COMPUTATIONAL STUDY OF SUPERSONIC FLOW PAST BLUNTED TANGENT-OGIVE NOSE CONE

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ABSTRACT

The present study numerically investigates the supersonic flow past a blunted tangent ogive at Mach number 2. The various parameters that play a significant role in modifying the aerodynamic characteristics of the nose cones are bluntness ratios and ogive radius. The studies were conducted on bluntness ratios of 0.4 and ogive radius of 100,150,200 and 250 mm in order to ascertain the optimized blunted tangent ogive nose cone geometry that provides minimum drag. The structure of the bow shock formed ahead of the nose as well as the shock detachment distance is represented by the Mach number contour. It is observed that the aerodynamic drag attains a minimum value at higher ogive radius for a fixed bluntness ratio. Thus, the current study adequately illustrates that the blunted tangent ogives are crucial for accomplishing better performance (i.e., minimum drag) in supersonic vehicles.

Keywords: Aerodynamic drag, blunted tangent ogive, bluntness ratio, ogive radius, supersonic flow.

Nomenclature: C_d=total drag coefficient, C_p=pressure coefficient, M=Mach number, r=Nose Radius, R=Base radius, r/R= Bluntness ratio, ρ=Ogive ratio, δ (Δ) =Shock detachment distance.

I. INTRODUCTION

The need to design long range and efficient supersonic flight vehicles has motivated the classical approach of minimum drag geometry in supersonic flow. An appreciable drag reduction can be achieved by optimizing the nose cone geometries. In this study, a numerical simulation is carried out to predict the aerodynamic characteristics of blunted tangent ogives of different configuration in order to obtain optimum nose cone geometry for min aerodynamic drag. Ogive nose cone is similar to conical shape except that the platform shape is formed by arc of circle instead of straight line. It has slightly greater volume for a given base and length, a blunt nose providing structural superiority and slightly lower drag than the conical section. The shape of the bow shock formed ahead of nose cone, shock detachment distance etc. play a very significant role in controlling the performance (i.e. drag reduction characteristics) of blunted nose cone. Relevant literatures on the supersonic flow past over blunted tangent ogives are discussed here-

Owens [1] experimentally studied the effect of bluntness ratios on the aerodynamic characteristics of the nose cones for the range of Mach numbers from 0.5 to 5. It was observed that at higher Mach numbers, the effect of bluntness on the aerodynamic characteristics such as normal force coefficient, fore body drag coefficient etc., were significant for the smaller semi-cone angles whereas it is insignificant for the larger ones.

Perkins [2] measured the drag and pressure distribution on a series of hemispherical blunted nose cones at zero angle of attack for the range of Mach numbers and Reynolds numbers from 1.24 to 7.4 and 1.0×10^6 to 7.5×10^6. He found that the diameter of the hemispherical tip might be quite large without clearly increasing the fore drag over that of a sharp pointed cone of the same fineness ratio.

Egger [3] performed the analytical and experimental comparison on supersonic flow past over a several bodies of revolution of fineness ratio of 3 and 5 and Mach numbers from 2.73 to 6.28. This calculation was carried out by for the same given conditions as calculated by newton's law of resistance. It is verified, that the body having the blunt shape has 20 percent less fore drag coefficients than a cone of the same fineness ratio.

II. OBJECTIVE

The paper focuses in providing a detailed numerical study to determine the effect of nose cone parameter like bluntness ratio and ogive radius on flow characteristics such as aerodynamic drag, pressure coefficient, shock detachment distance (standoff distance) etc. The shock layer, shock detachment distance, location and shape of the bow shock etc., play a significant role in modifying the aerodynamic performances (i.e., drag reduction for efficiency enhancement), which finds enormous applications in the design of high speed aerodynamic vehicles. The studies were conducted for different combinations of two different bluntness ratio 0.4 and four different ogive radius of 100,150,200 and 250mm. The physical differences in flow characteristics of different blunted ogives are systematically compared using Mach number contours, shock detachment distance etc. For sake of comparison, entire studies were conducted by maintaining base radius (R) of nose cone as constant i.e. 25 mm.

