Drag Optimisation of Nose Cone Configuration in Supersonic And Hypersonic Regimes

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ABSTRACT

Nose cones are essential in high-speed vehicles to ensure minimum aerodynamic drag and change the air flow behavior of incoming air. This paper makes a comparison between the drag forces experienced by different configurations of nose cones at different altitudes and Mach numbers. The change in the drag force with altitude or Mach number is studied to understand the effect of these parameters. Three different Mach numbers 1,3 and 5 are considered, while altitude is considered from sea level to 15 km in steps of five - 0km, 5km, 10km and 15km. The results obtained provide an idea about the optimum operating region for the nose cone designs

1. INTRODUCTION

The nose cone is the part of the vehicle that interacts first with the medium through which it is passing. Nose cones are mainly used on missiles, rockets, submarines, torpedoes, submersibles and so on. For rockets, the nose cone is the front most part, which is used to decrease drag and change the air flow in a way to minimize drag. It is exposed to high temperature due to aerodynamic heating, so the outer surface of the nose cone is built with refractory material. Ablative heat shields are the popular choices to withstand it. In satellite vehicles, the nose cone acts as a barrier for the satellite and separates after the orbital speed is reached or it becomes the satellite itself after the nal stage. The nose cones help to avoid speed reduction caused by air passing on the surface of the nose cone.

Previous research has considered different problems connected to the nose cone. Neely et. al.[1] used thermal paints on nose cones for the mapping of structural temperature on hypersonic flight test vehicles. These thermal paints can change color due to chemical reactions as a function of temperature. They used a HIFIRE-0 test vehicle for testing the characteristics of this paint. Deepak, Roy and Boyce[2,3] carry out shape optimization on hypersonic vehicles. They are mostly concentrated on reduction of total drag on nose cones. Experiments[2] involve an inner part of a nose cone to protect it from thermal and structural load during the ascent through the dense part of the atmosphere. The experiment is based on two mach numbers, i.e., 3 and 8 and involves a nose cone used for HyShot 3 flight.

The work carried[3] out is about optimization of nose cones for drag reduction. The approach used is a multi-objective constrained algorithm. The experiment involves protection of the nose cone to avoid high structural and thermal load by reducing overall drag. The mach numbers used were 3 and 8, using a HyShot 2 flight, which is a sounding rocket with near vertical launch angle to boost the experiment into a ballistic trajectory.

There have been several other research on different nose cone models. Xue et. al.[4] Conducted experiments proving the reason for reduction in drag analyzed with the Mach number up to 4.5 on a newly optimized spiked disc tip. This was analyzed by both mathematical formulations, numerical method and grid technique. Ericsson[5] talk about effect of nose bluntness on the hypersonic aerodynamics of slender cones. It is analysed and the combined effect of nose bluntness and semi-cone angle can be represented by a scaling parameter and then the scaling concept can be extended to include the effects of moderate angles of attack. In the work by Zing and Elias[6], Mach number with a range within 0.64 and 0.78 was taken into consideration and presented data related to Multipoint Aerodynamic shape optimization, Algorithm Description, Simple Two Point example, Automated Selection of Sampling Points and Weights and o design performance.

In this research, three different nose cones are considered with some dimensional changes. The comparison is of drag forces, based on parameters altitude and mach number. The changes on drag based on these parameters are noted. The HIFIRE-0, HyShot 2 and HyShot 3 configurations are taken for our purpose here.

2. METHODOLOGY

The configurations of nose cones are designed using CAD software, and suitable meshes are created in order to properly map the domain. ICEM CFD was used to create meshes for the models, and the analysis was done using ANSYS FLUENT. The Spalart-Allmaras turbulence model was used for our current analysis. It is a one-equation model, which generally provides good performance in high-speed flows. The outflow boundary condition was applied to the outlet downstream of the model, while the inlet ahead of it was anointed as velocity-inlet. The nose cone body was set as a no-slip wall.

The Reynolds Averaged Navier-Stokes (RANS) equations are solved to simulate the flow around the wingtip with and without jet injection numerically. A finite volume formulation is used with a second-order implicit discretization scheme for pressure correction. The QUICK (Quadratic Upstream Interpolation for Convective Kinematics) scheme, a third-order accurate scheme near wall, is used for momentum and turbulence equations. SIMPLEC (Semi-Implicit Pressure Linked Equation – Consistent) algorithm36 is used for pressure velocity coupling.

