Visualization of Vortex Behavior and Its Effects on the Characteristics of a Plane Jet

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Relation between coherent vortices and entrainment was experimentally investigated in a natural or an acoustically excited plane jets through a flow visualization and hotwire measurement. For the natural jet, the entrainment increased when shift from the symmetric to the antisymmetric vortex arrangement occurred in the nonlinear interaction region. When antismmetrically excited, the entrainment was greatly enhanced and jet width was enlarged. For the symmetric excitation, vortex tubes had wavy configuration in the nonlinear interaction region. As the intensity of excitation increased, the wavy configuration maintained until more downstream but its scale became smaller. At $u_f/U_0 = \pm 8\%$, the vortex pairing occurred and sub-harmonic components appeared in the energy spectra.

Key Words: Plane jet, Coherent structure, Entrainment, Transition, Acoustic excitation

1. Introduction

The arrangement of coherent vortices appears as a mixture of symmetric and antisymmetric modes[1] in a plane jet. Repeatability of the modes can be improved by exciting velocity fluctuations with their fundamental frequencies[2]. Its difference exerts decisive influences on the aspects of streamwise evolution of the jet; laminar to turbulence transition, a growth rate of the jet width and an entrainment of surrounding fluid by the main flow. The present study aims to investigate the behavior of coherent vortices and its effects on the jet's characteristics through smokewire visualization and hotwire measurement.

2. Experimental Setup

The plane jet tunnel has an exhaust of 10mm(=2h)×400mm, see Fig. 1. Mean velocity distribution is parabolic with the maximum velocity of U_0=6m/s at the jet exhaust. The Reynolds number is, then, 3850. The fundamental fluctuation corresponding to each Strohal number was given by loud speakers installed in the settling chamber (symmetric mode) or beside the test section(antisymmetric mode). Three types of smokewire visualizations were made and their results were analyzed by comparing them with the results of hotwire measurement.

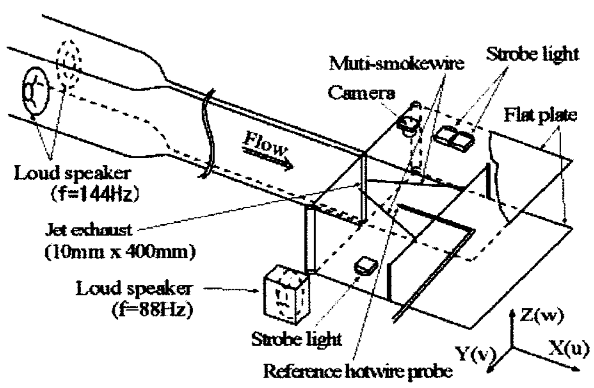

Fig. 1 Experimental setup.

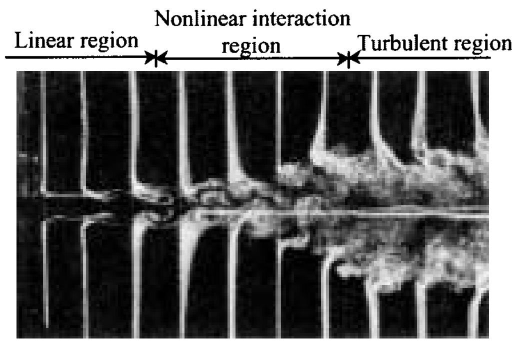

Fig. 2 Vortex arrangement for the symmetric excitation at u_f/U_0=±0.08

3. Experimental Results

For both of the excitation modes, the jet flow is classified into the linear region, the non-linear interaction region and the turbulent interaction region[1] from the upstream as shown in Fig. 2. To observe the effects of the coherent vortices on the entrainment, the behavior of the surrounding fluid drawn by the jet is visualized in Fig. 3. For either the natural or the excited jets, the coherent vortices develop linearly in the linear region, where the surrounding fluid is drawn toward the jet edge but doesn't

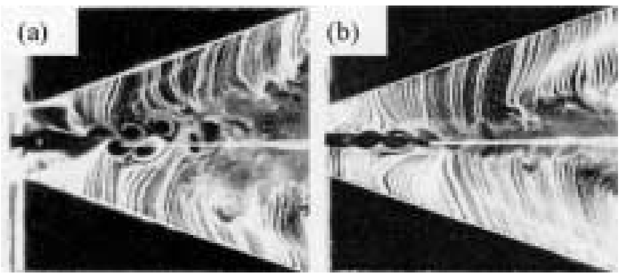

Fig. 3 Entrainment for (a)the antisymmetric excitation at $u_f/U_0=\pm 0.05$ and (b)the symmetric excitation at $u_f/U_0=\pm 0.10$.

