Drag Analysis for Sounding Rocket Nose Cone

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Abstract - *A nose cone is shaped to offer minimum aerodynamic resistance and is meant to pass through different layers of the atmosphere at different speeds. Hence it is important to analyze the different shapes of the nose to determine the geometric shape that will give optimum performance. Comparison and analysis of conventional nose profiles for specific atmospheric level and at variable Mach numbers have been done. The objective was to identify the optimum nose cone profile for varying temperature and velocity for a given atmospheric level. The data was gathered by mathematical modelling and simulation using ANSYS Fluent software. The analysis was done on different nose profiles, including but not limited to ogives, Von-Karman, and Power series, with Mach number ranging from 0.8 to 2.0. Nose profiles were analyzed for specific atmospheric pressure and air density values as present in a given layer of the atmosphere.*

***Key Words*: Drag Force, Nose Profile, Shock Waves, Turbulence, Mach Number, Aerodynamics**

1. INTRODUCTION

The nose cone is an aerodynamic part of the rockets as well as airplanes. In commercial aircraft, nose cones are designed for maximum stability rather than maximum efficiency because of the high factor of safety required, while in fighter jet planes, the nose cone is designed to ensure maximum efficiency and the stability remains to be a secondary factor. In rockets, the optimum nose cone is used for all atmospheric conditions from which a rocket passes through. Also, in rockets, the nose cones are not strictly an aerodynamic part and they house the payload and other scientific experimental instruments. Sometimes the speed of the rocket can reach up to 5 Mach or more. Due to this high speed and temperature variations in different atmospheric layers, rocket nose cone has some special applications. There are different types of nose cones used and it depends on the application.

There are mainly three types of drag force: Form drag or Pressure drag, Skin friction drag, and Wave drag experienced by the rocket nose. Form drag mainly depends on the form or shape of the object. Skin friction drag depends on shear stress between moving surface and fluid. Wave drag is produced in supersonic flow due to the formation of a shockwave.

Meanwhile, airspeed measurements in supersonic flow are different from the subsonic flow. In supersonic flow, a shockwave is generated in front of the nose cone. Shock waves are a very thin region across which severe changes in flow properties take place. These changes are as follows:

I. The Mach Number **Decreases.**
II. The Static Pressure **Increases.**
III. The Static Temperature **Increases.**
IV. The Flow Velocity **decreases.**
V. The Total Pressure P_o **decreases.**
VI. The Total Temperature T_o **stays the same** (For Perfect Gas)

The gas molecules that collide with the tip of the nose cone, set up a disturbance in the flow, which then propagates, by means of weak pressure waves, to other regions of the flow away from the nose cone, at the local speed of sound. In subsonic flow, this pressure wave works its way upstream and is felt by all other regions upstream. On the contrary, when the flow is supersonic, the speed of the flow is greater than the pressure waves, which propagate at local speed of sound. Thus, these pressure waves can't work their way upstream. Instead, these disturbances merge at a finite distance from the tip to form a shock wave. The flow upstream of the shock waves are unaffected by pressure disturbance while the downstream flow is affected by this pressure disturbance. Usually, this shock wave is a very thin region of 10^{-4} cm or less.

1.1 Problem Definition:

The objective of this paper is to find an optimum nose cone profile for sounding rockets. Sounding rockets are the rockets used by researchers to experiment and gather data from the few kilometers of the atmosphere from the earth. There is a lot of data available for nose cones of space rockets but very less data is available for nose cones of sounding rockets. So, in this paper, the CFD analysis is carried out on different nose cone profiles using ANSYS Fluent, and the drag coefficient is compared to find the optimum profile. Mach numbers are taken from the range of 0.8 to 2.0.

CFD analysis is carried out on a total of 12 different profiles (ref. table-1) with fineness ration of 3.

1.2 Mathematical Model:

The turbulent model we used for the solution is the Spalart-Allmaras Turbulence model. The main advantage of this model is that it is local. So, the result at one point does not depend on other points. It is compatible with grids of any structures and Navier-Stokes solvers in two or three dimensions.

1.3 Computational Method:

CFD analysis was carried out in 3 steps.

i) Pre-processing – Design, meshing and boundary conditions
ii) Processing – Solving fluid flow system till convergence is reached
iii) Post-Processing – Graphical representation of results with contours and graphs.

To generate profiles from the equations mentioned in Table-1, The python code was written for each profile to generate coordinates.

Meshing was done with the orthogonal quality between 0.85 to 0.98 and skewness of 0.1 to 0.4. Total number of nodes was in the range 100K to 120K.

