COMPUTATIONAL AERODYNAMIC BEHAVIOUR OF LOCATION AND INCLINATION OF LATERAL PLATE /JET - INTERACTIONS WITH HYPERSONIC FLOWFIELD

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Abstract

Hypersonic plate/ jet-interaction flow for blunted cone geometries is a topic of interest in the fields of aerodynamics and gas dynamics as its potential is being examined for its effectiveness to improve performance and efficiency of various aerodynamic configurations. In this sequence, objective of our previous work was to carry out a study of a lateral jet interaction with an incoming hypersonic flow at Mach 9.7 for a biconic configuration at incidences [1], later study was extended by modelling jet of cold air as a solid cylinder with sharp edges, projected as a plate analogous to jet [2], conic configuration considered for the study is an adaptation from reference [3]. Present study is now only focused to mounting of the cylindrical plates on a blunted cone at various locations and with different angular orientations, in this study aerodynamic flow behaviour is studied for a fixed location of plates placed aft and forward to a mean position, as well as with their different angular orientations, pitching forward and aft with the body centreline. Aerodynamic flow field behaviour was studied for hypersonic free stream interaction with lateral plate position and angles by visualizing axial and lateral pressure distributions and by plotting pressure contour plots. CFD calculations were made using PAK-3D [4], a Navier-Stokes solver. Similar pressure distribution trends have been obtained as reported in experimental findings [9]. Forward position and inclination were found effective for hypersonic flow interactions.

Nomenclature

M	Mach number
M_j	Jet exit Mach number
R_e/m	Reynold's number per unit length
α	Angle of attack [degree]
P	Local pressure [Pa]
P_{inf}	Reference pressure [Pa]
D	Cylinder/ Plate base, body diameter [m]
H	Height of cylinder/ plate [m]
θ	Angular position of cylinder/ plate [degrees]
C_D	Axial drag force coefficient
Cp	Non dimensional pressure coefficient
L	Length of the body [m]
q_∞	Non-dimensional free stream dynamic pressure

1 Introduction

Flow interaction of control jets is of concern for maneuverability of a vehicle in high altitude flights. In free molecular rare field flow they provide the sole source of control [5]. A control jet exhausting from the side of a vehicle may be thought of as an obstruction to the on coming flow. An approximation of this obstruction is to use an analogous solid object, replacing jet by a solid cylinder [5]. For the flights of high Mach number in low density medium, more area requirement for conventional pitching moment aerodynamic surfaces results in higher drag giving rise to reduced efficiency of flight. Lateral jet/ plate is an alternate mechanism to produce desired pitching moment controllability in the upper atmosphere flights. Injection of supersonic lateral jet in a hypersonic flow field itself a very complex phenomena to predict numerically. The jet initially is continuum but then enters in rare field of very low density and thumps with the strong boundary layer which generates a complex shock/ shock interaction [5], [6] and [8]. Moreover, due to boundary layer separation on the leeward side of the body a relatively high change of density and pressure is visualized on the upstream and downstream of the jet/ plate, this pressure difference is the main cause of generating aerodynamic pitching moment. Present study using CFD analysis was conducted as an extension of earlier work presented in [1] and [2]. Alteration of position and inclination of plates were studied for Mach 5 and 9.7 flows for pressure distributions in case of a blunted cone geometry for a fixed H/D; reference [3] was used for adaptation of blunted biconic geometry. With establishment of an analogous behaviour of a lateral plate / jet interaction with an incoming hypersonic flow at Mach 9.7 [2], investigation was made for Mach 5 and 9.7 flows for a blunted cone configuration at an angle of attack of negative 12 degrees, by modelling a jet of cold air as a solid short circular cylinder projected as a lateral plate over a blunted cone mounted at the location of nozzle exit [2]. Single plate height equal to cylinder diameter was used in these analyses. Aerodynamic flow field behaviour for hypersonic free stream interaction with lateral plate was analyzed by calculating axial and lateral pressure distributions. Flow visualization was made through plotting of pressure contour plots. Three different positions of plates were used, by translating plate 5D forward and 5D rearward from the mean position, secondly, inclination of plate from the mean position was pitched 45 degrees forward and 45 degrees aft from the body centerline. CFD calculations were made using PAK-3D [4], Navier-Stokes solver and quantitatively good corroboration was found with the experimental pressure distribution trends reported in [9].

