AERODYNAMIC ANALYSIS OF COMPUTED PLATE / JET - INTERACTIONS FOR BLUNTED CONE-CYLINDER IN HYPERSONIC FLOW

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OVERVIEW

The study carried out presently is an extension of an earlier work for lateral jet/ plate interaction for conic geometries at incidence, now extended for cone-cylinder geometry, considering a 10.4 degree cone with attached cylinder affixed with short plate geometry for an incoming hypersonic flow of Mach 5.0, 6.0 and 9.7. Aerodynamic effects were found analogous to lateral jet-interactions for different Mach numbers, static aerodynamic coefficients and axial pressure distributions were determined using CFD tools; It has been concluded that short protuberance/ plate installed on a blunted cone-cylinder causes an increase in net normal force through altering pressure distribution, with a consequent development of an aerodynamic pitching moment, while similarity in predicted pressure distributions, using CFD analysis with an overall prediction accuracy of ± 10 % was found with the computational and experimental results in the literature.

KEYWORDS

Hypersonic flow, Blunt nose cone-cylinder, Jet Interaction (JI), Short Protuberances, Lateral plate, CFD, Static Aerodynamic Coefficients, Axial Pressure distribution.

NOMENCLATURE

M	Mach number
X	Axial distance on cone surface [m]
D	Protuberance cylinder/ plate base diameter, body diameter [m]
H	Protuberance height [m]
x/D	Non dimensional axial distance on the surface
H/D	Non dimensional height of protuberance, plate/ cylinder
R_e/m	Reynold's number per unit length
α	Angle of attack [degrees]
P	Local pressure [Pa]
P_{inf} , P_∞	Reference pressure [Pa]
Cp	Non dimensional axial pressure distribution coefficient
L	Length of the body [m]
q_∞	Non dimensional free stream dynamic pressure

Subscripts

∞	Freestream conditions

1. INTRODUCTION

Reviews and surveys in JI based on CFD approaches, estimates aerodynamic forces and pressure and velocity fields, in general flight requires conventional aerodynamic surfaces or jets to deliver required force in order to maintain desired stability; in absence of atmosphere, low velocity, lower dynamic pressure. For bodies of revolution type of geometries, supersonic jets are in vigorous use for attitude or roll control on vehicles undergoing atmospheric flight, upon encountering a crossflowing freestream reoriented to provide flow interactions, though jets in crossflow (JICF) is one of the classic problems of fluid mechanics, however, necessary data for aerodynamic applications are lacking [1]. For vehicles using aerodynamic control surfaces for any kind of maneuvering at high altitudes or at lower velocities encounter lower efficiencies of control surfaces, similar requirements for maneuvering of aerodynamic vehicles lead to an introduction of lateral jet positioned forward and aft for attitude controls [2]. As the jet-in-cross flow interaction is an inherently unsteady flow, accurate computational prediction of the mean flowfield behaviour generally requires knowledge of the instantaneous turbulent properties, which can come only from experiments [3]; Flow interaction for hypersonic flows is difficult to produce numerically, owing to complexity of its nature, where strong bow shock interaction with weak boundary layer separation shock causes formation of a low density region upstream as well as downstream of the jet [4]. Jet displaces the supersonic crossflow as if a bluff body were inserted into the flow [5]. Control jets are used to influence the maneuverability of vehicles flying in the upper atmosphere, for lower altitude, the interaction of the jet with the shock layer in conjunction with maneuverable surfaces considerably effect the aerodynamic performance of the vehicle [6]. A validation exercise for CFD code was executed by considering control jet exhausting from the leeward side of the cone-cylinder configuration as an obstruction, a first order approximation of this situation is to consider a solid cylinder, and hence the flow interaction is more of a plate/jet-interaction type.

