Interaction of Parallel Turbulent Plane Jets

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Abstract

RESEARCH was done on the interaction of two plane parallel turbulent jets issuing into a still surrounding. Because of the entrainment of surrounding air, the two jets attracted each other, merged together, and eventually combined to resemble a single jet. Thus, the flowfield can be defined by three regions: 1) region A, the converging region; 2) region B, the merging region; and 3) region C, the combined region. The mean velocities, mean flow directions, turbulent intensities, and Reynolds shear stress of these three regions were measured by using a split-film probe on a constant temperature anemometer and are presented here.

Contents

Previous investigators of twin-jet flows[1,2] were interested in comparing their results with a single jet flow, so they took their measurements quite a distance downstream of the combining point in region C, where the twin-jet flow most closely resembles that of a single jet. This paper describes a twin-jet flow in the area that these researchers did not adequately describe. In addition, this paper reports results obtained by using a split-film probe. To date, all other research on twin-jet flows has been done with single-wire and X-wire probes. Since flow direction was indeterminable with a hot-wire anemometer, other instruments were used auxiliarily. However, these probes were much less sensitive to flow reversals than a split-film probe.

Two cases were investigated and the results compared. In case I, the jets issued from two plane parallel nozzles and a connecting end wall was placed between them so that the entrainment between the two converging jets was restricted. In case II, the jets issued from two free standing nozzles without a connecting end wall. The surrounding air could entrain into the converging jets. The investigations in both these cases were carried out under the same flow conditions. In addition, both cases also tested the effects of variances in nozzle spacing on twin-jet flows.

The flowfield was produced by a subsonic flow of air issuing from two identical plane parallel nozzles restricted by two plates. The width of the nozzle D was 2 mm and the height of the nozzle H was 180 mm, so its aspect ratio was 90. Nozzle spacings S were chosen at $S/D = 30$, 35, and 40. Ceiling and floor boundaries (i.e., side plates) over and under the jet flow maintained the two-dimensional character of the jets with ambient air. The nozzles were held vertical and were aligned parallel to the X axis of the traversing system. The original turbulent intensity at the nozzle exit was approximately 0.8% at 57 m/s. The exhaust velocity of the jet was maintained to within 1%. All measurements were made with split-film probes, constructed from an 0.15-mm-diam alumina-coated platinum cylindrical film sensor with a length of 2 mm that was split into two separate sensors on a single quartz rod. A TSI gas-probe calibrator, Model 1125, was used for the calibration of the split-film probe. The details of split-film probe calibration were reported by Lin.[3] Visualization of the flow was obtained by using a TiO_2 oil film on a black plate that was placed on the middle plane between the ceiling and floor plates. It was found that the flowfield can be defined by the following three regions.

Region A begins at the nozzle exit plane and extends to the point where the two jets start to merge. A feature of flow in this region is the entrainment of the surrounding fluid by turbulent jet mixing, which creates a lower pressure region between the nozzle exit plane and the reattachment point. The two jets attract each other. Thus, a recirculating flow is formed between them. The vortex centers VC obtained from the streamlines were located at about $X/D = 20$ for case I and about $X/D = 28$ for case II, and the merging points were located at about $X/D = 27.6$ for case I and about $X/D = 32.4$ for case II, at a nozzle spacing ratio of $S/D = 40$. They show that the flow of case II developed more slowly than that of case I. However, as shown in Table 1, although the ratios of the distance of the merging point from the nozzle exit plane to the nozzle width Xmp/D were distinct for variances in the nozzle spacing ratio S/D in both cases, the normalized distance Xmp/S went almost unchanged.

Region B begins downstream of the merging point and continues to the section where the streamwise velocity in the central plane is maximum. The two jets intermingle strongly in this region. The locations where the two jets joined together to form a single jet are shown in Table 2. They were $X/S = 1.0$ for case I and $X/S = 1.3$ for case II, as S/D varied from 30 to 40. This suggests that the twin-jet flows at various nozzle spacings have almost the same normalized trajectories of maximum velocity.

