Mixing Characteristics of Elliptical Jet Control with Crosswire

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Abstract. The aerodynamic mixing efficiency of elliptical sonic jet flow with the effect of crosswire is studied computationally and experimentally at different range of nozzle pressure ratio with different orientation along the minor axis of the exit. The cross wire of different orientation is found to reduce the strength of the shock wave formation. Due to the presence of crosswire the pitot pressure oscillation is reduced fast, which weakens the shock cell structure. When the cross wire is placed at center position we see high mixing along the major axis. Similarly, when the cross wire is placed at ¼ and ¾ position we see high mixing promotion along minor axis. It also proves, as the position of the cross wire decreased along minor axis there will be increase in the mixing ratio. In addition to that we also found that, jet spread is high in major axis compared to minor axis due to bifurcation of jet along upstream.

1. Introduction

Controlled jet has huge application and vast applicability in several engineering and non engineering areas [1-8]. From previous studies and papers we aware of that, the performance of the system can be improved by controlling the jet flow. In case like aviation, the jet engine performance is increased by controlling the fuel and air mixing ratio and exhaust control. In previous research they controlled the flow of jet using different types of tabs [4, 6]. In this paper we going to present the stainless steel cross wire as replacement of the tabs to improve the mixing capability. These crosswire is placed at minor axis at three different positions of ¼, ½ and ¾. Recent days, these elliptical jets are experimented extensively rather than rectangle and circular jet due to its efficiency in mixing. This type of flow control using extra surfaces like tabs, cross wire are called as passive jet control. We opted elliptical jet when compared to circular jet since the unexplored area is huge and only least experiments are conducted on it.

Vijayaraja studies the characteristics study on supersonic elliptical jet at mach 2 on convergent and divergent nozzle [4]. The aspect ratio taken to be 2:1 with favourable pressure gradient. They found that mixing of jet on elliptical outlet is high when compared to the circular outlet is high when compared to the circular outlet and they also proved that decay of elliptical jet is higher than circular jet in all regions.
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In addition to this, they also depict the elliptical jet spreads faster in minor axis than major axis. At the nozzle pressure ratio of 4 to 5 the jet shifts upstream. By shadowgraph visualization pictures they reveal waves in circular jet are stronger than elliptical jet. Rouly and Andrew carried out experiment on low divergence elliptical jet nozzles which has capability to produce high pressure fluid jets [1]. The aspect ratio of jet is 1 and 2.45 and divergence of 0.4 degrees. Nozzle pressure ratio is 3 and 4.45 with the flow rate of 13.6 to 37.9 LPM. Daniel and Mitchell tested the elliptical jet for instability models using particle image velocimetry and schlieren image using acoustics fields [3]. They took the jet of aspect ratio 2 with the favourable nozzle pressure ratio of 2.2. They conclude that flapping mode jet decay is more rapidly with the generation of acoustics tone in form of het screech. In addition to that, they also say flow is dominated in major axis of plane during flapping mode. Manigandan et.al, studied the effect of jet shape on flow [20-21]. Vijayaraja had done experiment on supersonic jet to study the effect of aspect ratio in elliptical jet with different levels of expansion [6]. They have taken the three different aspect ratio of 2, 4, and 6 at nozzle pressure ratio of 2 to 5. The results show that mixing is good in elliptical when compared to circular. They also claim aspect ratio show strong effect on jet mixing. The jet mixing at aspect ratio 4 and 6 is inferior to the aspect ratio of 2. Zaman studies the effect of exit geometry on jet mixing. They investigated the nozzle if 3:1 with Mach number of 1.5 under expanded and over expanded conditions. They found that azimuthal of elliptical jet gives advantageous to the mixing process. They claim that elliptical jet decay faster than circular jet field. They also prove that azimuthal symmetry is gives the faster decay of elliptical jet.

2. Experimental details

The experiment is conducted using supersonic Aerodynamics Laboratory, Jeppiaar Engineering College, Chennai. The tank is used to store the compressed air and it is allowed to discharge when the experiments are conducted. The air is charged and stored in the tank for favourable pressure and the control valve is used to regulate the flow. The mixing length of the facility is 2m between settling chamber and valve. Honeycomb mesh like structure is kept on settling chamber to ensure the flow is streamlined approximately. The favourable nozzle pressure ratio NPR is achieved by controlling the atmospheric pressure and chamber pressure. Models are designed of single aspect ratio of 2 and they exposed to the three different position with the NPR 2 and 2.5. The Kevlar fiber crosswire used as mixing promoter [9-13] and it is fixed at the exit of the flow. We ensured that the blockage is below 5%. The previous research says the effect of blockage is complicated as it affects the mixing promotion, so we taken blockage below 5%. The Reynolds number of 2 X 105 to 5 X 105 is taken respectively with different NPR.