With this background of flow analogy for jet and plate/ short-protuberance, computational aerodynamic study using CFD analysis was conducted [7], [8] and [9]. All computations were made using CFD code, PAK-3D [13] and results were post processed by post processing code LOOK [14]; the present paper only focuses main inferences related to addition of short protuberance/ plate to the cylindrical portion, for Mach 5, 6 and 9.7 flows for studying pressure distributions for a blunted cone-cylinder geometry for a fixed H/D. With establishment of an analogous behaviour of a lateral plate / jet interaction with an incoming hypersonic flow at Mach 9.7 [9], investigation was made for Mach 5, 6 and 9.7 flows for blunted cone-cylinder configurations for single plate location at an angle of attack of negative 12 degrees, by modelling a jet of cold air as a solid short circular cylinder protuberance projected as a lateral plate over a cylinder mounted at the same location of the nozzle exit [10]. Single protuberance height equal to cylinder diameter was used in the current analyses. Aerodynamic flow field behaviour for hypersonic free stream interaction with lateral short plate was analyzed by calculating axial and lateral pressure distributions and static aerodynamic coefficients, flow visualization was made through pressure contours and velocity vector plots.

2. GEOMETRY

In the present study, model selected was a blunted cone-cylinder configuration having a blunted cone with a half-cone angle of 10.4°, representation of jet as a short protuberance is at the same location as the nozzle exit position [10]. Analyses were made with the geometry comprised of cone and cylinder fitted with a plate, with half-cone angle of 10.4° and its base diameter is 0.21m and the nose radius is 0.01m. Geometrical features are described in Fig. 1. The plate centre line is at 0.71 m form the nose tip, and the base diameter (D) of the plate is same as the nozzle exit diameter [11], which is 0.0141m. The cylinder/ plate have sharp edges. Height (H) of the cylinder/plate is measured along the plate centre line, which is normal to the centre line of the cone-cylinder geometry.

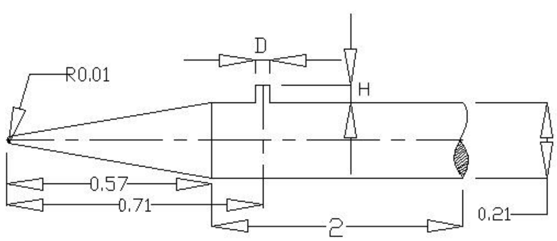

FIG 1. Geometry of blunted cone-cylinder installed with a short protuberance.

3. MESH GENERATION

Density and packaging of computational grids for hypersonic flows was implemented from earlier studies conducted [7] and [9], satisfactory convergence with grid independence studies was attained, grid generation was performed using software PAK-GRID [12]. Structured grid was generated for each case, a 180 degree gird was found appropriate. A typical grid used for Mach 9.7 computations for blunted cone-cylinder configuration with accompanying short protuberance contained eight blocks and contains more than two million grid points. Some details of the computational grid are as shown in Fig. 2.

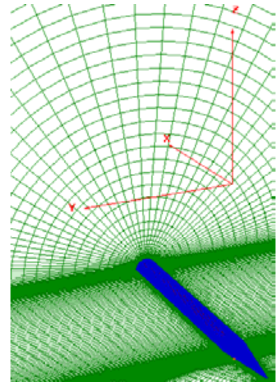

FIG 2. Typical Grid for cone-cylinder geometry.

4. RESULTS AND DISCUSSIONS

Effect of protuberance/ short plate were investigated first in case when the plate was installed on a blunted conic configuration fitted with a cylinder [9], later, study was extended for blunted cone –cylinder geometry with short protuberance installed on the cylindrical portion, in order to determine the flow interaction effects of protuberance location. Results were later compared with the CFD data of [10] which showed a similar effect with the unsteady jet conditions by putting the jet on and off. With a fixed H/D of 1.0, analogous behaviour was found as compared in Fig.3.

