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Jet Noise Abatement by Elliptical Perforated Tabs

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ABSTRACT

Paper deals with noise abatement by elliptical perforated tabs with 7.55% blockage. During the course of analysis the orientation of major axis of elliptical perforation is kept horizontal and vertical to the tab. Tabs were fastened diametrically opposite at the convergent nozzle. The tests were conducted for Mach 0.5, 0.7 and 0.9 respectively. The Mach number decay along the centerline in case of subsonic was measured. Similarly Mach profiles along and normal to the tabs were also calculated. Many literatures reported that solid tabs are effective for jet noise reduction. Major disadvantage associated with these tabs is thrust loss. In order to trounce this disadvantage perforated tabs are being used. Tab with elliptical perforation, major axis vertical acts as superior tool for reducing jet noise than other the tabs at all Mach numbers investigated. The web width varies from center to extreme end therefore web width also plays a vital role in manoeuvring vortices size. As high as 59% reduction in core length is achieved with tab of elliptical perforation, major axis vertical for Mach 0.5 jet. The corresponding core length reduction, tabs with elliptical perforation, major axis horizontal is 48%. Also results were compared with circular and square perforated tabs of similar blockage (7.55%).

KEYWORDS

Elliptical, perforation, vortices, potential core, mixing enhancement and noise reduction

INTRODUCTION

For the jet noise reduction mixing enhancement by promoting small scale vortices are require to be introduced into the jet at the nozzle exit examined by Reeder & Samimy. There are numerous active and passive methods studied by the scholars. Passive control in the form of tab has become very popular because of its simple geometry and efficient mixing promoting ability. Jet control has become active source of research due to its vast application potential, such as reduction of aero acoustic, minimization of base heating, improvement in stealth capabilities etc. Major part of these applications involve mixing enhancement of the jet, i.e. the mass from the surrounding atmosphere entrained by the jet has to be mixed with the jet fluid mass as rapid as possible explored by Reeder & Zaman. Tab geometries viz. rectangular, triangular, circular, arc etc. have been studied extensively. However these solid tabs shed mixing promoting small vortices of uniform size only. It is more beneficial if the mixing promoting vortices themselves possess mixed size. To generate such small scale mixed size, tabs with perforation have been used in present research.

Rapid development of mixing layer was founded by Reeder & Samimy when tabs were introduced. The effect of streamwise tab location within the nozzle was studied by Reeder & Zaman. They found that tabs located on the exit plane increased entrainment into the jet, whereas tabs located further upstream in the nozzle caused an emission of core fluid. The effect of wedge-shaped projections on the development of a low – speed jet was probed by Bradbury & Khadem. The effect of these tabs was seen to distort the jet parameter. Sreejith & Rathakrishnan proved that the limit for tab length is the nozzle exit radius and not the boundary layer thickness. This limit of tab length is termed "Rathakrishnan limit". Bohl & Foss, Wishart et. al. & Zaman et. al. have clearly concluded that the tab produces a pair of counter-rotating stream wise vortices. The deformation started by a mechanical tab is due to a pair of stream wise vortices and which must be responsible for the phenomenal entrainment stated by Zaman et. al. Bohl & Foss investigated that, the two possible sources of stream wise vortices for the flow over a tab are the pressure gradients, which flux stream wise vortices into the flow and the well-known 'necklace' or 'horseshoe' vortices due to boundary layer reorientation. It should be noted that, the sense of rotation of the vortex pair from the pressure hill is always opposite to that of the necklace vortex pair.

Verma & Rathakrishnan carried out the work on mixing enhancement and noise attenuation in notched elliptic slot free jets. The study was carried out on correctly expanded sonic jets and Underexpanded sonic jets with expansion levels of NPR2. The presence of notch was found to restrict the growth of jet in the notched plane (minor axis plane) thereby intensifying the shrinkage of the major axis side. There was a significant increase in the centerline pressure decay at full expansion as the angle of sharp corner was reduced from 90o to 60o. This resulted in shorter potential core, and hence enhanced mixing.

