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Effect of Orifice Position on Flow Characteristics of a Three Dimensional Wall Jet.

S.V. H. Nagendra, Prasant Nanda, D V S Bhagavanulu

Abstract: ***The present work is based on the analysis of wall jet developing on plane surface and at the corner of the wall. Square orifice is used to develop the wall jet on both the surfaces. Experimental and computational analysis on both plane and corner wall jet system are done. The mean velocity profiles like longitudinal and lateral, maximum velocity decay and half width growth are recorded and calculated for comparison of the corner wall jet with the plane wall jet. The mean velocity profile shows good agreement with the plane wall jet profile and also with the computational results. The decay of maximum velocity is slower in the corner wall jet when compared to plane wall jet in the longitudinal direction. The growth of half width is higher in the corner wall jet when compared to plane wall jet.***

Index Terms: ***CFD, Corner wall Jet, k-ε model, mean velocity profile, Plane wall jet, square orifice, Wall jet***

I. INTRODUCTION

The wall jet is formed when a jet of fluid strikes a surface at any angle. If the striking angle is 0^0, then the plane wall jet is formed and if the jet is striking the plate at 90^0, then the wall jet formed is known as radial wall jet. There are many practical applications of the wall jet in the field of civil, mechanical and aeronautical engineering. The present work is particularly important because the corner wall jet generally occurs in some practical applications such as heating and ventilation applications when the air discharge is mounted in a corner, effluent discharge from submerged pipes, and electronics cooling applications. It is found from the literature that there are two studies available on the corner wall jet (Hogg and Launder [1] and Barette Poole and Joseph W Hall [2]). Hogg and Launder's [1] corner wall jet was formed using a long square duct so it fits in the corner perfectly. Using a Pitot tube, they measured the mean velocity profiles on the corner bisector (the plane of symmetry) and across the jet along the wall at y_{max}, height of the maximum velocity point. Their results indicate that the mean velocity profiles along the corner bisector were self-similar. Hogg and Launder [1] also did a complete mapping of the mean velocity field at 50 diameters downstream. Barette and Joseph [2] used a circular pipe for generating corner wall jet and they measured mean velocities and turbulence intensities. They measured up to a distance of 40 times the diameter of pipe.

The present paper is based on the analysis of plane wall jet and corner wall jet when the jet is issued from a square orifice. Fig. 1 shows general flow configuration of wall jet developed at the corner. In the present investigation, the width of square orifice is taken as 34 mm with diffuser type edge at 45^0 angle. The jet exit Reynolds number is 67000. The velocity is measured using two digital micro-manometers with a range 0-5 m/s and 0-50 m/s. Total pressure probe is used for measurement of velocities at different points both on the y and z directions. 2m x 2m x 1m traverse table is used to move the probe in different planes. A well designed jet tunnel is used to issue the air at 28 m/s and shown in Fig 2. Commercial CFD code is used to solve the dynamics of fluid flow. The two equation model is used as the physics model to define the problem.

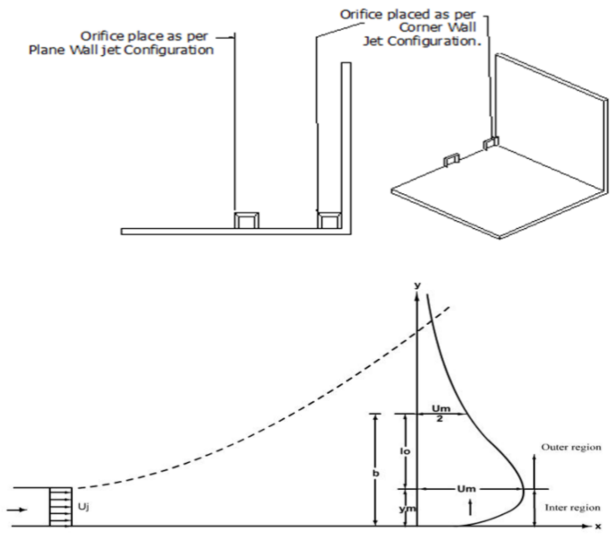

Fig. 1 Schematic of Corner and Plane Wall jet.

