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Computational Studies of Mixing Characteristics by Fluidic Secondary Injection

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ABSTRACT

A Numerical investigation had been carried out on the jet behaviour by using secondary injection technique which creates the large and small scale vortices.The investigation had been carried out in convergent nozzle geometry by using the K epsilon turbulence model with standard wall functions. The objective of this investigation is to study the effect of air tabs in jet mixing, therefore to investigate on these parameters the present study focus on controlling subsonic jet using two slot injections which were positioned in a diametrically opposite location to the convergent nozzle exit. The primary jet was controlled with same mass flow rate and air-tabs are controlled with different exit Mach numbers, such that the mass flow rate of the air tab is varied. The results that are obtained are compared with the circular plain jet to analyse the jet behaviour. The computational study was carried out at sub-sonic and sonic Mach numbers of 0.4, 0.6, and 0.8 and secondary Mach numbers of 0.5, 0.6, 0.7, 0.8, and 1 using CFX solver. It is well established that the centre line Mach number decay can be taken as a direct measure of jet mixing. Therefore, to quantify the characteristics of the jet, Mach number decay along the jet centre line is determined from the computational software ANSYS. The centre line Mach number is decaying by increasing the exit Mach number. The maximum reduction in potential core length is achieved at primary jet Mach number at 0.6 which is controlled at 1.2 injected jet Mach no. The peak percentage of reduction in potential core length and the total pressure is 15 and 25.The reduction in potential core helps in enhancing the mixing characteristics and total pressure reduction enhances the noise reduction greatly.

KEY WORDS: Secondary injection, Air tabs, injected jet, Large and small scale vortices, Potential core, noise reduction, ANSYS and CFX.

