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CFD Analysis of Various Nose Profiles

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ABSTRACT

Comparison of various nose profiles is to be carried out to know performance over existing conventional nose profiles is discussed in this paper. The paper objective was to identify the types of nose profiles and its specific aerodynamic characteristics with minimum pressure coefficient and critical Mach number. The scope of this paper is to develop some prototype profiles with outstanding aerodynamic qualities and low cost for use in construction projects for missile increasing their range and effect on target. The motivation for such a work is caused by a lack of data on aerodynamics for profiles of some nose cones and especially improved aerodynamic qualities that can be used in designing missiles/ rockets. The present problem is analyzed using ANSYS software. Flow phenomena observed in numerical simulations during Mach 0.8 for different nose cone profiles are highlighted, critical design aspects and performance characteristics of the selected nose cone are presented.

General Terms

CFD, Ansys.

Keywords

nose profiles, pressure coefficient, critical Mach number

1. INTRODUCTION

In many countries aerospace projects involve designing, building, and launching experimental sounding rockets or research rockets and missiles carrying payloads that perform scientific experiments in a sub-orbital trajectory that reach apogees up to 3 to 4 km. Throughout its trajectory within the atmosphere, they develop an adverse pressure gradient, that is, pressure increasing with increasing distance from the nose tip, will occur at some point along the forebody of the rocket. As the angle of attack is increased, the adverse pressure gradient on leeward side becomes more severe eventually inducing boundary layer separation. A pair of vortices form, one on each side of the body forms at the start of leeward side boundary layer separation. As the vortex pair moves aft they will cause rolling moments on the tail fins of sounding rockets which can lead to roll lock-in or a catastrophic yaw. In roll lock-in the roll rate follows the pitch natural frequency. This prolonged resonance engenders excessive drag and structural loading with extremely adverse consequences to the mission.

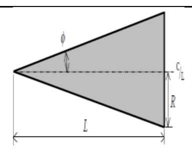
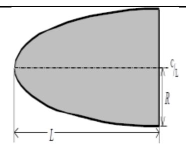
There are two causes of an adverse body pressure gradient. First, if local supersonic flow occurs, returning to local subsonic conditions will be done by a normal shock wave. The onset of this phenomenon is when the local surface Mach number reaches unity. The free stream Mach number corresponding to this condition is called the critical Mach number. At higher speeds, the sudden jump to a lower Mach number across a normal shock will be accompanied by a jump in static pressure. Second, since local flow near the body must be faster than free stream, it must continuously return to free stream conditions. This happens at all Mach number. In both cases, the driving consideration is the static pressure at the base of the forebody. The lower this is, the lower the critical Mach number and the greater the negative pressure gradient of the cylindrical afterbody.

2. PROBLEM DEFINITION

The objective of this paper is to show that boundary layer separation can be postponed by the shape of the nose of missile. The idea here is to get the static pressure at the base of the forebody to be as large as possible. This will give the greatest critical Mach number and the least adverse pressure gradient over the cylindrical afterbody. Although vortices cannot be avoided, they can be mitigated by using the best nose cone shape. Shapes that can produce high critical Mach numbers give the greatest Cp with respect to ambient pressure. This is because the closer the Cp local minimum is to 0, the weaker the adverse pressure gradient becomes, which results in a small vortex strength.

So, in the present paper CFD Analysis is carried out using ANSYS for different profiles of nose like Cone, Parabola, Ogive and Von karman Ogive with a fineness ratio of 6 to improve aerodynamic characteristics of missile or rocket in subsonic conditions.

Table 1 Various Nose profile shapes

S. No	Nose Profile	Equations	Shape
1	Cone	$y = \frac{xR}{L}$	
2	Parabola	$y = R\left(\frac{x}{L}\right)^n$ n=0.5	

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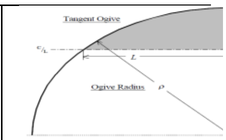
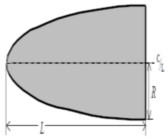
3	Ogive	$\rho = \frac{R^2 + L^2}{2R}$	
4	Von Karman Ogive	$\theta = cos^{-1}\left[1 - \frac{2x}{L}\right]$ $y = \frac{R\sqrt{\theta - \frac{\sin(2\theta)}{2} + Csin^3}}{\sqrt{\pi}}$ C=0	

From above table a MATLAB code has been written to generate points and plotted as shown in figure below.

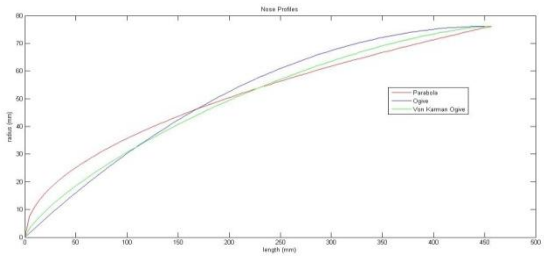


Fig 1: Nose profiles from MATLAB Code

3. COMPUTAIONAL METHODOLOGY

CFD Analysis is carried out in three steps i.e (i) Pre processing – Designing, meshing, boundary conditions and numerical method, (ii) Processing – Solving fluid flow governing equations by numerical method till the convergence is reached and (iii) Post processing – extracting results in terms of graphs, contours which explains the physics of flow and required results.

