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Computational Study of Effect of curvature on the Heat Transfer of Wall Jet

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Abstract: The present work is carried out to understand the effect of curvature on heat transfer in case of plane as well as curved wall jet flows. Two different physics model i.e turbulence models v2f (velocity scale function - elliptical relaxation function) and k - Epsilon (Turbulence Kinetic Energy - Turbulence eddy dissipation) are used to study the variation of temperature along the centre line of the surface. Experimental study is conducted on both plane and curved surface to capture flow parameters for the existing problem for comparison purpose. The mean flow parameters like mean velocity profile, centre line temperature has been measured. And the same parameters are derived from the Computational analysis results in the form scatter graphs. v2f as well as K-epsilon both the turbulent models show good agreement with the experimental results. It also holds good correlation with the earlier investigation done on the same type of system.

Index Terms : v2f,*κ–ε, wall jet, mean velocity, centreline temperature, wall jet*

1. INTRODUCTION

The wall bounded flows often known as wall jet and computational and experimental study carried out in the present investigation to find the mean flow characteristics and temperature. It is mentioned that the results obtained from the code has been validated by experimental work. The term 'Wall Jet' is used when a jet of fluid strikes a surface at an angle, and the angle decides whether the jet formed is plane wall jet or radial wall jet (Glauert, 1956). It has various applications such as downwash of VTOL/STOL aircraft, rocket nozzle to electronics chipset cooling, automobile air conditioning outlets etc. The first reported experimental study of a wall jet was conducted by Forthmann (1934). An extensive overview of experimental work done until 1980 is given by Launder and Rodi (1981). An overview of numerical work until the beginning of the 1980's is presented by Launder and Rodi (1983). Commercial CFD code Fluent is used to simulate the flow dynamics and structure. The realizable *κ–ε* turbulent model and *v2f* model is used to predict the flow behaviour. Figure 1 shows the computational domain having initial straight portion equals to 20 times of width and the remaining portion is curved with a radius of 3m. Figure 2 shows the surface with velocity profile and Fig. 3 shows the jet tunnel configuration of the experimental system. The curved portion as well as the initial straight portion is maintained at lower temperature i.e. 283^0K and the air flowing on the surface are kept at 300^0K. The grid density is increased by the factor of 1.5 until the grid is above the dependency. The number of the cell finally taken for both the turbulence models is 200,000.

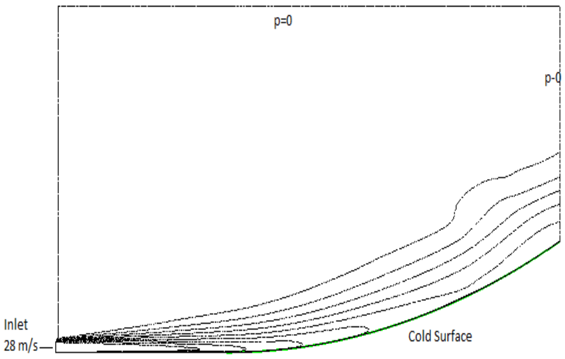

Fig. 1 CFD Domain showing wall jet on concave surface

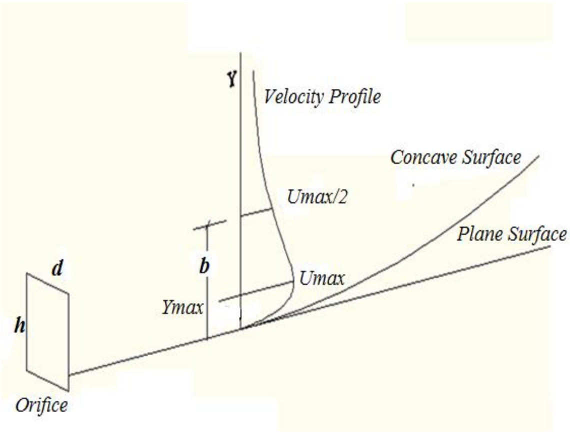

Fig. 2 Jet configuration on the curved and plane surface.