1.INTRODUCTION

Extensive research on jet mixing enhancement and noise suppression has been under way for several decades. Many techniques (both passive and active) have been suggested, such as lobed mixers, solid tabs, acoustic excitation, serrated nozzles, etc. A summary of the major fluid dynamic properties of these devices has been provided by Gutmark and Grinstein, Seiner, Knowles and Saddington.The technique that has therefore received most attention to date is the passive control device involving use of solid tabs. Tabs are small protrusions placed at the jet nozzle exit; usually more than one is used, spaced around the jet periphery. Even though the solid tab promotes the jet mixing, the penalties of introducing solid tabs are thrust loss, increase in base drag, and making the jet become asymmetric. Zaman conducted a systematic study on jets with different tab blockages and concluded that the thrust loss varied from 4.1 to 23.7% when the flow blockage area to the nozzle exit area increased from 1.1 to 14.1%. The concept to use secondary control jets, later called air tabs, to enhance primary jet mixing was proposed by Davis. He placed two air tabs at diametrically opposite locations at the exit of a Mach 0.8 nozzle and found that the air tab significantly increased the mixing of the free jet. The mixing increases with the square of the control-jet relative velocity and with the cube of its relative diameter. Surprisingly, for a10% reduction in main-jet velocity, the smaller-diameter control jet requires only a 0.44% mass flow of the main jet, whereas the larger diameter control jet requires about 0.56%. The jet distortions induced by two and four active injectors are seen to extend farther downstream than the eight injectors. Wan and Yu applied the air-tab technique to the subsonic and supersonic jets, respectively, and they reported that the air tab could enhance the jet's mixing as effectively as the solid tab, although it would not introduce any thrust loss. In contrast to the results of Wan and Yu, Behrouzi reported that the solid tabs are superior to the air tabs.However, a point to be noted is that the blockage introduced by the tabs of Behrouzi is higher than Wan and Yu. Yu performed an ideal analysis of force balance at the nozzle exhausts and reported that the thrust loss associated with the air tabs was only 0.05%. Behrouzi and Wan and Yu, reported that the vortex generation mechanism was the same as the solid tab case. The fluidic injection seems more attractive, because it can be easily adapted to the flow conditions; additionally, air-tabs are expected to reduce weight, cost, and mechanical complexity .The objective of the present work is to study the effect of air-tab diameter, Mach number, and mass flow rate on the jet mixing. Therefore, to evaluate these parameters, the present work focuses on controlling subsonic and correctly expanded sonic jets using two tubes, which were positioned in a diametrically opposite location to the nozzle exit, termed as air tabs. Rather than the conventional air tab, which is a nozzle type, in this study, the air tabs are simple constant-diameter tubes. The transverse gas injection into the main supersonic flow of an axi-symmetric convergent-divergent (C-D) propulsive nozzle is investigated for the fluidic thrust vectoring (FTV) possibilities as the segment part of the project. Truncated ideal contour and conical C-D nozzles with different position and the secondary circular injection port are selected as test models in the current numerical and experimental study. Analytical approach revealed parameters which affect the FTV efficiency from experiments. Strong bow shock generated by a secondary transverse injection at divergent (supersonic) portion of a nozzle is mainly responsible for diverting the nozzle jet. Resulting flow field is characterized with the complex flow structures featuring strong adverse pressure gradients accompanied with the three-dimensional (3D) vortex and shock regions, boundary layer separation, shock generation, and their interaction, wakes, flow reattachment, and mixing shear layers. The secondary injectant in the flow is acting as an obstacle and source of main jet momentum change. The upstream separation distance is in general determined by the flow nature of the boundary layer (laminar or turbulent) and by the penetration height of the injectant, as reported by Spaid and Zukoski. Supersonic main flow foresees the secondary injectant plume as an obstacle and generates the bow shock as a response. In the basic case of supersonic cross-flow interaction, the turbulent boundary layer of the main flow detaches upstream of the injection port due to an adverse pressure gradient, which is the consequence of the bow shock, and it is followed by the weak separation shock. Further downstream, separation shock is interacting with the strong bow shock. This interaction and the shock structure contribute in development of main flow deflection steeper gradient while between the shock region and the wall recirculation, shock bubble is formed. The structure between the wall, shock region, and the injectant plume (see Fig. 1) involves the counter rotating vortex pair, commonly known as the primary upstream vortex (PUV) which develops along the wall boundary and smaller counter rotating secondary upstream vortex(SUV) near the injectant plume.The separation shock formed along the displaced boundary layer by these vortices and sonic surface in between them are initially deviate the incoming flow. After separation region, main flow then faces strong bow shock and rapidly deflects. Sonically injected gas is under expanded; thus, it is expanding in the main flow through the Prandtl-Meyer fan and is recompressed with the Mach disk at the end of this process.on the downstream side of the injection, low-pressure region behind the jet creates suction which turns the injectant plume towards the wall. The low-pressure region is in greater part responsible for the wake which is dominated by strong vertical motions of primary and secondary downstream vortices (PDV and SDV). The closing edge of the pressure bubble on the downstream wall side, driven by the trailing edge of SDV and recompression shock reattaches the flow to the wall. Spaid and Zukoski constructed analytical model for prediction of the penetration height as a key parameter and pressure distribution in separated region.

1.2.INTRODUCTION TO SECONDARY JET CONTROL

Secondary jet control is the active control type which needs separate energy supply to influence the flow properties by means of injecting with air or water at the downstream of the nozzle. Secondary jet creates the vortices which will influence the nozzle exit plane profile drastically. For the present investigation two air tabs are used which are placed diametrically opposite to the nozzle exit plane and which are having same mass flow rate.