Ho & Gutmark studied a single elliptical jet from a contoured nozzle. They revealed axis switching and showed that the mixing rate was 'several times' higher for a circular or two-dimensional jet. Elangovan et al observed the mixing rates of two closely spaced elliptical jets from sharp-edged orifices. They compared the jet mixing rate with that in reference Ho and Gutmark. The two experiments had lots of differences between each other.

Baty et al investigated a correctly expanded supersonic jet from an elliptical nozzle. They were primarily concerned with acoustics and jet stability analysis but they did present some data relevant to jet mixing. The jet potential core was shown to extend to only 5D. Measurements of momentum thickness showed that there was no tendency for the jet to distort until near the end of the potential core.

Thanigaiarasu et. al. examine that the effect of Arc-Tabs on the mixing characteristics of subsonic and correctly expanded sonic jets. They studied two configuration of the tab, namely concave surface facing the flow exiting the nozzle (arc tab facing in) and convex surface facing the flow (arc tab facing out). These tabs were compared with solid tab for the blockage ratio of 7.64%. It was found that the centerline Mach number decay of 80% was achieved in arc tab facing in the flow configuration compared to 50% in arc tab facing out and plain tab configuration. Mach profiles showed that the arc tab facing in distorts the jet effectively by spreading the jet wider in the plane normal to the tab compared to the arc tab facing out.

In general, jets from rectangular nozzles spread faster than round jets and jets from elliptical nozzles spread faster than those from rectangular nozzles, at least initially. The explanation for this is given by Quinn. 'Non circular jets entrain more ambient fluid than their circular counterparts because of the non-uniform self-induction, brought about by azimuthal curvature variation, of the initial vortices generated at the nozzle exit plane. The non-uniform, self-induction causes the minor-axis sides, with the lower curvature, to move faster than the major-axis sides and this generates a mechanism for pumping large amounts of ambient fluid into the jets. The presence of flat sides and corners in rectangular jets may, in the initial region; cause mass entrainment in the jets to be less than in elliptical jets.

EXPERIMENTAL SETUP

The experiments were carried out at High Speed Jet Laboratory, Madras Institute of Technology - Anna University Chennai shown in Figure 1. The test facility contains air supply system (compressors and storage tanks) and free jet testing facility. Compressed air was passed to the settling chamber, where the flow reaches a settled condition. Required stagnation pressure (P_0) in the chamber was maintained with the pressure-regulating valve. The stagnant air from the chamber was expanded through a convergent nozzle, fixed at the end of the settling chamber. The pressure in the chamber was controlled to achieve the desired Mach number at the nozzle exit.

Uncontrolled Jet

A convergent nozzle of exit diameter (D) 20 mm made of gunmetal was used in this study. The nozzle was fixed at the end of the settling chamber with "O" ring sealing to avoid leak. Required pressures were maintained in the settling chamber to generate the desired jet Mach number. A Pitot tube made of stainless

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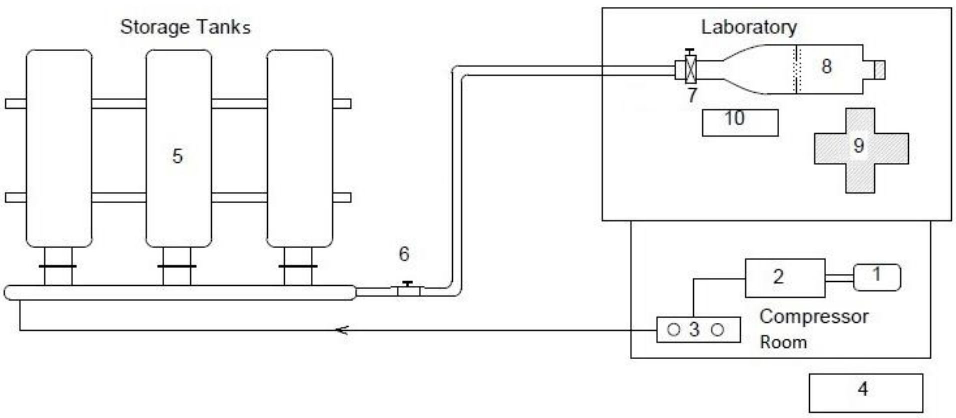
steel tube of inside diameter 0.4 mm and outside diameter 0.6 mm, mounted on a traverse mechanism was used for pressure (P) measurements along and across the jets. The Pitot tube was connected to a 16 channel pressure transducer for pressure measurements. Pitot probe should be small enough such that there is negligible disturbance to the incoming flow because of its presence. Thus the ratio of nozzle exit area to the probe area is (20/0.6)2 = 1111.11, which is well above the limit of 64, for regarding the probe blockage as negligible. The Pitot tube was connected to a pressure transducer to record pressure.

