Investigation on Comparison of Fluid flow Characteristics of Two parallel Plane Jets and an Offset Jet

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Abstract: There is a number of similar features between offset jets and two parallel plane jets, namely, the existence of a recirculation zone (reattachment point versus merging point) and the plane of symmetry in the two parallel jets affecting flow development in a manner similar to that a solid wall in a reattachment offset jet. It is obvious; however, that there are also fundamental differences between the two flows. Firstly, a no-slip condition applies at the wall of the offset jet where as plane of symmetry applies in two parallel jets. Second, further downstream, an offset jet develops into a wall jet while the two parallel jets combine to form a single free jet. Through the use of comparisons, the interaction of two inner shear layers on both sides of the symmetry plane in two parallel plane jets results in a much more turbulent near field than that of the offset jet. A code is used to solve a laminar, two dimensional viscous fluid flow and heat transfer. At the last, it is shown that this code is ready to use for modification for mean flow solution of the turbulent two parallel plane jets and an offset jet.

Keywords: *Turbulent flow, Separation ratio, offset jet, offset ratio,* $\kappa - \varepsilon$ *model, Reynolds number, Plane jets.*

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I. Introduction:

A jet is defined as a free or bounded one depending upon the distance of the confining boundaries. When the boundaries (parallel to inlet axis) are sufficiently away from the origin of the jet, it is termed as free jet. A bounded jet will occur when the flow interacts with a parallel wall. It can be classified into three types based on the orientation: (a) Impinging jet aimed toward the boundary; (b) Wall jet where fuid is discharged at the boundary; and (c) Offset jet from a vertical wall of a stagnent pool issuing parallel to a horizontal solid wall. An off-set jet occurs when discharge of fluid, in the form of jet, occurs in the proximity of surface such that the surface influences the entrainment characteristics asymmetrically about the jet centre line. It commonly represents the flow like heat exchangers, fluid injectors, environmental dischargers, combustion chambers, cooling systems and many others. Two parallel plane jets have numerous technological applications such as the gas turbine combustion chamber, the air conditioner unit for automobile, the air curtain unit for refrigerator system, entrainment and mixing processes in boiler, injection systems and so on. In environmental fluid mechanics, an optimum spacing between exhaust stacks (chimneys) is required to dilute disposal plums to a specified level within a given from the chimney. The details of the flow were studied by several authors. The first detail experimental study of the mean flow was reported by Bourque and Newman[1], followed by Sawyer[2]. They have examined the effect of off-set height on the wall pressure distribution and reattachment locations. Rajaratnam and Subramanya[3] found that beyond the impingement region the flow represents similar to a wall jet flow irrespective of the off-set ratio. Tanaka[4,5] described the basic flow patterns and entrainment mechanism of parallel jets. Hoch and Jiji[6,7] have considered the case of an off-set jet in the presence of a free stream motion. The fluid flow solution has been provided by them. Utilizing this fluid flow solution, they later on have provided the analytical solution for the temperature distribution for the same geometry. Elbanna , H., Gahin, S., and Rashed[8] results showed that the mean velocity profile of the parallel jets agreed well with the single jet in the region downstream of the combined point. In a study, Pelfrey and Liburdy[9] have provided the details of the mean flow and turbulent characteristics and showed how entrainment and local pressure and turbulent energy components are affected by the jet curvature in the reattachment region. In this study, the plate parallel to the jet was as adiabatic. For large Reynolds number generally larger than the 10^4 the impingement distance becomes a function of the off-set ratio only. Computations of the off-set jet performed by Yoon et al[10] showed that in addition to the turbulence model. the numerical scheme also plays a profound effect in predicting the solution. It is observed that the numerical diffusion error due to the stream line to grid-skewness will be significant in the prediction of off-set jet flows Holland and Liburdy[11] presented the thermal characteristics of off-set jets in a condition similar to that of Pelfrey and Liburdy for different offset ratios. In the study, they examined the surface temperature distribution, the maximum temperature decay and the temperature variation in three regions. Lin and Sheu[12,13]. They used hot - wire anemometry to show that the mean velocity approaches self - preservation in both the merging and combined regions, while Reynolds shear stresses approach self - preservation in the combined region only. Nasr, A., and Lai, J. C. S.[14,15] provided an experimental comparison between parallel, plane jets and an offset jet (where a wall replaces the symmetry plane). In a later work, they performed an experimental investigation into the effect of jet spacing on the mean stream-wise momentum flux measured at the combined point. Anderson, E. A., and Spall,R. E[16] presented experimental and numerical results for isothermal, plane parallel jets at spacing s/w = 9, 13,and 18.25 (where s is the spacing between jet centre lines and w is the jet width.).

