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A NUMERICAL STUDY OF FLOW OVER A PROJECTILE

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ABSTRACT

Numerical study of flow over a projectile of circular arc profile with straight aft end is carried out by varying the nose angle and base radius for a supersonic case. Four different cases of base radius with seven values of nose angles are taken for simulation. Two dimensional axisymmetric Euler equations are solved using pressure correction technique to get the converged solution. The results show the effect of curvature of projectile profile on the aerodynamic characteristics and various flow field parameters. Drag is taken as the vital parameter to optimise the geometry of projectile. It is observed that the optimum geometry at which drag is minimum has nose angle between 6.225° to 5.274° irrespective of the base radius.

***Keywords*:** Drag coefficient, Projectile, Nose angle, Base radius, Recirculation

1 Introduction

The main objective while designing a projectile is to maintain a specific range so that the missile or projectile can hit the target. Usually flight range is reduced by the drag forces experienced by the projectile. Many researchers have investigated about the drag forces at the nose [1, 2] and at the base [3–5] . Research works on computational analysis for pressure distribution, shock wave interaction and calculation of aerodynamic coefficients of different shapes of projectiles have also been done [6, 7].

As base drag is very dominant in case of a projectile, it can be reduced by using base cavities, ventilated cavities, locked vortex afterbodies, multistep afterbodies and afterbodies employing a non-axisymmetric boattailng concept of base in the absence of jet flow at base [8]. Suliman et al. [5] did numerical study on base drag coefficients for 155mm artillery shell with boattail, base cavity or base bleed. They found that bottail geometry having angle 9.5° reduced the drag coefficient by 50% in both subsonic and transonic regime and 12% for supersonic regime. For 15° angle the drag reduction was 55% in subsonic flow. Base cavity caused smallest reduction (1%-2%) , but base bleed provided a reduction of 50% at subsonic and transonic flow and 10% at supersonic flow. For combination of the three effects, 60% drag reduction for subsonic and 20-30% reduction for transonic and supersonic regimes were observed.

Now-a-days different shapes of missiles have come into existence having speeds ranging from subsonic to hypersonic. Still research is going on for effective modifications in geometry of various missiles or projectiles. Computational analysis on this topic is getting importance. Three dimensional flow field analysis for different projectile shapes like secant-ogive-cylinder-bottail (SOCBT) configuration for different flow conditions and angles of attack was done by using flux split algorithm by Sahu [9]. Al-Kayeim et al. [10] used explicit technique with about 4000 time steps to achieve converged steady state solution (artificial viscosity 0.5). They captured the shock wave and aerodynamic flow field parameters around a seamless missile.

As drag depends more upon the profile or orientation of a projectile, so here a parametric study is done on variation of drag coefficient by varying the geometry of the projectile. Steady state solution is obtained by solving Euler equations for supersonic flow regime. The objective of this paper is to analyse the effect of certain geometrical parameters of the projectile on the aerodynamic characteristics of the projectile. Emphasis is placed on proposing the optimum design parameters of the projectile which can give the minimum drag.

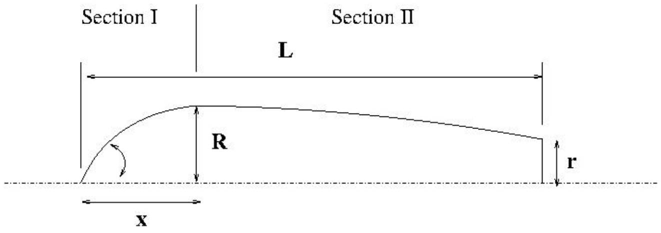


FIGURE 1: Geometry of projectile

2 Physical Model

Projectile geometry of length (L) 1m, radius (R) 60mm is chosen for numerical analysis which is shown in figure 1. Both L and R are kept constant for the entire study. The profile of the projectile consists of two different arcs; nose section (section I) and body section (section II). The variable parameters are base radius (r), which is varied as 0.3×R, 0.5×R, 0.7×R, 0.9×R and angle (α) made by the tangent to the arc of the nose profile with the axis of the projectile. By varying the angle α, x varies. For different values of x, drag coefficient (Cd) is calculated.

In this numerical analysis compressible flow is considered and two dimensional axisymmetric Euler equation is solved. In case of high speed flow around a projectile the value of Reynolds number is very high. Also the effect of turbulence is restricted only in thin boundary layers. In these high speed flows two types of drag is observed: frictional drag (due to boundary layer) and pressure drag or form drag. However, it should be noted that the viscosity does not have significant effect on the projectile aerodynamic characteristics [11]. To analyse the compressible flow around a projectile along with continuity and momentum equations, two other equations have to be solved, i.e conservation equation for thermal energy or total energy and the other is equation of state. Here, viscous effect is not considered, so energy equation is reduced to total enthalpy equation.

3 Results and Discussion

The important parameter based on which the comparisons of different shapes of projectiles are done in this numerical study is the drag force. At high speed viscosity of air has not much effect on drag force; therefore, it can be neglected [11]. Therefore skin friction drag has no significant contribution towards total drag. Generally pressure drag constitutes maximum percentage of the total drag experienced by a projectile. Therefore in this numerical analysis calculation of total drag is done using the pressure drag. The drag coefficient is calculated by using the formula:

$$C_d = \frac{F_D}{0.5 \times \rho_\infty \times A \times U_\infty^2} \tag{1}$$

where, F_D= drag force, ρ_∞= free stream density, U_∞= free stream velocity, A = frontal area
Input parameters are:
temperature = 288K
pressure =1bar
density of air=1.2kg/m^3