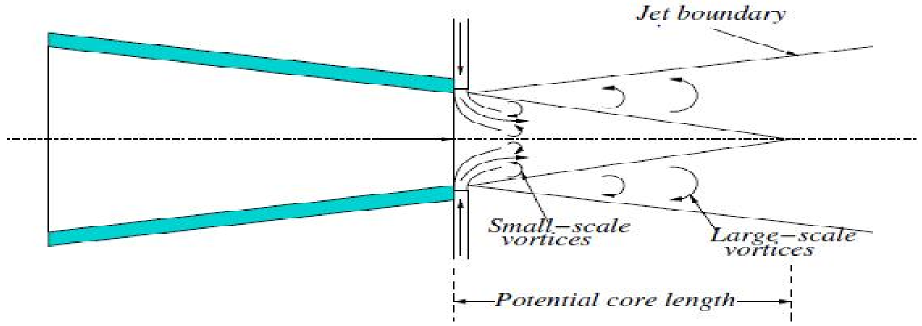

Fig 1.Flow behaviour with secondary injection

2. COMPUTATIONAL PROCEDURE

2.1Design

In Design Modelling (Design) and mesh of the work is explained where a pre-processor is a program which provides a graphical user interface (GUI) to define physical properties and data is used by the subsequent computer simulation. Further the solver and boundary condition arrangement is also described for convergent nozzle with injection and without injection.A two Dimensional or a three Dimensional model of any geometry is essential for a computational analysis. Hence convergent nozzle with and without injection is modelled by using CATIA V5R17.The designed model is meshed by using ICEM CFD.

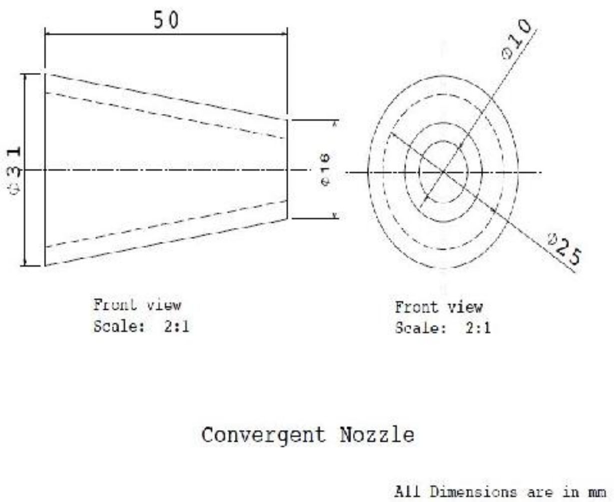

Fig 2. Convergent Nozzle without injection

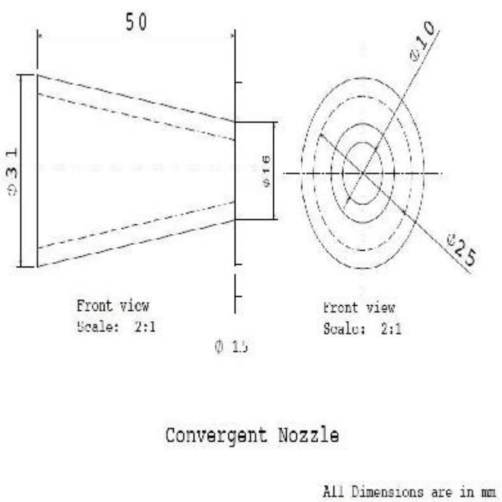

Fig 3.Convergent Nozzle with Injection

3.NUMERICAL METHOD OF SOLUTION

Numerical simulations have been carried out with the help of a two-dimensional steady RNG k-epsilon turbulence model with standard wall functions. Ideal gas is considered for analysis. The model uses a control-volume based technique to convert the governing equations to algebraic equations. The viscosity is computed based on Sutherland formula. A typical grid system in the computational domain is selected after a detailed grid refinement exercises. The grids are clustered near the solid walls using suitable stretching functions. The nozzle geometric variables and material properties are known *a priori*. Initial wall temperature, inlet total pressure and temperature are specified. At the solid walls a no slip boundary condition is imposed. The code has successfully validated with the help of benchmark solutions. Nozzle flow features have been examined with subsonic and sonic secondary jet nozzles at nozzle exit with different jet pressures.