Perforated Tab Jet

Perforated tabs used were made of stainless steel. The length and width of the tab were 5 mm and 3 mm, respectively. Two tabs were placed at diametrically opposite locations at the nozzle exit. The tabs were provided with a slot to fix the tab and the blockage area at the nozzle exit due to the tabs was 7.55%. The pitot pressures measured were converted to Mach number using isentropic relations, using the atmospheric pressure in the laboratory as the static pressure, because subsonic jets are always correctly expanded.



1. 80 HP induction motor 2. Reciprocating compressors 3.Activated Charcoal filter 4. Water cooling unit and Silica gel dryer units 5. Storage tanks 6. Gate Valve 7. Pressure Regulating Valve 8. Settling Chamber 9. Traversing system 10. Instrumentation Desk

Figure 1. Schematic diagram of high speed jet laboratory

Figure 2. A view of tab arrangement at nozzle exit.

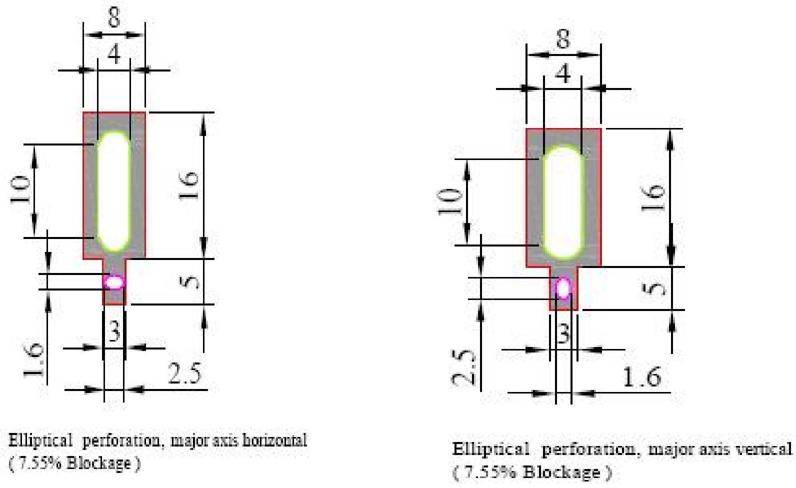


Figure 3. A view of tabs

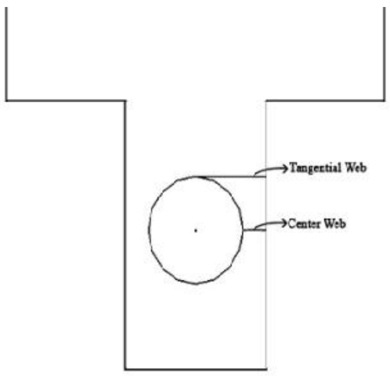


Figure 4. Schematic diagram of tangential and centre web

RESULTS AND DISCUSSION

Centerline Mach Number

Figure 5 demonstrates potential core length reduction with constant blockage of 7.55% at Mj = 0.5 for 2 mm circular perforation, elliptical perforation, major axis horizontal, elliptical perforation, major axis vertical and square perforation.

