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Computational Analysis of Aerodynamic Parameters For Supersonic Artillery Projectiles

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ABSTRACT

Aerodynamic parameters have a huge impact on a projectile trajectory, which in turn results in its range and accuracy. The influence aerodynamic parameters for the estimation of trajectory elements are drag Coefficients, lift Coefficients, attack angles, muzzle velocity, atmospheric conditions, and the projectile shape and size. Thus proper 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. In this paper, 57 mm and 37 mm anti-aircraft projectile was considered for the AnalysisAnalysis. Her main emphasis was given to determine the pressure coefficient, Drag coefficients, lift coefficient of the projectiles at different attack angles. The experiment was conducted in an open circuit subsonic wind tunnel to study the aerodynamic parameters where the uniform flow velocity is maintained across the flow direction. For the investigation, varied angles of the attack were considered. Here inclined manometer was used to determine the static surface pressure, and the pressure coefficient was determined from that. Then the drag & lift forces and their coefficients were determined. Finally, for the computational AnalysisAnalysis, the ANSYS Software was used to simulate the experimental data.

KEYWORDS - *Aerodynamic Parameters, Projectile, Drag Force, Lift Force, Pressure Coefficient, Drag Coefficient, Lift Coefficient, Angle of Attack, Computational Analysis, Ansys software*

I. INTRODUCTION

Accurate experimental methods for determining the aerodynamic parameters of the projectile is very important. In modern warfare, the design of the projectiles is largely focused on its range and accuracy. Aerodynamics forces have a huge impact on the trajectory of a projectile. The influence Parameters for the estimation of trajectory elements are drag Coefficients, lift Coefficients, angles of attack, muzzle velocity, atmospheric conditions, and the projectile shape and size. When a projectile is launched, it experiences someaerodynamic parameters, which is more than the gravitational force. These parameters depend on the attack's angles, the nose shape, velocity, and surface smoothness of the projectile.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. Theseparameters are the prime reason for reducing projectile velocity and accuracy. Therefore, it is very important to determine and minimize the effect of drag and lift.

In this paper, both experimental and computational Analyses are done on projectiles. Here, fair agreements between computational AnalysisAnalysis and experimental observations are obtained where the drag and lift coefficient is obtained at a different speed and different angle of attack.We have considered two different types of Projectiles, i.e., 57 mm and 37 mm anti-aircraft projectiles in the present study, to emphasize the pressure Coefficient from the static surface pressure. Then other parameters, i.e., drag & lift forces and its coefficient at various attack angles, were determined. The experiment was done in a subsonic wind tunnel, and computational AnalysisAnalysis was done through Ansys software.

II. REVIEW OF LITERATURE

Many studies and researches are performed to study the aerodynamic parameters for various types of projectiles in the past. All those researches are essential as any findings will improve the overall projectile's aerodynamic characteristics and performances.

Mohammad Amin et al. [1] prepared an article that focused on studying various methods for reducing the base drag of artillery projectiles calibre 122mm. The computational fluid dynamics (CFD) numerical simulations (RANS, 2-D axisymmetric configuration) were performed to investigate the projectiles' base drag characteristics. Chand et al. [2] discussed in their paper the feasibility of the application of the system dynamics approach in the artillery projectile motion analysis under the test and evaluation curriculum activities using a point-mass mathematical model.Goran et al. [3] present the modification of the existing guided missile in their study. The modification was performed based on required aerodynamic coefficients for the existing guided missile. The preliminary aerodynamic configurations of the improved missile front parts were designed based on theoretical and computational fluid dynamics simulations. Sahoo et al. [4], in their study, made a numerical estimation of the drag variation and trajectory elements of a supersonic projectile having two different nose shapes. The coefficient of drag (CD) obtained from the simulation is used as an input parameter for estimating trajectory elements. The numerical results, i.e., the drag coefficient at different Mach numbers and trajectory elements, are validated with the data recorded by tracking radar from an experimental firing.