II. METHODOLOGY

Measurements were carried out using total pressure probe for both the plane wall jet and corner wall jet. The readings are taken both in the longitudinal direction and spanwise direction i.e., xy and xz planes. The readings are taken at 1, 5, 10, 15, 20, 25, 30, 35 and 40 times the width of the square orifice. A control volume of the flow is extracted and modelled with the help of experimental data boundary condition.

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Then it is discritized using tetrahedral mesh element. Wall condition is modelled using inflation layer with thickness equal to the boundary layer thickness calculated on the basis of Reynolds number.

The **k-ε** model is used to solve the governing equation with higher order advection scheme. Further the results are explored in the form of xy data and compared with experimental data. The convergence criteria for all the cases are taken as 1e-4. Grid dependency test is performed for CFD analysis , the model started with 256140 elements and ended to optimzed grid size of 853108 elements as shown in fig 3.

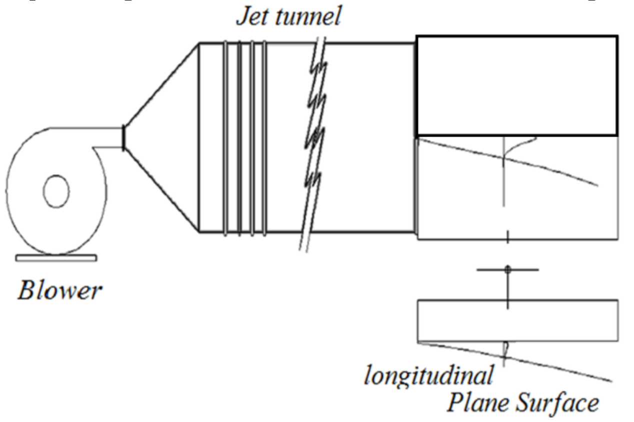

Fig. 2 Experimental Setup for Corner and plane jet

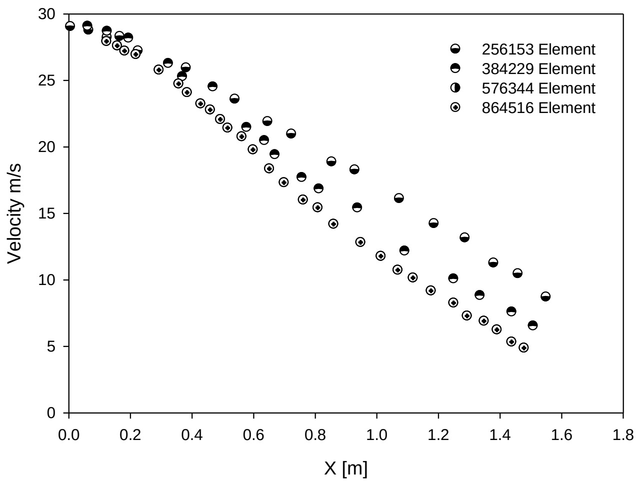

FIG 3 GRID DEPENDENCY TEST

III. RESULTS AND DISCUSSION

A. *Mean velocity profiles*

As described earlier, the measurements were carried out on plane surface initially using a square orifice. Also, measurements are carried out at the corner of the plate to produce corner wall jet. The computational analysis was done both for the plane wall jet and corner wall jet. Results are compared with the experimental results. Figure 4 shows the mean velocity profiles at x/h = 10, 15 and 20. From the figure, it is observed that the profiles follow the trend of Glauert [3] in the longitudinal direction and also seen that the profiles of corner wall jet have same shape of the profiles for the plane wall jet. But it is observed that the velocities are higher in the outer region of the wall jet. The position of the maximum velocity is 0.2 in the case of plane wall jet where as the position of maximum velocity is 0.34 in the case of corner wall jet. It is understood from the flow phenomenon that the mixing is more in the case of corner wall jet and it is due to the position of the wall on both planes. The mean velocity profiles at x/h = 30 is shown in the Fig. 5. In this figure also, similar trend is observed as that of Fig. 4. But, in the outer layer of the comer wall jet the velocities are much higher as compared to that of the plane wall jet profile. Figure 6 shows the mean velocity profiles in the longitudinal direction at x/h=40. In this figure also the velocities are higher in the outer layer of the corner wall jet.