2 Geometry

The model is a blunted cone geometry with fore cone half-angle 10.4° and that of the aft cone is 6°. The base diameter is 0.209 m, the diameter at the biconic junction is 0.104 m and the nose radius is 0.0083 m. The plate center line is at 0.417m form the nose tip which is at the same location as thruster nozzle center line [1] and the base diameter of the plate is same as the nozzle exit diameter [3], which is 0.0141m. The cylinder/ plate has sharp edges. Single plate height equal to, 1.0D was used; height (H) of the cylinder/plate is measured along the plate centre line and is normal to the centre line of the cone. Geometrical details of the conic geometry is as shown in Fig. 1.

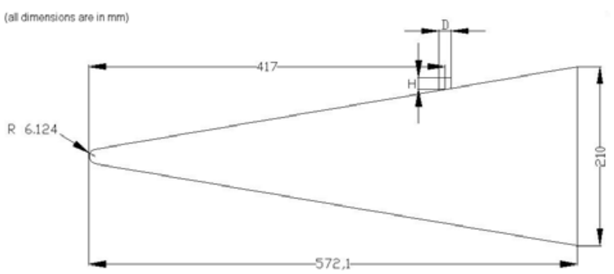

Fig. 1. Blunted Cone configuration with lateral cylinder/ plate, reference [3].

3 Flow Conditions

The computation is performed at the following conditions,

Mach number, M = 5 and 9.7
Angle of Attack = 0° and -12°
Specific heat ratio =1.4
Reynolds's Number, Re/m = 4.85×10^6 and 2.47×10^6.

4 Grid Generation

For the purpose of gird generation PAK-GRID [7] is used. The three dimensional structured grid is generated of each cases. A 180° gird is found suitable to perform the required aerodynamic calculations. Selection of grid for all computations was made after a systematic grid independence studies. The grid dimension for a biconic configuration with a lateral plate is with four blocks and 0.89 million cells. The grid scheme is as shown in Fig. 2.

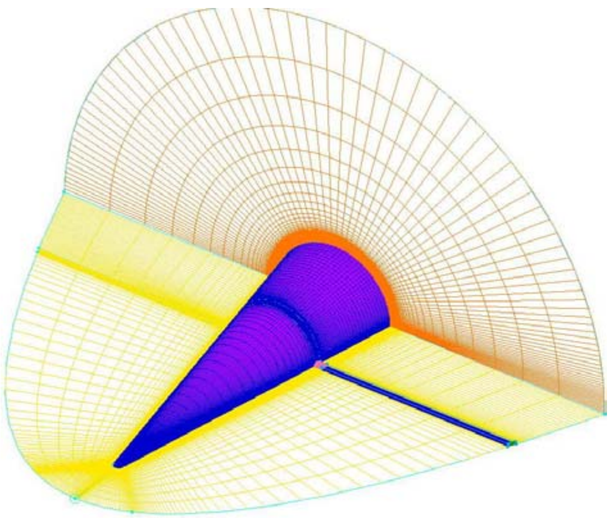

Fig. 2. Grid scheme around Blunted cone configuration with lateral plate.

5 Boundary Conditions

At the inlet hypersonic inflow condition has been used; the supersonic outflow (extrapolation) condition was used at outlet. The symmetric condition was used at the symmetry plane and no slip adiabatic condition has been employed at the surface of the body as well as at the plate/ cylinder.

6 Results and Discussions

Demonstration of aerodynamic flow interaction behaviour of a cylinder/ plate installed on blunted cone geometry with the incoming hypersonic flow, Mach 9.7 by a 5D forward and 5D aft locations of the mean position, axial pressure distribution is calculated on the leeward side of the body for an angle of incidence of negative 12˚ as plate is positioned on the leeward side of the blunted cone configuration. The axial pressure distribution in vicinity of the lateral plate is shown in Fig. 3 and lateral pressure distribution on plate is shown in Fig. 4 , respectively.

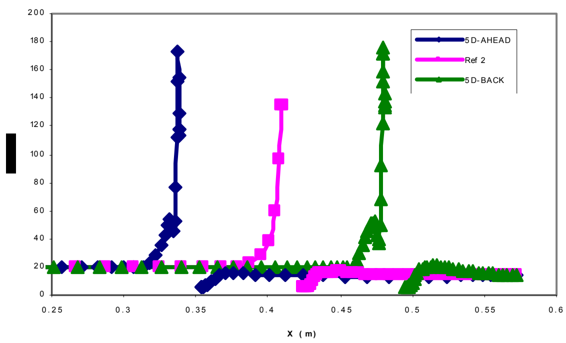

Fig. 3. Comparison of leeward surface axial pressure distribution for lateral plate at 5D forward, mean and 5D aft positions on blunted cone geometry for an angle of attack of -12 degrees.

