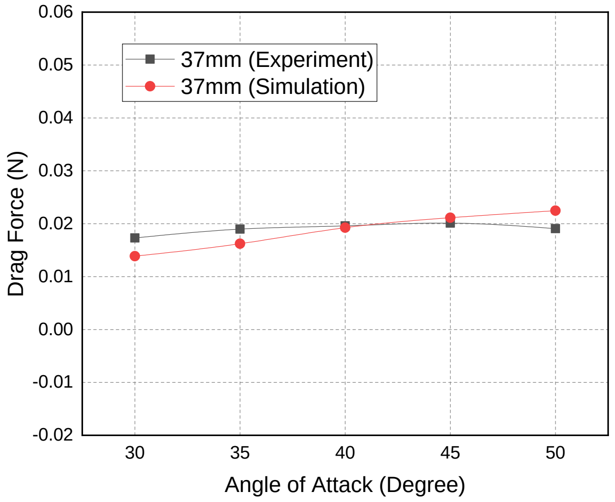


Figure 9: Angle of Attack Vs Drag Force.

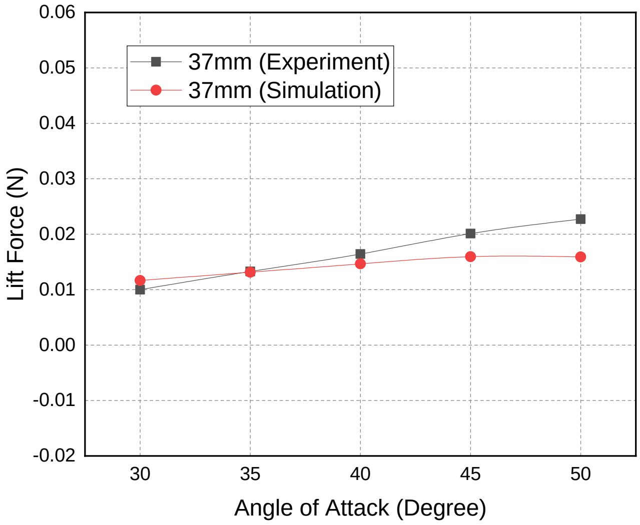


Figure 10: Angle of Attack vs Lift Force.

The simulated and experimental drag and lift coefficients are plotted in Figures 11 and 12.

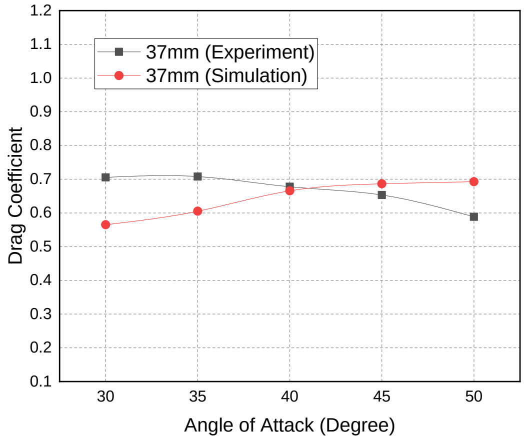


Figure 11: Angle of Attack vs Drag Coefficients.

The overall experimental drag coefficients of 37 mm hollow projectile is slightly lower than the simulation and the lift coefficient is slightly higher than the simulation. The deviation between the experimental and simulated results may be the result of measurement inaccuracies, geometrical inaccuracies, and ignored surface roughness.

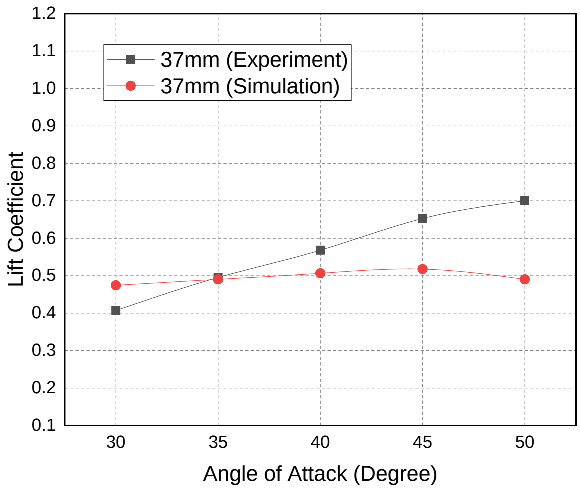


Figure 12: Angle of Attack vs Lift Coefficients.

