International Journal of Engineering Research in Electronic and Communication Engineering (IJERECE) Vol 2, Issue 3, March 2015

NUMERICAL SIMULATION OF SLANTED PERFORATED TABS USING AXISYMMETRIC JET CONTROL

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Abstract*- This paper deals with the optimization of slanted perforated tabs to enhance the mixing characteristics of subsonic and sonic axi-symmetric jets issuing from a convergent nozzle. Measurements of centerline axial velocity decay and radial velocity distribution were carried out. The effect of various perforation geometries such as circular, ellipse, square and triangular cross sections of 2mm equivalent diameter in the tab is analyzed and the corresponding area blockage are found to be 2.88%. In this paper the 3-D numerical simulations have been carried out using the commercial meshing tools and analysis software. The centerline velocity of the jet is found to decay at a faster rate for the tab with elliptical perforation geometry as compared to other geometries. Also the reduction in potential core length with elliptical perforation tab for the jet operated at Mach number of 0.4, 0.8 and 1 are found to be 43.8%, 49.5% and 50%.

Keywords: *Potential Core, Centerline Velocity Decay, Axi-Symmetric Jets, Circular Perforation, Ellipse Perforation and Square Perforation.*

Nomenclature

D = Nozzle exit diameter | *M = Mach number*
V_j = Centerline jet velocity | *V_e = Nozzle exit velocity*
P_a = Atmospheric static pressure | *P_o = Total pressure*

I. INTRODUCTION

High speed jets are great importance to aerospace as well as other industries. In an effort to enhance mixing in jet flows, a passive control method, using vortex generators in the form of mechanical tabs or small protrusions at the exit of a nozzle has been under investigation for the past several years. A tab is kept normal to the flow direction which can produce a pair of counter-rotating stream wise vortices, which can offer a considerable reduction of potential core length as well as the suppression in noise level. In order to achieve the reduced potential core length at the cost of minimum thrust loss, slanted perforated tabs can be used.

Bradbury and Khadem [2] were the first to study the effect of mechanical tabs on jet flows in detail. They reported that, at low jet speeds, mechanical tabs or small protrusions into the jet flow at the exit of nozzle can increase the jet spreading rate significantly, reduce the potential core length (from 6D for the conventional jet to 3D, where D is the nozzle exit diameter) and even bifurcate the jet flow. Rathakrishnan [3] studied an experimental investigation of rectangular tab with and without corrugation operated at Mach number 1.8. As high as 78% of reduction in core length was achieved with corrugated tabs for the jet operated at nozzle pressure ratio (NPR) of 7, the corresponding reduction with the plain tabs is only 54%. The mixing effectiveness of corrugated tabs increases progressively with increase of NPR whereas, the maximum mixing effectiveness of the plain tabs is found to be at the correctly expanded state. Thanigaiarasu.S [17] et.al found experimentally that the jet decays at faster rate in the case of arc-tab facing in configuration at all blockage levels as compared to arc-tab facing out and rectangular tab configurations. With arc-tab facing in, the core length was reduced by 80% and the corresponding reduction was 40% for the jet with arc-tab facing out and rectangular tabs. Dharmahinder Singh Chand[6] found that the jet control with perforated tabs at the nozzle exit. It shows the velocity decay is faster and the core length is reduced drastically as compared to uncontrolled jets at all subsonic and sonic correctly expanded conditions.

The objective of the paper is to optimize the perforated tabs to enhance the mixing characteristics of subsonic and sonic axi-symmetric jets issuing from a convergent nozzle. Tabs with various perforations geometries of same 2mm equivalent diameter are considered for the analysis. The effect of the perforated tabs at different Mach number on the mixing characteristics is investigated.

II. METHODOLOGY

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A. TAB GEOMETRY

A pair of perforated tabs (4x3x2 mm each) is kept opposite to each other at the exit plane of the nozzle as shown in figure 1. Four different perforation geometries are considered with equivalent diameter of 2mm and the perforation is exactly located at the center of the tab.

