Dynamics of 125 mm High Explosive Projectile for Main Battle Tank

Md Rafiqur Rahman, Military Institute of Science and Technology, Mirpur Cantonment, Dhaka, Bangladesh

Abstract— In the battle field tank ammunition was mostly used to create punching hole in the armour of other tanks in the very early days. With the changing technology, tank has become a mobile gun platform to provide infantry the close fire sp. Now a days the main battle tanks are using high explosive projectiles for all round purpose. Success of those projectiles largely depends on the range and accuracy of it. Again, there are some impact factors like drag & lift for which the trajectory of those projectiles will be affected and in turn, it will affect its range & accuracy. As soon as the projectiles leave the muzzle, drag & lift forces and its coefficients affect it. Main Battle Tank uses 125 mm high explosive projectile for its main gun. Our study in this paper mostly focused on to determine the drag and lift forces and its coefficients for 125 mm projectile of Main Battle Tank during its flight. To study the drag and lift forces, experiment conducted in a open circuit subsonic wind tunnel. For the experiment-varied angles of the attack was considered and inclined manometer was used to find out the surface static pressure and drag force, lift force & its coefficient was determined from that. Finally, the experimental results obtained from wind tunnel numerically validated by Ansys software.

Index Terms— Wind Tunnel, Projectile, Computational analysis, Ansys software, Drag Force, Lift Force, Pressure Coefficient, Drag Coefficient, Lift Coefficient, Angle of Attack.

1 Introduction

TANKS are used more and more in the modern warfare to provide close support for infantry. In the battle field tanks often provides Infantry the rapid access through obstacles like wall or other barrier and help to destroy urban target such as enemy bunker or buildings in enemy area including enemy personal. In the primitive era tank ammunition was entirely devoted to improve the means of punching hole in the armour of other tanks. With the changing technology, tank has become a mobile gun platform to provide infantry the close fire support. Now a days the main battle tanks are using high explosive projectiles for all round purpose. Success of those projectiles largely depends on the range and accuracy of it. Again, there are some impact factors like drag & lift for which the trajectory of those projectiles will be affected and in turn, it will affect its range & accuracy. As soon as the projectiles leave the muzzle, drag & lift forces and its coefficients affect it.

Main battle tanks require effective weapon control system and gun system in order to achieve the highest hit probability. Weapon control systems used in main battle tanks to stabilize the line of sight and line of fire in order to increase the firing accuracy while Fire Control System determines the necessary motions of the gun and the conditions that will achieve the highest shot hit probability. Beside all these, when the projectile is in motion its trajectory affected both by gravity and by drag & lift forces. Here the drag and lift forces are the predominant factors. So it is very vital to determine these forces. Main Battle Tank uses 125 mm high explosive projectile for its main gun. This paper mostly focused on to determine the drag and lift forces and its coefficients for 125 mm projectile of MBT 2000 during its flight. Here experiment conducted in an open circuit subsonic wind tunnel available at MIST at varied angles of the attack and then experimental results validated numerically.

2 Glossary Of Technical Term

a. Drag Force & Its Coefficient

Drag force is a rearward, retarding force caused by disruption of airflow by the projectile body. Drag force work opposite to the relative motion of any object. Drag forces depend on velocity and it is proportional to the velocity. The drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object. The drag coefficient is always associated with a particular surface area.

b. Factors Affecting Drag

Drag influenced by following factors:

1) Density of the Air.
2) Nose shape, texture and weight of the projectile.
3) Viscosity of the area.
4) Projected area.
5) Speed of the projectile.
6) Angle of attack and
7) Boundary layer separation

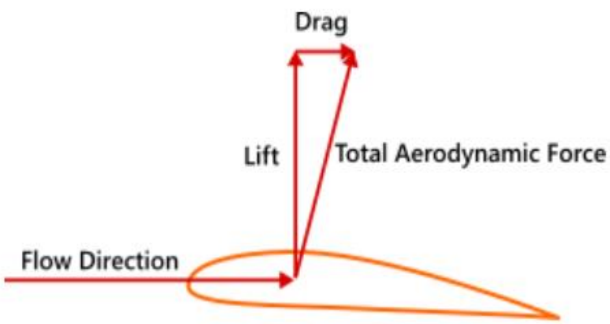

Figure 1: Drag and Lift Force

c. Lift forces and its Coefficient

Lift force produced by the dynamic effect of the air acting on the projectile and acts perpendicular to the flight path and perpendicular to the lateral axis. In level flight, lift opposes the downward force of weight. 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.

d. 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. However, as the angle of attack increases, the air deflected through a larger angle, and the vertical component of the airstream velocity increases, resulting in more lift.

e. 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. Every point in a fluid flow field has its unique pressure coefficient. in aerodynamics and hydrodynamics. Every point in a fluid flow field has its unique pressure coefficient.