Many other studies on this like Jian et al. [5] in their AnalysisAnalysis show a hypersonic aerodynamics analysis of an electromagnetic gun launched projectile configuration is undertaken to ameliorate the basic aerodynamic characteristics in comparison with the regular projectile layout. With a steady-state computational fluid dynamics (CFD) simulation, the basic density, pressure, and velocity contours of the EM gun projectile flow field at Mach number 5.0, 6.0, and 7.0 (angle of attack = 0o) have been analyzed. Mahfouz et al. [6], in their study, applied computational fluid dynamics (CFD) to simulate a 2-D hollow projectile with optimal geometry at different Mach numbers at $1 < Ma < 1.8$ and different angles of attack to investigate the shock wave structures and drag characteristics. Shubham et al. [14] presented in their paper steady-state, two-dimensional computational investigations performed on NACA 0012 airfoil to analyze the effect of variation in Reynolds number on the aerodynamics of the airfoil without and with a Gurney flap. Both lift and drag coefficients increase with Gurney flap compared to those without Gurney flap at all Reynolds numbers at all angles of attack. Damir et al. [8] show in this paper the research of aerodynamic characteristics of classic symmetric projectile. Based on constructed parameters and dynamic characteristics of the 40 mm projectile model, it calculates aerodynamic coefficients and their derivatives. Kiran et al. [9] investigated the aerodynamic properties of a standard M549, 155mm projectile. The detailed study was done and validated to reduce drag and see its effect on the projectile design for both transonic and supersonic speeds.

III. EXPERIMENT

The experiment will be conducted in an open circuit subsonic wind tunnel. The experiment comprises the measurement of aerodynamic parameters of the model in the wind tunnel. The wind tunnel has a bell mouth entry, a flow Straightener, a diverging section, and two axial flow fans. The projectile will be placed at the exit end of the wind tunnel. A set of dummy 37 mmand 57 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 tunnel (4.7 m/s) will be maintained at maximum to simulate the actual flow experienced by a projectile. 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.

A. Requirement of Model study

There are roughly four classes of techniques to predict aerodynamic parameters on a projectile in atmospheric flight. These are empirical methods, wind tunnel testing, computational fluid dynamics simulation, and spark range testing. In computational fluid dynamic (CFD) simulations, the fundamental fluid dynamic equations are numerically solved for a specific configuration. Wind tunnels testing and full-scale results are always different due to Reynold's number inequality. In most of the wind tunnel test, the full-scale Reynolds number is difficult to achieve.

For determining aerodynamic Coefficient data, including the total aerodynamic drag and lift, studies with the model and full-scale projectile are performed to validate the model. But full-scale experiments are both costly and challenging to perform. For the present study with anti-aircraft artillery projectiles, full-scale experiments will be complex and expensive. At the same time, it will be difficult to record reliable pressure distribution simultaneously on the single and a group of the projectile as there will be a variation of speeds and direction of the wind with time. The flow around projectile in the actual environment is very complex and the formulation of a mathematical model to predict the flow is almost impossible. Thus for solution accuracy model study of anti-aircraft artillery & tank projectile and various data obtained from the simulation will become very handy for practical AnalysisAnalysis.

B. Preparation of the Model (Dummy Projectile)

Projectiles of existing anti-aircraft Artillery, which are used worldwide, were selected to prepare the model. For this study, projectiles of existing 37 mm and 57 mm were used to prepare the model.We have prepared the dummy model with 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 weather changes. The wooden dummy model is shown in Figure1. The dimensions of the 37 mm and 57 mm projectiles are shown in Figure 2. The dummy projectile contained ten tapping points for 37 mm projectile and 17 tapping points for 57 mm projectiles.The distance between the consecutive tapping points was equal, as shown inthe figure. The inner diameter of each tapping point is 1 mm.

Figure 1: Dummy Model of existing 37 mm & 57 mm projectile

The tapings were made along the circular-section of the projectiles. Since the velocity was two-dimensional flow, this would not have 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.

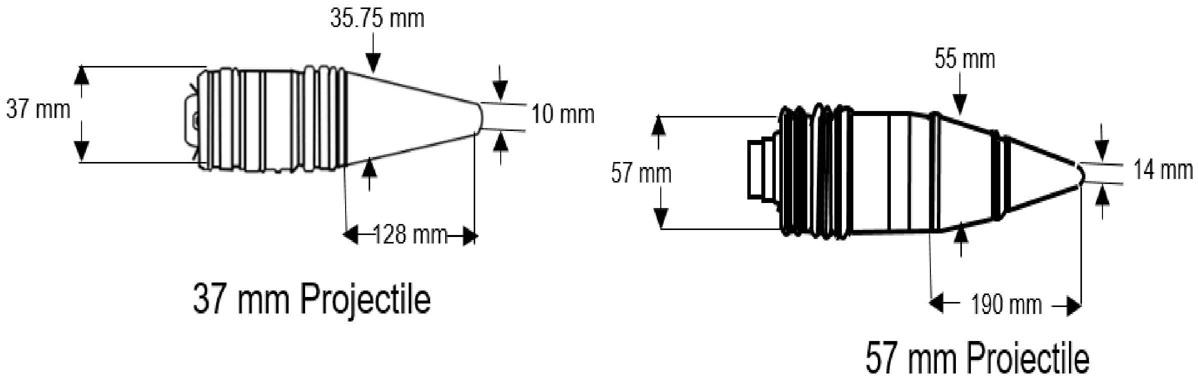


Figure 2: Dimensions are shown in Dummy Projectiles

The plastic tubes were connected with the copper capillary tubes 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 3.