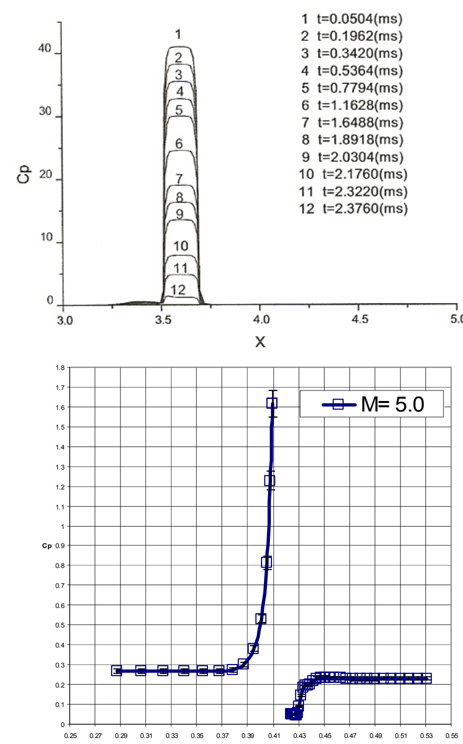

FIG 3. Cp distribution comparison for jet at various time-steps, Ref [10] with solid protuberance at Mach 5.

This comparison showed that under similar flow conditions, a short protuberance is analogous to an issuing jet from the blunted cone-cylinder configuration, while the plate height is representative of the jet momentum, plate height, H/D =1 considered was found effective in altering axial pressure distribution for Mach 5 flow conditions. Reasonable comparison was also obtained with the experimental data [16]. The aerodynamic flow interaction of a protuberance/ plate fixed on to a blunted cone-cylinder with the incoming hypersonic flow, axial pressure distribution was computed on the leeward side of the cylindrical part for an angle of incidence of negative 12 degrees, as short plate is positioned on the leeward side of the blunted cone–cylinder configuration. For Mach 9.7 interaction at an angle of zero and negative 12 degrees, the axial pressure distribution in vicinity of the lateral plate in the meridian plane with 4% error bars is as shown in Fig. 4. The rise in axial pressure while moving from zero to negative twelve degrees give rise to an increase in peak pressure which is in excess of 2.8 times of Cp obtained for zero angle of attack.

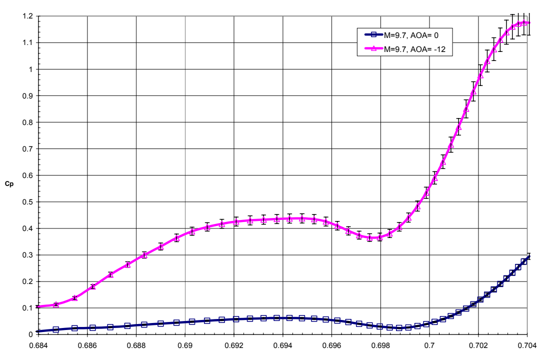

FIG 4. Axial Cp distribution in vicinity of the plate for Mach 9.7.

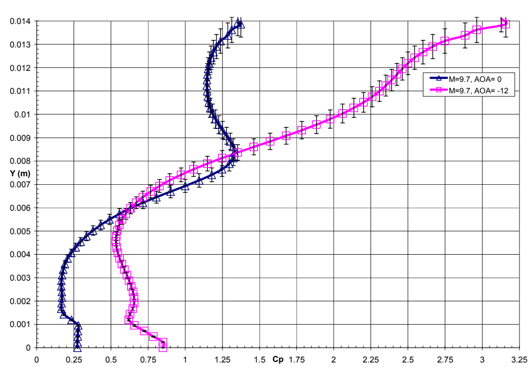

FIG 5. Lateral Cp distribution along plate height for Mach 9.7.

In the present analysis, while comparing the lateral Cp distribution pressure rise occurring in the vicinity of the lateral plate around 0.7 m, lateral plate 1.0D has showed effectiveness in case of -12° incidence compared to zero degree angle of attack, effectiveness was due to strong flow interaction, giving rise to a side force creating amplification of pitching moment, this finding is in consonance with [15] which has shown deamplification effects of negative angle of attack in case of a windward jet of Mach 2.2. For Mach 9.7 interaction at an angle of zero and negative 12 degrees, the lateral pressure distribution in vicinity of the lateral plate in the meridian plane with 4% error bars is as shown in Fig. 5. The rise in lateral Cp while increasing the incidence angle from zero to negative 12 degrees give rise to an increase in Cp which is in excess of 1.4 times of the Cp obtained at zero angle of attack.