III. DESIGN PROCEDURE FOR THE BLUNTED TANGENT OGIVES

A blunted tangent ogive is formed by capping tangent ogive nose with a segment of sphere. The following technique given below is adopted in the present study for the outline of various blunted tangent ogives nose cone models for increasing the drag reduction performance-

$$x_0 = L - \sqrt{(\rho - r_n)^2 - (\rho - R)^2} \quad \dots (1)$$

$$y_t = \frac{r_n(\rho - R)}{\rho - r_n} \quad \dots (2)$$

$$x_t = x_0 - \sqrt{r_n^2 - y_t^2} \quad \dots (3)$$

In all these models, the base radius of nose cone was maintained constant for unique comparison among the different geometries. A total of eight different blunted tangent geometries were considered in the present simulation for geometric optimization and hence to determine the nose cone geometry which provide minimum aerodynamic drag.

IV. GOVERNING EQUATIONS

$$\frac{1}{r}\frac{\partial(\rho r u_r)}{\partial r} + \frac{\partial(\rho u_x)}{\partial x} = 0 \qquad \dots (4)$$

$$\frac{1}{r}\frac{\partial(\rho r u_r u_r)}{\partial r} + \frac{\partial(\rho u_x u_r)}{\partial x} = -\frac{\partial p}{\partial r} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(\frac{\partial u_r}{\partial x} + \frac{\partial u_x}{\partial r}\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(2\frac{\partial u_r}{\partial x} - \frac{2}{3}(\nabla.\vec{u})\right)\right] - 2\mu\frac{u_r}{r^2} + \frac{2}{3}\frac{u_r}{r}(\nabla.\vec{u}) + \rho\frac{u_x^2}{r} \qquad \dots (5)$$

$$\frac{\partial(\rho u_x u_x)}{\partial x} + \frac{1}{r}\frac{\partial(\rho r u_x u_r)}{\partial r} = -\frac{\partial p}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(2\frac{\partial u_x}{\partial x} - \frac{2}{3}(\nabla.\vec{u})\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial u_r}{\partial x} + \frac{\partial u_x}{\partial r}\right)\right] \qquad \dots (6)$$

$$\nabla.E_t v = \rho f.v - \nabla.q - \nabla p.v \qquad \dots (7)$$

V. SOLUTION METHOD

5.1 COMPUTATIONAL DOMAIN, BOUNDARY CONDITION AND GRID INDEPENDENCE TEST

The computational domain is limited to 24 R and 16R in the axial and radial directions for predicting the multifaceted flow/shock features around the blunted tangent ogive for different nose cone configurations. The computational grid with varying mesh was constructed using CFD for supersonic flow past a blunted tangent ogive.

The grids with number of cells varying from approximately 150000 -200000 were generated for different bluntness ratios and different ogive radius. The grids were made fine in the shock dominated regions in order to capture the multifaceted flow/shock structures and coarse where the flow effects are less. The grid sensitivity studies were carried out by varying the number of cells as: 150000, 175000 and 200000. The study revealed that the current results obtained with 150000 cells at r/R value of 0.4 and different ogive radius of 100,150,200,250mm are almost invariant to further grid refinement. The variation of static temperature and pressure coefficient with the upper body respectively for various grids is shown in Fig. 1 for a bluntness ratio and ogive radius of 0.4 and250 mm.

VI. TURBULENCE MODEL

The Spalart-Allmaras turbulence model is a moderately simple one-equation and low-cost RANS (Reynolds Averaged Navier Stokes) model that solves a modeled transport equation for the kinematic eddy (turbulent) viscosity near the wall. The transported variable in the Spalart-Allmaras model is equivalent to the turbulent kinematic viscosity (i.e., kinematic eddy viscosity) except in the viscous-affected (near-wall) region.