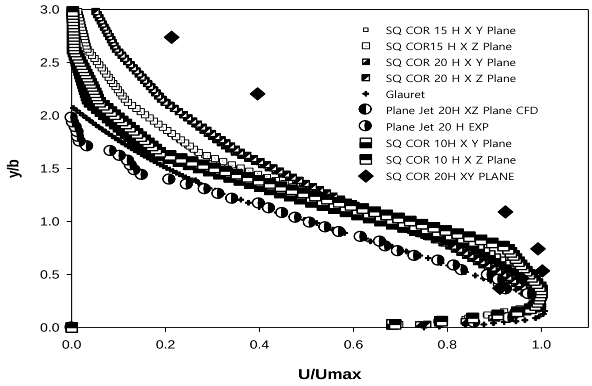

Fig. 4 Mean Velocity Profiles in the longitudinal direction

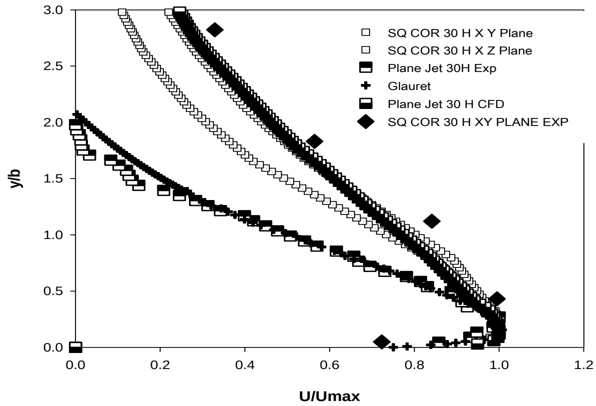

Fig. 5 Mean Velocity Profiles for both the cases at 30H

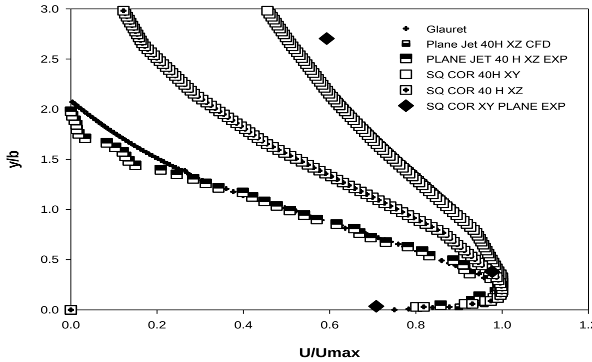

Fig. 6 Mean Velocity Profiles in the longitudinal direction at x/h=40

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B. *Lateral Velocity Profiles*

Fig 7 and 8 shows the experimental and CFD results of lateral velocity profile for plane wall jet configuration at 20h, 30 h and 40 h , it shows similar trend to that of free jet profile which is also known as normal distribution curve fit. Figure 8 shows the velocity profile drawn at 30 h on both the plane XY and XZ . It is observed that on the both the plain the maximum velocity shift more on XY plane when compared to XZ plane, it also shows similarity to half asymptotic curve of the free jet profile.