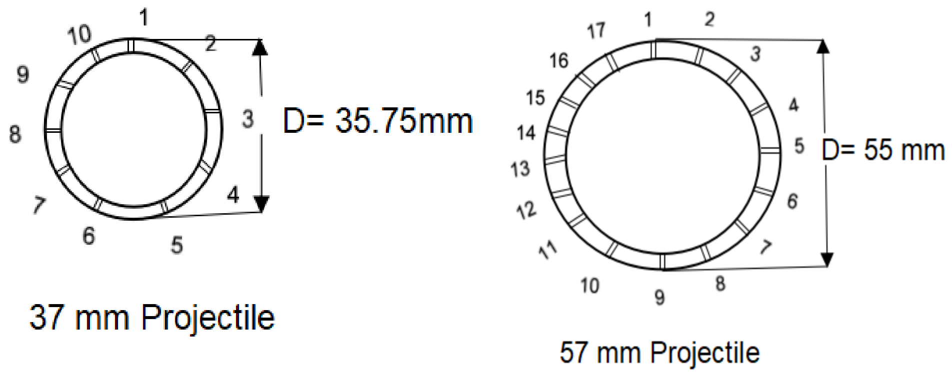


Figure 3: Tapping position is shown on Projectiles

In the experimental investigation, the initial reading was taken, placing the single projectile in front of the wind tunnel shown in Figure 4. The wind velocity across the test section of the wind tunnel was measured with 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.

Figure 4: Experimental setup of the projectile for measuring static pressure.

C. Experimental Conditions:

The static pressure was measured with a manometer, and it had a minimum deflection of 1 mm. The experimental conditions are shown in Table 1. A Computational Fluid Dynamics (CFD) simulation was done with ANSYS Multiphysics software on similar situations to compare the experimental and simulation results.

Table 1.Experimental Conditions for Different Projectiles.

Projectile Size (mm)	The angle of Attack, AOA, (°)	Air Velocity (m/s)	Number of Tapping Points
37	30, 35, 40, 45, 50	4.7	10
57	30, 35, 40, 45, 50	4.7	17

IV. Mathematical Model

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

$$P = \Delta l_k \rho_k g \text{ ....}(1)$$

Where

P = Static Pressure

Δl_k= Manometer reading

ρ_k = Density of Kerosene

g= Gravitational Acceleration

The acting force on a single segment is calculated from Equation 2.

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

Then the Total Force acting on the projectile will be

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

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

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

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

The Drag Coefficient (C_D), Lift Coefficient (C_L), and Pressure Coefficient (C_P) are calculated from Equation 6, 7, and 8.

The drag coefficient is a dimensionless quantity used to quantify an object’s drag or resistance. The drag coefficient is defined as

$$C_D = \frac{2 * L_D}{S_{Total} * \rho_k * U_\infty^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (6)$$

The lift coefficientis a dimensionless coefficient that relates to the lift generated by a lifting body.The lift coefficient is defined by

$$C_L = \frac{2 * L_L}{S_{Total} * \rho_k * U_\infty^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$C_p = \frac{\Delta P}{0.5 * \rho_{air} U_\infty^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$\text{Where } \Delta P = P - P_\propto$$