2.1 Isometric View

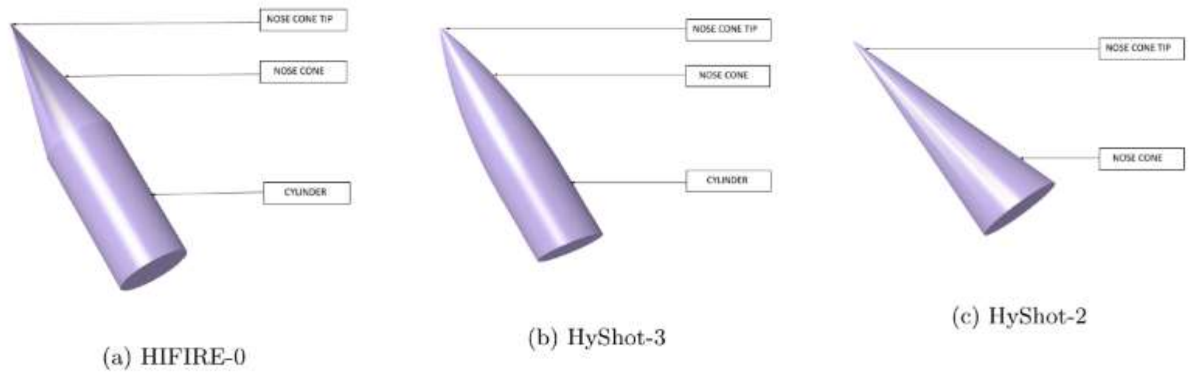


Figure 1: Isometric view of Nose Cone Designs

2.2 Section View

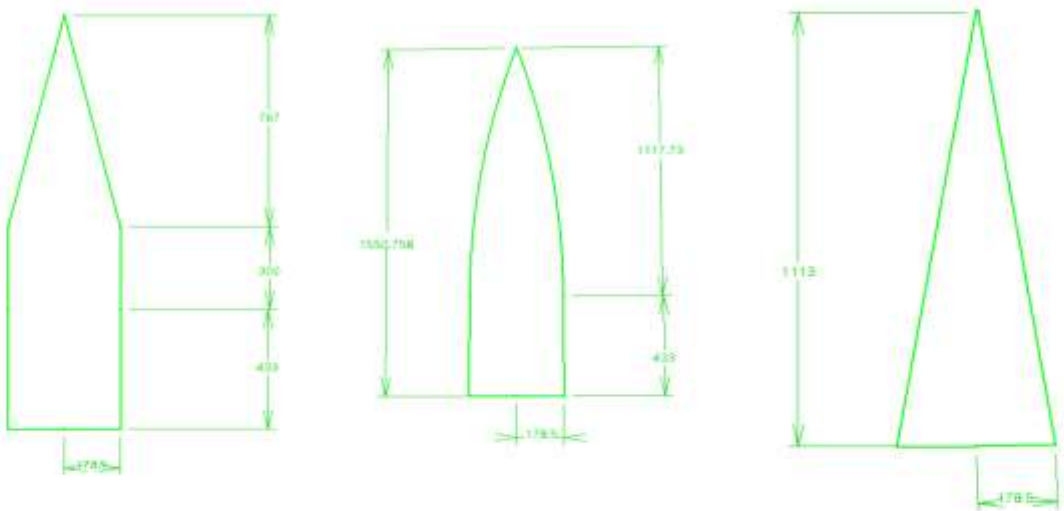


Figure 2: Section view of Nose Cone Designs: (a) HIFIRE-0, (b) HyShot-3, (c) HyShot-2

The base radius is the same for all the three models used.

