Mixing and Entrainment Characteristics of Jet Control with Crosswire

S. Manigandan, K. Vijayaraja, G. Durga Revanth and A. V. S. C. Anudeep

Abstract This paper aims to study the effect of passive control on elliptical jet at different levels of nozzle pressure ratio. This experiment is carried out for three different types of configurations at two, four, five, and six NPRs. The results are captured and compared to one another. The rectangular crosswire is used as a passive control and tested at Mach number of two. The crosswire running along the major axis of the elliptical jet exits. The pitot pressure decay and the pressure profiles are plotted for various nozzle expansions. The crosswire is placed at three different positions ¼, ½, and ¾ to alter the shock wave successfully and to promote the mixing of jet. The shock waves are captured using numerical simulations. Due to the introduction of passive control at the exit of issuing jet, the shock wave weakens effectively, which stimulates the mixing promotion of jet by providing a shorter core length. It is witnessed that the efficiency of the mixing is superior when the crosswire is placed at ½ positions than ¼ and ¾. In addition, we also had seen a notable change in axis switching of the jets.

Keywords Nozzle · Supersonic jet · Crosswire · Core length

1 Introduction

Among various non-circular and circular jets, elliptical jet witnessed huge exciting features. There are several notable works made on the elliptical jet with different types of passive control [1–10]. This paper also deals about the passive control called crosswire, which is placed at the exit of the nozzle. The crosswire is tested at three different positions to study the ability of jet development process. This paper explains the dark side of the passive control since they possesses high value in

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aviation and automobile sectors. Passive control by tabs was studied by several pioneers due to its simple arithmetic. Several researchers concluded that introduction of tabs alters the shock wave and increases the mixing promotion without disturbing the explicit property of the jet [6–10]. Further, Rouly et al. [2] studied the effect of jet at low divergence. They conclude that divergence is also responsible for the mixing promotion. Quinn [3] investigated the effect of the square jet and found the vortices are shed due to skewing of shear layer. Samimy et al. [4] noticed the jet emits three unique layers which are responsible for shorter core length is potential core decay, pitot pressure, and far filed decay. Similar work is carried out by Kumar and Rathakrishnan [1]. They found elliptical jet gives profound effect than circular jet which is highly appreciable.

Arvindh et al. [5] investigated the elliptical jet at Mach number of two on CD elliptical nozzle at different levels of expansion. They proved that the elliptical jet performs better than other circular and non-circular jet. In addition, they also witnessed the decay of the jet is faster compared to other profiles. Recently, Manigandan and Vijayaraja [8] investigated the effect of tabs on CD nozzle. They found that tabs are performing better when they placed diametrically opposite. They also studied the acoustics details of the jet. Recently, a similar study was carried by Manigandan and Vijayaraja [9], they investigated the flow field and sound relationship of the jet passing elliptical throat. They found mixing promotion caused by the elliptical throat is higher than the circular throat due to the weakening of the shock waves. Further, they seen at NPR 6, the mixing efficiency is very rich and dynamic when compared to other nozzle pressure ratio. In addition, they also found the axis switching is the main factor to stimulate the efficiency of the jet at all expansion ratio. Srivastava and Kaushik [11] have demonstrated experiment on rectangular jet with crosswire. They proved crosswire has an ability to reduce the core length by 88% compared to uncontrolled jet.

Introduction of tabs at the nozzle lip is done by many scholars and researchers. Here, tabs are replaced with crosswire to achieve higher mixing promotion than tabs.

The crosswire is placed at one quarter, half quarter, and three quarter (¼, ½, and ¾) to enhance the generation of large and small vertical structures which is responsible for mixing promotion. We have taken the jet as elliptical, and the quantum of work is carried out by several researchers. All literatures concluded that non-circular jet gives better mixing than circular jet due to shed of vortices. This study concentrates on the effect of crosswire on issuing jet.