The core length with elliptical perforation, major axis vertical and 2 mm circular perforation extends up to X/D = 2.1, whereas it stretches upto X/D = 2.7 for elliptical perforation, major axis horizontal and square perforation. However solid tab core length is about X/D = 1.77, more blockage can be regarded as thrust loss a major disadvantage. The mixing enhancement with elliptical perforation, major axis vertical is prominent upto about X/D = 6.7. At the beginning vortices shed by elliptical perforation, major axis vertical are powerful, which may be due to axis switching phenomenon reported by Ho & Gutmark 198 and Lee & Baek, as flow progresses downstream phenomenon gets carried away in the high potential flow surrounded by it.

Figure 6 depicts potential core length drop with invariable blockage of 7.55% at Mj = 0.7 for 2 mm circular perforation, elliptical perforation, major axis horizontal, elliptical perforation, major axis vertical and square perforation. The core length shortens by 55% with elliptical perforation, major axis vertical. It was noticed that, core length reduction of 53% with square perforation and 62.5% with 2 mm circular perforation. The

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mixing enhancement at the downstream with elliptical perforation, major axis vertical and square perforation is almost similar or even better than solid tab. This may be due to the fact that, effective shear layer interaction and entrainment of fresh air from surrounding as examined by Quinn.

Figure 7 describes potential core length variation with 2 mm circular perforation, elliptical perforation, major axis horizontal, elliptical perforation, major axis vertical and square perforation at Mj = 0.9 with the identical blockage. Uncontrolled jet and solid tab are taken as upper and lower references for comparison. Potential core length appears to be same, i.e. X/D = 2.2, with elliptical perforation, major axis vertical and square perforation. A slight variation in Mach number in the downstream location of X/D = 7.3, with square perforation may be observed. This is because of an active transverse momentum exchange taking place for this tab. Due to this rapid exchange of transverse momentum, the flow along the centerline decays. This rapid decay of centerline Mach number is due to the breakdown of large scale vortex structure into fine scale structure as studied by Verma & Rathakrishnan