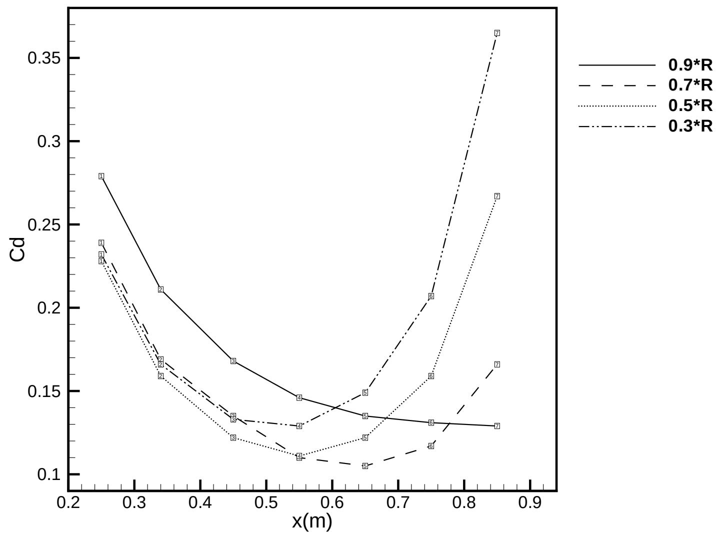


FIGURE 2: Variation of drag coefficient with x for different base radii

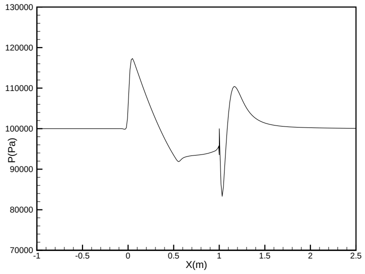
specific heat of air = 1.005 KJ/kg.K
Inlet velocity = 408.2 m/s

3.1 Drag coefficients:

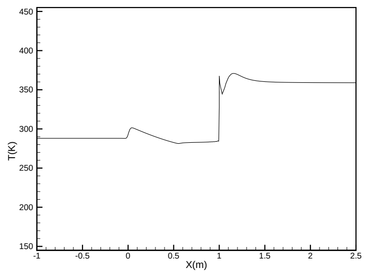
Figure 2 presents the comparison of drag coefficients for different shapes of projectiles with different base radii. The comparisons can be done in two ways: (i) By fixing x and varying base radius (r) and (ii) By fixing r and varying x. From the above plot, it is observed that at a particular base radius, the drag coefficient at first decreases with increase in x. After reaching a certain minimum value, it further increases. But exception is noticed in case of 0.9×R, i.e 54 mm base radius. For this case Cd consistently decreases with increasing value of x. But when the value of x is kept constant the variation of Cd with r follows no specific pattern. For x upto 0.45 Cd declines till a certain value by decreasing r; then its value goes up. For a larger value of x (smaller is the value of nose angle), drag becomes less when radius of the aft end of projectile is more. At subsonic speed, at a lower x value, Cd decreases when a decrement is made in r. But at higher values of x, Cd is minimum for the higher value of base radius (r).

From the above plot, it can be concluded that at supersonic speed minimum drag occurs in case of r = 0.7×R (42 mm) and x = 0.55-0.65 (nose angle 6.225-5.274). Therefore, the optimal design parameters, i.e. r= 0.7×R(42 mm) and x= 0.55, are considered for a comparative analysis of variation of pressure, temperature, and Mach number (refer figures 3).

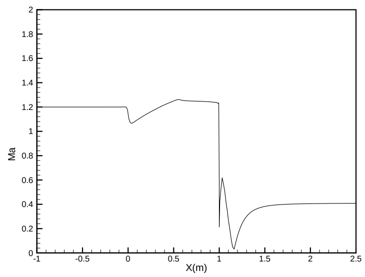
According to Fig.3a, at supersonic speed there is a sudden rise in pressure at nose tip. At this point, the pressure turns out very high, then it gradually decreases till the mid portion of projectile body. Here pressure is less than atmospheric, then it intensifies towards the aft end of missile/projectile body. But at base there is an abrupt change in pressure. It becomes very low (much less than atmospheric pressure) exactly at the base due to recirculation of air at the base and then it goes up to a high value (not as much



(a) Variation of pressure



(b) Variation of temperature



(c) Variation of Mach number

FIGURE 3: Variations of different parameters on projectile surface at supersonic speed

it is at nose tip). At the base region there seems a large variation of pressure, which is the main cause for the drag experienced by the projectile at higher speeds. After that, again the pressure decreases and becomes atmospheric.

The temperature at the negative pressure region at the base is higher than any other point of projectile body including the nose tip also. At this region, exactly at the base end of projectile a sudden upswing in temperature occurs, then it again drops slightly and again increases and falls down to a steady value. This steady value of temperature is much higher than ambient temperature of 288K in case of supersonic speed, but in subsonic and transonic cases it is not that much high as compared to ambient temperature. At nose tip temperature is also more than 288K, but it goes down gradually towards the body section. The Mach number variation is shown in figure 3 (c). In the dead air region the reattachment point occurs at 0.18 m from the base of projectile.

4 Conclusion

Two dimensional axisymmetric analysis is done for projectile of circular arc profile. It is noticed that the circular arc profile of projectile has a significant effect on the vortex formed at the base of the projectile. The projectile profile should be adopted to increase the base pressure by decreasing the recirculation generated in the dead air region. Therefore, while changing the profile to decrease the base drag, the increase in the curvature of body of the projectile creates a low pressure region over the projectile surface. This low pressure region over the body section of the projectile has some contribution towards the drag force. By considering the drag coefficients and variation of different flow field parameters it can be concluded that with x value ranging between 0.55 to 0.65 (nose angle 6.225°to 5.274°), an optimum geometry can be obtained for a projectile with circular arc profile at a particular base radius.

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