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DESIGN AND OPTIMISATION OF HIGH SPEED PROJECTILE NOSE FOR MAXIMUM EFFECTIVENESS AND STABILITY

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ABSTRACT

Effectiveness of a projectile is defined as the amount of kinetic energy of the projectile at a given range. Therefore, maintaining maximum range while satisfying required minimum kinetic energy, or maintaining maximum possible kinetic energy for a given range while maintaining the stability is the main aerodynamic design objective. In this study design and optimization of a nose section of a projectile is presented. Design parameters for the nose geometry are introduced and these parameters are coupled with different standard nose types. Then, aerodynamic analyses and comparisons for these geometries are presented. This process is followed by geometric optimization of the nose geometry using optimization techniques for the maximum range and/or maximum kinetic energy at range.

INTRODUCTION

Range and effectiveness of a projectile are two main design objectives of the aerodynamic design phase. For the projectile fired from a barrel, geometric design parameters are often very limited since the diameter and total length of the projectile are generally fixed. Moreover, often projectile has no aerodynamic surfaces. Usually only geometric property that can be altered is the nose geometry.

In this study, design process and optimization of a high speed projectile nose geometry is elaborated. For this purpose, the effects of the common design parameters and characteristics of the common nose types are investigated for axial force and stability. Two important design parameters for the nose geometry used in this study are nose fineness and nose bluntness ratio. Additionally, nose types investigated through this study are chosen as Cone, Ogive, Karman and Power series nose types

In the second part of the study, using the design information gathered from the common nose types and geometric parameters, a multi-objective optimization methodology is utilized to maximize range and maintain gyroscopic stability. Candidate optimized geometries are evaluated for the range/ effectiveness and structural integrity.

METHOD

In this study, an unguided, spin stabilized projectile body is investigated. The base geometry investigated in this project is a slender body, which is currently in inventory. Using the information on the operational data of the projectile, it is assumed that the angle of attack of the projectile during flight is relatively small and projectile performs flight in the linear aerodynamic zone.

The geometry of the nose has a dominant effect on the drag coefficient, hence the range and effectiveness at the range of a projectile. Therefore optimization of the nose geometry, while maintaining the gyroscopic stability will increase the effectiveness of the projectile. In fact, nose geometry is one of the few aerodynamic design areas to improve projectile's performance.

For this purpose, a geometry matrix is determined to find the optimization parameters. Geometric parameters subject to geometric optimization are nose bluntness ratio, nose fineness and common nose profiles which are found in the literature. Nose profiles investigated in this study are selected as

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Ogive, Karman, Power Series and Conical profiles [Fleeman]. In the first part of the study calculations are performed at Mach regime extending from low transonic to high supersonic region.

In the second part of this study, using the information gathered at the aerodynamic investigation on the geometry matrix, nose shape optimization process is employed to find a drag optimized nose geometry. Response surface based method is used for this part [Engelund].

Rather than performing aerodynamic analysis for the entire flight regime for the second part, a constant flight regime is selected for the aerodynamic analysis and optimizations, and it is assumed that the optimized geometry shall perform a similar behavior for the rest of the flight regime.

Investigation of Nose Design Parameters

Nose bluntness Ratio

Literature review on the nose geometry shows that nose truncation can decrease aerodynamic drag at supersonic speeds [Crowell]. Considering that the projectile will perform most of the flight at the supersonic regime applying nose truncation can decrease total drag of the projectile. Figure 1 shows the change in drag coefficient with nose bluntness ratio. It can be seen that, for a nose bluntness ratio of 0.15, the drag is minimized. For high Mach numbers, drag gain can be as high as 8%. Therefore, this value is taken as 0.15 for the geometric parameters investigation and then, this value is verified at the optimization process.