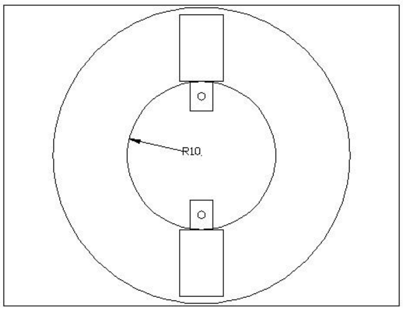

Figure. 1 Sketch of Nozzle Geometry with Perforated Tabs

B. NUMERICAL MODEL

The computational domain was modeled and meshed in GAMBIT. It consisted of a convergent nozzle of length 40mm with inlet diameter of 40mm and exit diameter of 20mm followed by a rectangular domain. The flow is assumed to be axi-symmetric, compressible and turbulent. The computational domain consisted of an axi-symmetric unstructured mesh with approximately 310000 tetrahedral cells. The turbulent calculations were carried out in Realizable k-ε turbulence model. The boundary condition for the nozzle was set as a pressure inlet with a prescribed total pressure, static pressure, total temperature and turbulence intensity. The far field and outlet boundary was set as a pressure outlet with a prescribed static pressure and static temperature.

III. RESULTS AND DISCUSSION

A. CENTERLINE AXIAL VELOCITY PROFILE

From figure 2 to 4 shows the centerline velocity Decay for Mach 0.4, 0.8 and correctly expanded for controlled and uncontrolled jets. The centerline jet velocity was normalized by the corresponding nozzle exit velocity [6]. The non-dimensionalised velocity (V_j/V_e) variation along the axial distance (x/D) for different Mach number. At Mach 0.4, the potential core length is about x/D = 8 for uncontrolled jet whereas it is about 4.5 when the elliptical perforation is introduced in the tabs at the nozzle exit. Figure 3 compares the centerline velocity decay of uncontrolled and controlled jet with elliptical perforated tabs at Mach 0.8, the core length reduces from about x = 9.3D to 4.7D. The decay of correctly expanded sonic jet is shown in figure4, the core length comes down from about x/D = 10 (uncontrolled jet) to about 5.1 (elliptical slanted perforated tabs).

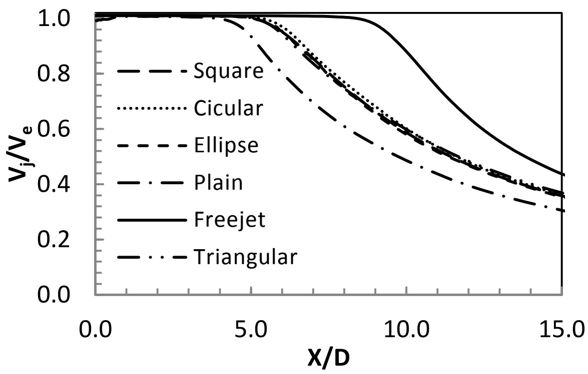

Figure 2. Centerline velocity decay of M=0.4.

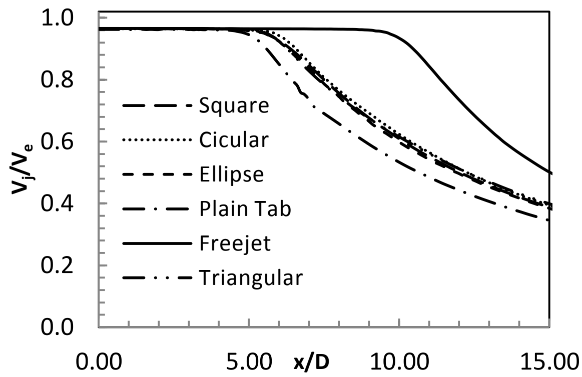

Figure 3. Centerline velocity decay of M=0.8.

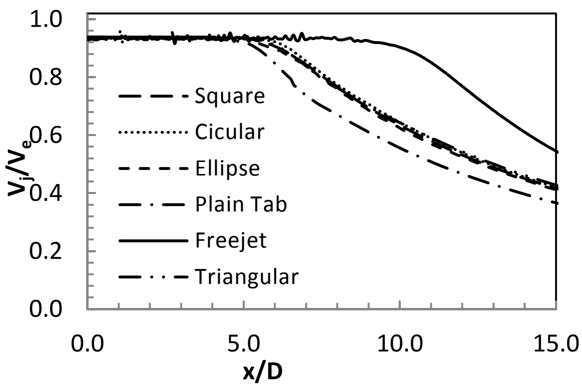

Figure 4. Centerline velocity decay of sonic Mach number (correctly expanded condition).

