Interaction of Two Nonequal Plane Parallel Jets

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Abstract

MEASUREMENTS of mean static pressure and mean and fluctuating velocities are reported for the flowfield generated by the interaction of two parallel two-dimensional jets. From these measurements, effects of the velocity ratio of the two jets on the flowfield are studied. The mean velocity profiles show the process whereby two jets interact and merge with each other. Upstream of the merging region, the mean velocity profiles are not similar. The axis of the combined jet comes closer to the power jet as the velocity of the weak jet decreases. In "ventilated" jets, complete confluence of the two jets occurs at larger distance from the nozzle exit than that for "unventilated" jets. Negative static pressure is encountered upstream of the merging region, while the highest pressure is developed in the confluence region. The total momentum is constant at each cross section of the two interacting jets, and the principle of conservation of momentum holds.

Contents

The characteristics of mixing of two parallel jets is an important turbulent shear flow problem. Recently, detailed experiments for examining the dual jet flow were carried out by the authors[1] and other investigators.[2-5] However, no work concerned with nonequal parallel jets is found in the literature. In the present work, the spacing S between the centerline of the two nozzles has a value 27.64 times the slot width t_p. The nozzle contraction ratio is 13.1, and the slot has a width $t_p = 5.5$ mm and a length $\ell = 490$ mm. The nozzle blocks are free-standing between two confining horizontal plates. The confining plates extended 2 m downstream of the slot and 1 m to either side of the midline between the two nozzles.

Turbulence and mean velocity measurements were carried out using a DISA 55M01 constant-temperature anemometer. Measurements of static pressure were obtained with a static-pressure probe of the disk type similar to the one used by Tanaka[2] and Miller and Comings.[3] For the two unequal jets experiments, the issuing velocity U_{01} of the higher-velocity jet was kept constant at 45.5 m/s, corresponding to a Reynolds number based on the slot width t_p of about 16,600. The second parallel jet velocity U_{02} was adjusted to be 1, 0.75, 0.5, and 0.25 that of U_{01}.

Figure 1 shows the variation of mean velocity U, axial velocity fluctuation u', and static pressure P with downstream distance x for the case of $U_{02}/U_{01} = 1$. At nozzle exit plane, the pressure is subatmospheric and, as x/t_p increases, the pressure increases due to confluence up to a maximum value near $x/t_p = 42$. Further downstream, the pressure decreases rapidly due to the change of pressure energy of the two confluent jets to kinetic energy. The mean velocity distribution along the x axis shows that the velocity of the secondary flow reaches minimum value at $x/t_p = 24$ where the inner edges of the two confluent jets approach the x axis. Downstream of $x/t_p = 24$, the mean velocity rises to a maximum value at x/t_p near 60. Hence, it seems that the initially individual jets have merged completely at this point. This can be detected from Figs. 2 and 4, which show that the flow variables at $x/t_p = 60$ resemble those of a single jet. Figure 1 suggests also that maximum pressure along the x axis occurs in the confluence region midway between $U_{\mathfrak{C}_{min}}$ and $U_{\mathfrak{C}_{max}}$. The distribution of $u'_{\mathfrak{C}}$ shows a maximum value at $x/t_p = 42$ which agrees with the position of maximum pressure $P_{\mathfrak{C}_{max}}$.

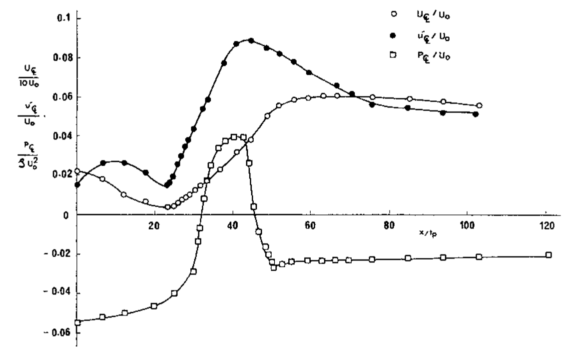

Fig. 1 The distribution of mean velocity, turbulence, and static pressure along the centerline for $U_{02}/U_{01} = 1$.

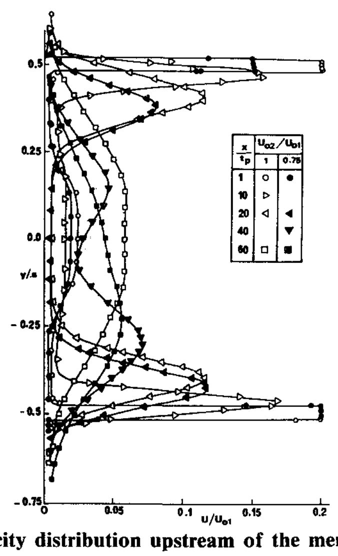

Fig. 2 Velocity distribution upstream of the merging region.

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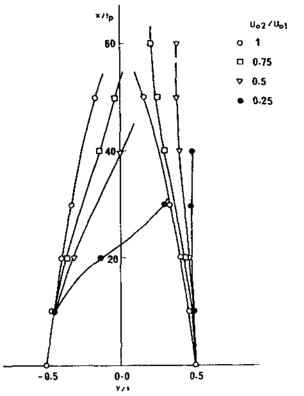

Fig. 3 Trajectory of the central streamline of each of the two jets.