3 Experiment

Presently MIST has a subsonic wind tunnel in the fluid mechanics laboratory and the experiment conducted in that wind tunnel where the dummy projectile placed at the exit end of the wind tunnel. 125 mm high explosive dummy projectiles considered for the experiment. The dimensions are collected from the commonly used projectiles for MBT 2000. At different angles of attack (less than 60o), experiment was done in the wind tunnel.

a. Wind tunnel

The test was done in an open circuit subsonic wind tunnel as shown in Figure 2. It was the low-speed wind tunnel having the maximum wind velocity of 4.7 m/s in the test section. The tunnel consists of various components such as fan, valve, silencer, honeycomb flow straightener. It is 6.16-meter-long with a test section of 490-mm x 490-mm cross-section. To make the flow uniform a honeycomb is fixed near the end of the wind tunnel. There is a converging bell mouth shaped entry. To generate the wind velocity, two axial flow fans are used.

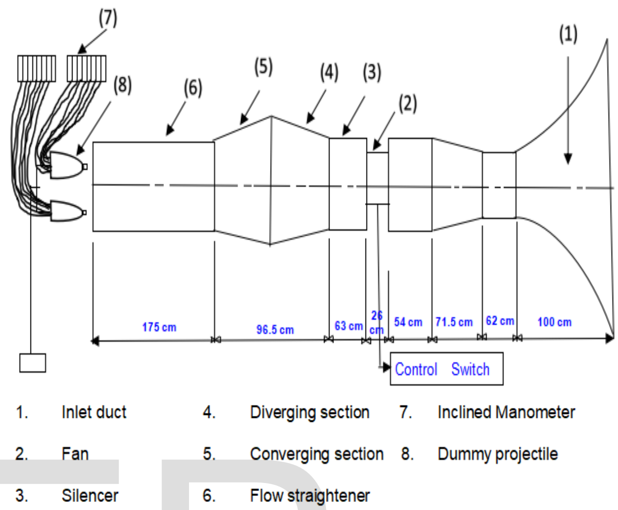

Figure 2: Schematic diagram of a wind tunnel

Each of the fans connected with the motor of 2.25 kilowatt and 2900 rpm. There is a regulator to control the wind speed. There is a silencer as shown in the figure. The control longitudinal axis of the wind tunnel maintained at a constant height of 1010 mm from the floor. The axis of the model coincides with that of the wind tunnel. The converging mouth entry incorporated in the wind tunnel for smooth entry of air into the tunnel to maintain uniform flow into the duct-free from outside disturbances. The induced flow through the wind tunnel produced by a one-stage rotating axial flow fan of capacity 10.20 m3/s at the head of 152.4 mm of water and 1475 rpm.

A variable frequency drive used to control the flow. A silencer fitted at the end of the flow controlling section to reduce the noise of the system. This section is having a honeycomb. The diverging and converging section of the wind tunnel is 965 mm long and made of 18 GMS sheets. The angle of divergence and convergence is 29 degre which has been done to minimize expansion and contraction loss and reduce the possibility of flow separation. After the diverging section, there is a 175 cm long flow straightener to convert the angular flow into straight & horizontal directions. Wind velocity measured directly with the help of a digital anemometer. The flow velocity in the test section is 4.7 m/s approximately.

ISSN 2229-5518

b. Test Section

The reading was taken at the exit end of the wind tunnel in the open air as shown in Figure 3. The projectiles placed at the same level as the wind tunnel at the exit end. In the middle of the dummy projectile, grooves prepared and connected with a plastic tube. Either side of the plastic tube connected with an inclined multi-manometer. Circular projectiles was equally spaced and made 30 grooves for 125 mm projectiles. Each manometer made with 30 tubes and connected with projectile grooves. 30 scales were fixed along the 30 tubes in the manometer to take the reading.