II. κ-ε Turbulence model:

$\kappa - \varepsilon$ Turbulence model is the most common model used in computational fluid dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions. It is a two equation model which gives a general description of turbulence by means of two transport equations to present the turbulent properties of the flow. This model solves for two variables: κ- the turbulent kinetic energy and ε- the rate of dissipation of kinetic energy. The wall functions are used in this model, so the flow in the buffer region is not simulated. This model is very popular in industrial application due to its good convergence rate and relatively low memory requirements.

III. Problem specification:

In general for parallel plane jets, the flow field can be classified into three parts: the converging region, where the reverse flow is created near the nozzle exit. The merging region, where the velocity profile shows two local peaks without reverse flow. The combined region, where the velocity profile becomes similar to that of the single free jet. On the other hand the off-set jet behaves differently in various regions. In the near field with in a very short distance from the point of discharge, the jet in momentum dominated flow having the properties of free jet. Attachment may occur when the jet is deflected by an adjacent solid wall or a free surface and tends to flow along the boundary. In the region around attachment point, that is, the impingement region and part of pre- attachment region, the jet has characteristics similar to an impingement jet. The jet becomes a wall jet in the far field. The other factors such as ambient motion (free- stream velocity), buoyancy (density difference), discharge orientation, etc. further complicate the jet boundary interaction and the behavior of an off-set jet. The turbulent phenomena of the jets are studied using the $\kappa - \varepsilon$ model. The flow pattern of the two parallel plane jets is shown in figure1.