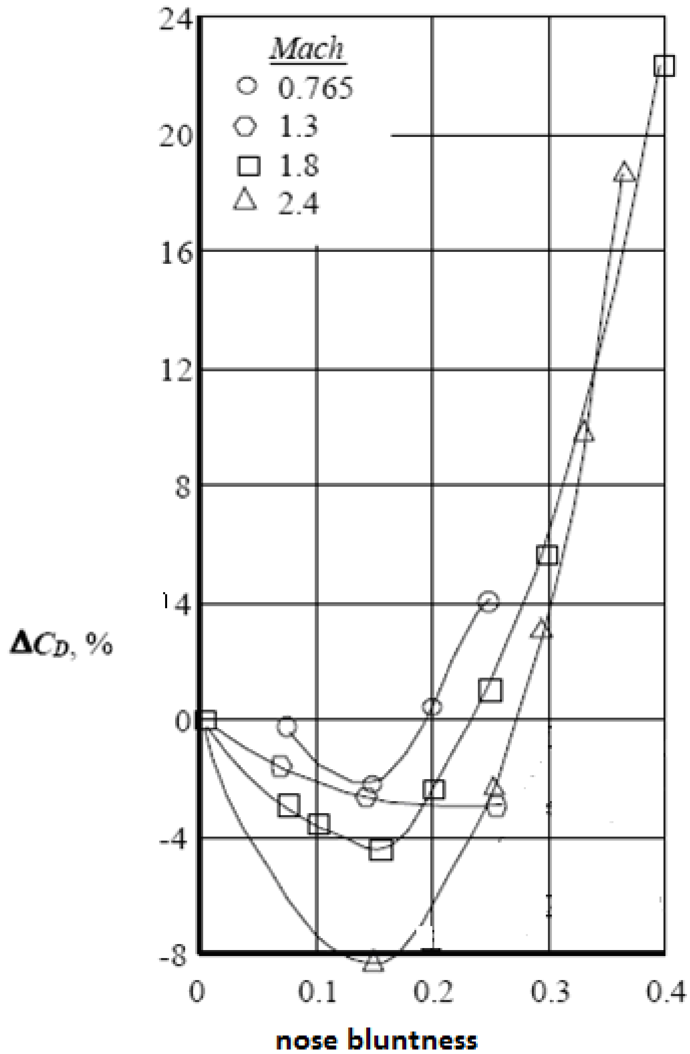


Figure 1: *Nose bluntness ratio vs. change in Drag Coefficient.*

Nose shape and fineness

Nose shape has a dominant role on the performance of a missile. Different nose shapes are selected according to the requirements as well as the flight regime of the aircraft. Among the many standard nose types that may be found in literature, four different nose shapes, which are known to perform well at supersonic speeds are selected for this study. These nose geometries are listed in the Table 1.

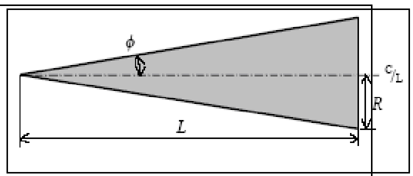
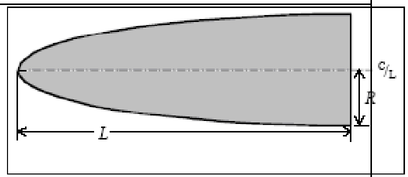
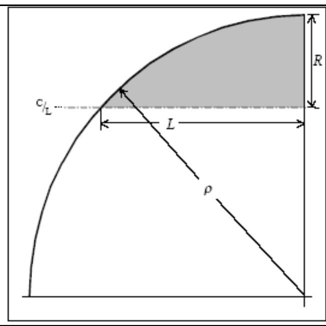
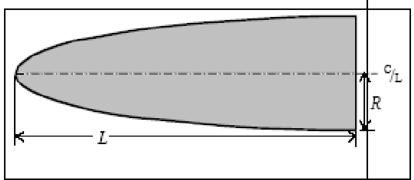
CONICAL • Easy to produce • Low drag characteristic	y=x R / L Φ=tan-1(R/L) y= x tan Φ	
POWER SERIES • n=1 converges to CONE • n=0.5 is ½ POWER (PARABOLA) • n=0 is CYLINDER	$0 \leq n \leq 1$ $y = R\left(\frac{x}{L}\right)^n$	
TANGENT OGIVE • Popular due to easiness of production • Nose length should be smaller than the ogive Radius.	Radius of the circle is called ogive defined as: $\rho = \frac{R^2 + L^2}{2R}$ $y = \sqrt{\rho^2 - (x - L)^2} + (R - \rho)$	
KARMAN SERIES Unlike the other methods, mathematically driven method for low drag at high Mach numbers..	$\theta = \cos^{-1}\left(1 - \frac{2x}{L}\right)$ $y = \frac{R\sqrt{\theta - \frac{\sin(2\theta)}{2}}}{\sqrt{\pi}}$	