VII. VALIDATION

7.1 COMPARISON OF SHOCK DETACHMENT DISTANCE OBTAINED FROM THE CURRENT OBSERVATIONS WITH THE THEORY

The Mach number contour and its enlarged view depict the estimation of shock detachment distance in the present numerical simulation of the supersonic flow past a blunted tangent ogive. The shock detachment distance obtained from the present computations for bluntness ratios of .4 at ogive radius of 100mm is compared with theoretical relation for shock detachment distance given by T.S SANKARA and S.K Sreekanth in

JOURNAL OF APPLIED PHYSICS (1997). It is noticed that the predicted shock detachment matches well with the theory and the equation given in the respective journal for an r/R value of 0.4. It is observed from the predictions and theory that the detachment distance is seen to be dependent on the nose radius. The theoretical formula given below (from the Journal of applied physics (1997)) for detachment distance is only a function of nose radius and Mach number which seems to be highly accurate for the entire ogive radius.

$$\frac{\Delta}{D} = 1 - [1 - \frac{4}{(\gamma+1)^2}\left(\frac{1}{M^2} + \frac{\gamma-1}{2}\right)]^{1/2} \qquad \dots (8)$$

VIII. RESULTS AND DISCUSSIONS

8.1 VARIATION OF MACH NUMBER AND STATIC PRESSURE WITH POSITION ALONG THE AXIS OF A BLUNTED TANGENT OGIVE

The variation of Mach number and static pressure with position along the axis of a blunted tangent ogive at an r/R value of 0.4 is shown in Fig. 2 & Fig. 3 respectively for different ogive radius of 100,150,200,250mm. It clearly shows the location of bow shock near the nose cone surface represented by sudden jump in the Mach number and static pressure plots. The distance between the nose surface and the normal component of the bow shock is known as shock detachment distance, which occurs as sharp change in the slope of the Mach number/static pressure plots. The sharp decrease of Mach number is accompanied by the corresponding increase of static pressure due to the formation of bow shock and is represented as change of slope for both the r/R (0.4) and the different ogive radius of 100,150,200and 250mm.

8.2 VARIATION OF PRESSURE COEFFICIENT ALONG THE CONE SURFACE FOR A BLUNTNESS RATIO AND DIFFERENT OGIVE RADIUS

The variation of pressure coefficient with position along the surface of blunted tangent ogive for various bluntness ratio of 0.4 and different ogive radius of 100, 150, 200 and 250mm is shown in Fig. 4. It is observed that the pressure coefficient decreases sharply from the nose to a certain distance along the wall (i.e. for the nose cone part), then slightly increases and after that (i.e. for the ogive part) starts decreasing slowly. The reason for the higher pressure observed near the nose might be due to viscous interaction, which decays further downstream pressure distribution, approaches the inviscid value far downstream from the nose. it is observed that for a particular r/R value of 0.4, the pressure coefficient decreases on increasing the ogive radius.

8.3 VARIATIONS OF DRAG WITH INCREASE IN OGIVE RADIUS AT A PARTICULAR BLUNTNESS RATIO

The variation of total drag (i.e., pressure drag + viscous drag) for different ogive radius of 100,150,200,250mm at a bluntness ratio of .4 shown in Table-2. It is observed in the present study that the total drag decreases with increase in ogive radius. The drag force is least for the ogive radius of 250mm. It shows that the blunted tangent ogives, an appreciable drag reduction is achieved and minimum drag force (sum of pressure drag i.e. form drag and friction drag i.e. viscous drag) is observed at the large ogive radius. The large amount of kinetic energy present in the supersonic flow is slowed down by the viscous effect and thus the lost kinetic energy will be converted into internal energy of the gas (i.e., viscous dissipation). The viscous dissipation also occurs in curved shocks due to strong entropy gradients (inevitable in curved shocks).

XI. CONCLUSIONS

A detailed computational study of the supersonic flow past blunted tangent ogives of different configurations were carried out to understand the flow/shock features such as shock detachment distance, pressure coefficient, aerodynamic drag etc. and hence to determine the optimized geometry of the blunted tangent ogive that provide minimum drag. The studies were conducted for a bluntness ratio of 0.4 and different ogive radii of (100,150,200,250 mm) and total of four different nose cone geometries were investigated for drag reduction characteristics.