In addition to quantify the flow interaction effects, computation of static aerodynamic coefficients was made to demonstrate the behaviour of the lateral plate interaction with the incoming hypersonic flows in case of blunted cone-cylinder geometry; calculations were made at an angle of attack of zero degree and -12 degree's angle of attack for the free stream Mach number of 9.7. Comparison of aerodynamic coefficients for the plate installed on cone [9], were made with the coefficients for the plate installed on the cylindrical portion, as given in Table 1, all computations were made with an accuracy of ± 10%.

Aerodynamic Coefficients/ Angle of Attack	Cone with plate and cylinder		Cone –cylinder with plate	
	0^0	-12^0	0^0	-12^0
C_Y	-1.36×10^{-2}	-1.03719	-3.42×10^{-3}	-1.24559
C_X	-9.44×10^{-2}	-0.136	-0.08671	-0.21896
C_m	6.53×10^{-4}	0.448533	1.75×10^{-4}	0.555759
X_{Cp}/L	-4.80×10^{-2}	-0.43245	-5.11×10^{-2}	-0.44618

TAB 1. Static aerodynamic coefficients for blunted cone-cylinder configuration with cylindrical plate at M = 9.7.

In order to determine the flow interaction effects of protuberance location, just by changing the position of the protuberance from cone part to cylindrical portion resulted in an increase in static aerodynamic pitching moment, which further resulted in some improvement in the overall static stability. Qualitative trends in the form of pressure contours and velocity vector plots in the vicinity of lateral plate are compared.

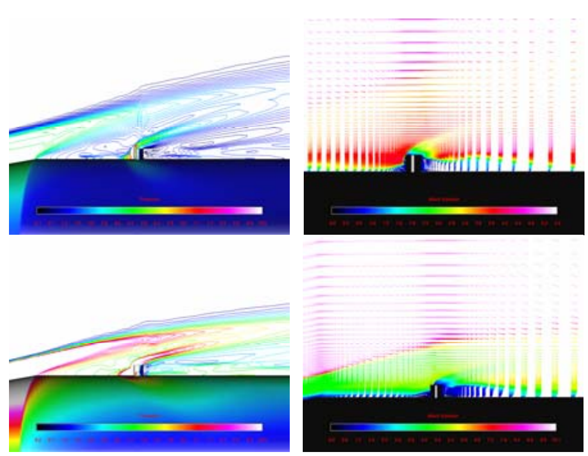

FIG 6. Pressure distribution and close up velocity vector plots at Mach 5.0 and 9.7, angle of attack -12 degrees.

Pressure contours are plotted with increasing Mach from 5 to 9.7 for an angle of attack of negative 12 degrees, details are as shown in Fig. 6. In general, CFD computations got validated with the experimental findings of [15] and [16] and good corroboration was found with the CFD-CFD comparisons with [10].

CONCLUSIONS

1. The aerodynamic flow interactions for protuberance/ short plate installed on a cylindrical portion of blunted cone-cylinder geometry in hypersonic flow were investigated, its effectiveness was observed when it is installed at the leeward side of the cone-cylinder configuration when the angle of attack was increased from zero to -12 degrees with Mach 5, 6 and 9.7 flows; increase in axial Cp was found analogous to lateral jet.

2. It has also been concluded through estimation of the static aerodynamic coefficients, that the protuberance/ short plate installed on the cylindrical part of a blunted cone-cylinder in contrast to its installation on the conical part relatively produced a greater aerodynamic pitching moment by altering axial pressure distribution and with almost same static stability in the hypersonic Mach range.

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