Table 1: Selected Base Nose Shapes

Three different nose fineness ratios are chosen as the geometry parameter. Therefore, keeping the bluntness ratio as constant, twelve different geometric combinations are generated. Solid models and computational meshes for each model are generated. Then, CFD simulations are performed for each of these geometries for the flight domain defined before. For the viscous calculations, k-w turbulence model is employed. To determine the stability of the projectile, all calculations are performed at a small angle of attack.

In Figure 2, axial force parameters for each nose type for constant fineness are given. For each fineness ratio, it is seen that Power Series and Karman type nose shapes shows lower axial force coefficient. Cone type nose shape also reduces the axial force.

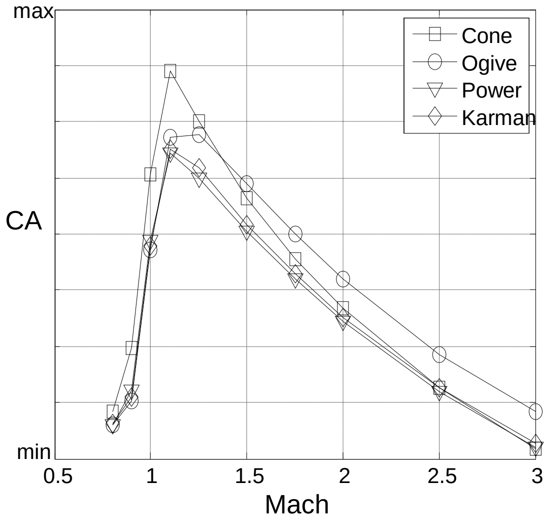


Figure 2: *Change of Axial Force coefficient with nose type*

Regarding the effect of the fineness ratio, one can observe that increasing the fineness reduces the axial force coefficient as it is seen in Figure 3. This is true for each nose type and it is observed that effect of nose fineness does not change significantly after 3.

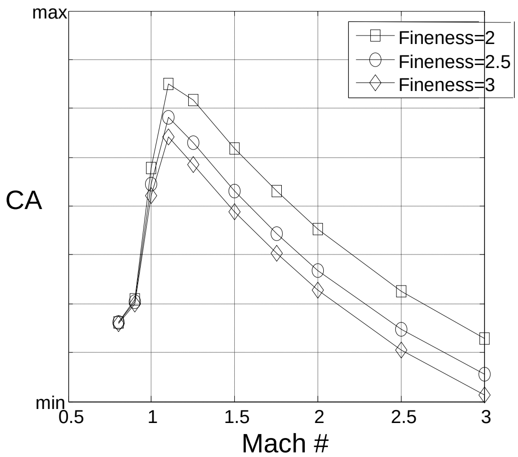


Figure 3: *Change of Axial Force coefficient with nose fineness*

From Figures 2 and 3, it seems that any of the Karman, Power Series and Cone types with higher fineness can be chosen for the best performing projectile. However, considering that projectile is statically unstable due to missing fins, projectile should have gyroscopic stability. Observing the pitch moment coefficient, it is seen that increasing the nose fineness reduces the pitch moment coefficient and hence increases the gyroscopic stability.