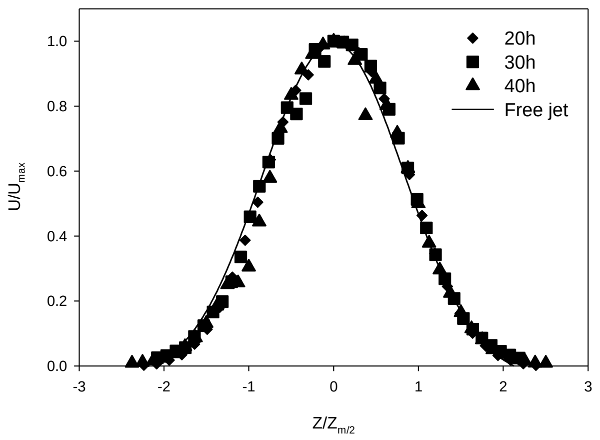


Fig .7 Shows the CFD results of Lateral velocity profile of Plane wall jet setup

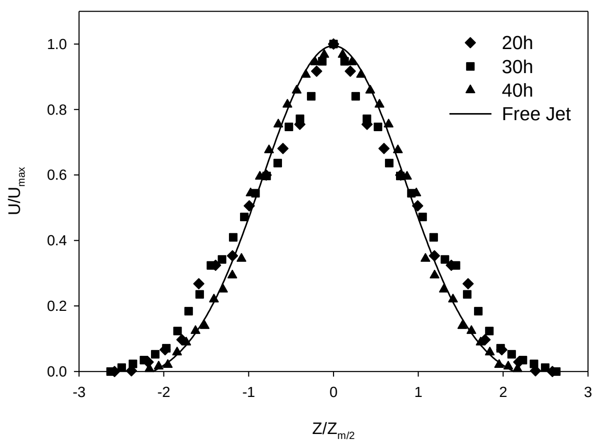
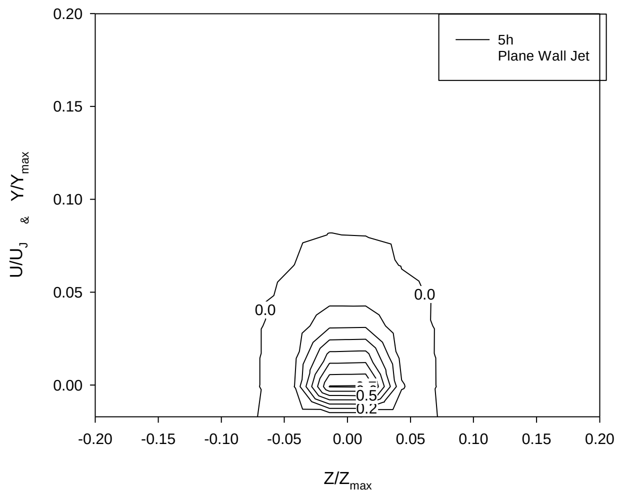


Fig. 8 Shows the Experimental results of Lateral velocity profile of Plane wall jet setup

C. *Velocity Contours*

Numerical results are mean velocity contours are shown in fig 9 to fig 12 for plane wall jet and corner wall jet. They are drawn on the virtual plane parallel to inlet i.e. YZ plane at 5h , 20h 30h and 40 h stations respectively. It is clearly observed that shape of the orifice have significant effect in plane wall jet upto 20 h but after which the lateral spread (in Z direction) is more compared to longitudinal spread(in Y direction) and it well agrees with existing literature. In case of corner wall jet the longitudinal growth (Y direction) and lateral growth (Z direction) growth are near to same upto 20 h , after which the behavior changes and lateral growth is faster compared with longitudinal growth. It is observed that the corner jet grow faster near the wall. But still it is sluggish when compared to three dimensional wall jet. The same behavior is well observed by Poole and hall . The initial width at inlet is more in the present analysis as the shape of the orifice is diffuser type with and angle of 45^0