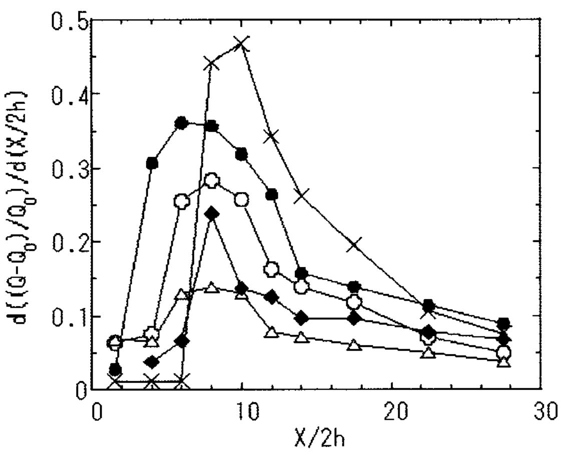

Fig. 4 Streamwise evolution of the entrainment rate.
Natural jet; ×
Antisymmetric excitation; ●:$u_f/U_0=\pm 0.05$
Symmetric excitation; ○: $u_f/U_0=\pm 0.05$, ◆:±0.08
△:±0.10

effectively entrained into the core of the jet. Large antisymmetric vortices appear in the nonlinear region and the surrounding fluid becomes effectively entrained into the core of the jet through between the vortices. Fig. 4 shows the amount of the entrained fluid at each streamwise distance by integrating the mean velocity distributions. The entrainment is more strengthened in the nonlinear region than in the linear region due to the appearance of the large antisymmetric vortices as shown in Fig. 2. For the antisymmetric excitation, the entrainment is enhanced from more upstream, the transition occurs earlier and accordingly the jet width increases more greatly. This is because the transition to the antisymmetric arrangement occurs in more upstream region. On the other hand, for the symmetric excitation, the symmetric vortex arrangement

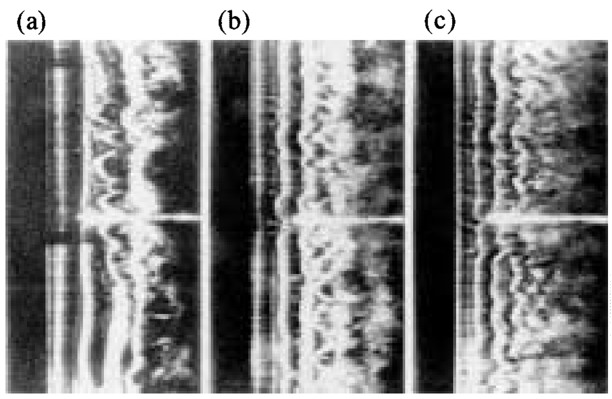

Fig. 5 Vortex tubes for the symmetric excitation at (a) $u_f/U_0=\pm 0.05$, (b) $u_f/U_0=\pm 0.08$ and (c) $u_f/U_0=\pm 0.10$.

became maintained until more downstream with increased intensity of excitation. Then, the entraiment is decreased and the jet width is reduced comparing with the natural and the antisymmetrically excited jets. Fig. 5 shows the result of a visualization of vortex tubes for the symmetric excitation at $u_f/U_0= \pm 0.10$. In nonlinear interaction region, the vortex tubes become wavier as the intensity of excitation increases. The scales of the wavy configuration along the vortex line decreased with rise in the intensity of excitation; $z/2h \fallingdotseq 2.5$, 2.1, 1.9 for $u_f/U_0=\pm 0.05$, ±0.08, ±0.1, respectively. Such wavy configuration of the vortex tubes became maintained until more downstream as the intensity of excitation increased except for $u_f/U_0=\pm 0.08$. At $u_f/U_0=\pm 0.08$, a pair of wavy vortex tubes alined in the streamwise direction merged in the nonlinear region. The paired vortices conformed larger antisymmetric coherent vortices. Then, the entrainment increased as shown in Fig. 4.

4. Concluding Remarks

Effects of vortex arrangement on entrainment were investigated in a plane jet. For the symmetric excitation at $u_f/U_0=\pm 0.08$, coherent vortices apparently merged in the nonlinear region and the mechanism of the pairing was closely related to the three-dimensional deformation of vortex tubes. The shift from the symmetric to the antisymmetric vortex arrangement after the pairing advanced the laminar to turbulence transition and greatly increased the entrainment.

References

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2) Sato,H., J.Fluid. Mech. 7(1960) 53.