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4. RESULTS AND DISCUSSION

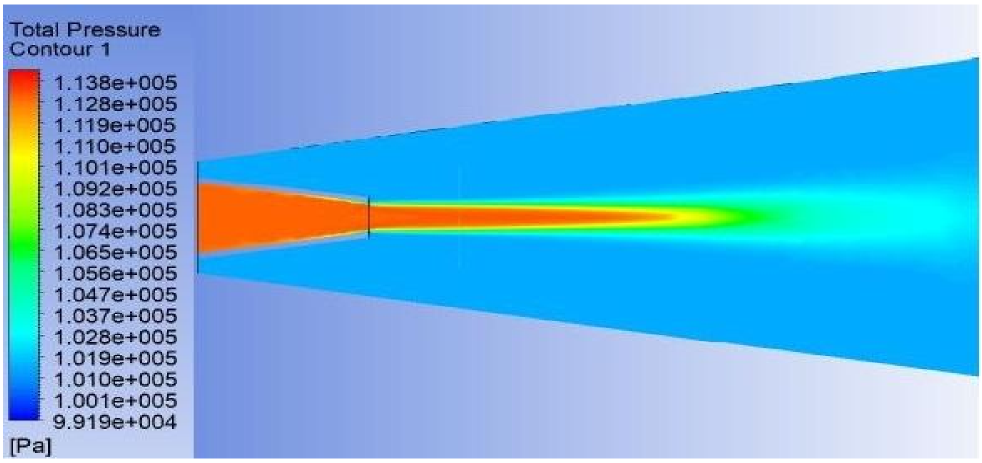

Fig 3. Total Pressure contours for M 0.4 jet without Injection

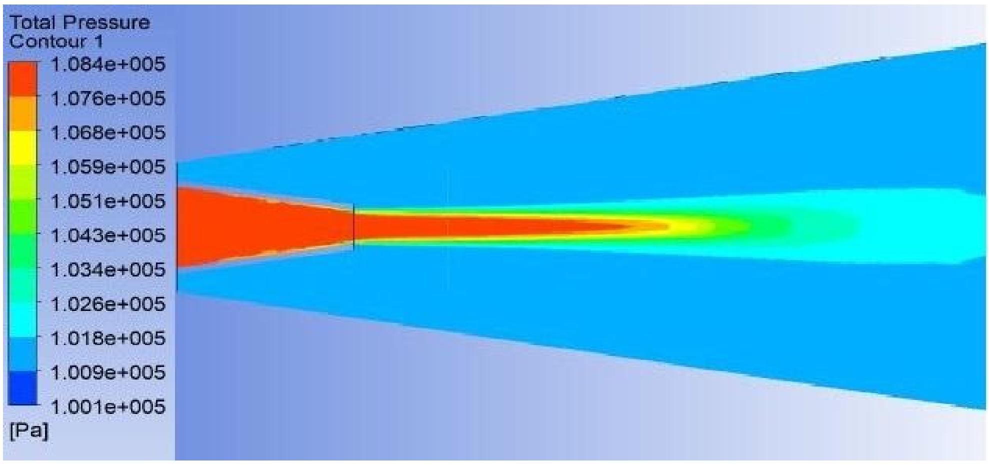

Fig 4. Total Pressure contours for M 0.4 jet with Injected jet M 0.6

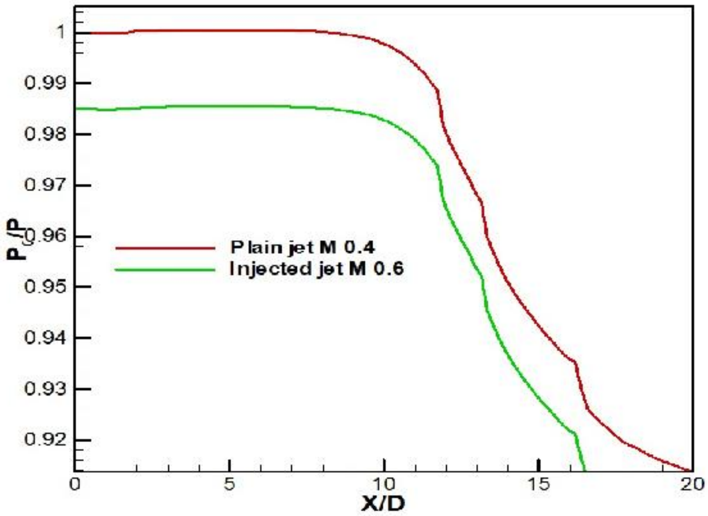

Fig 5.Variation of Total Pressure in Centreline Direction for M 0.4 jet with M 0.6 injected jet