2.3 Enclosure Mesh Details

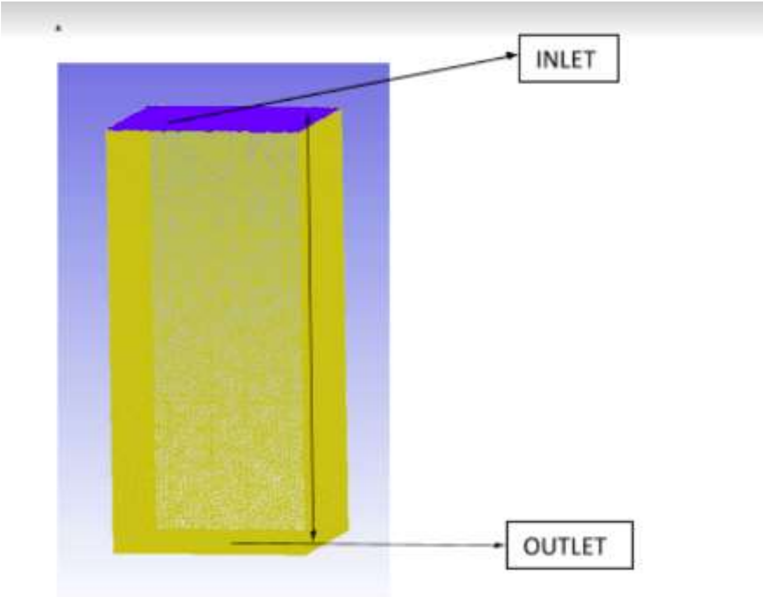


Figure 3: Enclosure Mesh used for CFD Analysis

The domain enclosure used for the models is shown in figure 3. The boundaries are 5m away from the tip of the nose cone and 1m away from the bottom of the model. The walls surrounding the models are 1m away from the sides of the nose cone. The face in front of the nose cone is defined as inlet, while all the other walls are defined as an outlet.

2.4 Nose Cone mesh details

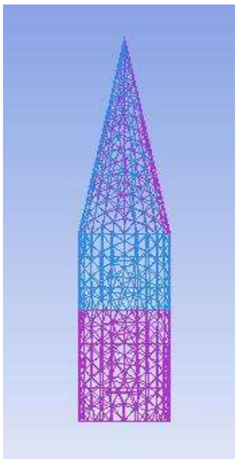
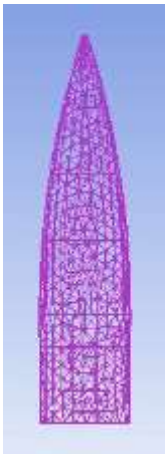
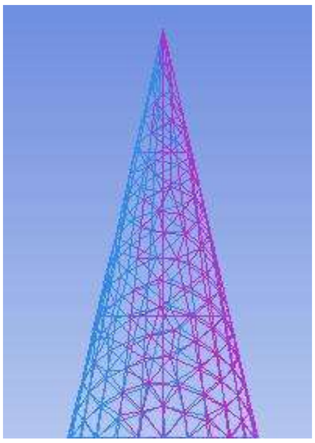
		
(a) HIFIRE-0 Mesh	(b) HyShot-3 Mesh	(c) HyShot-2 Mesh

Figure 4: Mesh details of models

	Mesh Elements	Nodes
HIFIRE - 0	1823183	306798
HyShot-3	2205637	371276
HyShot-2	1728913	291113

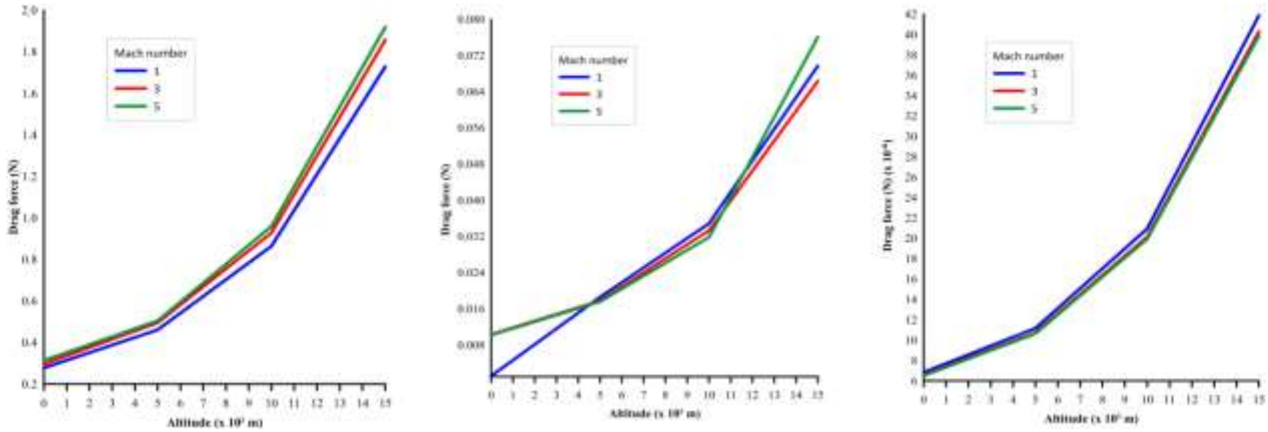
Table 1: Mesh Details of the Nose Cone Designs

Different altitudes and Mach numbers are utilised in this work. Table 2 shows the pressure, temperature and density values at different altitudes for the test conditions used in this research.