The Mach number contours clearly depict the structure of bow shock formed near the nose, which comprises strong and weak regions of flow separated by a sonic line through which flow re-accelerates to the supersonic velocity. The corresponding shock locations ahead of the blunted tangent ogive are indicated by the sudden jump in Mach number and static pressure plots. The Mach number plot shows a sharp decrease and the static pressure plot shows a sharp rise for the detached shock. The pressure coefficient as well as aerodynamic drag coefficient decreases with increasing the ogive radius for a fixed bluntness ratio.

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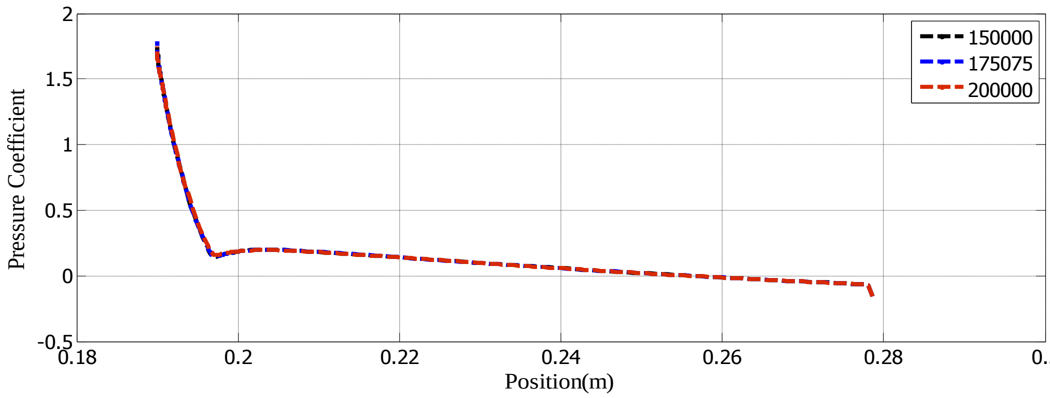

Fig. 1: Variation of Pressure coefficient with upper body of a blunted tangent ogive (r/R =0.4, and ρ =250mm) for various grids showing grid sensitivity.

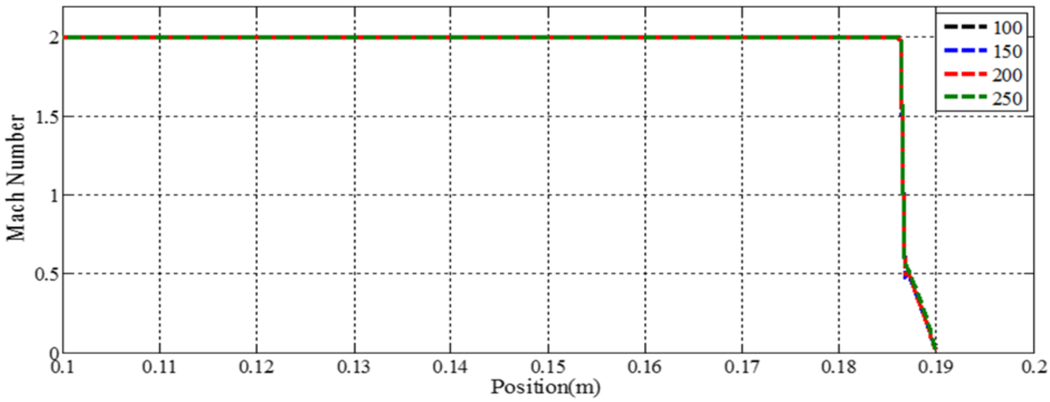

Fig. 2: Variation of Mach number with position along the axis of a blunted tangent ogive at r/R = 0.4 (r = 10 mm, R = 25mm) for (a)100mm (b)150mm (c)200mm (d)250mm