Region C is the region after the jets merged, where the two jets combine to resemble a single-jet flow. The start of region C is referred to as the combining point CP. The characteristics of mean flow in this region tend to become similar to those of a single-jet flow as the distance from the nozzle exit plane increases.

A comparison of Tables 1 and 2 and Fig. 1 showing the trajectories of maximum velocities suggests that flows in both cases have geometrically similar configurations.

Table 1 Location of merging point

	Case I		Case II	
S/D	Xmp/D	Xmp/S	Xmp/D	Xmp/S
30	21.6	0.70	23.5	0.80
40	27.6	0.69	32.4	0.81

Table 2 Ratios of downstream distance from nozzle exit to the location where the combined region starts

	Case I		Case II	
S/D	Xcp/D	Xcp/S	Xcp/D	Xcp/S
30	30.5	1.02	40.0	1.30
40	40.0	1.00	52.5	1.30

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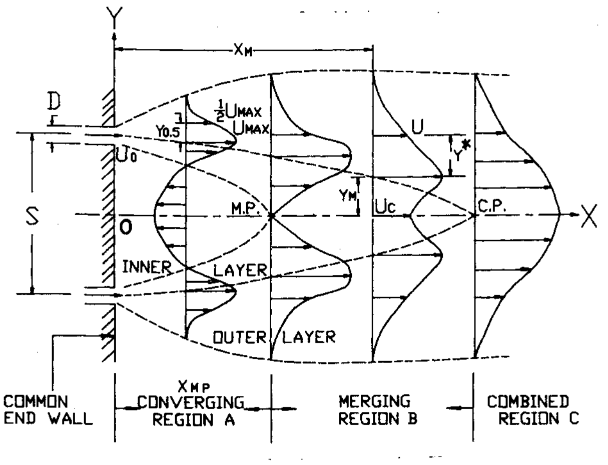

Fig. 1 Notation for dual-jet flow.

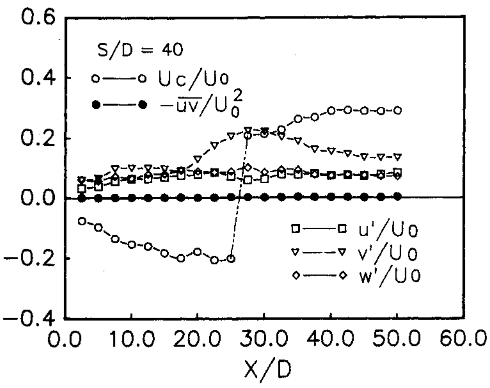

Fig. 2 Variation of mean velocity and turbulent intensities along central plane or unventilated twin-jet flow.

The decay of maximum velocities and the spread of the twin-jet flow for both cases are linearly distributed downward along the X axis in region A and region C. They can be represented by two empirical equations. The decay of the maximum velocity in case I is greater than that in case II in region A, but both are approximately the same in region C. The rates of the jet spread linearly increase in regions A and C. The spread of the converging jet is greater in the outer layer than the inner layer. The jet spread in case I is greater than that in case II. However, the spread of the twin jets (i.e., 0.117) is approximately the same as that of the single jet (i.e., 0.105), for both cases in the combined region.

The distributions of axial mean velocity and turbulent intensities along the plane of symmetry for case I are shown in Fig. 2. The velocity fluctuations in the X, Y, and Z components increase linearly as the distance from the nozzle exit plane increases up to the section where vortex centers exist. They have approximately the same order of magnitude. In region B, due to the strong interaction of the two intermingling jets close to the merging point, the value of the lateral velocity fluctuation grows rapidly as X/D increases and reaches its maximum at the combining point CP. Lateral velocity fluctuation is greater than the fluctuations of axial velocity and transverse velocity. In region C, downstream of the combining point, the lateral velocity fluctuation decreases slowly with increases in X/D and tends to have the same order of magnitude as the axial and transverse velocity fluctuations.