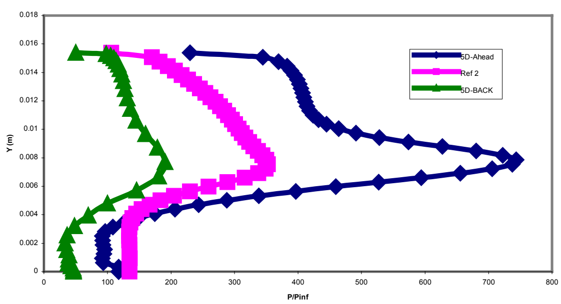

Fig. 4. Comparison of lateral pressure distribution for plate at 5D forward, mean and 5D aft positions on blunted cone for an angle of attack of -12 degrees.

The trend of pressure distribution for plate on blunted cone geometry showed similarity as in case of Mach 6 and 9.7, having a sharp pressure rise occurring initially in vicinity of the plate in all the forward and aft cases. However, in the downstream of the plate, slight drop and associated pressure rise remained representative of corresponding positions with increasing magnitudes. Lateral plate with forward 5D position with size1.0D has showed most effectiveness for negative 12° incidence, these results are consistent with earlier findings and is in agreement with [9] which has shown deamplification effects of negative angle of attack in case of a windward jet of Mach 2.2. Lateral pressure distribution showed stronger flow interaction, giving rise to a side force and generates amplified pitching moment, observed in case of 5D forward location compared to mean and aft positions. Qualitative trends in the form of pressure contours in vicinity of the forward and aft plate locations at Mach 9.7 are shown in Fig. 5.

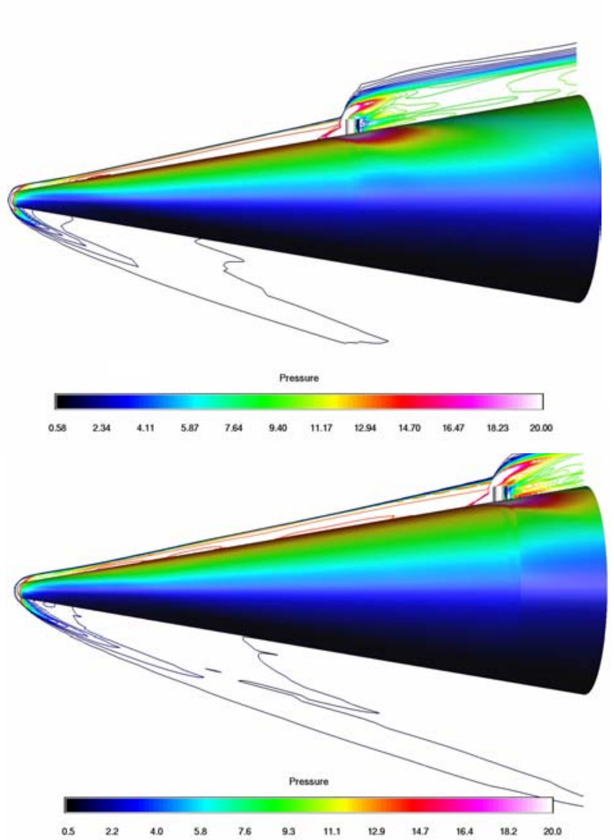

Fig. 5. Pressure contour for lateral plate at 5D forward and 5D aft positions respectively on blunted cone for Mach 9.7 and an angle of attack of -12 degrees.

Later, same geometry of lateral plate was studied while installed on a blunted conic geometry with the incoming hypersonic flow, Mach 5 by pitching it 45 degree forward, zero position and 45 degree aft angle, axial pressure distribution is calculated on the leeward side of the body for an angle of incidence of negative 12˚ as plate is positioned on the leeward side of the blunted cone configuration. The axial pressure distribution in vicinity of the lateral plate for both forward and aft angular positions is shown in Fig.6, while transversal pressure distributions are shown in Fig.7.