Table. I Comparison data of % reduction in potential core length

S. No	Mach No.	% reduction in potential core length				
		Plain	Circle	Ellipse	Square	Triangle
1	0.4	50	36.3	43.8	38.8	38.1
2	0.8	51.6	41.9	49.5	44.6	45.7
3	1	51	44	50	47	46

The table 1 shows the percentage reduction of potential core length for various perforation geometries. The perforated tabs are efficient mixing promoters and enhance the jet mixing in both core and transition zones of subsonic and correctly expanded sonic jets. Among

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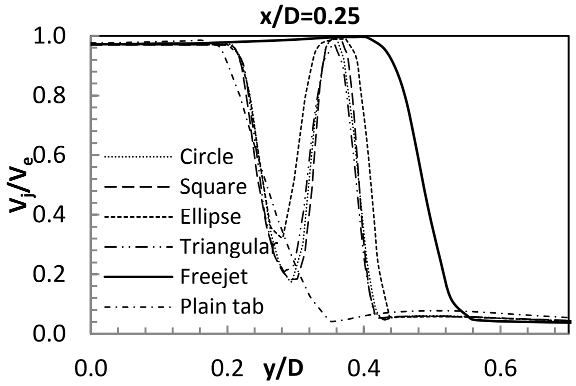
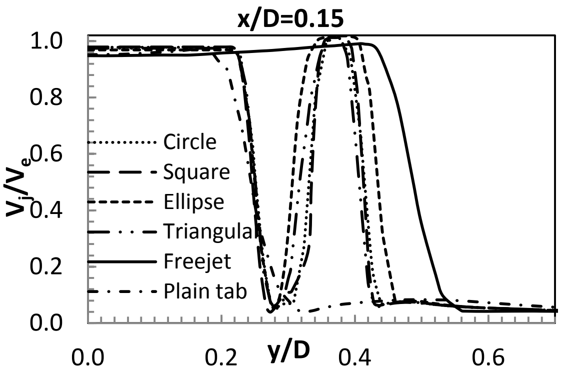
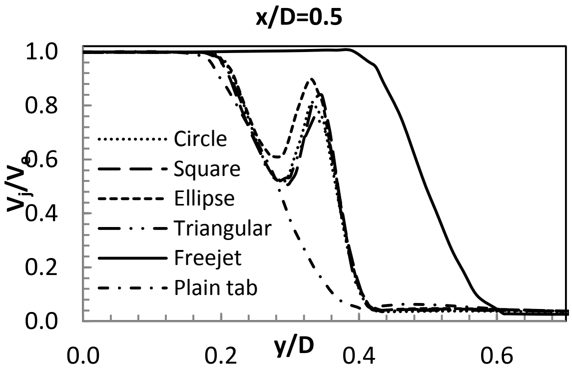
these results clearly demonstrate the ellipse perforation gives better mixing characteristics of the jets.

B. RADIAL VELOCITY PROFILE

The radial velocity profiles for controlled and uncontrolled jets at various axial distances for M= 0.4, 0.8 and correctly expanded nozzle are shown below. The radial velocity profiles for controlled and uncontrolled jets at various axial distances for M= 0.4 are shown in figure 5. For uncontrolled jet, at x/D = 0.15 along the axis the jet velocity is maximum. Away from the jet axis the velocity remains constant up to y/D =0.42, followed by a steep decrease from 0.42 to 0.54. Beyond y/D =0.54 the velocity remains almost constant. In the radial direction, the velocity decreases gradually, attaining the minimum velocity at y/D =0.56.