Figure 3: Wind tunnel test section

The projectiles 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 placed at the exit end of the wind tunnel first line at 30o angle of elevation. Then it was gradually elevated at the interval of 5o each and data recorded. In this way, projectiles were elevated up to 50o and necessary data recorded and subsequently, calculations carried out.

c. Preparation of Wooden Model (Dummy Projectile)

Projectiles of existing medium Tank used for the preparation of the model. Here we have selected 125 mm projectile of MBT 2000. We have prepared the dummy model by wood. The model was made of seasoned teak wood to avoid bucking and expansion due to the change in weather. The wooden dummy model shown in figure 4. Projectile contained 30 tapping and distance between the consecutive tapping points was equal. Inner Diameter of each tapping point is 1 mm.

Figure 4: Dummy wooden model and the original 125 mm HE projectile

Each tapping was identified by a numerical number from 1 to 30 and tapping's were made along the circular-section of the projectiles. Keeping the outside of the projectiles intact the inside of the projectiles made hollow, through which the plastic tubes allowed to pass. The plastic tubes 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.

d. Requirement of dummy model

For determining drag and lift, studies with the dummy model and full-scale projectile are performed to validate the model. However, full-scale experiments are both costly and difficult to perform. For this study with 125 mm projectiles, full-scale experiments will be a complex and costly. At the same time, it will be difficult to record reliable pressure distribution simultaneously. The flow around projectile in the actual environment is very complex and formulation of a mathematical model to predict the flow is almost impossible. Thus for solution accuracy dummy model study of 125 mm tank projectile and various data obtained from the simulation will become very handy for practical analysis.

e. Experimental Conditions

The angle of attack for measuring the static pressure of 125 mm projectile will be within 30° to 50° with a interval of 5°. The static pressure was measured with a manometer and it had a minimum deflection of 1 mm. Air velocity found in wind tunnel test section is 4.7 m/s. After obtaining, the experimental data Computational Fluid Dynamics (CFD) simulation was done with ANSYS Multiphysics software on similar conditions to compare the experimental and simulation results.

4 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 4.7 m /s, measured directly with an anemometer, which 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
Δlk = Manometer reading
ρk = 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
P_{air} = the density of the air
U_∞ = the free stream velocity
In our experiment ΔP can be obtain 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 (CD) 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.

$F_1 = P * S projected\ 1 \ldots \ldots \ldots \ldots \ldots \ldots (2)$

Then the Total Force acting on the Projectile will be

$F_1 = F_1 + F_2 + F_3 + * S projected\ 1 \ldots \ldots \ldots + F_n \ldots \ldots (3)$

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.

$$L_D = F \cos \alpha \ \ldots \quad \ldots \quad \ldots \ (4)$$
$$L_L = F \sin \alpha \ \ldots \quad \ldots \quad \ldots \ (5)$$

Now with the help of Drag and Lift forces, Drag and Lift Coefficient can be determined.

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

Where,
STotal = Total Active Projected Area (S1+S2+S3+………+Sn)

5. Computational Simulations

a. Solid works of the Model

A SolidWorks model of 125 mm projectile is made and the projected area of each strip is measured by using SolidWorks 'evaluate' tool. The segment numbers on the projectiles are different. The top and bottom surface of the projectile is segmented into equal segments and they are connected with 3D drawings. A 2D drawing was drawn on a plane facing the air and the area of all segments was not calculated. The back of the projectile can't be seen due to the angle. As they can't be seen from the front of the plane facing the wind, turbulence could create fluctuating pressure in those manometer reading and that is not very dependable. Figures 5 show the projected area measurement by SolidWorks.

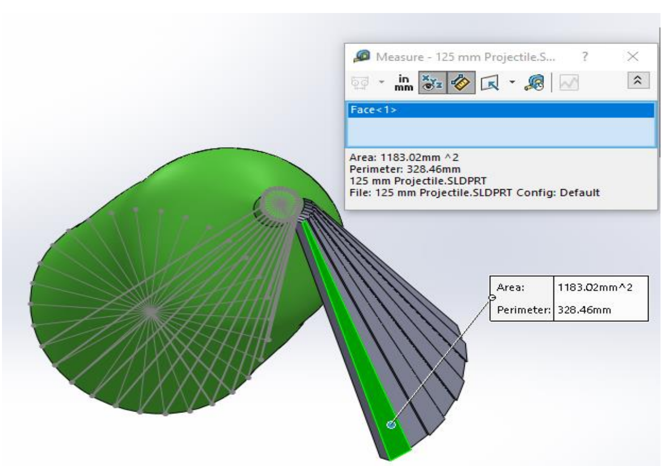

Figure 5: Measurement of the projected area.

b. Geometrical setup

For the computational simulation, we need to prepare the geometry of the projectile. Here we have considered the dimensions of 125 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 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 125 mm projectiles.