P = Static pressure on the surface of the projectile

$P_\propto$= The ambient pressure

ρ_{air} =the density of the air

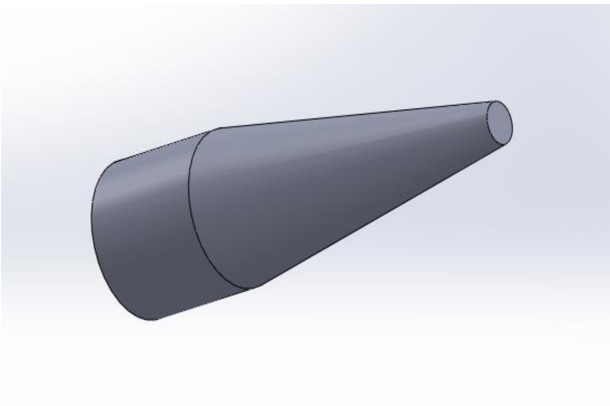
u=the free stream velocity

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

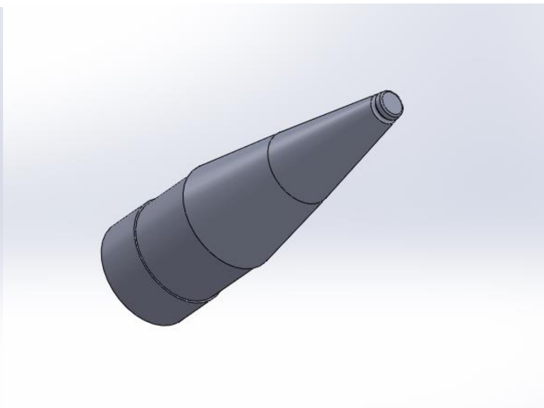
V. COMPUTATIONAL SIMULATIONS

A. Geometrical setup

The geometry of the projectile was prepared for computational simulation. Here we have considered the dimensions of 37 mm and 57 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 analyze the CFD model. The dimensions of the geometrical domain highly influence numerical results. The projectile is considered a solid domain, and outside of it is considered an air domain. The k-ε turbulence model is used for solving the problem. The inlet condition was 4.7 m/s air, and the outlet condition was an atmospheric condition, similar to the experiment. The rest of the surface is considered a wall. Figure 5 shows the geometry of the 37 mm and 57 mm projectiles.



(a)

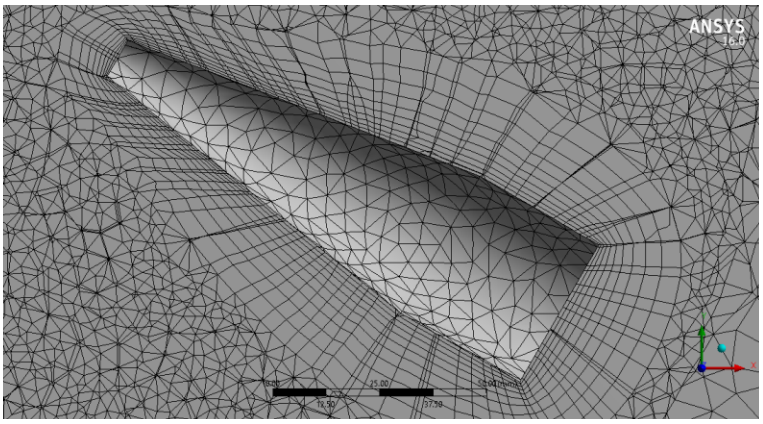


(b)

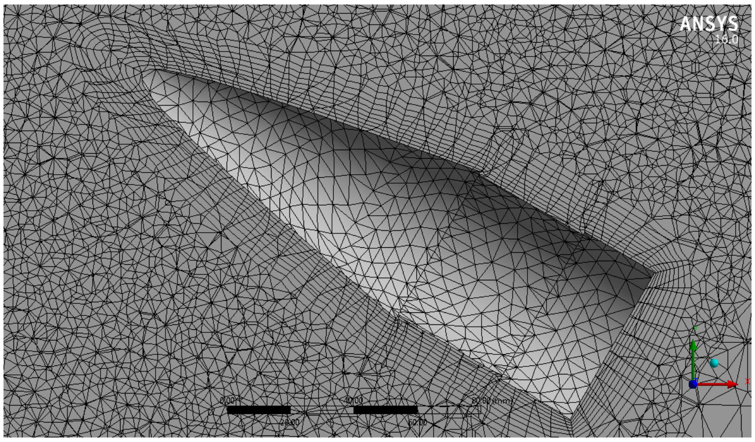
Figure 5. Geometry files for CFD simulation of (a) 37 mm and (b) 57 mm Projectiles

B. Meshing and other Simulation of Projectile

The projectile meshing was done for rendering a computer screen and for physical simulation, i.e., for finite element analysis or CFD. 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 6, and the simulation settings for the projectiles are shown in Figure 7.