2 Experimental Details

In this present study, we investigated an elliptical nozzle jet with crosswire. The crosswire is a thin rectangular structure made of Kevlar composites. The elliptical passive control jet tested at two Mach number at two, four, five, and six NPRs, respectively. The blockage of the tabs is 3%. The experiments are carried out at

Aerodynamics Laboratory, Jeppiaar Engineering College, Chennai, India. The experiment was demonstrated at Mach number of two. The desired NPR is achieved by controlling the flow regulator. The pressure gauge helps us to adjust the regulator to the appropriate levels of NPRs (Figs. 1 and 2).

The distance between the settling chamber and the nozzle is approximately 2 m, which is sufficiently adequate for mixing [9]. This facility utilizes the honeycomb structure on the lip of the settling chamber to achieve the smooth flow without turbulence. The elliptical jet with rectangular crosswire is tested at two, four, five, and six NPRs, and the values are plotted. After postprocessing, the results are compared to find optimized position to place the crosswire. The nozzle where designed at aspect ratio of two. The length of nozzle is 150 mm. The distance between the inlet geometry and the throat section is 65 mm. The nozzle and crosswire were made of mild steel using particle energy discharge process. The crosswire is bonded along the major axis of the jet at three different positions.

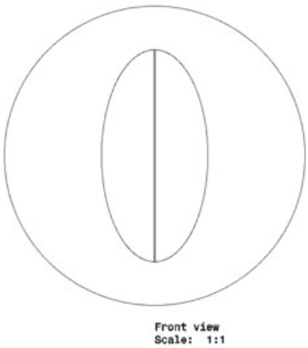


Fig. 1 Nozzle CAD drawing

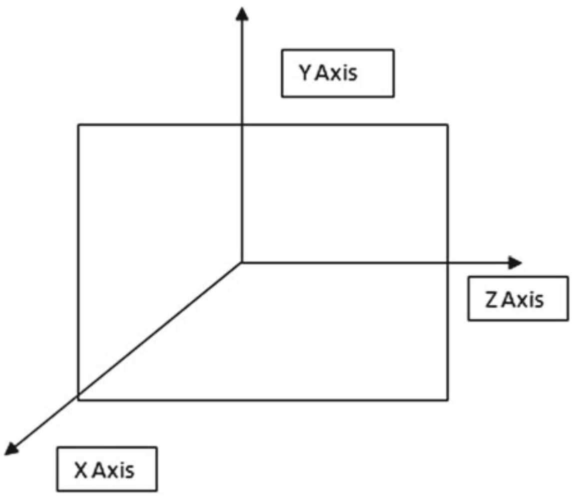


Fig. 2 Schematic diagram of jet axis

The flow is made to pass through at different levels of expansion, and the magnitude of Pt/Po is measured with respect to X/D. The values of the pressure are calibrated using three-dimensional transverse mechanisms. The effectiveness of the crosswire is analyzed using numerical simulation technique.

3 Results and Discussion

Estimating the supersonic jet core remains clumsy task for all pioneers. Precise calculation of the pitot pressure is very important to derive the accurate result. Hence, it is necessary to calibrate the pitot pressure accurately. Pitot pressure is plotted against X-axis alone to avoid such unwieldy conditions and errors. The X-axis distance made non-dimensional by dividing with the diameter of the nozzle exit.

3.1 Centerline Pitot Decay

The pitot pressure decay for three configurations is calibrated at under-expanded condition corresponding to NPR 2 which is plotted in Fig. 3. The shock strength is considerably less when crosswire is placed at ½ positions than compared to ½ and ¾. The core length of ½ position extends up to X/D = 10. Further, it is seen that the core length of the ½ and ¼ is X/D = 21 and 22 which is considerably higher. Hence, it is apparent that crosswire has the ability to generate higher efficiency in