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From the above fig 5, it is observed that the potential core region is preserved up to X/D = 9 for plain jet case at Mach number 0.4 and for the injected jet the potential core is observed up to X/D = 8.5 at Mach number 0.6.The percentage reduction in potential core is 5 with respect to plain jet for injected jet. Where as in Y direction the pressure variation is 1 for plain jet case and 0.985 for injected jet case which results in noise reduction greatly, and also the transition region is decayed very firstly for the injected jet case when compared with the plain jet case, this indicates that the secondary injection enables the higher turbulence than the normal jet. From X/D = 12 to 20 both the jets behaviour is same because the turbulence is dominating the flow field at that region.

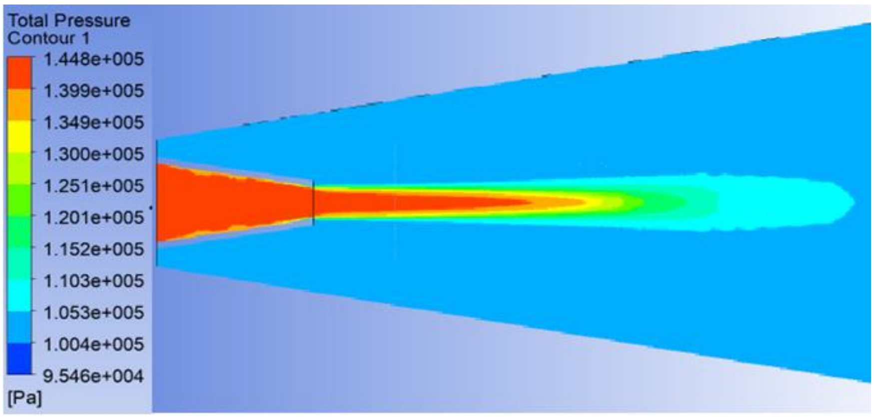

Fig 6. Total Pressure contours for M 0.6 jet without Injection

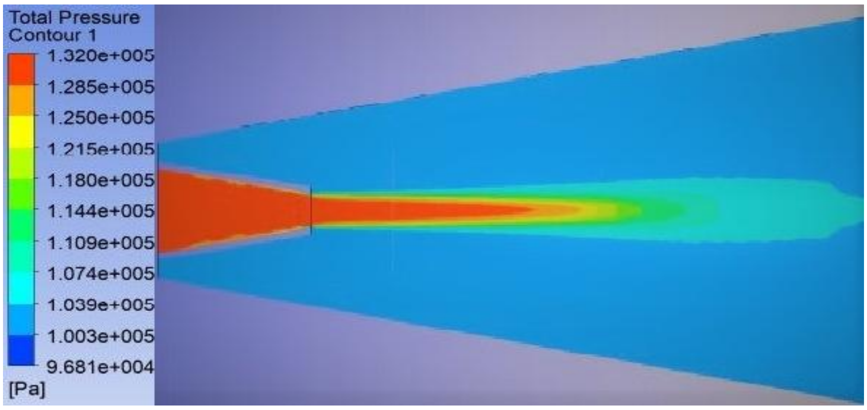

Fig 7. Total Pressure contours for M 0.6 jet with Injected jet M 0.8

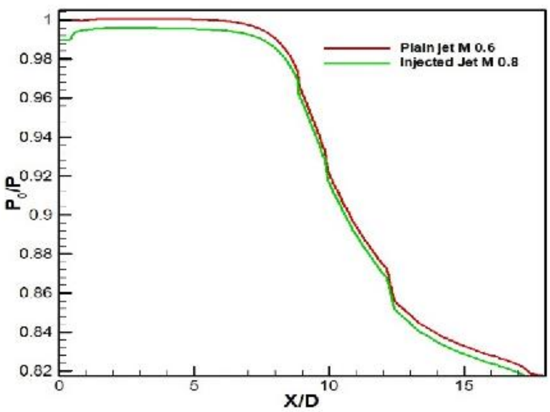

Fig 8.Variation of Total Pressure in Centreline Direction for M 0.6 jet with M 0.8 injected jet