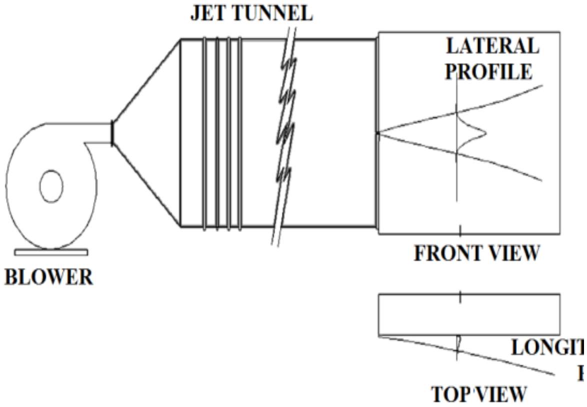

Fig. 3 Jet Tunnel arrangement with profile plates.

2. METHODOLOGY

Mean velocity profiles and temperature gradient profiles are measured with help of digital micro-manometers of range 19.99 Pa to 1999.99 Pa and Palm type Hot wire anemometer probe of range 0-30 m/s range. Temperature data logger is also used to measure plate temperature with “K” Type thermocouple. Further, the measurements are taken both in the spanwise and longitudinal direction at different axial distances. The distances are the multiples of slot width of the orifice. Measurements are conducted at x/h=1, 2, 4, 6, 8, 10, 12, 14, 16 , 18, 20, 25, 30, 35 and 40 respectively.

3. RESULTS AND DISCUSSION

3.1 MEAN VELOCITY PROFILE

Figure 4 shows the mean velocity profiles with the profile at x/h=30 on the plane surface. The mean velocity generated from v2f and k-e model are also included for comparison purpose. It si found that there is no difference between the profiles obtained due to experimental work and models used in the present investigation. Figure 3 shows the mean velocity profile at station 30h. In this figure also, it is observed there is not much variation in the shape of the profile, but found that the velocities are higher in the outer layer of the wall jet on concave surface. There is a good agreement with the profile of Glauert (1956) and Veroff (1963).

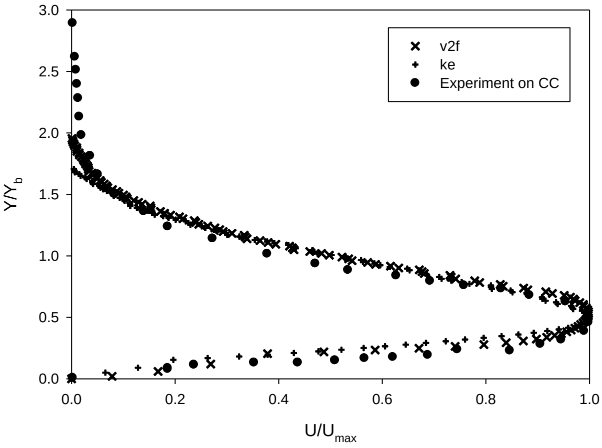

Fig. 4 Mean velocity profile at x/h=40.

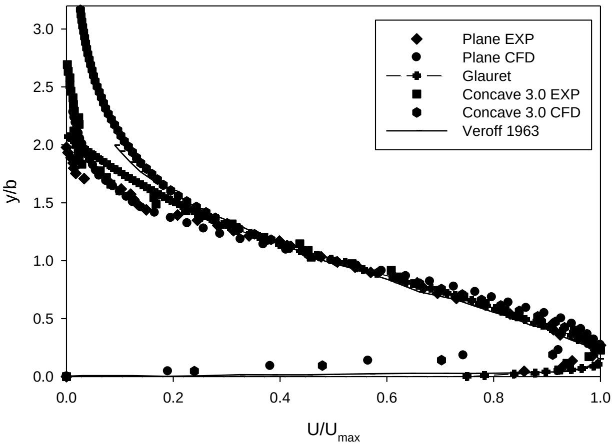

Fig. 5 Mean velocity profile at 30h

3.2 NUSSELT NUMBER

Figure 5 shows the variation of surface Nusselt number . The result shows that there is a good correlation between experimental results with plane surface (k-e) model and concave surface (k-e). Experimental results shows that nusselt number is increasing after 20h on concave surface and similar observation can be seen for both the turbulence models. Total heat flux from the curved surface is about 2218 w/m^2 where as in the case of plane surface it is 2087 w/m2 and this is due to the decay of maximum velocity is slightly slower on concave surface. Also, it is observed from the Fig. 5 that the velocities in outer layer on concave surface are slightly higher when compared to velocities on plane surface.