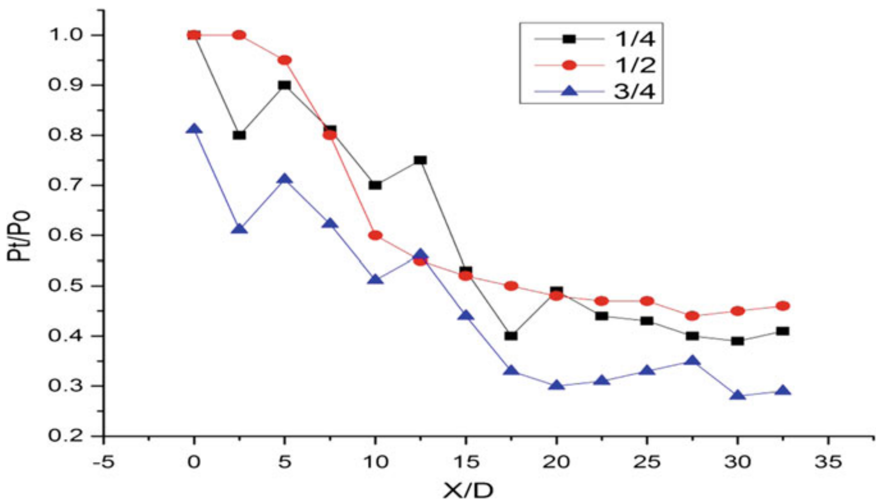


Fig. 3 Centerline pressure decay at NPR 2

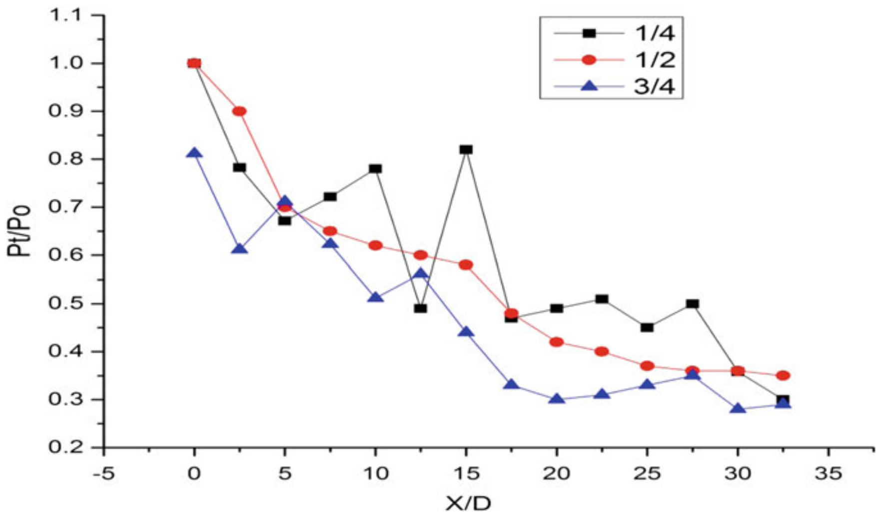


Fig. 4 Centerline pressure decay at NPR 4

mixing when they placed at center axis of the major axis of the jet due to the shock cell strength.

At NPR 4, the flow is marginally expanded. From Fig. 4, it is evident that the shock wave shows an appreciable change due to the presence of crosswire. However, the performance of crosswire which is positioned at ½ performs better by having the 50% reduced core length. The core length of ½, ¼, and ¾ are 5, 18, and 19, respectively. The configuration ¼ and ¾ witnesses small notable change in core length compared to NPR 2 which is appreciable.

At NPR 5, the flow is almost partially expanded. The pitot pressure decay is plotted in Fig. 5. It is seen that core length of the crosswire at ½ position is X/D = 4.5, whereas for other two configurations are X/D of 21 and 23. The crosswire at center of major axis performs superior than ¼ and ¾ positions. At NPR 6 Fig. 6, the flow is perfectly expanded for Mach number two. The core length of ½ position is X/D = 2, which is nearly 60% lower than NPR 5. This welcome change takes place due to the zero pressure gradients and weakening of shock waves. The core length for the other two positions remains identical to one another at X/D = 21.