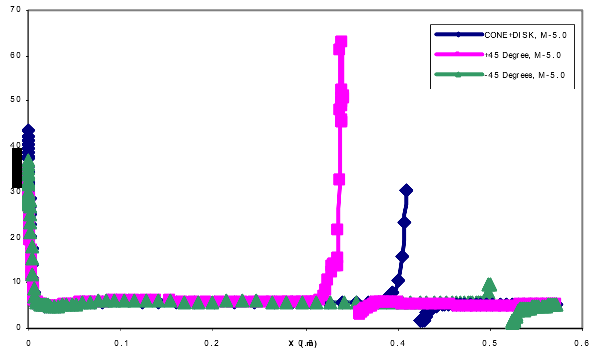

Fig. 6. Comparison of leeward surface axial pressure distribution for lateral plate at 45 degree forward, mean and 45 aft inclinations on blunted cone geometry for an angle of attack of -12 degrees.

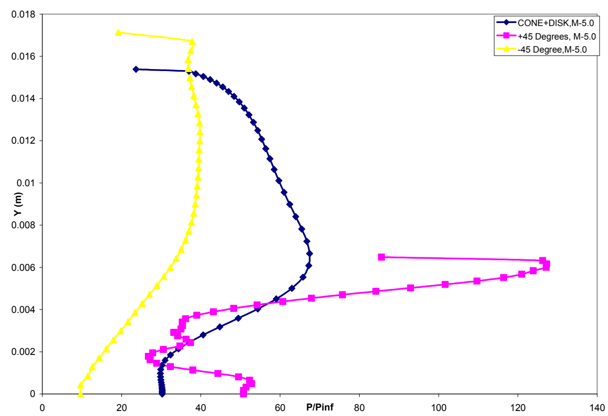

Fig.7. Comparison of transversal surface pressure distribution on plate at 45 degrees forward, mean and 45 degrees aft angular locations on blunted cone for an angle of attack of -12 degrees.

Qualitative trends in the form of pressure contours plots in vicinity of the plates at 45 degrees forward and 45 degrees aft inclination angles are shown in Fig. 8.

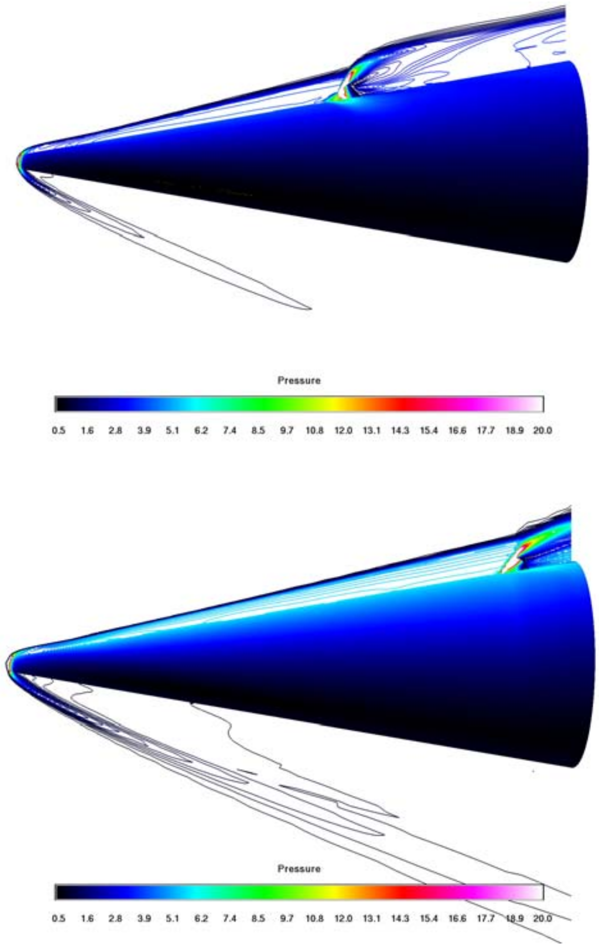

Fig. 8. Pressure contour for lateral plate at 45 degrees forward and 45 degrees aft inclination respectively on blunted cone for Mach 5.0 and an angle of attack of -12 degrees.

6 Conclusions

The aerodynamic behaviour of flow interactions for plates, H/D = 1 on blunted cone geometry in hypersonic flows were found effective in case of -12 degree angle of attack as introduced at the leeward side of the cone at Mach 9.7 for forward 5D position and at Mach 5 for 45 degree forward inclinations. Rise in pressure responded to specific corresponding Mach, producing strong flow interaction in the presence of the plate and effective in generation of aerodynamic side force and aerodynamic pitching moments for blunted conic configuration in hypersonic flows.

Acknowledgement

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