Hypersonic Flow Interaction of Pitched Plates on Blunted Cone at Incidence

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Abstract—High speed flow interactions for short protuberances installed on a standard blunt cone configuration were studied, aerodynamic effects were found analogous to lateral jet-interactions for Mach 3.5 to 9.7 on a conic geometry at incidence. Static aerodynamic coefficients, axial and lateral pressure distributions were determined using CFD tools for flow interaction effects of pitched short protuberance geometries of cylindrical cross-section. It has been further established that pitched short protuberance fixed on a blunted cone, causes an increase in normal force through altered pressure distribution, with a consequent development of an aerodynamic pitching moment, forward deflection of the protuberance was found to be more effective in comparison with an aft inclination, while similarity in predicted pressure distribution using CFD analysis with an overall prediction accuracy of $\pm 8\%$ was found with the experimental results in the hypersonic range.

Keywords—Blunted Cone, Hypersonic Flow, Aerodynamics, Pitched Plates.

Nomenclature—

α	Angle of attack [degree]
P	Local pressure [Pa]
P_{inf}	Reference pressure [Pa]
y	Normal distance on cylinder/ plate surface [m]
D	Protuberance cylinder/ plate base diameter, body diameter [m]
C_X	Axial drag force coefficient
C_m	Pitching moment coefficient
C_Y	Side force coefficient
X_{Cp}/L	Non dimensional centre of pressure
H/D	Non dimensional height of protuberance, plate/ cylinder
L	Length of the body [m]

I. INTRODUCTION

Side thruster is a highly responsive means for attitude control [1], with this background computational aerodynamic study using CFD analysis was conducted earlier, presented in [2], [3] and [9]; current work presented is with pitching of short protuberance forward and aft, to get a more realistic fluid flow situation, analogous to inclined jets, inferences presented here are for Mach 5 and 3.5 flows for study of static aerodynamic coefficients and axial pressure distributions for a blunted cone geometry for a fixed H/D tilted forward and rearward from its mean position.

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Single protuberance height equal to cylinder diameter was used and aerodynamic flow field behaviour for hypersonic free stream interaction with lateral short protuberance in pitched forward and aft positions were analyzed by calculating static coefficients, axial and lateral pressure distributions.

Flow visualization was made through pressure contours and velocity vector plots. CFD calculations were made using Navier-Stokes solver and quantitatively good corroboration was found with the experimental pressure distribution trends reported in [5] and [6].

II. GEOMETRY

The standard conic model is a blunted cone with half-cone angle of 10.4 degrees, jet is represented as a short protuberance is at the same location where the nozzle exit is situated as in reference [4], i.e., at 417mm from the blunted nose. The diameter of the cylindrical plate is equal to the nozzle exit diameter which is about 14.2mm, and the height of the plate is taken as 1.0 D, pitched positions of the plate were defined as inclined forward and aft of its mean position. Geometrical features are as depicted in Fig. 1.

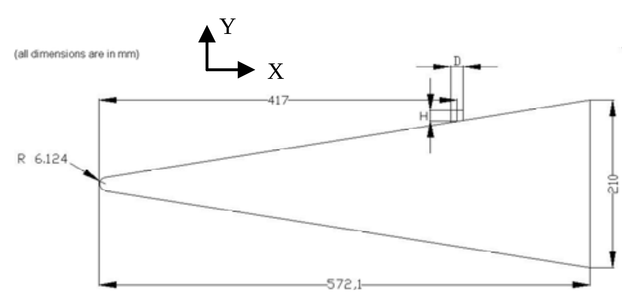

Fig. 1 Blunted cone configuration with lateral short plate.

III. GRID GENERATION

Satisfactory convergence with grid independence was employed. Structured grid was generated with 180 degrees for axisymmetric case. A typical grid used for Mach 5.0 computations for a blunted cone configuration with pitched short protuberance contained four blocks and about 0.1 million grid points. Some grid details are elaborated and are as shown in Fig.2.

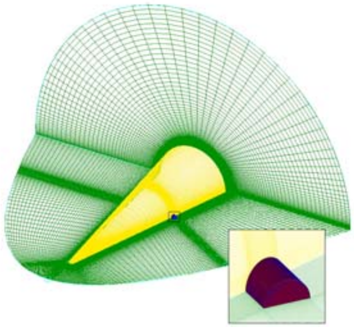

Fig. 2 Typical M=5.0 grid for pitched short protuberance fixed to the blunted cone.