The above three steps are carried out in ANSYS using ICEM CFD for designing and meshing with Hybrid grid i.e prismatic layer around nose and unstructured grid with tetrahedral cells around 0.4 million elements are used. Simulations are carried out using ANSYS CFX a finite volume solver at with inlet conditions Mach 0.8 by using SST turbulence model with convergence criteria of 10-4.

4. RESULTS AND DISCUSSIONS

The results are extracted from CFD POST after the analysis from CFX solver as shown in below figures. These results give the coefficient of pressure and Mach number distribution over the missile for various nose shapes. Coefficient of pressure is given by following equation:

$$C_p = \frac{P - P_\infty}{\frac{1}{2}\rho V_\infty^2}$$

Fig 2: Pressure and Mach contour of Conical nose

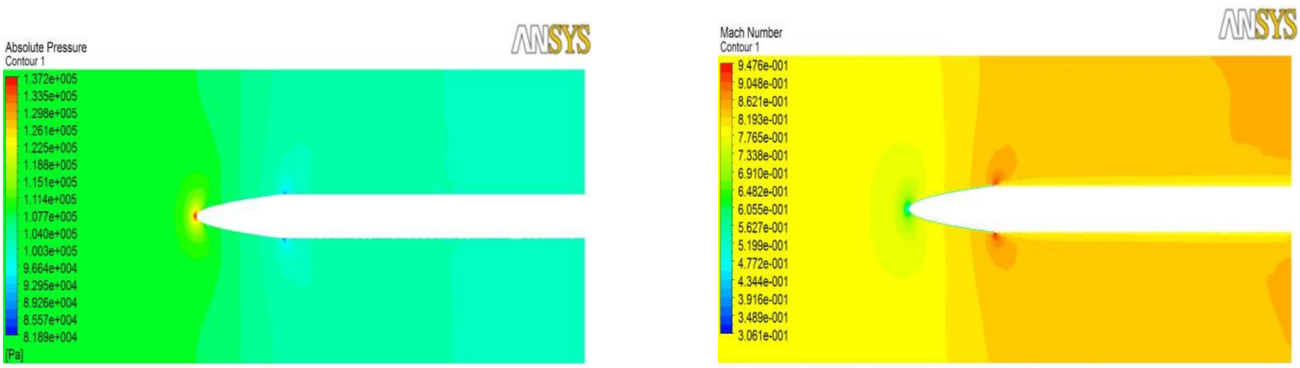


Fig 3: Pressure and Mach contour of Ogive nose

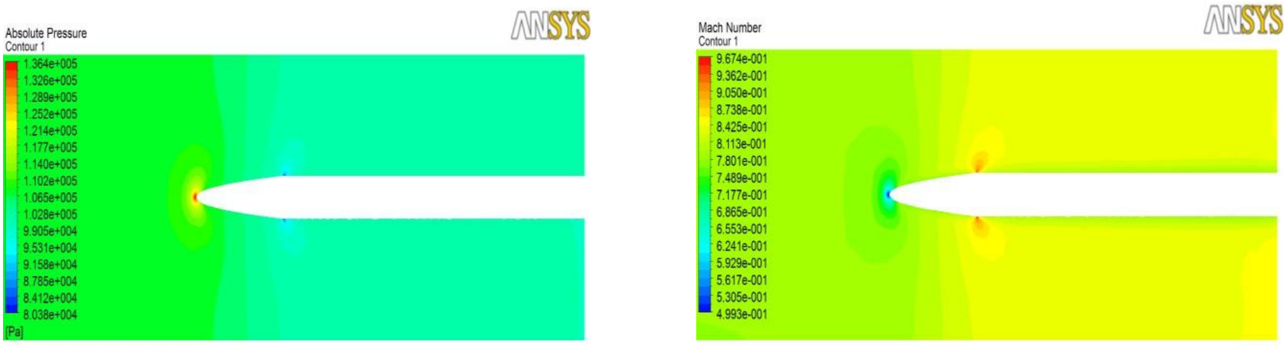


Fig 4: Pressure and Mach contour of Parabola nose

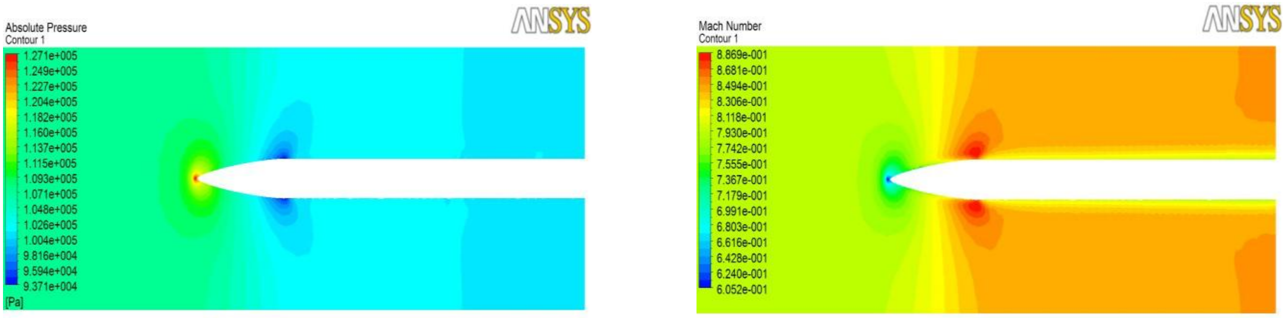