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. Tapping Point Vs Pressure Coefficients for 37 mm Projectile is shown in Figure 13.

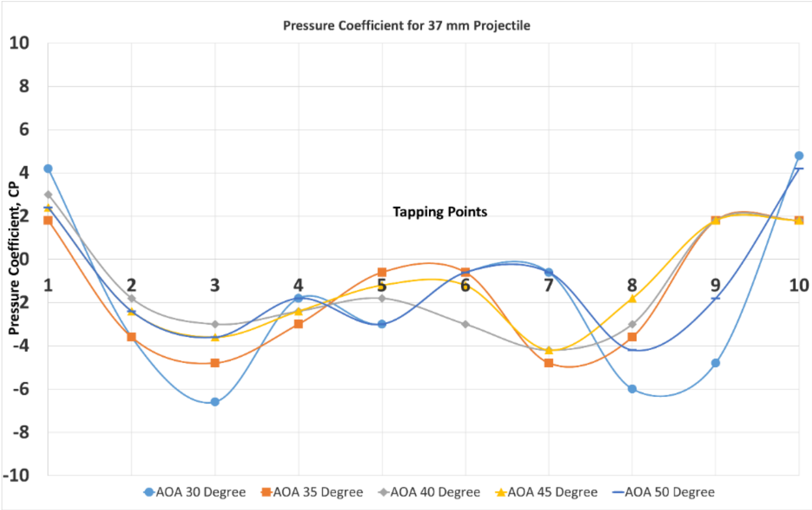


Figure 13: Tapping Point Vs Pressure Coefficients for 37 mm Projectile.

The simulation pressure and velocity plots is shown for 37 mm projectiles in Figures 14 and 15.

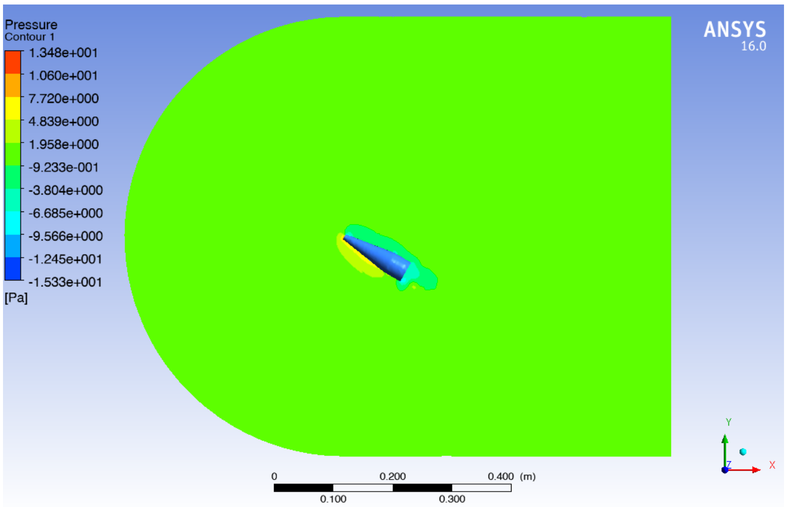


Figure 14: The pressure contour for 37 mm projectile.

The velocity plot shows the turbulence due to the shape of the projectiles. The pressure was mostly felt at the front of the projectile at 45° angle regardless of their sizes and shapes. However, the velocity streamline plots show that the streamline is flowing over the 37 mm projectile.

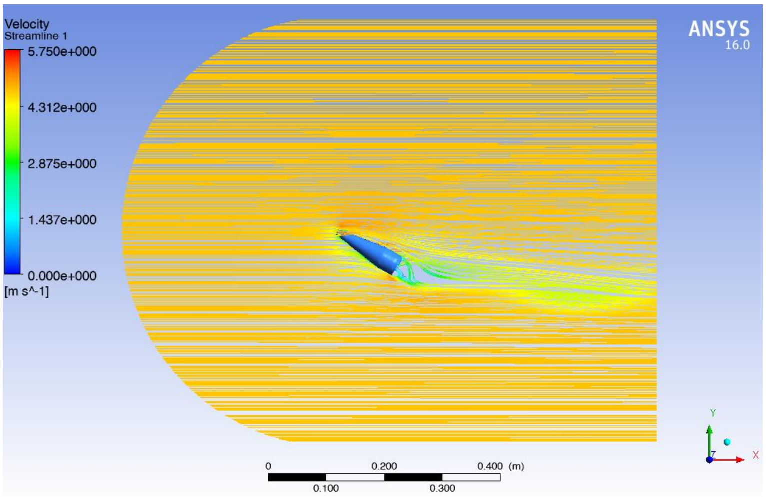


Figure 15: The velocity contour for 37 mm projectile.