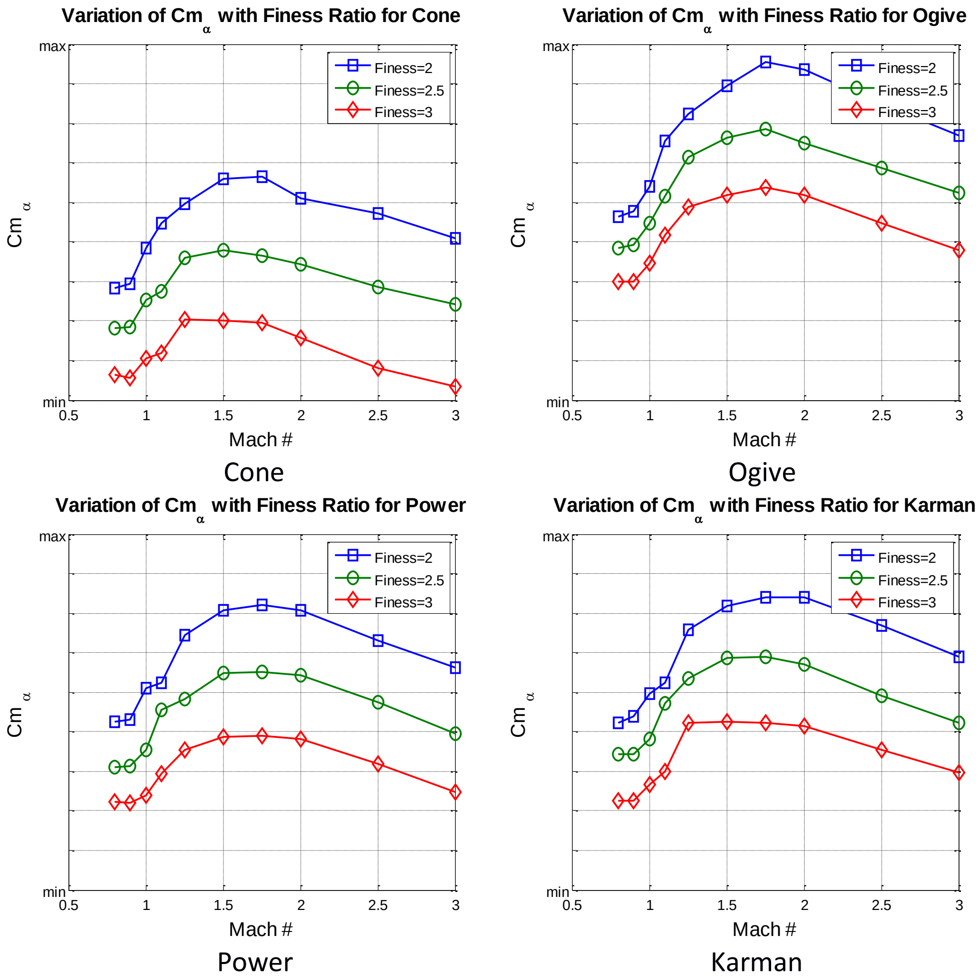


Figure 4: *Change of Pitch Moment coefficient with nose type and nose fineness*

Optimization

In the second part of the study an optimized geometry with lowest drag, while keeping the gyroscopic stability in a good margin is searched using optimization algorithms. Accordingly, the geometry is modeled with five points where, three points on the nose curve that can move only at radial direction, one point that defines nose bluntness ratio and one point that defines nose fineness. A response surface method based on second order polynomials is employed to determine an optimized geometry that satisfies the goals using these parameters.

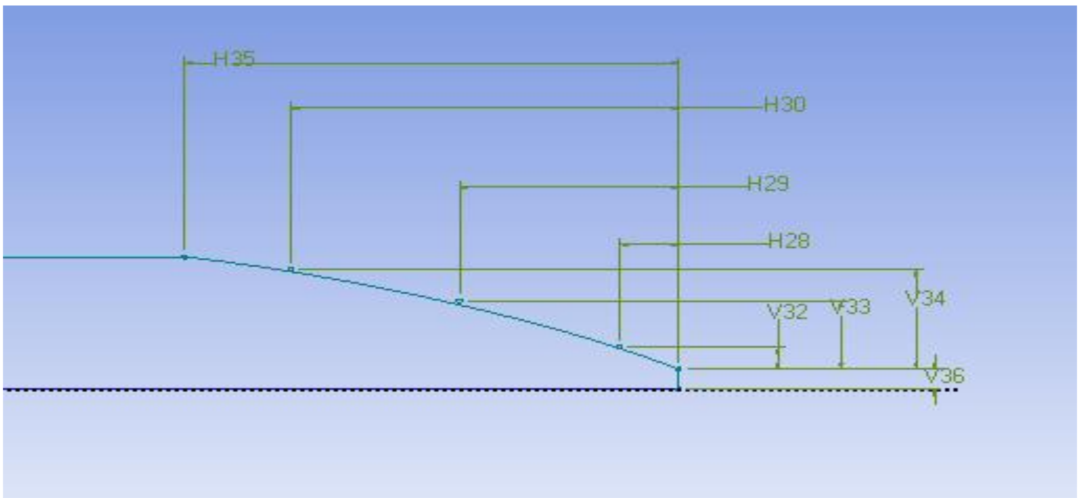


Figure 5: *Schematic view of design points*

After completing the response surface analysis and optimization procedure, following conclusions can be drawn on the design parameters