Sr. No.	Altitude	Pressure	Density	Temperature
1	0 km	105 kN/m^2	1.25 kg/m^3	290 K
2	5 km	53 kN/m^2	0.75 kg/m^3	255 K
3	10 km	25 kN/m^2	0.40 kg/m^3	225 K
4	15 km	12 kN/m^2	0.20 kg/m^3	219 K

Table 2: Pressure, Density and Temperature Details based on Altitude

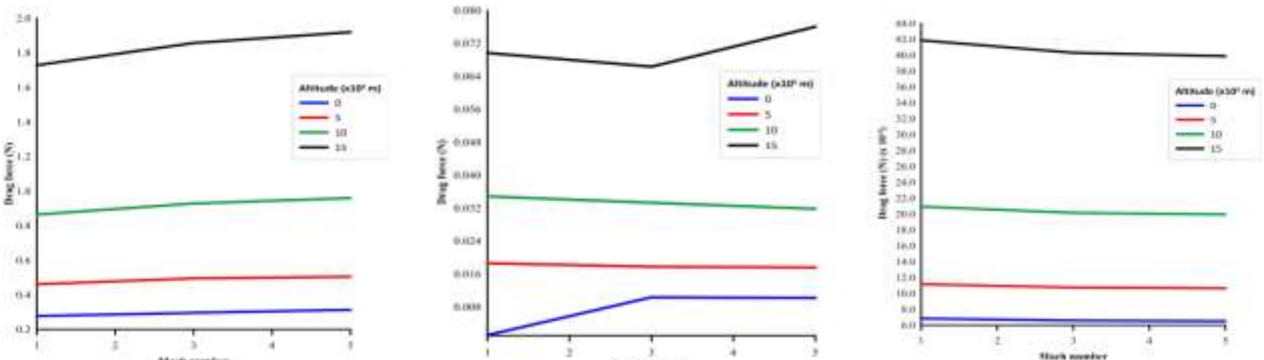
3. RESULTS AND DISCUSSIONS



(a) HIFIRE-0 (b) HyShot-3 (c) HyShot-2

Figure 5: Drag vs Altitude

The drag values noted from the simulations are plotted against mach number and altitude to study its variation with both. Figure 5 shows the variation with altitude. It can be seen clearly that drag increases with altitude. Additionally, for HIFIRE-0, the drag force is unequivocally higher at higher Mach numbers. This cannot be put forth as a blanket rule, however, as for HyShot-2, the highest drag force is experienced at Mach 1, with both Mach 3 and 5 conditions producing lesser drag. It's more complicated for HyShot-3, where the variations are less definitive.



(a) HIFIRE-0 (b) HyShot-3 (c) HyShot-2

Figure 6: Drag vs Mach number

It can be expected that similar results would be seen in variation with Mach number in Figure 6. In this case, a blanket rule can indeed be applied, as drag force increases with increasing altitude. There is a significant jump from 10 km to 15 km in the values, which shows how much more drag is experienced at such high altitudes. As for variation with Mach, it is slight, but still understandable. As with Figure 5, we can detect an increase of Drag with Mach number for HIFIRE-0, and a decrease for the other two models. The entire set of values obtained is tabulated below.

	HIFIRE-0			HyShot-3			HyShot-2		
Altitude	Mach 1	Mach 3	Mach 5	Mach 1	Mach 3	Mach 5	Mach 1	Mach 3	Mach 5
0 km	0.2772	0.2956	0.3133	0.00114	0.01033	0.01018	0.000006835	0.0000065784	0.000006508
5 km	0.4608	0.495	0.5044	0.01858	0.01776	0.01757	0.00001116	0.000010745	0.000010631
10 km	0.8639	0.9281	0.9594	0.03483	0.03329	0.0318	0.000020931	0.000020146	0.000019933
15 km	1.7279	1.8563	1.9189	0.06967	0.06633	0.07603	0.000041862	0.000040293	0.00003986

Table 3: Table of Results

4. CONCLUSIONS

The results obtained show the advantage of HyShot-2 over the other two designs - HIFIRE-0 and HyShot-3 - by a large margin. The difference is seen in the order of the drag experienced.Although the models were scaled down, the difference in the drag experienced is significant. Here, we have analysed the drag for the nose cone only. In reality, the flow diverted by the nose cone interacts with the rocket / RLV's body and other aerodynamic parts. This results in a complex flow which needs to be studied separately.

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