IV. BOUNDARY / INITIAL CONDITIONS

Appropriate hypersonic inflow conditions for a half-body, 180 degree grid were used, while the extrapolation condition was applied at the outlet section, symmetric condition was employed at the symmetry plane and no slip adiabatic condition was imposed at the surface of the body as well as on the inclined short protuberance. The computation is performed with the Mach number, M = 3.5 to 5.0 with an angle of attack of zero and -12 degrees, air specific heat ratio, γ considered as 1.4.

V. RESULTS AND DISCUSSION

Aerodynamic flow interaction behaviour of a pitched short protuberance installed on blunted cone geometry with the incoming hypersonic flow, axial pressure distribution was initially calculated on the leeward side of the body for an angle of incidence of negative 12 degrees as protuberance is positioned on the leeward side of the blunted cone configuration. The trend of pressure distribution for vertical protuberance showed similarity for Mach 5 and 9.7 flows [8] and [9]. After benchmark study of a lateral short protuberance, the same cylindrical geometry was studied by pitching it forward and aft of its mean vertical position, all inclination angles are considered from vertical plane to the centre line of the blunted cone, inclination considered as 30 and 45 degrees forward and aft for hypersonic flow at Mach 3.5 and 5.0 at -12 degree cone incidence, transversal pressure distributions were calculated along the plate height, and are as shown in Fig. 3.

The rise in peak pressure value for a specific Mach is a representation of strong flow interaction, moreover a forward inclination of 45 degrees showed relatively stronger interaction in comparison with 45 degree aft pitching angle. Details are as shown in Fig.4. On the quantitative analysis part, static aerodynamic coefficients were computed to quantify the effects of pitching forward and aft of the short protuberance at Mach 9.7 while blunted cone is at an angle of attack of zero and -12 degrees.

Aerodynamic pitching moment created due to hypersonic flow interaction grossly showed a similar behaviour for forward pitched short protuberances in case of 30 and 45 degree forward tilt, so its usefulness is almost of the same magnitude and about 11 % more effective in comparison with the case of pitching it in an aft direction. Details of computed static aerodynamic coefficients for Mach 9.7 are given in Table 1 for 30 and 45 degrees tilt in forward direction.

Table 1
Static aerodynamic coefficients for 30 and 45 degrees forward pitched at M = 9.7.

Aerodynamic Coefficients	Forward 30 degrees pitch		Forward 45 degrees pitch	
	AOA = 0^0	AOA = -12^0	AOA = 0^0	AOA = -12^0
C_Y	-0.0191	-0.38615	-0.01529	-0.3813
C_X	-0.10139	-0.13958	-0.10112	-0.13979
C_m	0.009742	0.231935	0.006244	0.227524
X_{cp}/L	-0.51006	-0.60063	-0.40835	-0.59671

Qualitative trends in the form of pressure contours, Mach plots and close-up of velocity vectors at various Mach numbers in vicinity of the pitched short protuberance are shown in Fig. 5.

VI. CONCLUSIONS

The aerodynamic behaviour of flow interactions for pitched forward and aft short plates, H/D = 1 on leeward side of a blunted cone geometry at -12 degree angle of attack in supersonic-hypersonic flows showed that:

1. Forward pitching for all investigated hypersonic flows, i.e., 3.5 and 5.0 were found effective in creating aerodynamic normal force and aerodynamic pitching moments in comparison with aft inclinations. Rise in interaction force with the increase in Mach number as well as with an increase in the pitching forward angle of 30 to 45 degrees. Static pressure rise of the order of 58 to 60 % was observed for increase in Mach from 3.5 to 5.0 and with the tilt angle.

2. For Mach 9.7, maximum flow interaction was observed with a forward 45 degree tilt, while about 2% increase in aerodynamic pitching moment was caused by increasing the forward pitch angle from 30 to 45 degrees. Finally it was concluded that the rise in pressure responded to specific corresponding Mach number, strong flow interaction with consequent aerodynamic pitching moment was produced with forward pitched plate when installed on blunted cone at incidence, interacting with supersonic-hypersonic flows.