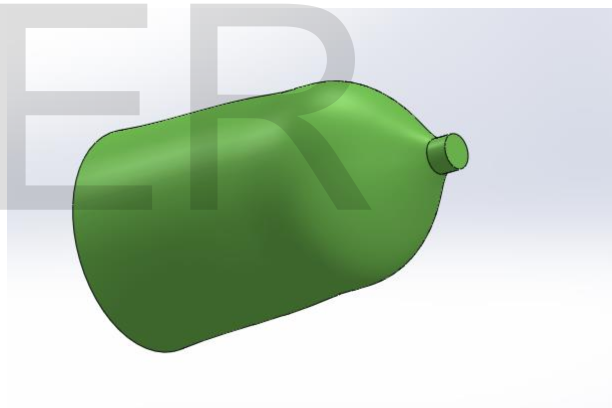

Figure 6: Geometry files for CFD simulation of 125 mm Projectiles

c. Meshing and other Simulation of Projectile

Unstructured meshing of the projectile was done for physical simulation i.e for finite element analysis or Computational Fluid Dynamics. 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. 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.

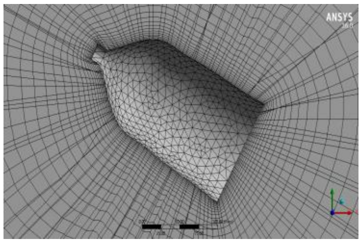

Figure 7 : Mesh for 125 mm (zoomed) Projectiles

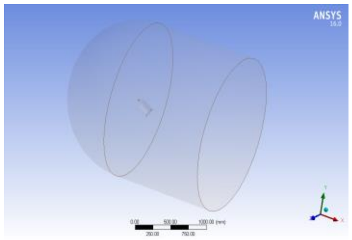

Figure 8 : Ansys CFD Simulation setting.

The results obtained during the grid dependency tests a finer mesh are compared with a coarse mesh. The pressure coefficient found for the finer mesh varies with the coarse mesh by 0.64% which is concurrent to the dependency test. At the outlet, the pressure outlet condition is applied in the domain. The steady and incompressible flow of air is considered in this Analysis. In these calculations, the second-order upwind scheme based on a multidimensional linear reconstruction approach is used. The simple algorithm for pressure velocity coupling with a second-order upwind discretization scheme is used to obtain a solution for the equations of Momentum, Turbulence Kinetic Energy, and Turbulence Dissipation Rate.

6. Results And Discussion

A dummy model of 125 mm high explosive tank projectile tested in front of wind tunnel at varied angle of attack to determine the effect of drag and lift. After taking physical test reading, the validation done numerically. From the wind tunnel primarily with the help of inclined manometer, the static pressure on the surface of the 125 mm projectiles at various angles of attack measured, then the distribution of the static pressure coefficients on the surface of the projectile compared numerically.

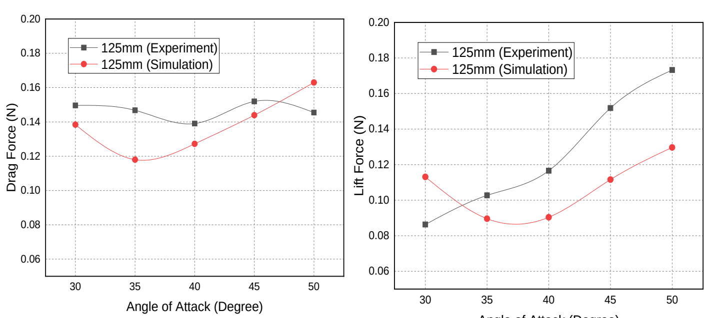

Figure 9 : Angle of Attack Vs Drag and Lift Force

Finally, the drag & lift forces and its coefficient also compared. Combining the drag and lift forces acting on each segment of the projectiles, the total force acting on the project tile can be determine. Results for the CFD analysis of the dummy projectile models obtained during validation. For the angle of attack 50°, the drag forces for 125 mm projectile found 0.1629 N and lift forces increase by 0.1296 N for 125 mm projectiles. Drag force and lift force Vs angle of attack is shown in Figure 9.