Fig 5: Pressure and Mach contour of Von karman ogive nose

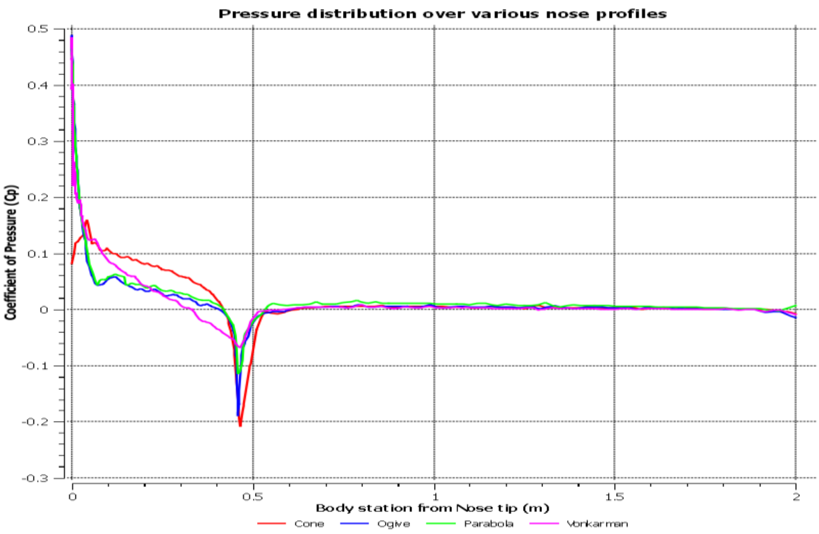


Fig 6: C_p variations along missile about various nose profiles

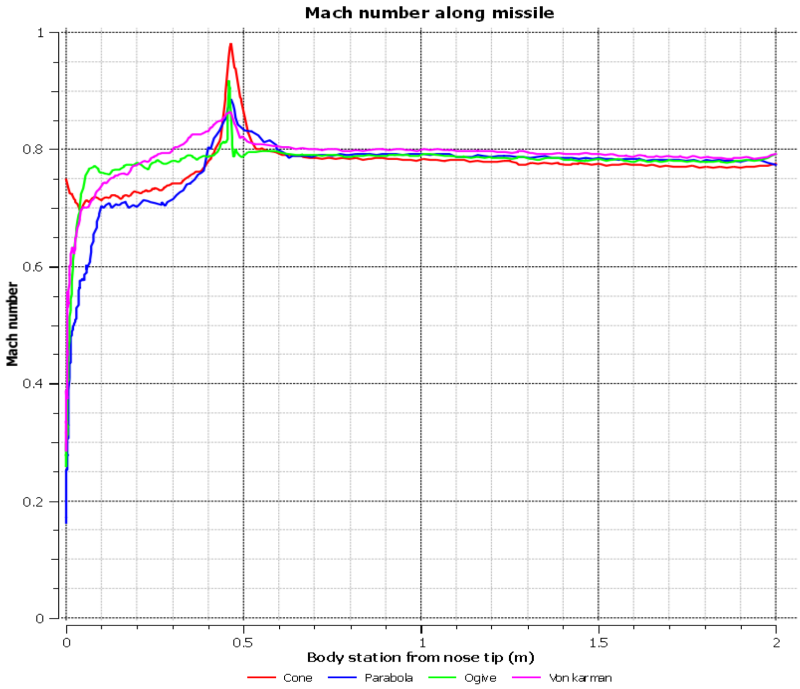


Fig 7: Mach number variations along missile about various nose profiles

Effect of nose profile is shown in figures 6 and 7. As coefficient of pressure is a factor for adverse pressure gradient and strength of vortices is minimum for vonkarman ogive when compared to other profiles. Because of its profile the flow is speeding up slowly in case of vonkarman ogive profile resulting in higher critical Mach number.

5. CONCLUSIONS

The purpose of this paper is to propose a solution for performance improvement using various missiles nose profiles. By referring to above results von karman ogive nose profile give higher critical mach number and minimum pressure coefficient which is desirable for the subsonic flows as stated in problem definition.

6. REFERENCES

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