Viscous Spalart-Allmaras with strain-vorticity production model was used with default model constants. Convergence criteria were set to 10^{-5}. For Boundary conditions, far-field pressure was taken 26500 Pa and the far-field temperature was taken 223.26 K which are the atmospheric condition at 10 km height. The analysis was done for Mach 0.8, 0.9, 1.2, and 2.0 for each profile.

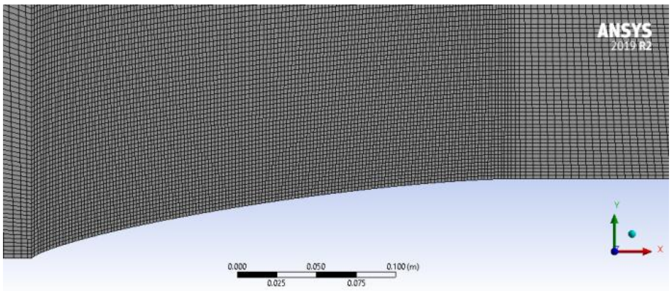
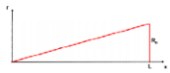
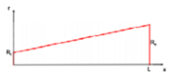
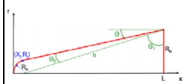
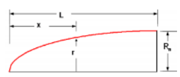
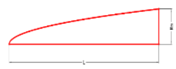
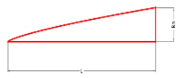
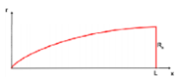


Fig-1: Meshed Profile for Von-Karman Nose Cone

SR. NO	NOSE PROFILE NAME AND EQUATION	NOSE PROFILE
1	SHARP CONE $r = \frac{R_n}{L}x$	
2	TRUNCATED CONE $r = \frac{R_n - R_t}{L}x + R_t$	
3	BLUNTED CONE $r = \frac{R_n - R_j}{L - X_j}(x - X_j) + R_j$	
4	ELLIPTICAL $r = R_n\sqrt{1 - \frac{(L - x)^2}{L^2}}$	
5	PARABOLA $r = R_n\left(\frac{x}{L}\right)^{1/2}$	
6	¾ HYPERSONIC $r = R_n\left(\frac{x}{L}\right)^{3/4}$	
7	HEMISPHERICAL $r = \sqrt{{R_b}^2 - (R_b - x)^2}$	
8	SHARP HAACK $r = \frac{R_n\sqrt{\nu_1}}{\sqrt{\pi}}$ $\nu_1 = \Phi - \frac{\sin(2\Phi)}{2} + {}^{1}/_{3}\, sin^3(\Phi)$ $\Phi = \cos^{-1}\left(1 - \frac{2x}{L}\right)$	

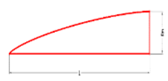
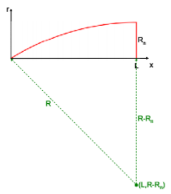
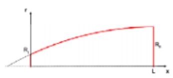
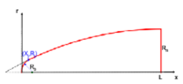
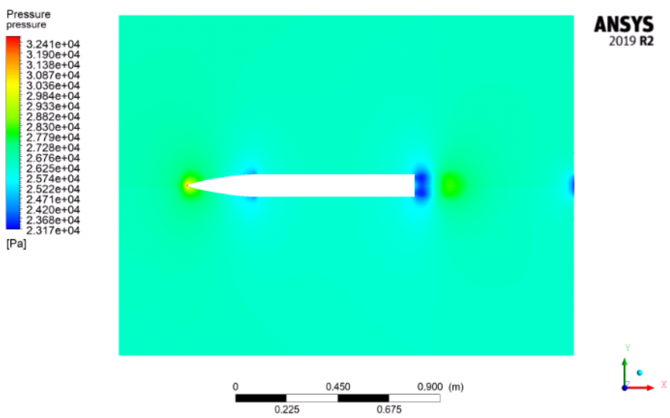
9	SHARP VON KARMAN $r = \frac{R_n\sqrt{\nu_1}}{\sqrt{\pi}}$ $\nu_1 = \Phi - \frac{\sin(2\Phi)}{2}$ $\Phi = \cos^{-1}\left(1 - \frac{2x}{L}\right)$	
10	TANGENT SHARP OGIVE $R = \frac{L^2 + {R_n}^2}{2R_n}$ $r = \sqrt{R^2 - (L-X)^2} - (R - R_n)$	
11	TANGENT TRUNCATED OGIVE $R = \frac{L^2 + {R_n}^2 + {R_t}^2 - 2R_nR_t}{2(R_n - R_t)}$ $r = \sqrt{R^2 - (L-X)^2} - (R - R_n)$	
12	TANGENT BLUNTED OGIVE $R = \frac{L^2 + {R_n}^2 - 2R_bL}{2(R_n - R_b)}$ $r = \sqrt{R^2 - (L-X)^2} - (R - R_n)$	