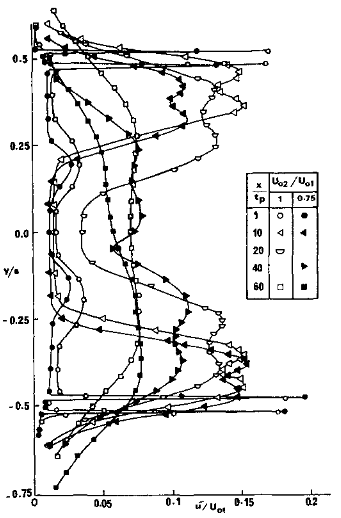

Fig. 4 Turbulence distribution upstream of the merging region.

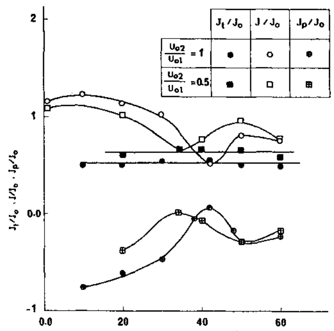

Fig. 5 Variation of momentum along the x axis.

Figure 2 shows mean velocity profiles along the y axis at different x/t_p values. The figure indicates the process of interaction and merging. As shown in the figure, the maximum velocity of the jet decreases, its location from the x axis decreases, and the jet width increases with the distance from the nozzle. For $U_{02}/U_{01}=1$, complete merging of the two jets occurs at $x/t_p=60$. This value of the merging point is about 2.5 times that reported by Tanaka[2] for unventilated jets with $S/t_p=25$, which is near the value of $S/t_p=27.64$ in the present work. This shows that air ventilation causes weaker interaction between the two jets. For $S/t_p=24$, Shimoda et al.[5] reported a value of 120 t_p for the location of the merging point, which is twice that found in the present work for $S/t_p=27.64$. However, their mean velocity data show that up to $x/t_p=40$, the maximum longitudinal velocity in each of the two jets lies at a lateral distance from the centerline greater than $S/2$. This may indicate that the two jets were more probably inclined outward at an angle to the midline between the two nozzles. This may explain the relatively far downstream distance of 120 t_p, which they reported for the merging of the two jets. From lateral velocity measurements, the position of maximum velocity at different x/t_p stations can be obtained. The location of the maximum velocity that describes the trajectory of the central streamline of each jet is shown in Fig. 3. The figure indicates that the weaker jet is more attracted to the strong jet as the velocity ratio U_{02}/U_{01} decreases.

The profiles of the axial velocity fluctuations are shown in Fig. 4. The distribution reveals the existence of two peaks in positions corresponding to the edges of each nozzle, and minimum values appear corresponding to the center of each jet and the secondary flow. The two peaks spread with downstream distance. In the region where the two jets combine, the inner peak decays rapidly and the distribution tends to be similar to that of a single jet. It is noted that there are significant differences in the profiles for different velocity ratios. These may be attributed to differences in production, transport, and dissipation of turbulent energy between the two inner regions of the two intermingled jets associated with different velocity ratios.

In the absence of wall shear stress effects, the momentum conservation equation is

$$J_t = J + J_p = \text{const}$$

where

$$\mathrm{J} = \int_{-\infty}^{\infty} \rho(U^2 + u'^2)\mathrm{d}y \qquad J_p = \int_{-\infty}^{\infty} p\mathrm{d}y$$

The distribution of the velocity momentum J, the pressure momentum J_p, and the total momentum J_t is shown in Fig. 5. The velocity momentum J/J_0 increases just after the nozzle exit due to the acceleration induced in the air between the two jets. Due to confluence, the kinetic energy changes into pressure energy. Therefore, the velocity momentum reaches a minimum value in the confluence region, whereas the pressure momentum shows a maximum value. Further downstream, the velocity momentum approaches a maximum owing to pressure decrease and finally decreases gradually with a corresponding increase in pressure momentum. As shown in Fig. 5, the total momentum J_t/J_0 has nearly a constant value; that is, the conservation law of momentum flux holds.

Acknowledgments

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References

[1]Elbanna, H., Gahin, S., and Rashed, M. I. I., "Investigation of Two Plane Parallel Jets," *AIAA Journal*, Vol. 21, July 1983, pp. 986-991.

[2]Tanaka, E., "The Interference of Two-Dimensional Parallel Jets (1st Rept)," *Bulletin of the JSME*, Vol. 13, No. 56, 1970, pp. 272-280.

[3]Miller, D. R. and Comings, E. W., "Force-Momentum Fields in a Dual-Jet Flow," *Journal of Fluid Mechanics*, Vol. 17, Feb. 1960, pp. 237-256.

[4]Marsters, G. F., "Interaction of Two Plane, Parallel Jets," *AIAA Journal*, Vol. 15, Dec. 1977, pp. 1756-1762.

[5]Shimoda, S. Y. E. and Jotaki, T., "Hot Wire Measurements in the Interacting Two-Plane Parallel Jets," *American Institute of Chemical Engineering Journal*, Vol. 25, No. 4, July 1979, pp. 676-685.