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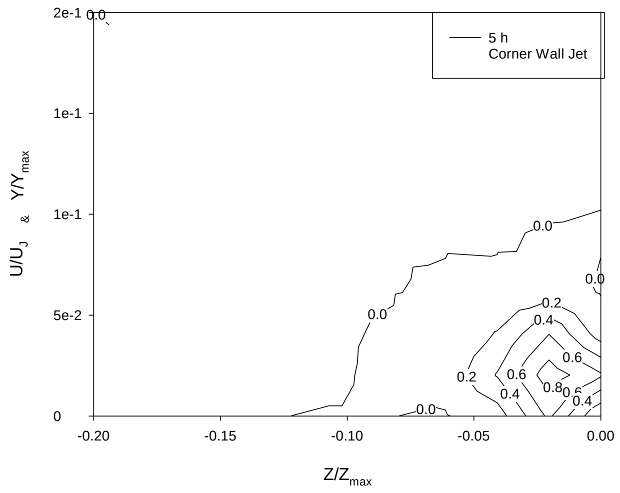

b)

Fig 9 a and b shows Normalized velocity Contour on YZ plane for plane and corner wall jet at 5h station

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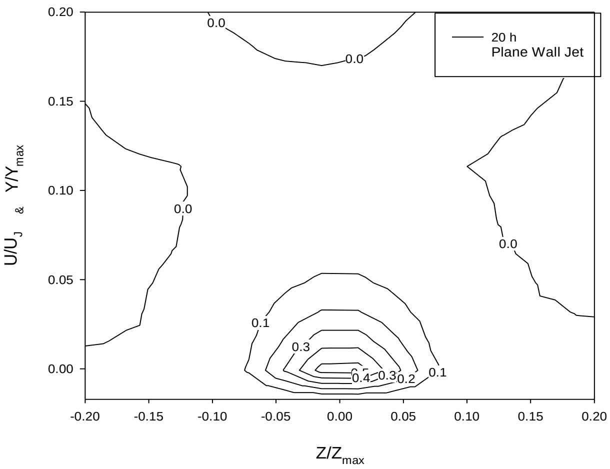

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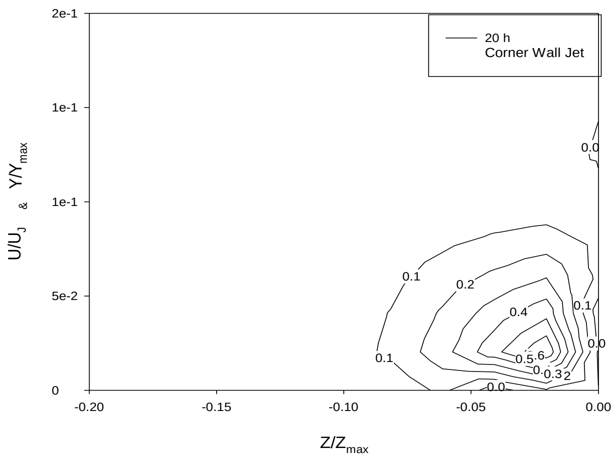
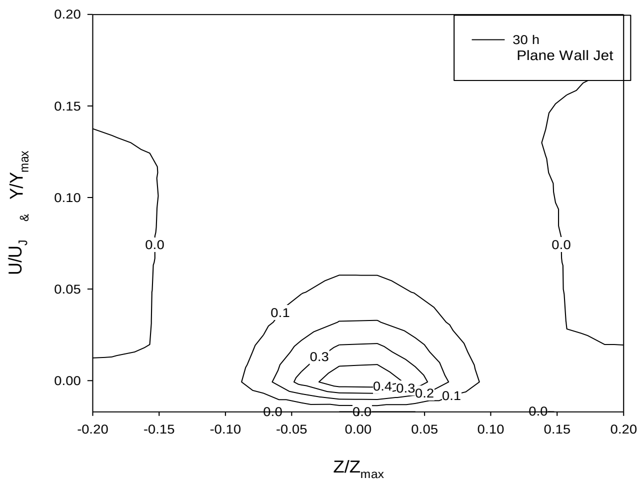


b)

Fig 10 a and b shows Normalized velocity Contour on YZ plane for plane and corner wall jet at 20 h station