1. Increasing the fineness of the nose decreases the drag coefficient. This is compatible with the findings of the previous analysis.

2. Nose bluntness is one of the most dominant factors on the total drag. However, it is seen that independent from other configuration parameters, response surface analysis yields a bluntness ratio around 15% to 17% for the lowest axial force. This result is consistent with the literature [Crowell].

Using this information, the parameters set for the response surface analysis and the number of optimization parameters are decreased to three, which consists of axial distances on the curve by eliminating the nose fineness and bluntness. For this purpose, nose bluntness is set to its optimal value of 15% and nose fineness is set to its maximum value. New sets of the optimization runs are applied starting from different initial configurations. Two of the most successful of these initial configurations are constructed from the Karman and Power Series nose profiles.

After the optimization process is completed, it is seen that the lowest drag is found starting from Karman series. Figure 6 and 7 shows the comparison of axial and moment coefficients for the original Karman nose geometry and optimized geometry. It is seen that, optimized geometry shows significantly better drag behavior for all flight regimes. Therefore drag optimization for the selected Mach number also improves the drag behavior for the entire region. Flight simulations show that 7 percent more range or 5 percent more kinetic energy at the given range can be obtained with the new geometry. It is also seen that optimized geometry shows significantly lower pitch moment coefficient, hence better gyroscopic stability.

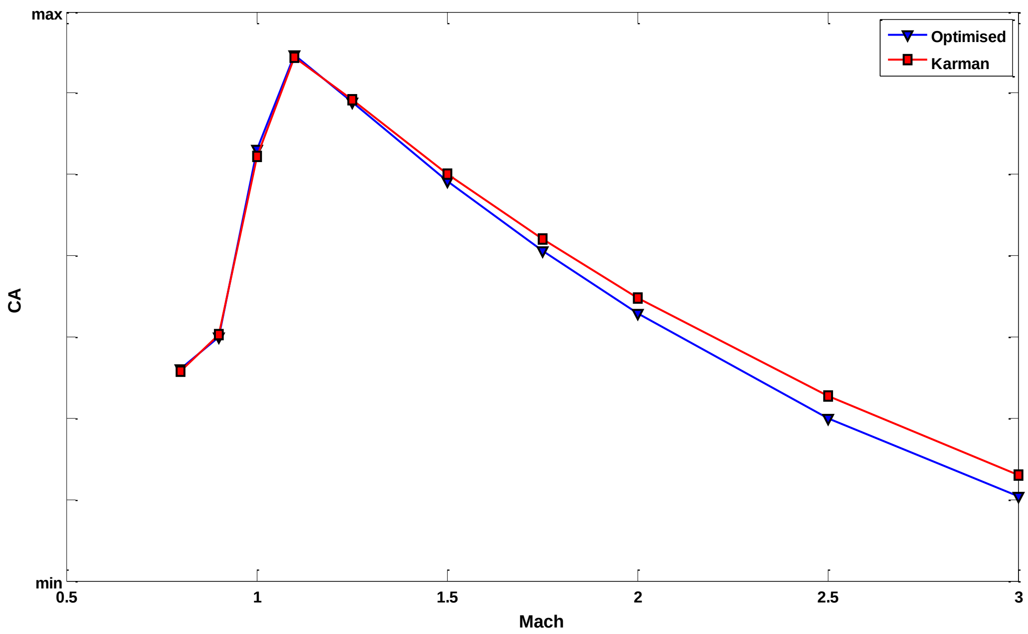


Figure 6: *Comparison of Axial Force coefficient for optimized and Karman nose type*