From the above fig 8, it is observed that the potential core region is preserved up to X/D = 8 for plain jet case for Mach number 0.6 and for the injected jet the potential core region is observed up to X/D = 6 for Mach number 0.8.Where as in Y direction the pressure variation is 1 for plain jet case and 0.99 for injected jet case which results in noise reduction, and also the transition region is decayed linearly for the injected jet case when compared with the plain jet case, this indicates that the secondary injection enables the higher turbulence than the normal jet. From X/D = 9 to 12 the potential core is started decaying for plain jet case, whereas for injected jet case X/D = 7 to12 the potential core is decayed and later on the atmospheric influence is drastic and the flow field is treated as fully developed region which is at X/D =14 onwards.

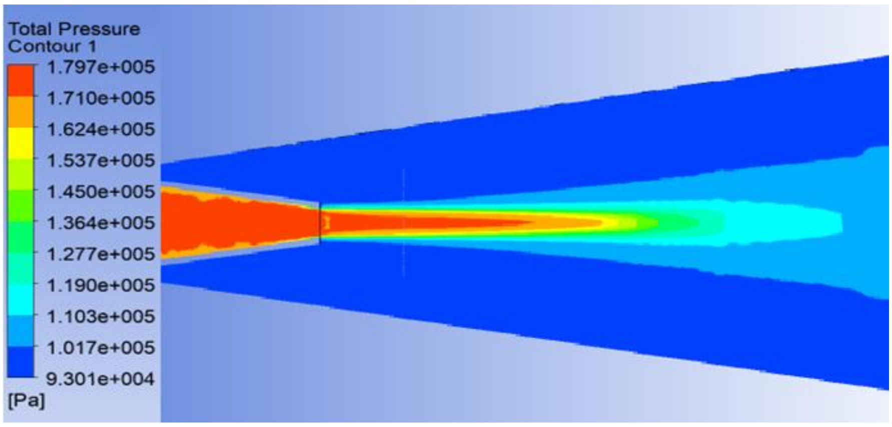

Fig 9. Total Pressure contours for M 0.8 jet without Injection

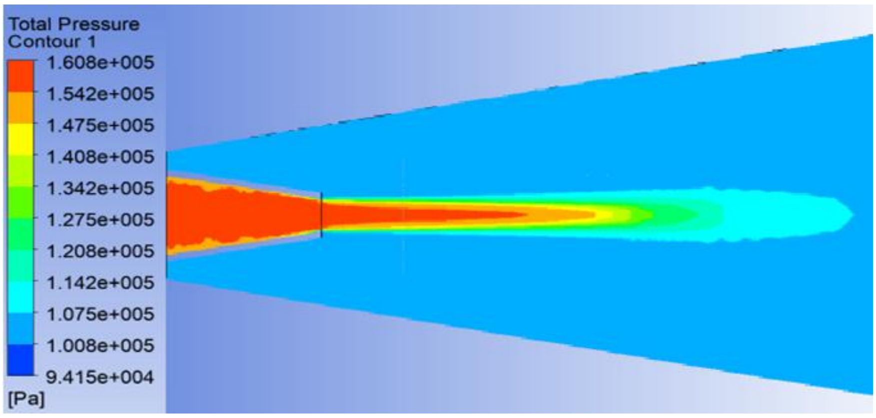

Fig 10. Total Pressure contours for M 0.8 jet with Injected jet M 0.9

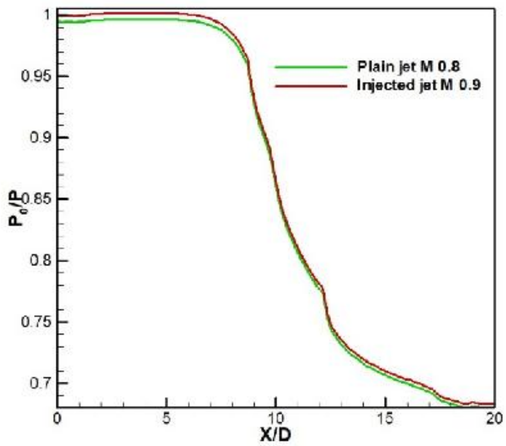

Fig 11.Variation of Total Pressure in Centreline Direction for M 0.8 jet with M 0.9 injected jet