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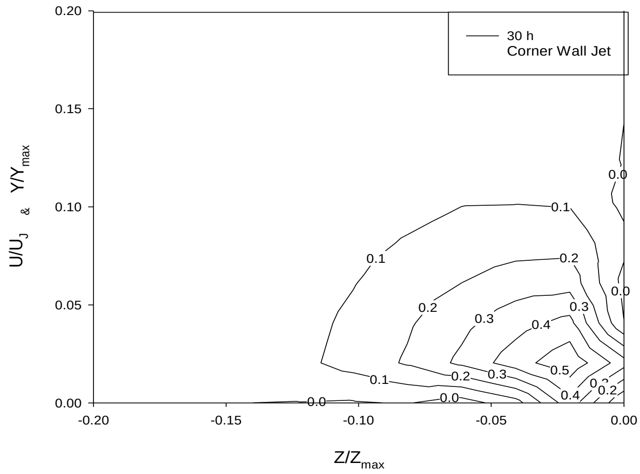

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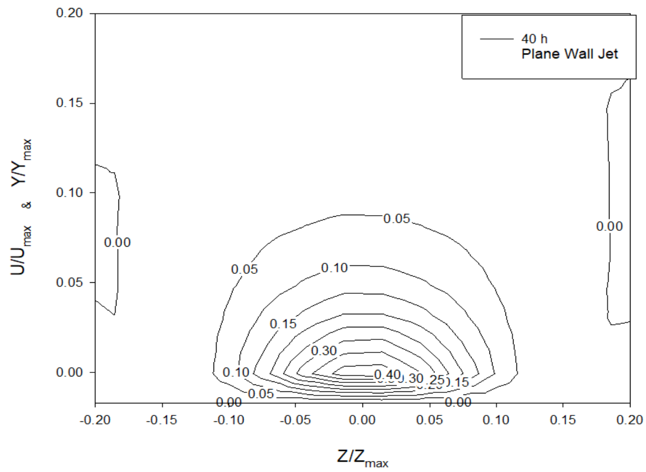
Fig 11 and b shows Normalized velocity Contour on YZ plane for plane and corner wall jet at 30 h station



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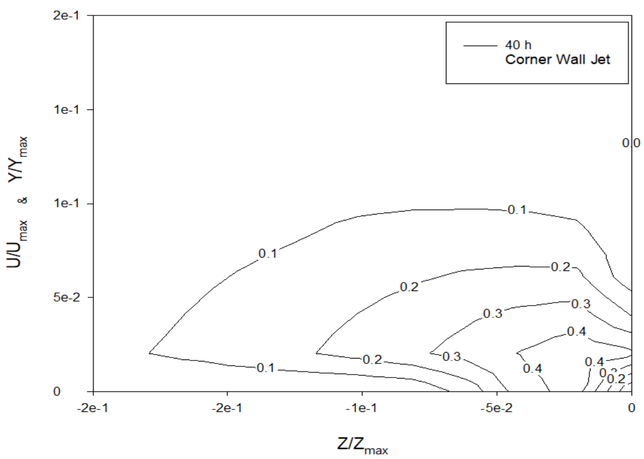

b)

Fig 12 a and b shows Normalized velocity Contour on YZ plane for plane and corner wall jet at 40 h station

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IV. Decay of Maximum Velocity

Fig. 13 shows numerical and experimental results for the decay of maximum velocity on plane as well as corner wall jet configuration . Potential core region exist upto 5 h in corner as well as plane wall jet. The maximum velocity change is almost same upto 10 h. The same has been observed by Poole 2016 [2] . Between station 20 to to 40 it is observed that the decay is slower in the corner wall jet when compared decay for plane wall jet in the longitudinal direction but the difference is not very large. But the numerical results shows much larger difference. It is also found that the decay exponent is n=1.01 in the case of plane wall jet whereas it is 0.89 for the corner wall jet. Hence it can be concluded that the decay in the corner wall jet is slower when compared to the decay over the plane wall jet.