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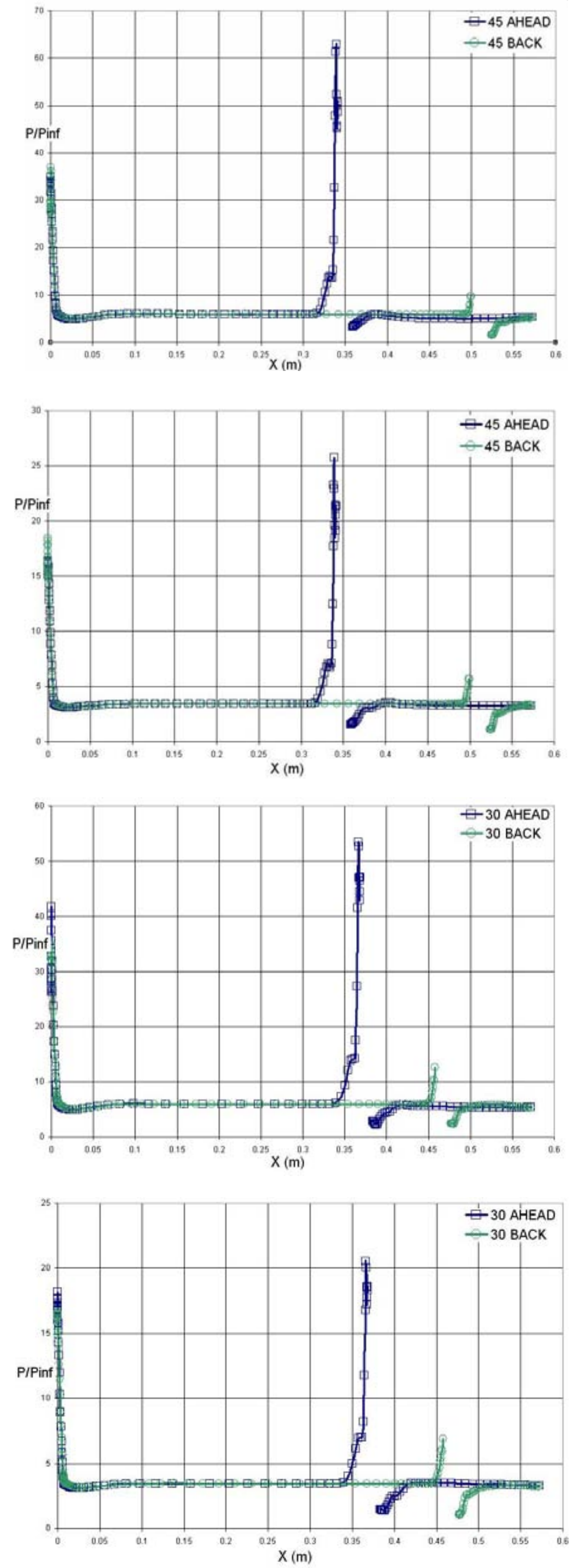

Fig. 3 Leeward surface axial pressure distribution for pitched 45 and 30 deg plate at Mach 5.0 and 3.5 respectively at α = -12degrees.