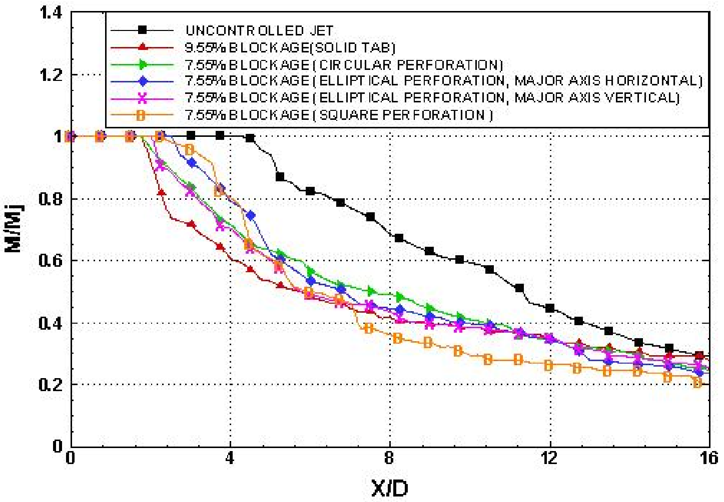

Figure 5. Centreline Mach decay at Mach 0.5 jet

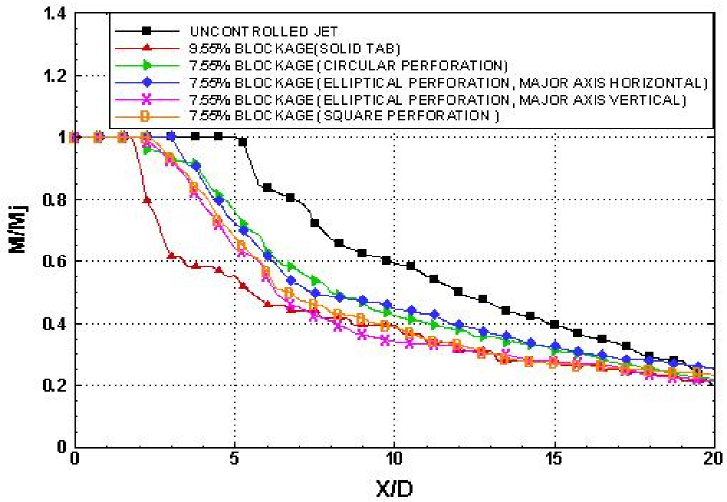

Figure 6. Centreline Mach decay at Mach 0.7 jet

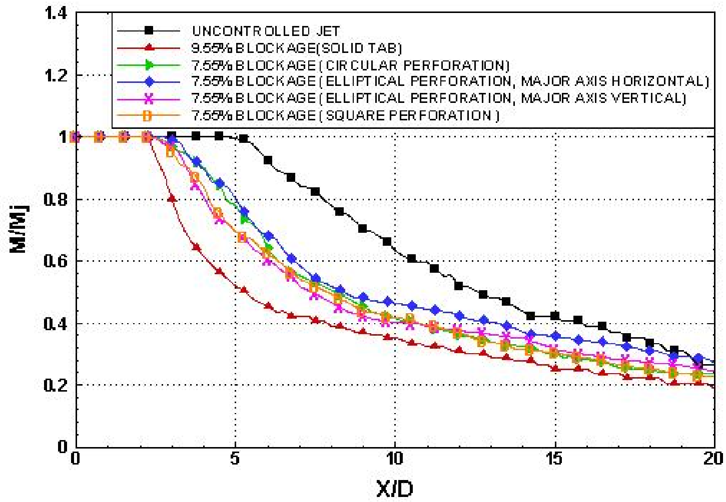

Figure 7. Centreline Mach decay at Mach 0.9 jet

Mach Number Profiles

Mach number deviation for uncontrolled jet at X/D locations of 0.15, 0.25, 0.5, 1, 3, 5, 7, 10 and 15 for Mach 0.5 jet are plotted in Figure 8. The Mach number is similar to jet Mach number at X/D = 0.15, 0.25, 0.5, 1 and 3 at the centerline and extends up to Y/D = 0.4. Uncontrolled jet centerline significant decay starts at X/D = 4.5. But it is has been enhanced for tabbed flow and transition happens to be much earlier depending upon tab configuration and dynamics of flow physics associated with them as represented in Figure 9 and Figure 10.

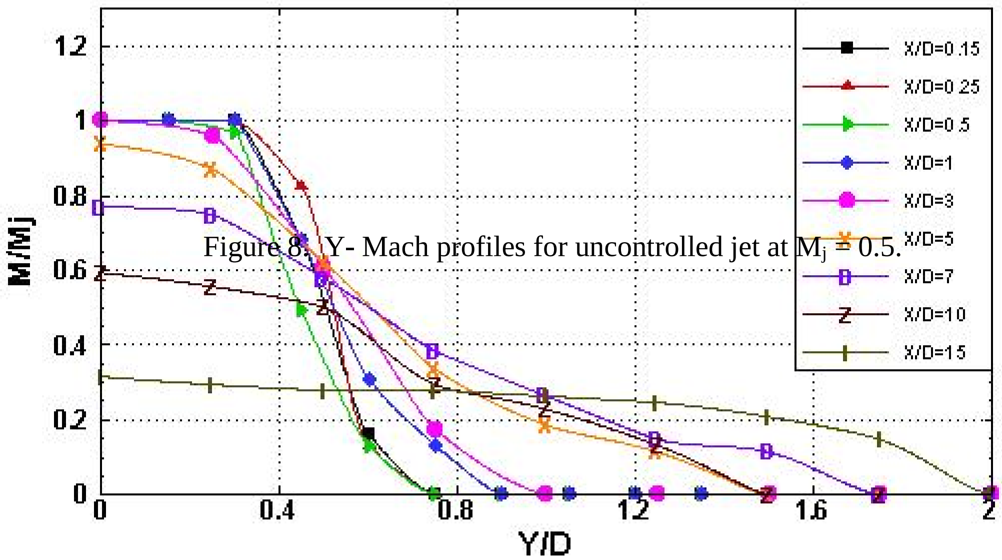

Figure 8. Y- Mach profiles for uncontrolled jet at $M_j = 0.5$.