From the above fig 5, it is observed that the potential core region is preserved up to X/D = 6 for plain jet case at Mach number 0.8 and for the injected jet the potential core is observed up to X/D = 5.5 at Mach number 0.9.Where as in Y direction the pressure variation is 0.99 for plain jet case and 0.98 for injected jet case , the transition region is same for both plain jet and injected jet and it is observed from X/D = 6 to X/D = 14.The percentage reduction in total pressure in y direction is less when compared with the previous cases, and also at higher Mach numbers the potential core is decreased for both plain jet and injected jet cases.

5.CONCLUSION

From the present investigation concluded that the secondary injection gives rise to better mixing results, thrust vectoring applications,sincesecondary jet control is a active control type which needs additional energy from outside which is drawback when compared to the passive control jets where which do not require any additional energy.

From the study the reduction in potential core is maximum for M 0.4 at injected jet M 0.6 when compared to other cases. The secondary injection influences jet behaviour rapidly for M 0.6 jet in downstream direction.

6. REFERENCES

1) P. Arun Kumar, S. B. Verma, and E. Rathakrishnan, ”Experimental Study of Subsonic and Sonic Jets Controlled by Air Tabs” Indian Institute of Technology Kanpur, Kanpur 208 016, India DOI: 10.2514/1.B35675

2) Behrouzi, P., Feng, T., and McGuirk, J. J., “Active Flow Control of Jet Mixing Using Steady and Pulsed Fluid Tabs,” Journal of Systems and Control Engineering, Vol. 222, No. 5, 2008, pp. 381–391. doi:10.1243/09596518JSCE543

3) Gutmark, E. J., Schadow, K. C., andYu,K. H., “Mixing Enhancement in Supersonic Free Shear Flows,” Annual Review of Fluid Mechanics, Vol. 27, No. 1, 1995, pp. 375–417. doi:10.1146/annurev.fl.27.010195.002111

4) Gutmark, E. J., and Grinstein, F. F., “Flow Control with Non-Circular Jets,” Annual Review of Fluid Mechanics,Vol. 31, No. 1, 1999, pp. 239– 272, doi:10.1146/annurev.fluid.31.1.239

5) Subanesh Shyam Rajendran, Aravind Kumar T.R, Nareshkumar K.S, “Studies on thrust vector control using secondary injection sonic and supersonic jets”.

6) A. J. Porzio and M.E.Franke "Experimental study of a confined jet thrust vector control nozzle", Journal of Propulsion and Power, Vol. 5, No. 5 (1989), pp. 596-601.

8) Bradbury,L.J.S., and khadem A.H., “The distortion of a jet by tabs,” journal of fluid mechanics .vol.70,no.4,aug.1975.pp-801-813.

9) Zaman, K.B.M.q., Reeder,M.F., and Samimy, m., “effect of tabs on the flow and noise field of an axisymmetric jet,” AIAA journal, vol.31,no.4,1993,pp.609-619.

10)Singh,N.K. and Rathakrishnan.E.,” sonic jet control with tabs”. International journal of turbo and jet engines vol.19, Nos,1-2.2002,pp.107-118.

11) Sreejith R.B., and Rathakrishnan,E.,”cross wire as passive device for supersonic jet control ”. AIAA paper 2002-4052,2002.

12) P. Arun Kumarand E. Rathakrishnan “Truncated Triangular Tabs for Supersonic-Jet Control” JOURNAL OF PROPULSION AND POWER Vol. 29, No. 1, January–February 2013

13)E. Rathakrishnan “Experimental Studies on the Limiting Tab” AIAA JOURNAL Vol. 47, No. 10, October 2009.