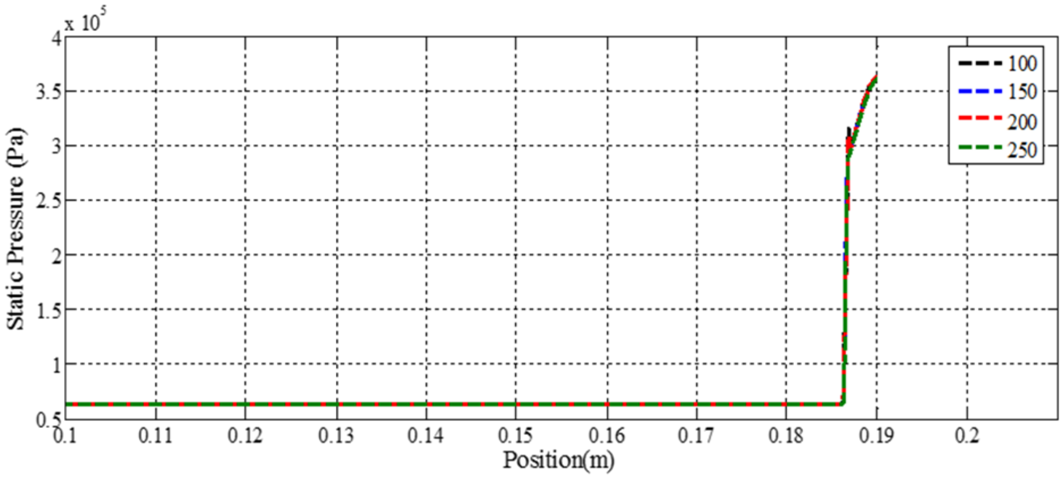

Fig. 3: Variation of Static Pressure with position along the axis of a blunted tangent ogive at r/R = 0.4(r = 10 mm, R = 25mm) for (a)100mm (b)150mm (c)200mm (d)250mm

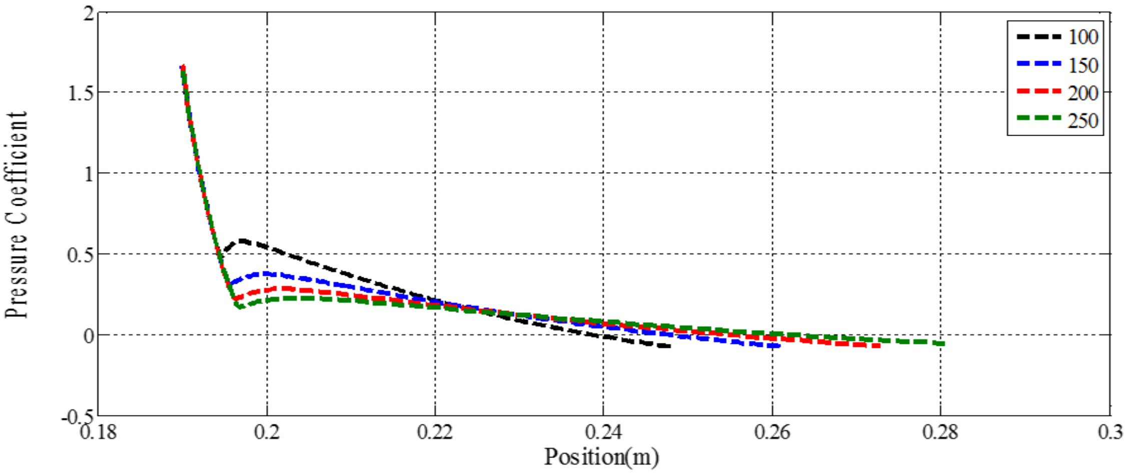

Fig. 4: Variation of pressure coefficient with upper body of a blunted tangent ogive at (a) r/R = 0.4 (r = 10 mm, R = 25mm) for (a)100mm (b)150mm (c)200mm (d)250mm

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Radius	100mm	150mm	200mm	250mm
Total coefficient(sum of pressure and viscous coefficient)	0.00124010	0.00108079	0.00098926	0.00008165

Shock detachment distance obtained from present simulation	Diameter of nose cone	Free stream Mach number (M)	Shock detachment distance from given theoretical relation	% deviation between theoretical relation and present simulation
3.607	20	2	3.4	5.07