(a)

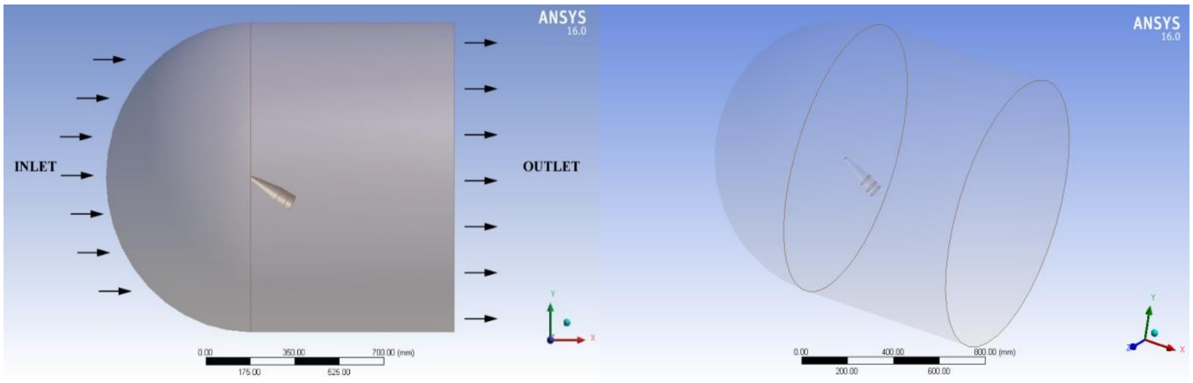


(b)

Figure 6: Mesh of the CFD Simulation for (a) 37 mm,

(b) 57 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 5. The projectile model was sketched on Solid Works 2017 then imported to ANSYS Geometry. The boundary is a 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 projectile diameter.



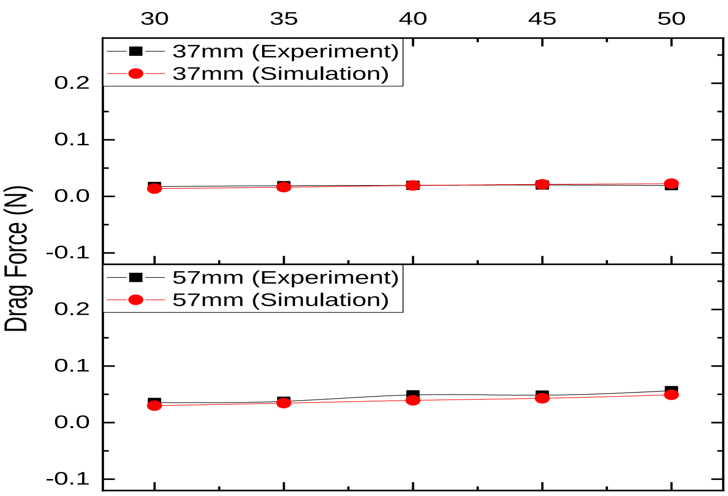
(a) (b)

Figure 7: Ansys CFD Simulation setting for (a) 37 mm and (b)57 mm Projectiles.

The air enters into the domain with a velocity of 4.7 m/s. The density of air was 1.225 kg/m3 and viscosity about 1.7894e-05 kg/m-s. At the outlet, the pressure outlet condition is applied in the domain. The steady and incompressible flow of air is considered in this AnalysisAnalysis. In these calculations, the second-order upwind scheme based on a multidimensional linear reconstruction approach is used. These computations are carried out using FVM solver (ANSYS FLUENT 2016), a commercial CFD package with a 3D double-precision Configuration. The default convergence criterion in FLUENT is maintained. This criterion requires that the scaled residuals decrease to 10^{-5}.

VI. Results and Discussion

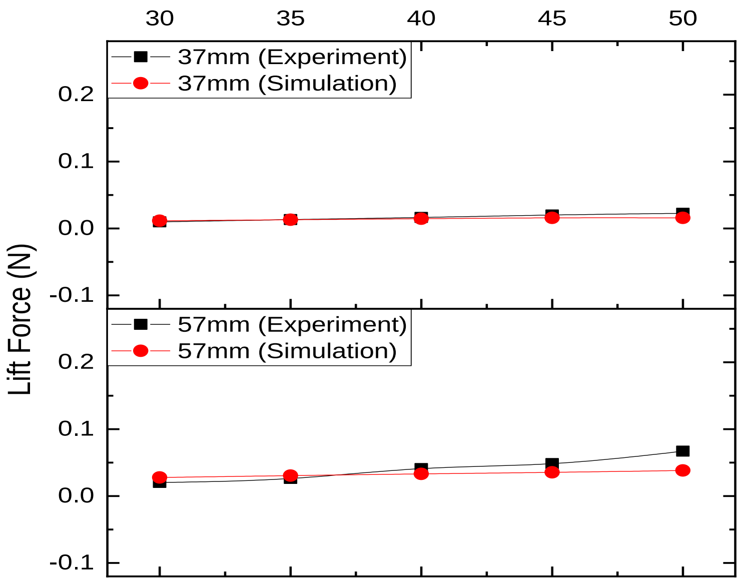
An experimental test for two types of dummy projectile models was done to determine aerodynamic parameters andtheir characteristics at various attack angles. Here computational AnalysisAnalysis was done to validate the experimental results. From the wind tunnel, primarily with the help of an inclined manometer, the static pressure on the projectiles' surface at various angles of attack was taken. The distribution of the static pressure coefficients on the surface of the projectile is compared numerically. Finally, the other aerodynamic parameters are also compared. Results for the CFD analysis of the dummy projectile models are obtained during validation. The static pressure acting on the projectiles is calculated from the inclined manometer. Here 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. Combining the drag and lift forces acting on each segment of the projectiles can determine the total force acting on the projectile.