From the above plots and discussions, it is crystal clear that the crosswire has an ability to reduce the core length and increase the mixing promotion effectively, Fig. 7. The crosswire at center position produces high mixing compared to ¼ and ¾. This occurs due to the shock cell growth and oscillations of the jet. The effective core length is achieved at NPR 6 for passive control jet.

The axis switching of the jet is seen in Figs. 8 and 9. The axis switching is captured numerically based on the few literatures. The flow property and the mathematic formulations are derived from the literature [11, 12]. The visualization

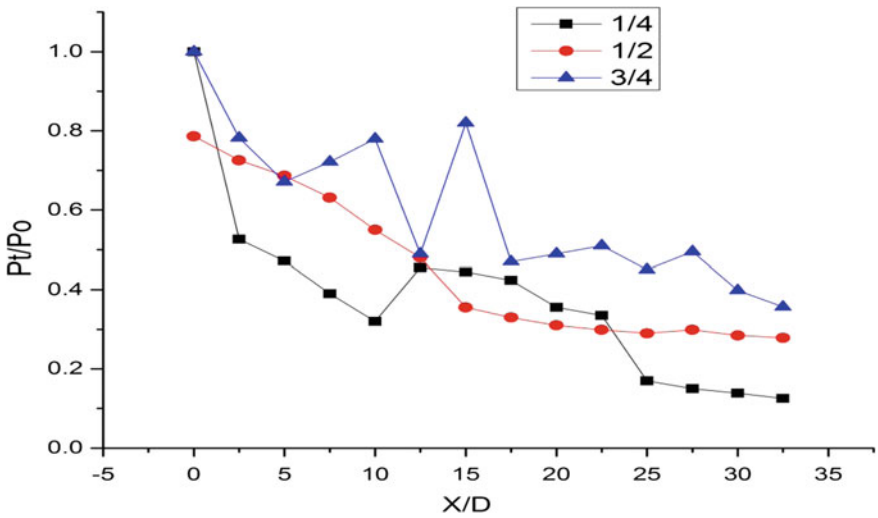


Fig. 5 Centerline pressure decay at NPR 5

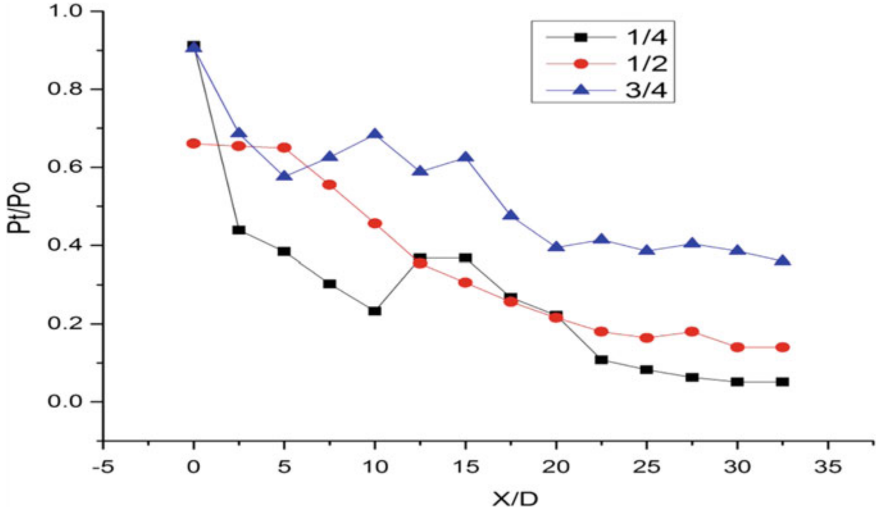


Fig. 6 Centerline pressure decay at NPR 6

image for the three types of configurations is shown in figure and is compared with each other to find the upstream and downstream flow property. Figures 8 and 9 show the axis switching of the jet at X/D of 5 and 10. Figures 8 and 9 show the flow is decayed from elliptic to circular due to the mechanism of the axis switching. It is evident that axis switching is the ultimate reason to achieve high mixing promotion using passive control.