Table -1: Various Nose Profiles and their equations

2. RESULTS



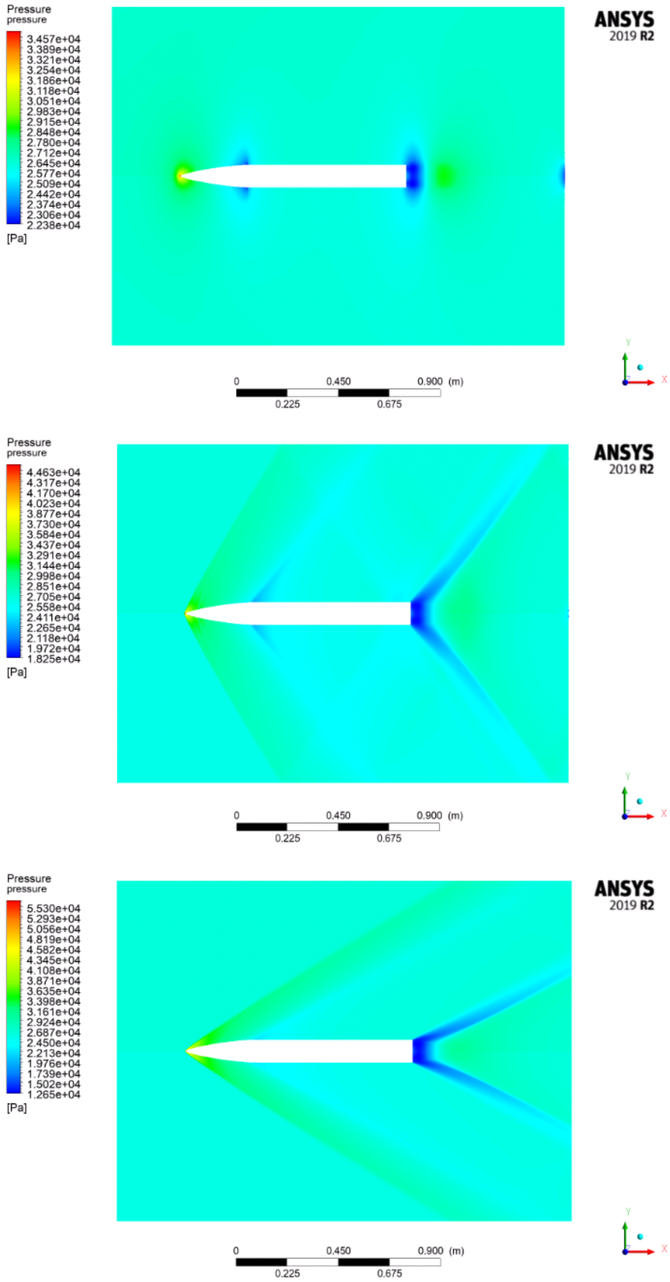


Fig-2: Pressure Contours for Sharp Von-Karman nose cone Mach-0.8-0.9-1.2-2.0

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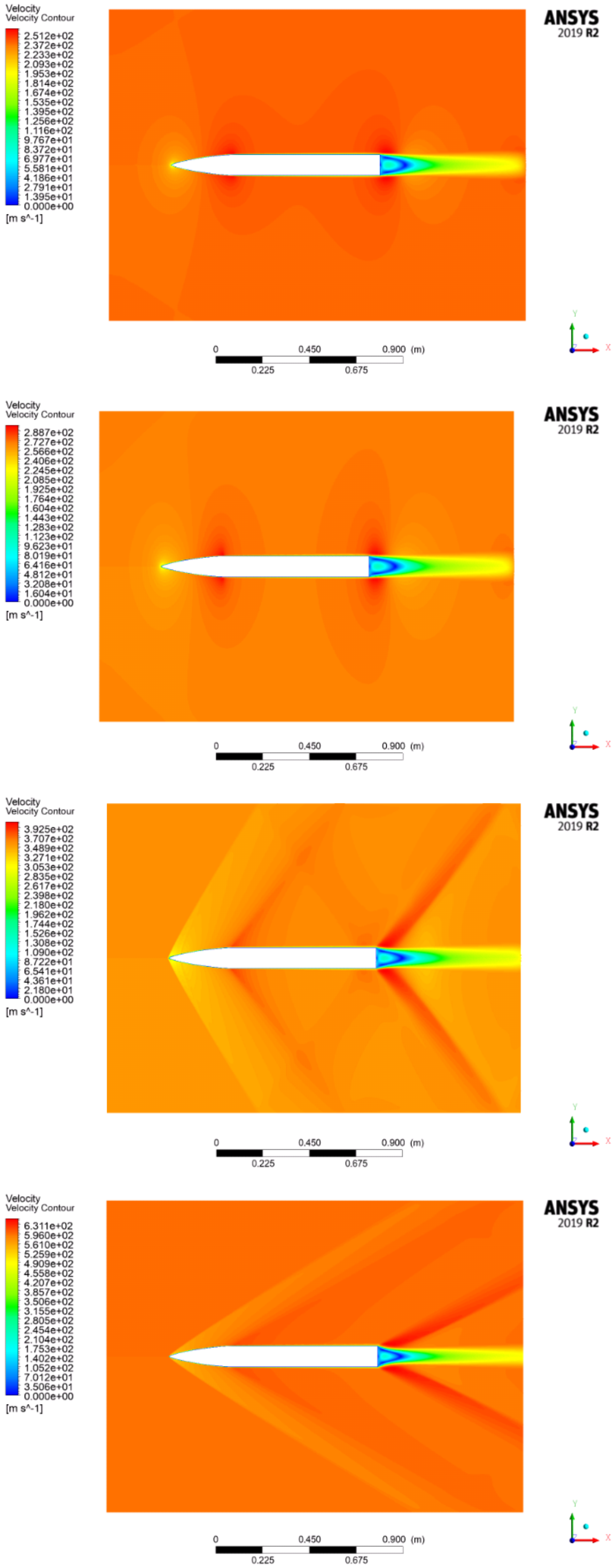

Fig-3: Velocity Contours for Sharp Von-Karman nose cone Mach-0.8-0.9-1.2-2.0

PROFILE	Cd (M=0.8)	Cd (M=0.9)	Cd (M= 1.2)	Cd (M= 1.2)
3/4 Hypersonic Powerseries	0.308	0.3469	0.4917	0.3354
Blunted Cone	0.3079	0.3402	0.4937	0.3913
Elliptical	0.3126	0.3318	0.4617	0.4017
Hemispherical	0.3379	0.4867	0.8882	0.9975
Parabola	0.3076	0.3324	0.4577	0.3396
Sharp Cone	0.3104	0.3649	0.5432	0.3542
Sharp Haack	0.3092	0.3299	0.4592	0.3579
Sharp Von Karman	0.3082	0.328	0.459	0.3403
Tangent Blunted Ogive	0.3143	0.333	0.4529	0.3977