The angle of Attack (Degree)

Figure 8: Angle of Attack Vs. Drag Force

The drag forces found for 37 mm & 57 mm projectile are 0.0224 N and 0.0492 N. The lift forces also increase from 0.0159 N to 0.0382 N for 37 mm & 57mm projectiles. Drag force and lift force Vs. The angle of attack is shown in Figures 8 & 9, respectively.



The angle of Attack (Degree)

Figure 9: Angle of Attack vs. Lift Force.

The drag and lift forces of the hollow projectile were found to be the function of the attack angle. As the angle of attack increases, the drag and lift forces also increases slightly. 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. There was some deviation between the experimental and simulated findings, which can be from the lack of precision measurement, the ignored friction coefficient of the projectile surface, and the geometrical inaccuracy due to manual fabrication. The increase in the drag and lift forces are common for all the projectiles. The corresponding data sets are shown in Tables 2 and 3.

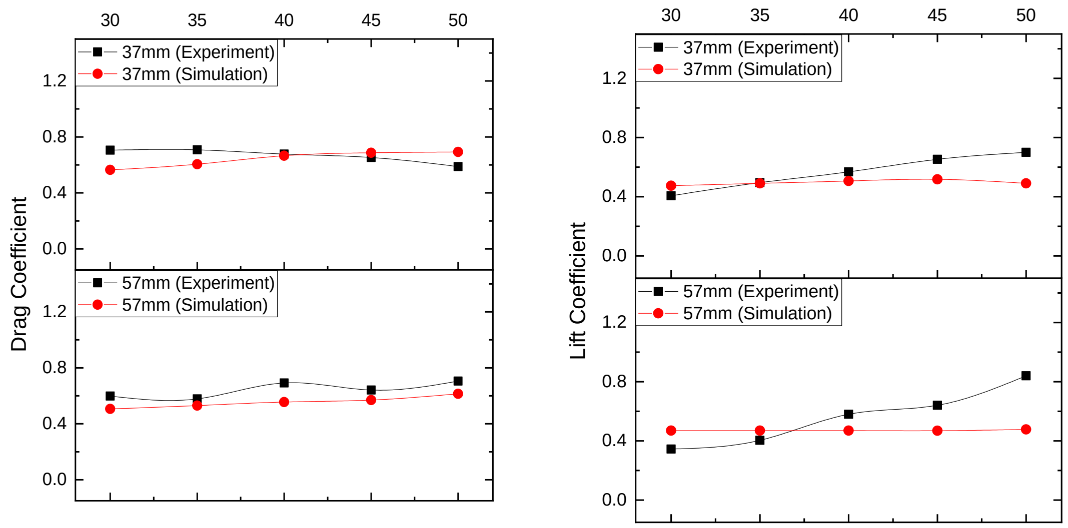
Table 2: Simulation and Experimental Drag Forces for 37 and 57 mm Projectiles at different AOA.

Angle of Attack (°)	37S (N)	57S (N)	37E (N)	57E (N)
30	0.0138	0.0300	0.0040	0.0204
35	0.0162	0.0345	0.0051	0.0308
40	0.0192	0.0393	0.0164	0.0551
45	0.0211	0.0431	0.0201	0.0643
50	0.0224	0.0492	0.0227	0.0806

Table 3: Simulation and Experimental Lift Forces on 37 and 57 mm Projectiles at different AOA.