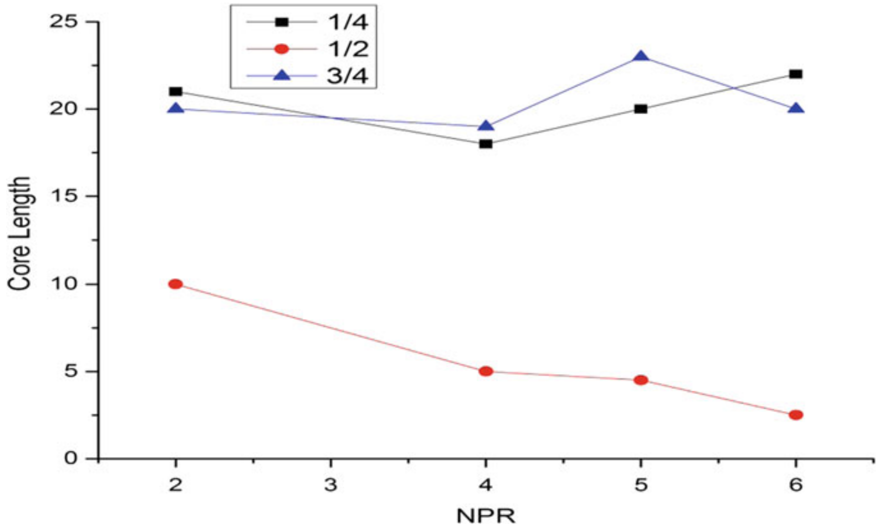


Fig. 7 Core length variation for different NPRs

Fig. 8 Isopitot velocity contour of jet with ½ position crosswire at X/D = 5

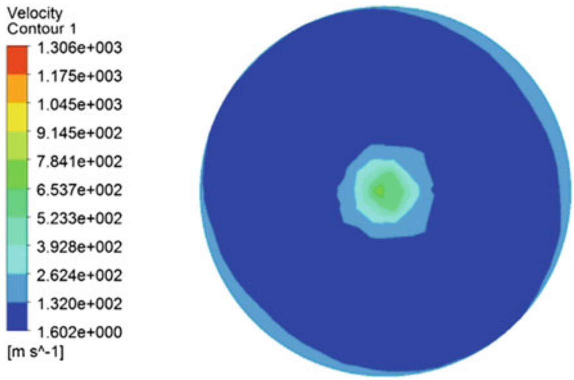
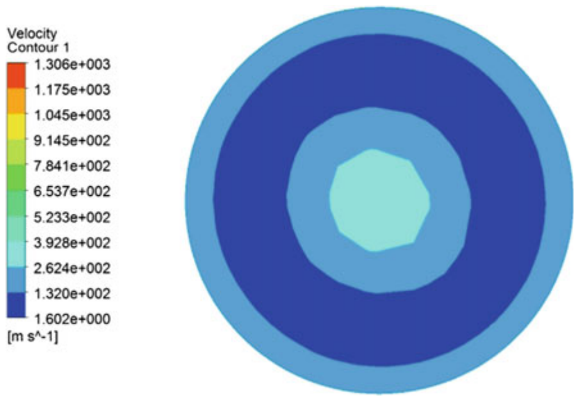


Fig. 9 Isopitot velocity contour of jet with ½ position crosswire at X/D = 10



4 Conclusion

The flow and mixing characteristics of the elliptical jet with crosswire under various levels of NPR have been experimentally studied. It is found that the crosswire has an ability to modify the shockwave due to which core length of the configurations shows an appreciable change. It is also found that crosswire at half quarter ½ produces a higher result compared to ¼ and ¾. As NPR is increased, the flow is expanded; at NPR 6, the flow is perfectly expanded leading to reduction up to 75%. Further, it is seen that when the crosswire positioned at center axis of the jet provides maximum mixing promotion as well as higher mixing efficiency in huge margin. The numerical result reveals that weakening of shock cell strength is the ultimate reason for reduction in core length. The visualization image exposed that due to reduction of shockwave at the jet, core mixing augmentation is bigger.

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