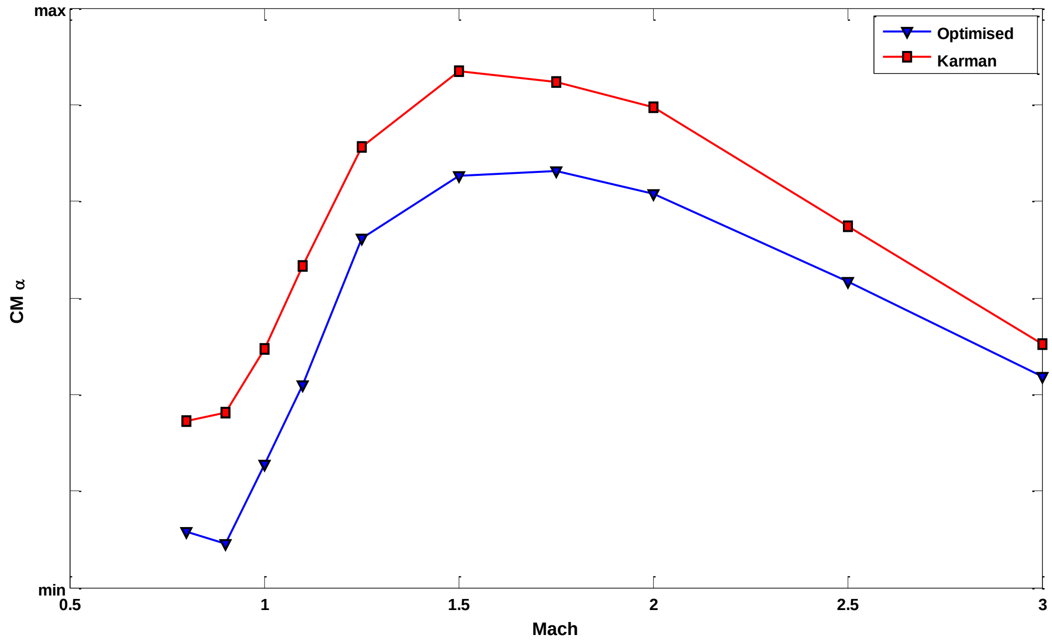


Figure 7: *Comparison of Pitch Moment coefficient for optimized and Karman nose type*

RESULTS

In this study, the effects of different nose geometries on flight objectives of a projectile are investigated on a real-life geometry and then an optimized nose shape that will improve performance of projectile on these objectives. The projectile is a finless spin stabilized aerodynamic body and performs most of its flight in supersonic regime.

In the first part of this study, four different base nose types, Cone, Ogive, Power Series and Karman, are investigated. Second design parameter is selected as nose fineness. It is seen that, increasing nose fineness improves the range of projectile, while decreasing spin stability. Additionally, it is observed that, Ogive type nose geometry provides the worst drag and stability behavior especially for the higher nose fineness values. Other three base geometries show better drag behavior, while for higher Mach numbers and higher fineness, stability may still be an issue for Karman and Power type geometries.It should be noted that,, a constant nose truncation is used for this part.

At the second part, flight parameters of selected nose geometries are further improved by response surface based optimization method by altering the nose shape. Initial optimization runs are applied to reduce the parameter space and it is seen that increasing nose fineness and setting the nose bluntness ratio at around 15% yields the best drag results.

After fixing these values, base geometries to improve drag are chosen as Power and Karman type, and new optimized geometries are produced by manipulating the nose shape using optimization methods. Cone type is omitted from this study, since the maximum nose fineness is limited due to manufacturing/ assembly difficulties.

Geometric optimization of the two base shapes yields different end geometries. It is seen that drag and stability characteristics of the Karman-based optimized geometry is generally better than that of Power series based geometries. Flight simulations on selected optimized geometry shows that 7 percent more range or 5 percent more kinetic energy at the given range can be obtained with the new geometry. It is also seen that optimized geometry shows significantly lower pitch moment coefficient, therefore better gyroscopic stability. Therefore total effectiveness of the projectile is improved significantly.

The main weakness of the applied optimization process is that, the optimization process is disconnected to solid mechanics and assembly constraints. A new multi-objective/ multi-constraint optimization method is under development to provide a ready-to-manufacture optimized aerodynamic model.

References

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