Angle of Attack (°)	37S (N)	57S (N)	37E (N)	57E (N)
30	0.0116	0.0278	0.00696	0.0355
35	0.0132	0.0306	0.00741	0.0441
40	0.0146	0.0332	0.01959	0.0657
45	0.0159	0.0355	0.0201	0.0644
50	0.0159	0.0382	0.0190	0.0677

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. For the lift coefficient, it is slightly higher than the simulation. The deviation between the experimental and simulated results may result from measurement inaccuracies, geometrical inaccuracies, and ignored surface roughness. The projectiles are made with a manual lathe, and therefore, the manufacturing deviation could play a vital role is the deviation of the results. The simulated and experimental drag and lift coefficients are plotted in Figures 10. Table 4 and Table 5 shows the corresponding data for drag and lift coefficients.



The angle of Attack (Degree) Angle of Attack (Degree)

Figure 10: Angle of Attack vs. Drag and Lift Coefficients.

Table 4:Simulation and Experimental Drag Coefficients on 37 and 57 mm Projectiles at Different AOA

The angle of attack (°)	37S	57S	37E	57E	37 S-E Error(%)	57 S-E Error(%)
30	0.0158	0.033	0.0173	0.036	8.4	6.8
35	0.0162	0.035	0.0190	0.038	14.5	8.3
40	0.0193	0.044	0.0196	0.049	1.76	9.5
45	0.0211	0.043	0.0201	0.049	5.08	11.1
50	0.0225	0.049	0.0191	0.056	17.7	12.8

Table 5:Simulation and Experimental Lift Coefficients on 37 and 57 mm Projectiles at Different AOA

The angle of attack (°)	37S	57S	37E	57E	37 S-E Error(%)	57 S-E Error(%)
30	0.012	0.023	0.009	0.020	16.6	11.6
35	0.013	0.031	0.013	0.026	1.0	16.2
40	0.015	0.035	0.016	0.041	10.8	14.1
45	0.019	0.046	0.020	0.048	5.7	6.1
50	0.02	0.058	0.023	0.067	12.3	13.3

A. Simulation at Supersonic Speed

A supersonic simulation was done to investigate the drag and lift forces. The simulation in supersonic speed is not the same as the subsonic speed; therefore, the simulation result's comparison was different. However, the trend was familiar as the lift and drag coefficient changes near our Experimental rate is almost negligible.

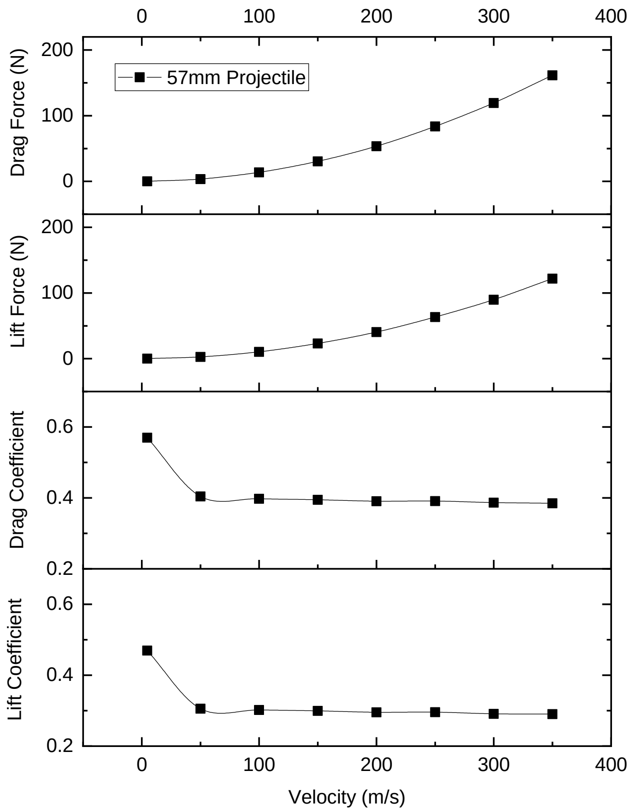


Figure 11: The lift and drag coefficient of 57 mm projectile at 45° AOA for supersonic speed.

B. Pressure and Velocity Simulation

The pressure was mostly felt at the front of the projectile at a 45° angle regardless of their sizes and shapes. The velocity plot shows the turbulence due to the shape of the projectiles. As the projectile size increases, the simulation's visual streamline shows that the smaller size projectile gets more turbulence compared to the large size projectile. The simulation pressure and velocity plots are shown for 37 mm and 57 mm projectiles in Figures 12 and 13.