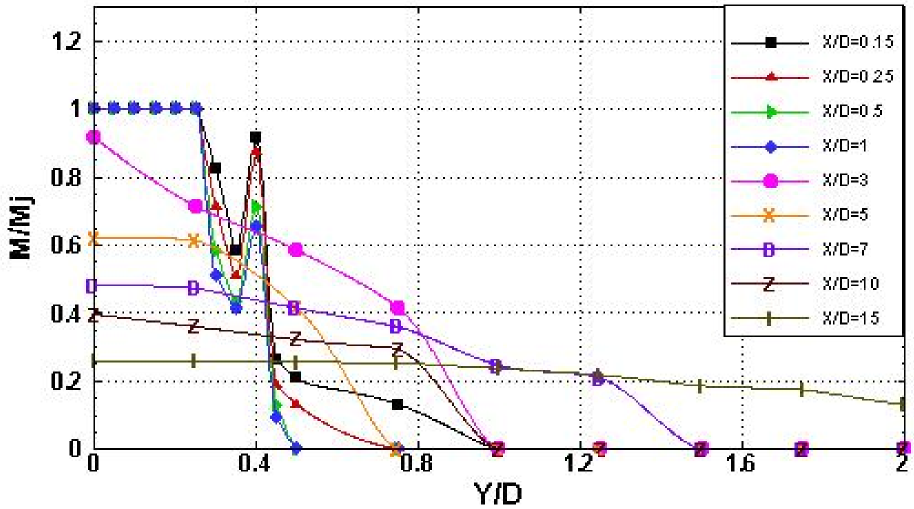

Figure 9. Y- Mach profiles along the tab for elliptical perforation, major axis horizontal at different axial locations at M_j 0.5

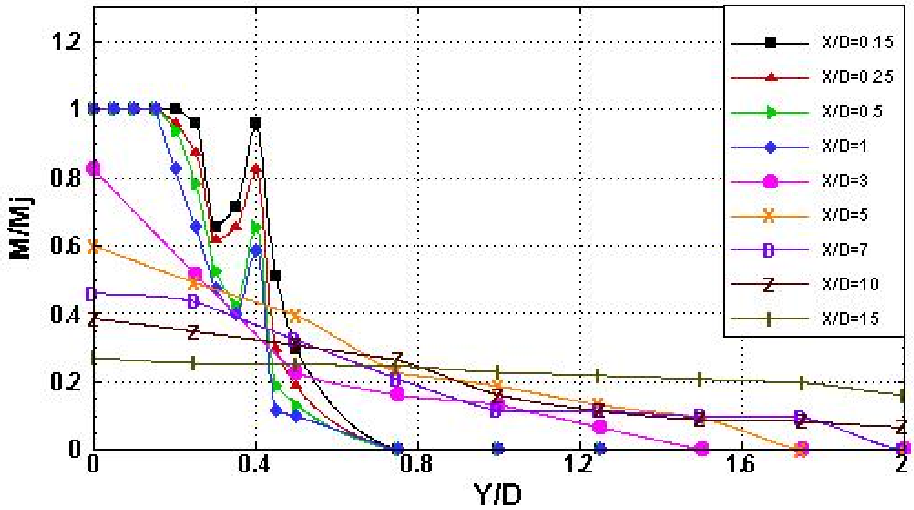

Figure 10. Y- Mach profiles along the tab for elliptical perforation, major axis vertical at different axial locations, $M_j = 0.5$