3. Results and discussion

When jet slow passes through the orifice there will be possible of shock wave due to pressure oscillation in the potential core region. Due to this there will be some deviation in accurate results. The potential core is defined as axial distance from nozzle exit. When cross wire is introduced at different orientation, the exit is separated into two parts of high speed region along major and minor axis. The jet is operated at nozzle pressure ratio of 2 to 6 with cross wire at the exit of orifice is presented in figures 1 to 5. The X/D is plotted against the pressure ratio (Pitot pressure/ Chamber pressure). The value of nozzle exit pressure (Pe) to the ambient pressure (Pa) of 1.05, 3.5, and 5.02 is chosen for the NPR 2, 4 and 6. The expansion waves are generated at the exit of the orifice to reduce the back pressure of the jet, thereby the jet moves to the equilibrium state. By implementing the stainless crosswire at the exit of orifice there is possibility of formation of vortices. These vortices are smaller than the azimuthal vortices formed at the exit of nozzle. It is said that the jet flow is supersonic and turbulent. Hence the Pitot tube is used to calibrate the core length
and the decay of jet. In order to acquire better characterization in aerodynamic mixing and acoustic, the pitot pressure is measured approximately 100 samples per second.

3.1 Crosswire at ¼ position of the jet minor axis

The pressure distribution of controlled elliptical jet is compared in figure 2. The plots and graphs show that the crosswire changes the characteristics decay of the jet. The pitot pressure oscillation at NPR 2 denotes that shock cell strength is low in controlled jet compared to uncontrolled jet. When cross wire is placed at the ¼ position along minor axis, the core length extends up to X/D= 4.8 for uncontrolled jet and for controlled jet X/D=3.4. The cross wire on the controlled jet provides faster decay and good mixing up to X/D=15.
3.2 Crosswire at ¾ positions along minor axis

The pressure distribution of controlled elliptical jet is compared in figure 1 and 2 at the NPR = 2 and 2.5. The plots and characteristics graphs show that the crosswire changes the decay of the jet. The pitot pressure oscillation at NPR of 2 and 2.5 denotes that shock cell strength is low in uncontrolled jet compared to controlled jet. When crosswire is placed at ¾ position of minor axis, the core length extends up to X/D=8 for controlled jet and for uncontrolled jet X/D= 9.6. The crosswire on the controlled jet provides fast decay and good mixing up to X/D= 18.

3.3 Crosswire at center of the jet

The crosswire is placed at center of the elliptical jet and tested at NPR of 2 and 2.5 with pressure ratio of 1.02bar. The model is tested and the results are compared with graphical representation. The plot shows, the crosswire changes the magnitude of decay. From figure 1 and figure 2, it is found that, when the crosswire is placed at center X/D=5.7 for uncontrolled jet and X/D=4.5 along major and minor axis. The above results depict that implementation of crosswire leads to weaken of shock structure.

3.4 Position of crosswire effect on jet mixing

The position of crosswire on has a huge effect on jet mixing for uncontrolled jets. At NPR of 2, the position of the crosswire moved along minor axis gives the better mixing as seen in the figure 1. The position ¾ and ¼ of minor axis gives less mixing, when compared to the ½ position of crosswire. At the controlled jet, the mixing is better in ¼ and ¾ position when compared to ½. The above theory clearly shows that he implementation of crosswire at the exit of orifice gives the better mixing at the levels of under expansion.

3.5 Elliptic Jet pressure profile

The effect of crosswire is studied for three different types of orientation on jet flow field. The figure 5 and results show the jet bifurcated into two regions due to the wire at the exit. These two regions called as high speed regions. The crosswire presence at jet exit will not support any effect on jet spread, however these controlled jet exhibits axis switching on upstream due to the jet spread along major and minor axis. We have seen jet spread is high in minor axis and lower in major axis. At the...
position of $\frac{1}{4}$ the uncontrolled and controlled jet gives the value of $X/D= 3.2$ and $4.6$ respectively and the axis switching moves to downstream. At the position of $\frac{3}{4}$ the uncontrolled and controlled jet gives the value of $X/D= 3.2$ and $4.6$ respectively and the axis switching moves to upstream.

4. Visualization

The effect of crosswire structure on the core is visualized using computational method at the NPR of 2 using numerical method[14-19]

![Figure 6. Jet deviation after crosswire of elliptical exit](image)

From the figure 6 it is evident that the crosswire weakens the shock cell structure. The jet divided into two high speed regions due to bifurcating [20-22]. The flow deviates due to the cross wire and the vortices shed. As the axial distances increases the core intensity is decreased due to vortices shed which forms a dead region.

5. Conclusion

The above plots and studies prove that the implementation of the crosswire at the orifice exit reduces the pitot pressure oscillation. Thereby this pitot oscillation reduces the shock cell strength and weakens them. The crosswire at the jet exit split the jet into two high speed regions on either side of the cross wire structure. In addition to this we also found that the spread of uncontrolled jet and controlled jet is more in minor axis when compared to major axis which tends to axis switching along upstream under favourable pressure gradient. Further, theories prove the length of core is less in $\frac{1}{4}$ and $\frac{3}{4}$ position compared to $\frac{1}{2}$.

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