Tangent Sharp Ogive	0.3088	0.3286	0.4678	0.3599
Tangent Truncated Ogive	0.3462	0.3632	0.5048	0.4784
Truncated Cone	0.3705	0.3898	0.5517	0.4421

Table -2: Drag Coefficient Values at Different Mach Numbers

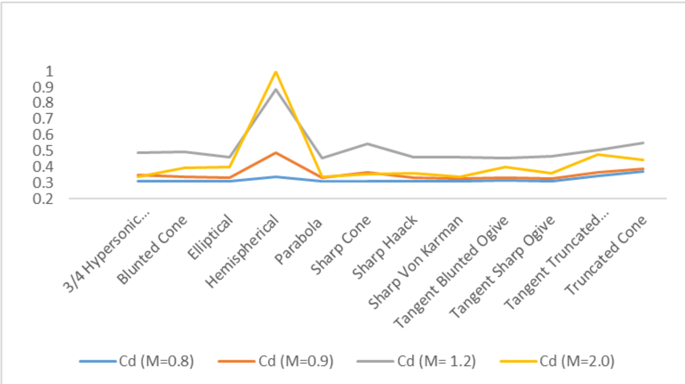

Fig-4: Drag coefficient Comparison of Different Nose Cones

3. CONCLUSION

By referring to the above results, obtained by ANSYS simulation, we reach to the conclusion that the Von-Karman nose cone profile is overall the best profile for Subsonic and Supersonic regions. For exclusively the subsonic region, the Von-Karman profile is optimum while for the Supersonic region, ¾ hypersonic power series profile is optimum. So, it is recommended to use the Von-Karman profile.

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