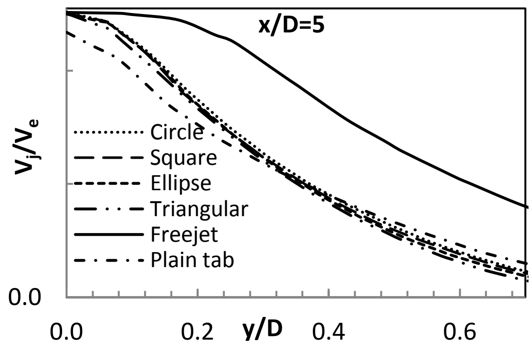
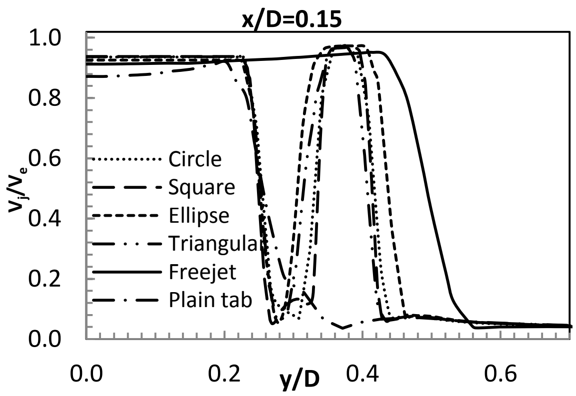
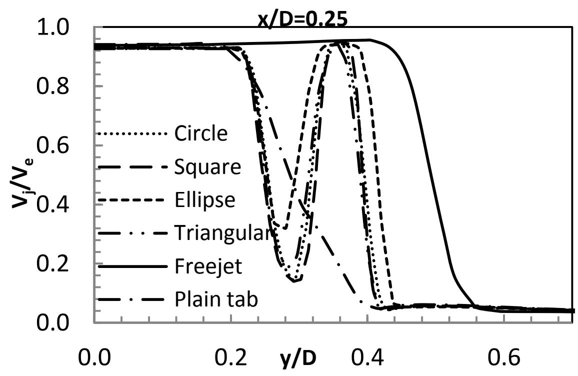


Figure 5. Radial velocity profile for M = 0.4





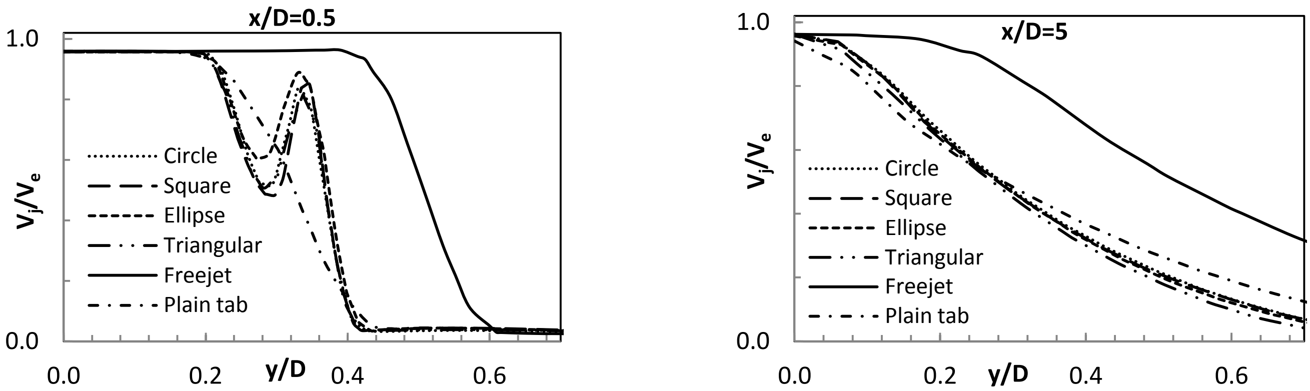
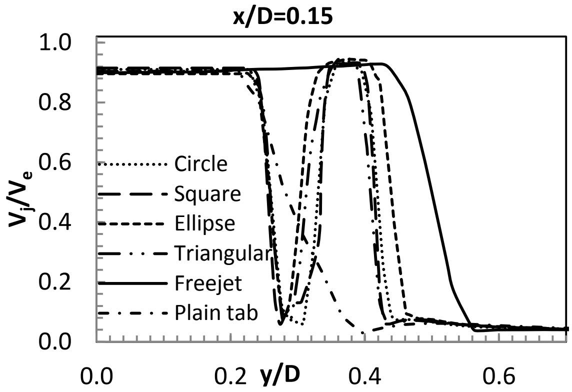
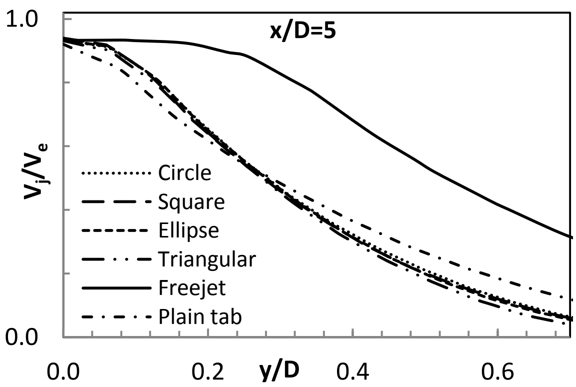
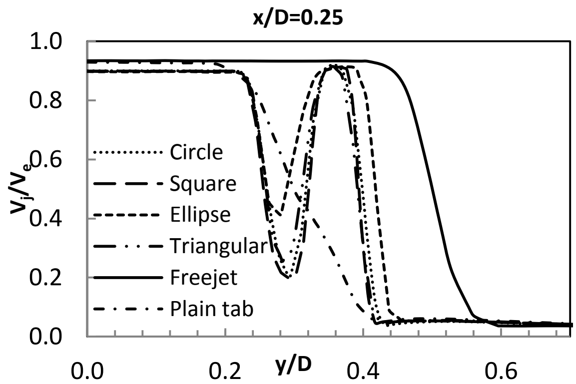