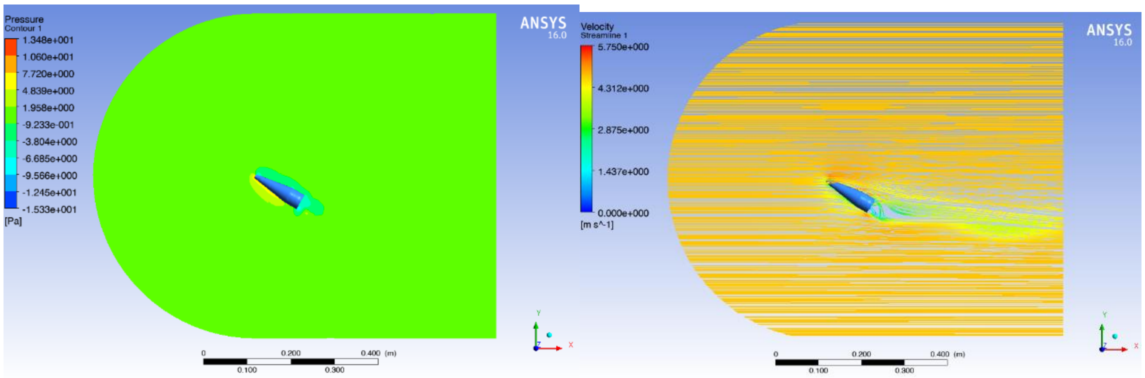


Figure 12: The pressure and velocity contour for 37 mm projectile at 45°AOA

The velocity of the air increases as the streamline passes over the projectile. The reason could be the shape of the projectiles. However, the velocity streamline plots show that the streamline is flowing over the 37mm projectile.

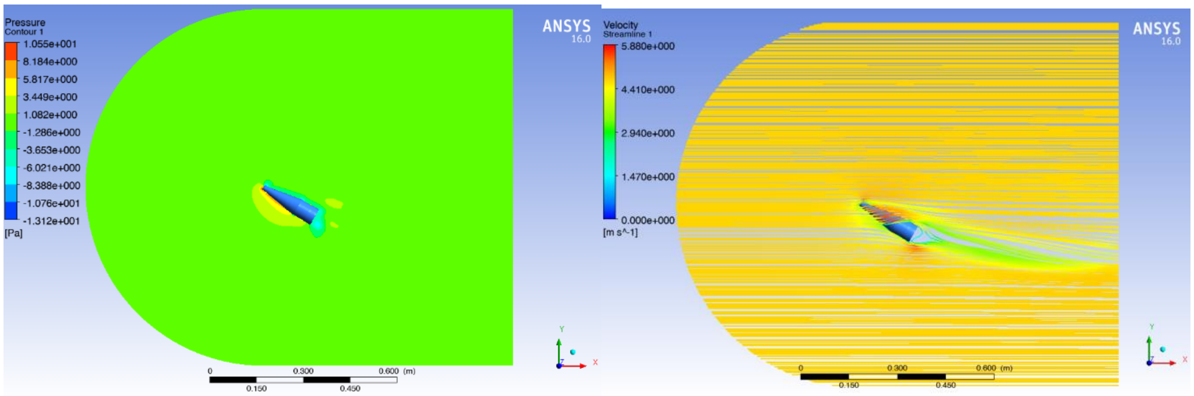


Figure 13: The pressure and velocity contour for 57 mm projectile at 45°AOA

VII. Conclusion

Aerodynamic parameters have a big impact on the range and accuracy of the projectile. The drag force will reduce the projectile range, and the lift force will increase the projectile range. For that, the main focus was given on the drag and lift forces of the projectiles both in experimental and Computational Analysis. In this study, the experiment was done on the projectiles model in a subsonic wind tunnel. Similar experimental conditions were applied for computational AnalysisAnalysis to investigate further parameters that cannot measure or visualize real-time through Ansys software. The projectile travels in the air at supersonic speed and not in subsonic speed. We have done the experiment at a subsonic wind tunnel. Herethe experiment is conducted at 4.7 m/s, which provides the initial flight scenario and its related aerodynamic parameters.

In our study, we have done one simulation at supersonic speed for 57 mm projectile through experimentally. It couldn't be done.The trend was familiar as the lift and drag coefficient changes near our experimental speed is almost negligible. The trend of the increase is found to be linear for subsonic airspeed. The lift and drag forces increase as the angle of attack increases.The lift forces increasing rate is a little higher, and it is similar for drag and lift coefficients.For the smooth conduct of the computational AnalysisAnalysis on the topic, experiment in a supersonic wind tunnel could have given more realistic results.

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