From Figure 10, it is clear that drastic Mach number downfalls at X/D = 4, which is not the case with other tab, viz elliptical perforation, major axis horizontal. This may be due to vortices structure that rolls in space, which entrains ambient air into the jet and increases mixing with the jet fluid. The effectiveness of this phenomenon may be demonstrate at X/D = 4 and 6, where M/Mj = 0.9 and 0.7 respectively. Also the variation in Mach profile dips due to perforation orientation can be observed from the plots. Complex nature of dips is predominant in case of elliptical perforation, major axis vertical. This behavior may be responsible for augmentation of mixing the jet.

Figures 11 & 12 demonstrate Z-profiles of uncontrolled jet, tabs with 9.55% blockage (solid tab), 7.55% blockage (2 mm circular perforation), 7.55% blockage (elliptical perforation, major axis horizontal), 7.55% blockage (elliptical perforation, major axis vertical) and 7.55% blockage (square

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perforation) at axial locations (X/D) of 1, and 7 for 0.5 Mach. Figure 11 shows that, the 'top - hat' extending upto Y/D = 0.45 with all perforated tabs. But there is dip and gradual rise in Z- profile. Dip in centerline and shift of off- centre peaks due to bifurcation with increase in streamwise distance for various locations of X/D. The off centre peaks in Mach profile of jet are due to the bifurcation of the jet field in the near- field. The shift in peak with increase in streamwise distance may be an indication of movement of vortices away from nozzle exit as they move downstream. The dips and off- centre peaks are not observed in the controlled jet in XZ-plane where jet seems to be shrunk. This may be due to the fact that the vortices get dissipated away from the tab.