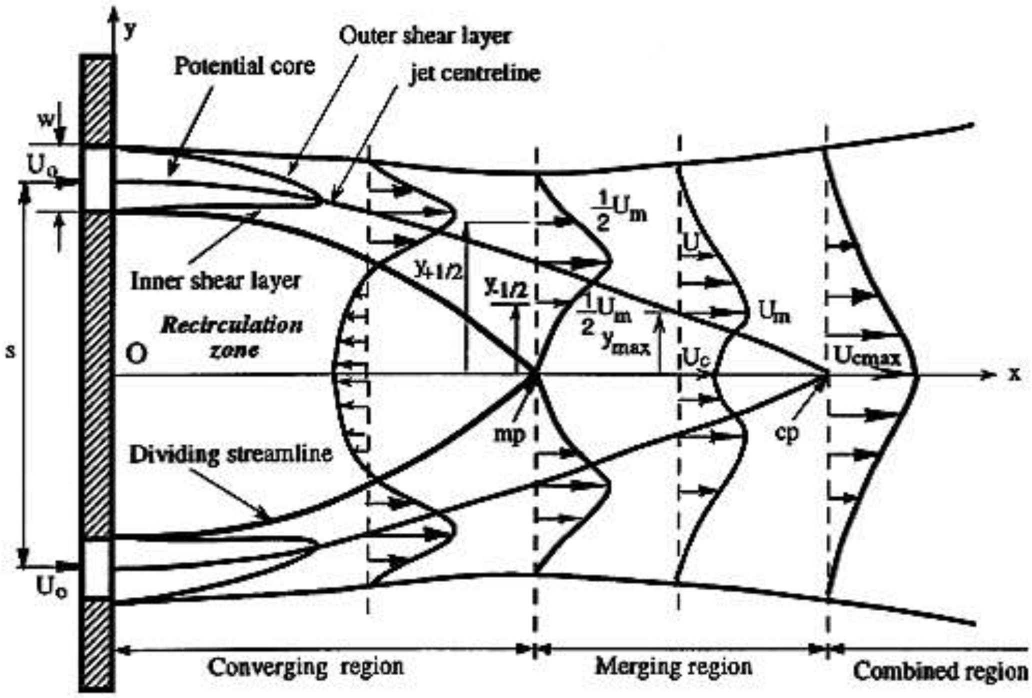


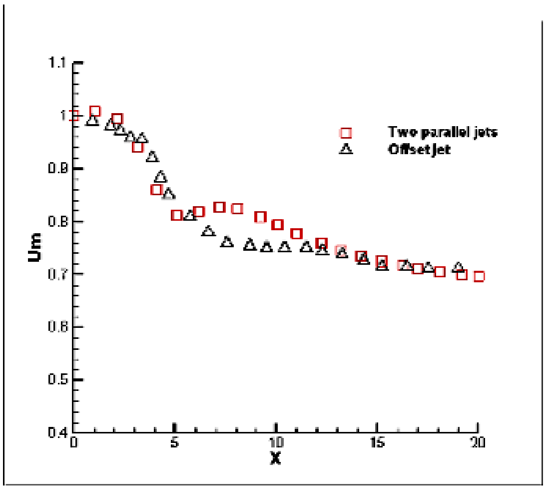
Figure 1: Diagram of two parallel plane jets

IV. Results & Discussions:

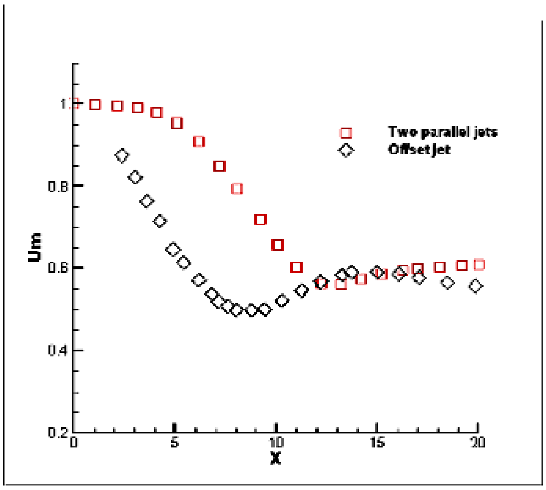
ode is run for two parallel plane jets with separation ratio of s/w = 4.25, 11.25 and15 and offset jet with offset ratio 2.125,5.625 and 7.5 respectively. The domain length in the x direction was varied from 15 to 30 nozzle widths whereas it was set at 10w or 15w in the y direction. The grid size of 151×101 is considered for all cases. The standard $\kappa-\varepsilon$ turbulence model with a power law discretization scheme is used. Here the working fluid is air and Reynolds number is 15000.

4.1 Mean stream wise maximum velocity decay:

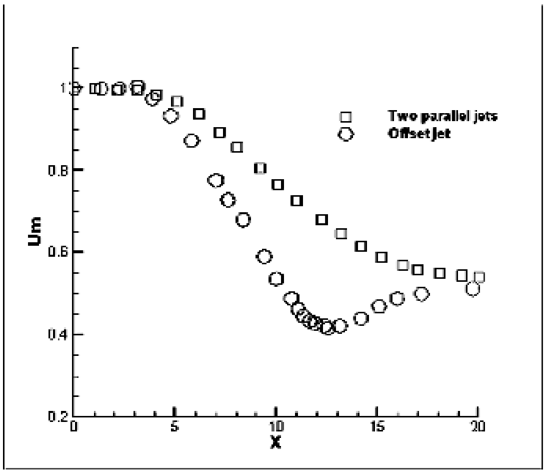
Decay of the mean stream wise velocity Um of the two parallel jets and an offset is compared in figure 5.8. Since the size strength of the recirculation zone are different for the offset jet and the two parallel jets, the influence of the recirculation zone on flow development near the nozzle exit would be different. Hence, a higher value of Um for the two parallel jets than for the offset jet is a result of a higher flow acceleration of the flow close to the nozzle plate, which is due to a lower Sub-atmospheric pressure zone.



[a]



[b]



[c]

Figure 2: Velocity decay of the two parallel jets and the offset jet at(a) O.R.=2.125, s/w =4.25 (b) O.R. =5.625,s/w =11.25 and (c) OR = 7.5,s/w = 15

4.2 Loci of the maximum velocity and half velocity points:

Loci of the maximum velocity and half velocity points are shown in figure (3) and figure (4).

Based on y_{max}, high flow curvature from the nozzle exit can be observed up to about x = 8 for the offset jet and up to about x = 10 for the two parallel jets. It can be seen that, near the nozzle plate, both the two parallel jets and the offset jet spread at nearly the same rate in the inner and outer shear layers. Downstream from x = 5, the outer shear layer spreads faster for the two parallel jets than for the offset jet because the offset jet is constrained by the wall on one side.