8. CONCLUSION

The drag force will reduce the projectile range and lift force will increase the range of the projectile. Thus it is vital to obtain the drag and lift forces to carry out a good design of the projectile. The study simulates the flow field of an optimal hollow projectile using experimental method through wind tunnel and numerical analysis through ANSYS software. Here main focus was given on the drag and lift forces of the projectiles both in experimental and simulation study. The projectile flies at supersonic speed and not in subsonic speed. This study allows observing the projectile behavior at low speed. The projectile starts at zero velocity, therefore, the experiment that is conducted at 4.7 m/s provides the initial flight scenario, the drag force and lift forces related to it.

The lift and drag forces are function of the Angle of Attack (AOA). The lift and drag forces increase as the angle of attack increases from 30° to 50°. The trend of the increase is found to be linear for subsonic airspeed. The rate of increasing the lift forces is higher than the drag force. The lift and drag coefficients are related to the lift and drag forces. Therefore, they follow a similar trend with AOA for drag and lift forces. The experimental and simulation process developed in this paper can be used to investigate the projectiles at a supersonic speed.

REFERENCES

1. Mahfouz E. W., Zhengui H. and Zhihua C. "Aerodynamic Characteristics and Flow Field Investigations of an Optimal Hollow Projectile". 5th International Conference on Mechanical Engineering and Mechanics, China, August 2014.

2. Damir D.J. and Marija S., "The Aerodynamic Characteristics Determination of Classic Symmetric Projectile", 5th International Symposium about forming and design in Mechanical Engineering, Serbia, September 2008.
3. Kiran. and Basawaraj, "Drag Prediction and validation of Standard M549, 155mm Projectile", International journal of Engineering Research and Reviews, India, 2014; 2(3): (26-32).
4. Suliman M. A., Mahmoud O. K., Al Sanabawy M. A. and Abdel Hamid O.E., "Computational Investigation of Base Drag Reduction for a Projectile at Different Flight Regimes", 13th International Conference on Aerospace Science and Aviation technology Coiro, Egypt, May 2009.
5. Elsaadany A. and Wenjun YI., "Investigation on Trajectory Correction for Typical Artillery Projectiles", 5th International conference on Mechanical Engineering and Mechanics, China, August 2014.
6. Wenjun Y., Dongyang S., Junjie T. and Dandan Y., "Experimental Research on Aeroelasticity of a Large Length to Diameter Ratio Projectile", International Journal of Modern Physics of Fluid, China, 2012; 19: (270-275).
7. Peter C., "Approximate Analytical Description of the Projectile Motion with a Quadratic Drag Force", Athens Journal of Science, Russian Federation, June 2014; 1(2): 2: (97-104).
8. Tyler B. and Semih M. O., "Experimental Study on The Effects of Nose Geometry on Drag Over Axisymmetric Bodies in Supersonic Flow", Thesis Paper for MSc degree, USA, 2014.
9. Alexandar B., "Long Distance Bullets and Shells", International Journal of Aerospace Science, Brooklyn, USA, 2013; 2(2): (29-36).
10. Liang K. , Zheng H. and Jing M. Z., " Optimal Design of the Aerodynamic Parameters for a supersonic Two-Dimensional Guided Artillery Projectile", Article on Defence Technology 13 pp. (206-211), Shanxi, China, 2017.
11. Alexey. M.L, Stanishlav, A.K, Ivan. G.R, “Optimization of Aerodynamic Form of Projectiles for Solving the Problem of Shooting Range Increasing”, AIP Conference Proceeding 1893, 030085, 2017.
12. A. Hemateja., B. Ravi Teja., A, Dileep Kumar., Rakesh, S.G., “Influence of Nose Radius of Blunt Cones on Drag in Supersonic and Hypersonic Flows”, Material Science and Engineering, 2017; 225: 012045.