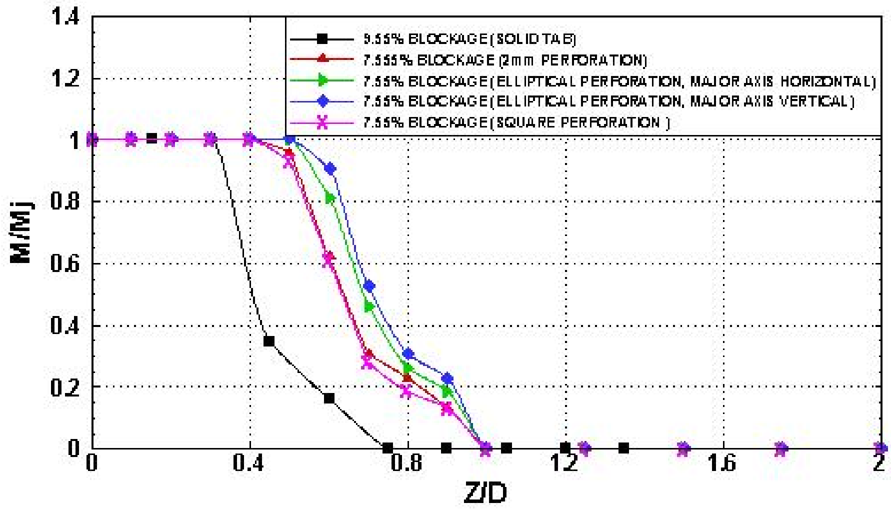

Figure 11. Z- Mach profiles for controlled jets at X/D = 1, Mj = 0.5

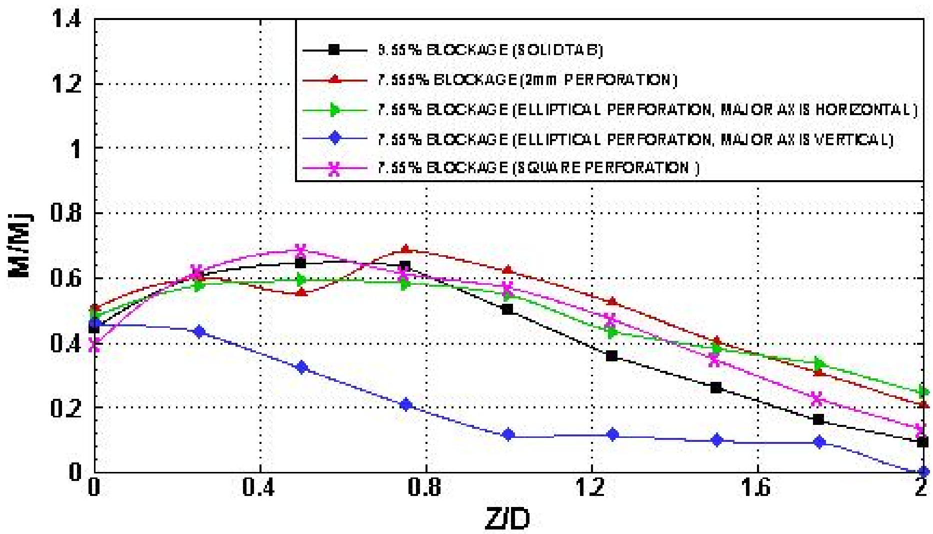

Figure 12. Z- Mach profiles for controlled jets at X/D = 7, M_j = 0.5

Figure 13 exhibits tab with 7.55% blockage (elliptical perforation, major axis vertical) shows mixing enhancement almost at all locations of X/D compared to other tabs. Also plots illustrate jet structure spread in XZ-plane at various locations of X/D. The jet bifurcation is more prominent and influential for the tab elliptical perforation, major axis vertical. The shift in peak with increase in streamwise distance may be an

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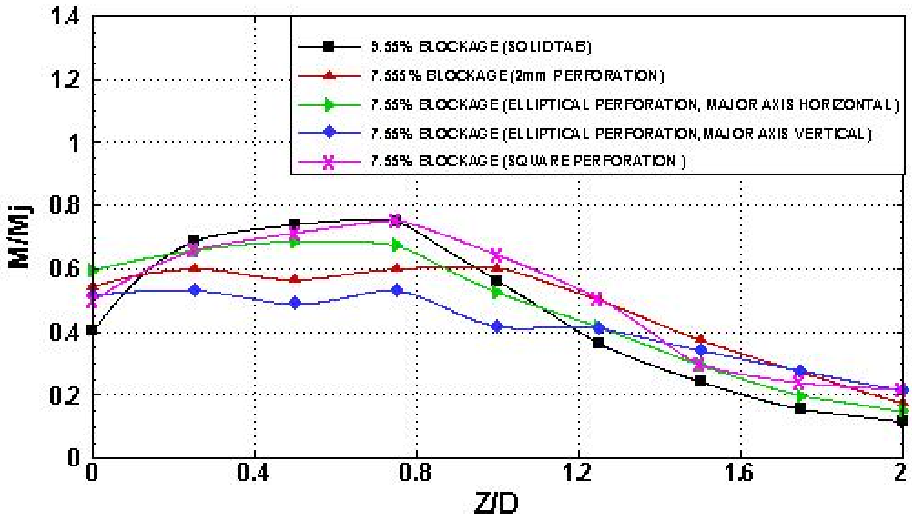

Figure 13. Z- Mach profiles for controlled jets at X/D = 1, M_j = 0.9

CONCLUSIONS

The present study is an experimental investigation to assess the noise reduction by mixing enhancement with elliptical perforated tabs subsonic flow. The results of the present study in subsonic jet control with perforated tabs show that, all the perforations studied are found to effective in promoting near field mixing. As high as 59% reduction in core length was achieved by the elliptical perforation, major axis vertical (7.55% Blockage) at Mach 0.5 jet. The corresponding core length reduction caused by the tab elliptical perforation, major axis horizontal is 48%. Therefore it authenticates that, the web width (w) and shear layer interaction between main jet and perforated jet plays a vital role in mixing augmentation. The size of the perforation has strong influence on the jet mixing even though the aspect ratio (l/b) and area are the same.

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