Figure 3 shows the distribution of the conventional rms values of the axial and lateral velocity fluctuation and Reynolds shear stress normalized with respect to the maximum axial velocity U_{max} in region C of unventilated twin-jet flow. It

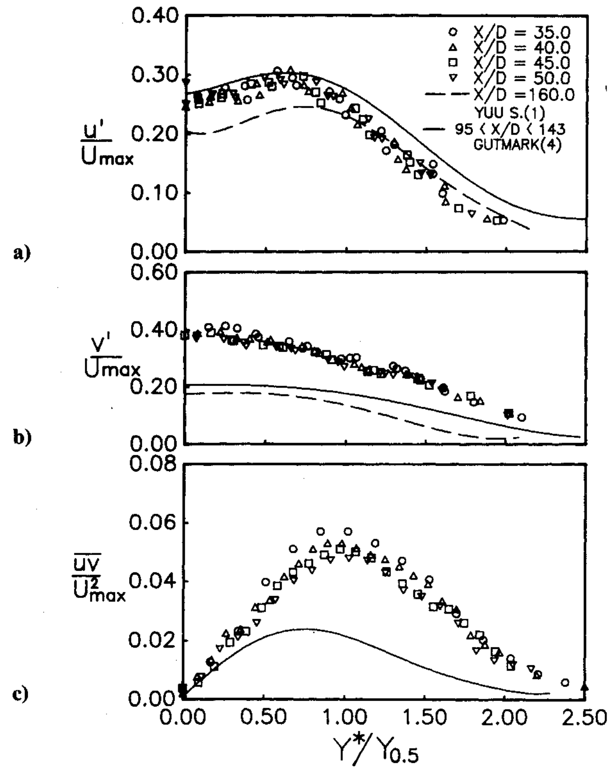

Fig. 3 Axial, lateral velocity fluctuation and Reynolds shear-stress profiles in the combined region of unventilated twin-jet flow.

shows that the distributions of turbulent intensities u'/U_{max} and v'/U_{max} and the Reynolds shear stress $\overline{uv}/U_{max}^2$ are similar to those of a single-jet flow and have almost self-preserving profiles.

The results of Gutmark's[4] investigation of a single-jet flow and Yuu's[1] investigation of an unventilated twin-jet flow are compared with the results of the present work in Fig. 3. They show that the values of u'/U_{max} have nearly the same magnitude in regions A and C and are comparable to those of a single-jet flow, whereas the v'/U_{max} and $\overline{uv}/U_{max}^2$ have significant differences in magnitude. And the lateral velocity fluctuations are greater than the axial and transverse velocity fluctuations in the present work. This can be verified by the turbulent quantities distribution along the central plane, as shown in Fig. 2. This can be explained by the fact that the terminal-measured section in the present experimental work is $X/D = 60$, which is the point where the mean velocity along the symmetric plane has just attained its maximum value and begins to decrease with increases in X/D. In this region, the lateral velocity fluctuation and the Reynolds shear stress are also decreasing with increases in X/D. It could be reasonably believed that the value of u'/U_{max}, v'/U_{max}, and $\overline{uv}/U_{max}^2$ tend to become close in values to the result of a single-jet flow as the measured section moves downstream of the combining point up to $X/D = 120$, where the combined jet is fully developed and completely resembles a single jet.

References

[1]Yuu, S., Shimoda, F., and Jotaki, T., "Hot Wire Measurement in the Interacting Two-Plane Parallel Jets," *AICHE Journal*, Vol. 25, No. 4, 1979, pp. 676–685.

[2]Elbanna, H., and Gahin, S., "Investigation of Two Plane Parallel Jet," *AIAA Journal*, Vol. 21, No. 7, 1983, pp. 986–991.

[3]Lin, Y. F., "Interaction of Two Plane Parallel Dual-Jet Flows," Ph.D. thesis, Dept. of Power Mechanical Engineering, National Tsing Hua Univ., Taiwan, ROC, 1989.

[4]Gutmark E., and Wygnaski I., "The Planar Turbulent Jets," *Journal of Fluid Mechanics*, Vol. 73, Pt. 3, pp. 465–495.