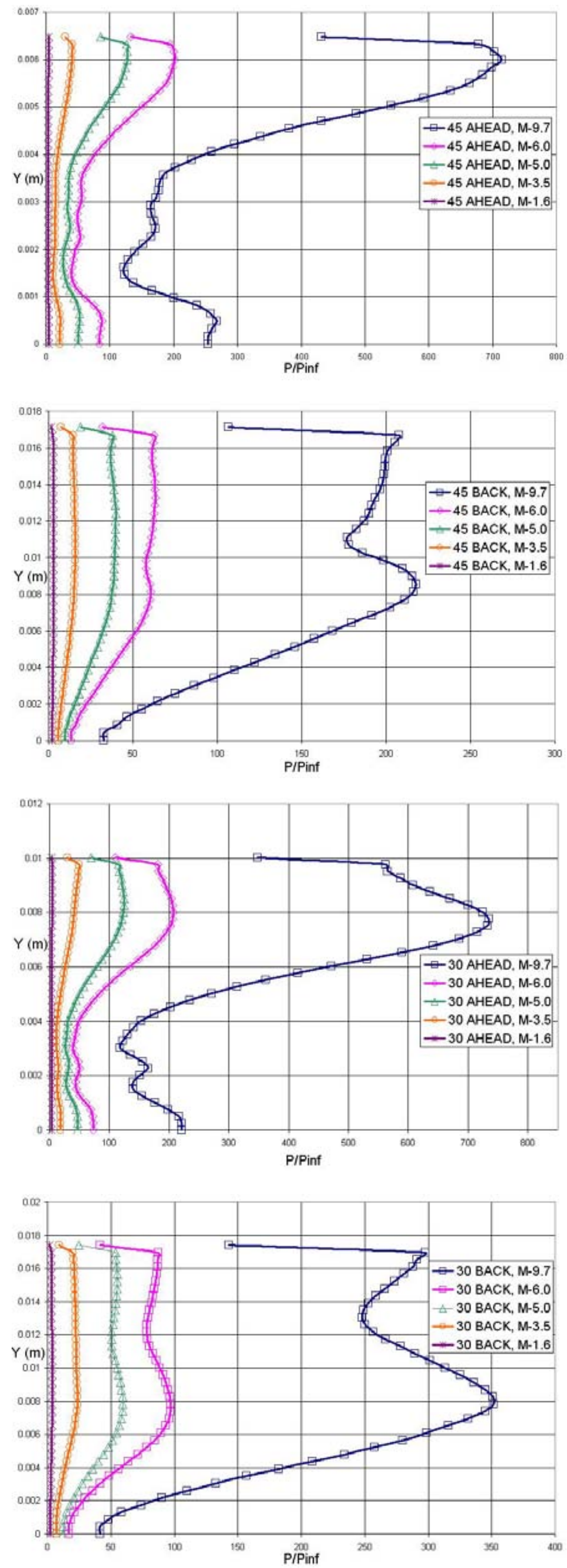

Fig. 4 Transversal surface pressure distribution on 30 and 45 degree pitched plate on a blunted cone at M = 5 and 3.5 respectively at α = -12 degrees.

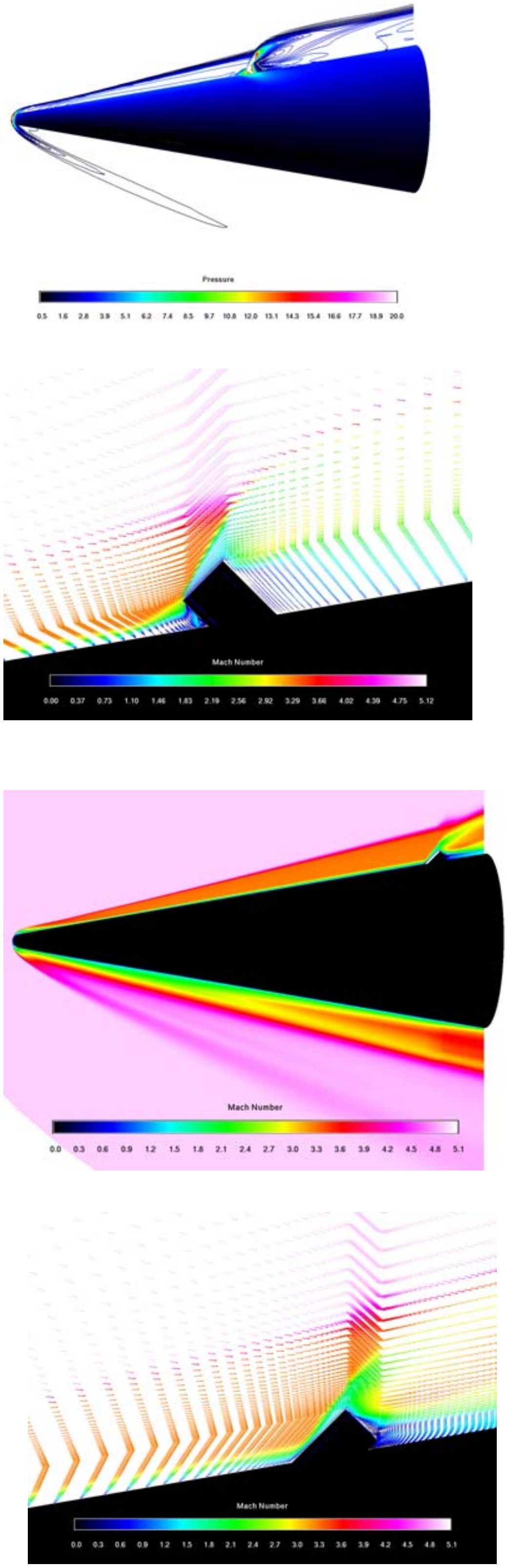

Fig. 5 Pressure contours and velocity vectors for lateral protuberance at 45 degrees pitched forward at Mach 5 and Mach and velocity contours for Mach 6 for 45 degrees pitched aft protuberance.

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