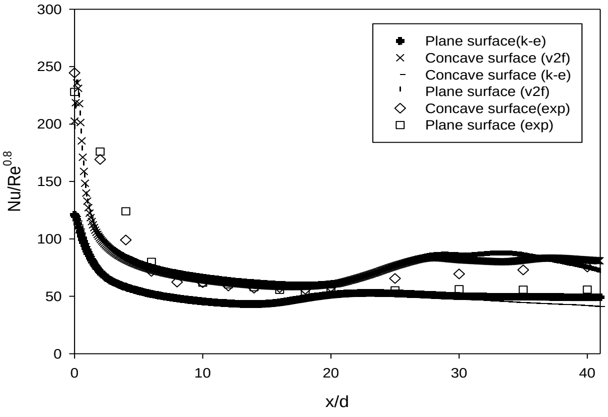

Fig. 6 Surface Nusselt number variation on plane and concave curved surfaces

3.3 TEMPERATURE PROFILE

Figure 6 shows the temperature distribution over the centreline of the surface of interest. It shows that the air temperature is dropping towards the end of surface. Both the turbulence model well predicted the drop and suggesting that the drop is more in case of concave region.

Figure 7 shows temperature distribution along the direction of flow at 25h, 30h 35 h and 40h respectively. More heat transfer is occurring as fluid moves forward i.e. when fluid is passing on the curved surface. Temperature profile approximately follows Pareto function

$$y = 1 - \left(\frac{1}{x^{-24.2}}\right) \quad - Eq.\ 1$$

on plane surface. *v2f* and κ–ε both show shows approximately same temperature drop towards the end.

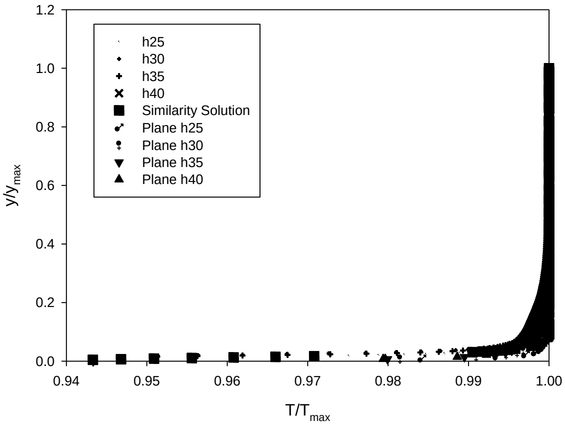

Fig. 7 Spanwise Temperature profile in longitudinal direction

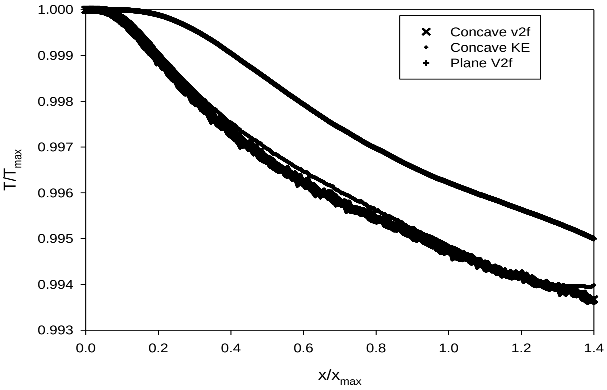

Fig. 8 Centreline temperature profile over the Surfaces

The centreline temperature profiles over plane and concave surface is given in Fig. 8. From the figure it is observed that decay in temperature is much higher on plane surface when compare to decay over the concave surface and this is mainly due to higher velocities in the outer layer of the wall jet profile over the concave surface.

4. CONCLUSION

Plane and curved wall jet has been studied using two turbulence models. Mean velocity profiles predicted by the *v2f* is more accurate when compare with κ–ε. Heat transfer rates shows significant enhancement on concave surface when compared to plane surface. Nusselt number is increased over the curvature area which is well predicted by both the models. Profile generated by κ–ε model for temperature drop on the centreline shows good agreement with the earlier investigations.

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