In this study, the rate of increasing the lift forces is more than the drag forces. As the angle of attack increases the drag force increases but after 45° it is decreasing. Lift forces increases continuously with the increase of angle of attack. There was some deviation between the experimental and simulated findings which can be coming from the lack of precision measurement, the ignored friction coefficient of the projectile surface, and the geometrical inaccuracy due to manual fabrication. The overall experimental drag coefficients is higher than simulated drag coefficients and it is same for the lift coefficient.

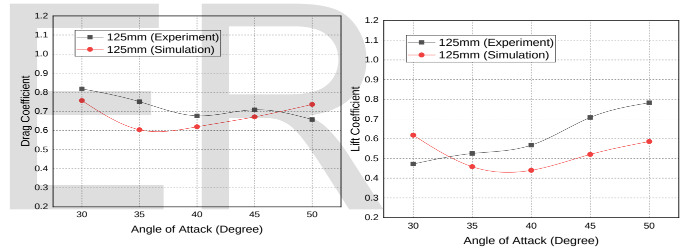

Figure 10 : Angle of Attack vs Drag and Lift Coefficients.

The deviation between the experimental and simulated results may be the result of 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 1 and Table 2 shows the corresponding data for drag and lift coefficients.

Table 1: Simulation and Experimental Drag Coefficients of 125 mm Projectiles

Angle of Attack (°)	125S	125E	125 S-E Error(%)
30	0.138	0.149	7.49
35	0.118	0.147	19.5
40	0.127	0.139	8.5
45	0.144	0.152	5.2
50	0.163	0.145	12.0

Table 2: Simulation and Experimental Lift Coefficients of 125 mm Projectiles

Angle of Attack (°)	125S	125E	125 S-E Error(%)
30	0.083	0.086	3.7
35	0.089	0.103	12.7
40	0.109	0.117	6.4
45	0.131	0.152	13.3
50	0.149	0.173	13.5

The visual streamline from the simulation shows less turbulence at the back of 125 mm projectile due to its bigger size. The simulation pressure and velocity plots shown in Figures 11. The pressure mostly felt at the front of the projectile at 45° angle regardless of their sizes and shapes. The velocity plot shows the turbulence due to the shape of the projectiles.

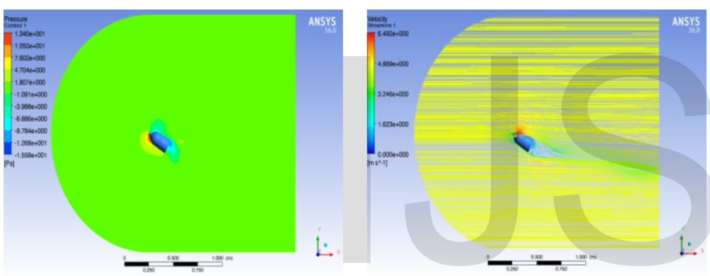

Figure 11 : The pressure and velocity contour for 125 mm projectile at 45°AOA

The velocity of the air increases as the streamline passes over the projectile. The reason could be the shape of the projectiles. The velocity streamline plots show that 125 mm projectile does not show any streamline flowing over them due to its little bigger shape. Therefore, the drag forces should be higher for larger projectiles. Now findings from the experiment and numerical simulations are as follows:

a. The drag and lift forces are found to be the function of the projectile sizes. For the angle of attack 50°, the drag forces of 125 mm projectile is 0.1629N. The lift force also increases by 0.1296 N but the rate of increasing for lift forces is more than the drag forces. Therefore, a large size projectile has the larger drag and due to its size, the lift force also increases.

b. The lift and drag forces are also a 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.

c. 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.

d. The simulation for the pressure contour of 125 mm projectiles shows that the maximum pressure is generated at the front where the air hits. This result validates the experimental findings where it was observed that the manometers at the front tapping points provide positive displacement and as the tapping points move away from the front the manometer deflection reduces gradually and after some point, it deflects the other way due to the negative pressure.