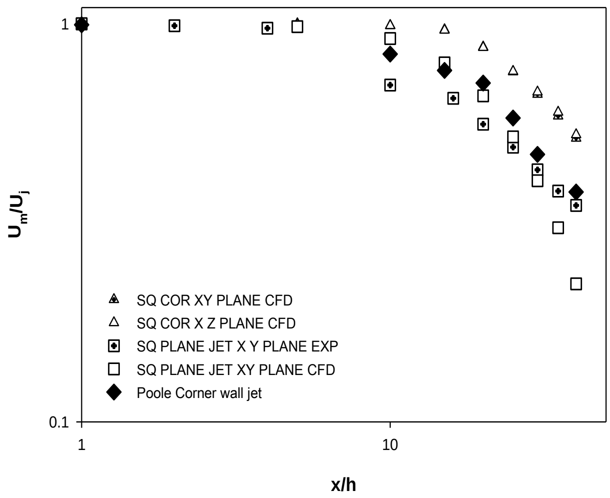

Fig 13 Shows Decay of Maximum Velocity for both cases.

V. Growth of Half Width

Fig. 14 shows the growth of half width in the longitudinal direction and lateral direction. Plane wall jet agrees good with literature and the constant is 0.047 and 0.148 in the longitudinal direction and lateral direction respectively. In the numerical results the value of b/h in Y axis is 0.036 in longitudinal direction and the lateral direction is about 0.122. The experimental results of corner wall jet gives 0.056 and 0.067 value of constant in longitudinal and lateral directions for growth of jet, where as the numerical results have good correlation between each other but the values of constants are under predicted. The current results It is observed that the growth of half width in the corner wall jet is much higher when compared to the growth of half width in the plane wall, jet. The growth of half width in the corner wall jet suggests that secondary flow formation is quite significant in the outer layer of the corner wall jet. As observed earlier, this phenomenon makes the decay of the maximum velocity slower and position of the maximum velocity shifts away from wall in the corner wall jet.

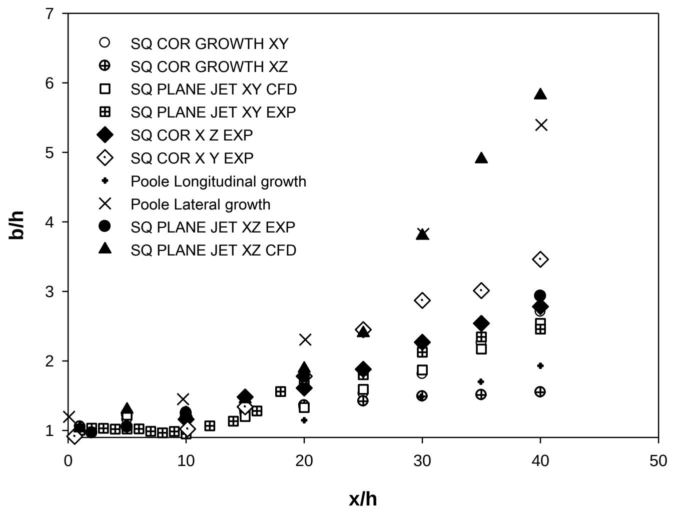

Fig. 14 Growth of Half Width in the longitudinal direction and lateral direction

VI. Conclusion

The mean velocity profile shows good agreement with the plane wall jet profile and also with the computational results. The lateral velocity profiles shows similarity with free jet configuration. The decay of maximum velocity is slower in the corner wall jet when compared to plane wall jet in the longitudinal direction. The growth of half width is higher in the corner wall jet when compared to plane wall jet.

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Dr. DVS Bhagavanulu has 22 years of Administrative, Teaching & Research experience. He did his BE (Civil Engg.), ME (Aeronautical Engg.), Ph.D from IIT Madras, Chennai and also a Post Doctoral. He is Director to Sree Vidyanikethan Engineering College, Tirupati. And has published 136 technical Pagers in Refereed Journals, International and National Conferences. He has completed funded projects worth Nearly Rs. 1 crore. He is a Life Member in Institution of Engineers, ISG, SSI, SHRM, ISC, IAE, ISSSE, ASCE, CSI, IWRS, and ISH.

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