Figure 6. Radial velocity Profile for M = 0.8







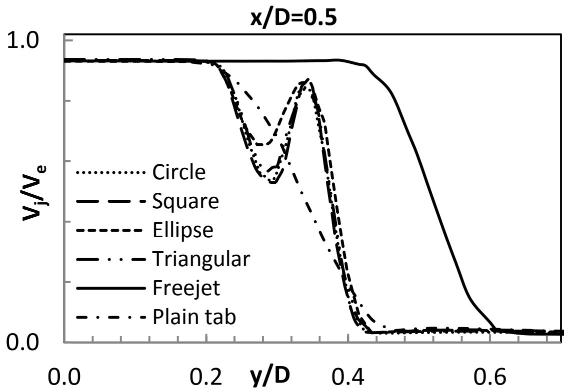


Figure 7. Radial velocity profile for M = 1. (Correctly expanded nozzle).

For controlled jet with plain tab, at x/D =0.15 the potential core extends up to at y/D =0.2 along the radial direction. These peaks were caused by two vortex cores produced by the bifurcation of the initially elliptic structure. At x/D = 5, the jet encounters characteristics decay, and further downstream the velocity decay almost fully developed region. For controlled jet with perforated tabs such as circular, elliptical, square and triangular geometries. From the fig 6 shows the effect of perforated tabs, at x/D =0.15 locations the flow through perforation as little mass which cause sudden rise in velocity at radial direction y/D = 0.38 to 0.42. At x/D = 0.25, the effect of secondary velocity has dissipated for elliptical perforated tabs compared to other geometries. Therefore the capability of uncontrolled jet is very less compared to perforated tabs. For sonic flow condition shows in fig 7, at x/D = 0.15 the value of y/D = 0.22 for perforated jet and at the same time the value of y/D = 0.45 for uncontrolled jet. Again at x/D = 5, y/D value is higher in uncontrolled jet than the perforation jet which obviously evident of enhanced mixing. It can be clearly seen that the elliptical perforation tab has higher spread along the plane compared to uncontrolled jet.

CONCLUSION

Tabs with circular, elliptical, square and triangular perforation geometries of equivalent diameter of 2 mm are considered and the jet flow with perforated tabs at different Mach numbers is numerically simulated. The effect of the perforated tabs on the mixing characteristics is investigated. The observation shows that mixing promoting vortices of mixed size shed by perforated tabs results in enhanced mixing of subsonic and sonic jets. Among the four different perforation geometries of circular, elliptical, square and triangular. The elliptical perforated geometry offers faster rate of centerline axial velocity decay and radial velocity decay.

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