7. Recommendation

For the smooth conduct of the thesis and also for subsequent study on a similar topic following recommendation are made:

a. The manufacturing of the projectiles model should be done with metal in CNC lathe to get realistic and more accurate results.

b. The experiment should have been done in supersonic wind tunnel to get precision measurement.

c. The flow behaviour around the projectile and effect of Reynolds number may be taken into consideration.

d. In future along with the study of drag and lift force, the design parameter of the projectiles should be studied. It will widen the scope for redesigning the projectile with optimized parameters with increased range and accuracy and with lesser effect of drag & lift forces.

8. Conclusion

The experiment was done on the 125 mm projectiles model in a subsonic wind tunnel and similar experimental conditions were applied for numerical validation to investigate drag and lift forces and also its coefficients. Both experiment and numerical simulation shows that once the projectile is in flight it is affected by drag & lift forces. These drag and lift forces increases with the increase of size and with the increase of angle of attack. Experiment results and numerical simulation also shows significant pressure develops at the front of the projectile which will directly affect its range & accuracy. So drag and lift has a big impact on the range and accuracy of the 125 mm high explosive projectile. The drag force will reduce the projectile range and lift force will increase the range of the projectile.

I have carried out the experiment in a subsonic wind tunnel but the projectile travel in the air at supersonic speed and not in subsonic speed so the results obtained from my experiment may vary for supersonic wind tunnel. At the same time there was some deviation between the experimental and simulated findings which may occur due to lack of precision measurement, the ignored friction coefficient of the projectile surface, and the geometrical inaccuracy due to manual fabrication. Besides, experiment was done in wind tunnels which may have underestimation of crosswind effects and model preparation also could not be done very accurately for that the experimental and simulation results show some deviation.

REFERENCES

Conference paper

[1] Mohammad A. D. and Slobodan J. , " Various Methods of Artillery Projectiles Base Drag Reduction", 8th International Scientific Conference on defence Technology Belgrade, Serbia, October 2018.

[2] 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.

[3] 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.

[4] Elsaadany A. and Wenjun YI., "Investigation on Trajectory Correction for Typical Artillery Projectiles", 5th International conference on Mechanical Engineering and Mechanics, China, August 2014.

[5] 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.

Individual Research/ Symposium / Scientific Paper

[6] Goran. J. O., Bosko P. R. and Aleksandar C. B., "Aerodynamic Shape Optimization of Guided Missile Based on Wind Tunnel Testing and Computational Fluid Dynamics Simulation", Serbia, Scientific Paper, Vol. 21, No. 3, pp. (1543-1554), 2017.

[7] 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.

[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] Motyl K., Magier M. and Zygmunt B., "Theoretical and Experimental research of Anti Tank Kinetic Penetrator Ballistics", Bulletin of Polish Academy, Poland, Vol. 65 No. 3, 2017.

Journals/Articles

[10] Chand K. K. and Pattnaik S., "Modeling Projectile Motion: A System Dynamics Approach", International Journal on Information Science and Computing Orissa, India, Vol.2, No.1, July 2008.

[11] Sahoo S. and Laha M.K., "Coefficient of Drag and Trajectory Simulation of 130 mm Supersonic Artillery Shell with Recovery Plug of Fuze", Defence Science Journal, India, Vol. 64. No. 6. pp. (502-508), November 2014.

[12] Jian S., Shaobo F., Yaxin J., Zhu Q. and Duan J., "Aerodynamics Analysis of a Hypersonic Electromagnetic Gun Launched Projectile", Journal Pre-Proof, China, Ref. DT 592, January 2020.

[13] Shubnam J., Nekkanti S. and Sriram K., "Effect of Reynolds Number on Aerodynamics of Airfoil with Gurney Flap", International Journal of Rotating Machinery, India, Vol.2015, August 2015.

[14] Kiran. and Basawaraj, "Drag Prediction and validation of Standard M549, 155mm Projectile", International journal of Engineering Research and Reviews, India, Vol-2, Issue 3, pp. (26-32), 2014.

[15] Tolga D., Firat B. and Utlu C.,"A Review of Gun Barrel Vibration and Control for a Main Battle Tank ", International Journal on defence technology 13, Turkey pp (353-259), May 2017.

[16] Sangeeta S. P., Gite L. K., Anandaraj A. and Rajan K. M., "Dispersion Sensitivity Analysis & Consistency Improvement of APFSDS", International Journal on defence Technology 13, India, pp (316-322), May 2017.

[17] Magier M., "The Conception of The Segmented Kinetic Energy Penetrators for Tank Guns", International Journal of applied Mechanics, Poland, Vol. 77, September 2010.