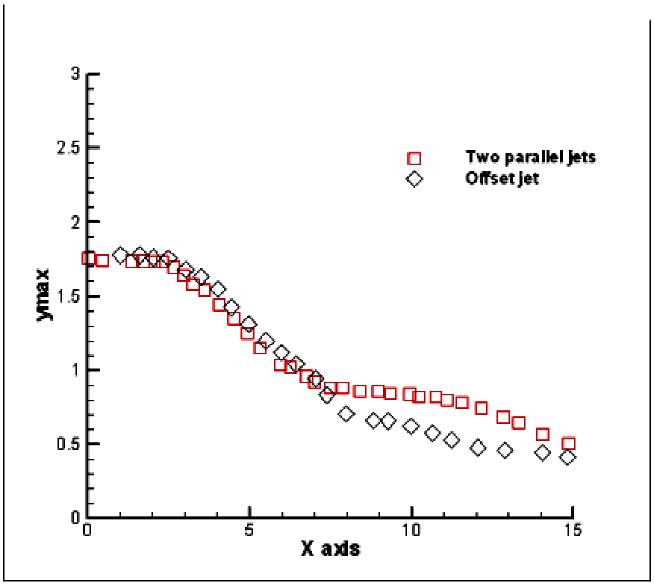
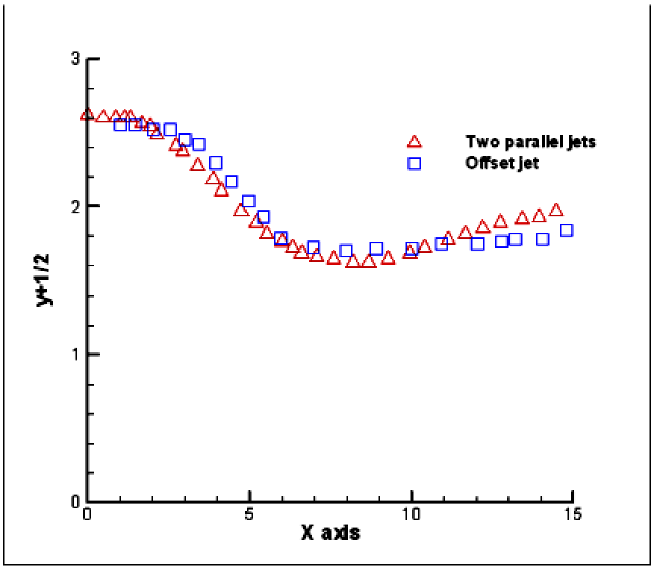
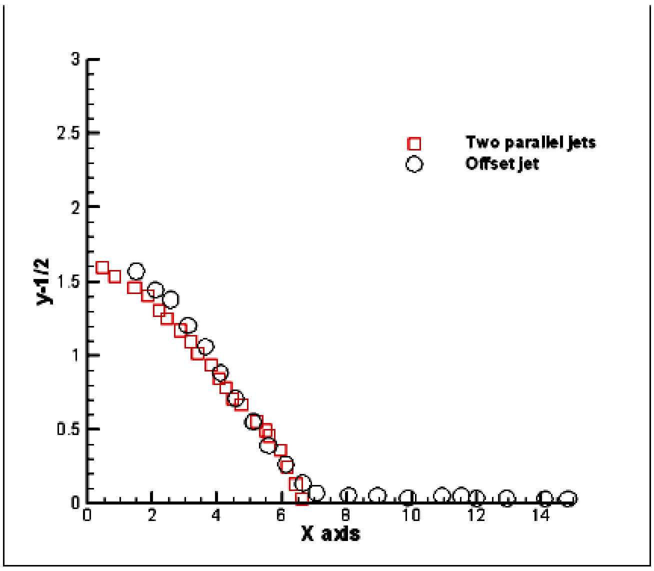


Figure 3: Loci of the maximum velocity



[a]



[b]

Figure 4: Loci of [a] +ve half and [b] -ve half velocity points

V. Conclusion:

The two parallel plane jets develop like a single free jet in the combined region. The outer shear layer spreads faster than the inner shear layer in the near field. The recirculation zone is significantly smaller for the two parallel plane jets than for the offset jet. Turbulence activities in the recirculation zone and the interaction of recirculation flow with the inner shear layer are significantly stronger for the two parallel plane jets than for the offset jet.

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