MANIPULATING A VEE-SHAPED BLUFF BODY WAKE USING A FLUIDIC OSCILLATOR

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Summary The vee-shaped bluff body was re-designed by employing the unsteady Coanda effect to induce self-sustained, periodically oscillating jet. The oscillating jet was directed into the near wake of the vee-shaped bluff body to modify the wake characteristics. Oscillating behaviors, frequency characteristics, and turbulence properties of the jet and wake were studied experimentally. Results showed significant enhancement in jet oscillation frequency and wake turbulence.

INTRODUCTION

Bluff body wake is frequently used in various applications due to its fluid mechanics features [1]. The Coanda effect has been discovered for decades by the fluid engineers [2], which is the fundamental physical phenomenon that the jet oscillates through a Hopf bifurcation when the Reynolds number is larger than a critical value. The authors tried to apply the principle of unsteady Coanda effect to the vee-shaped bluff body and develop a periodic jet-injected version in this paper. The self-sustained oscillating jet was directed through passages and then injected into near wake of the vee-shaped bluff body. The oscillating jet and the modulated wake are experimentally examined.

EXPERIMENTALS

The vee-shaped bluff body is made of Plexiglas and installed horizontally in the cross-stream direction in the test section of the wind tunnel, as shown in Fig. 1(a). The side-plates of the vee-shaped bluff body are arranged at 90^o and has an slit width d=3mm at the leading edge, as shown in Fig. 1(b). A target blockage with a horseshoe surface facing the upstream slit is placed in the room between the vee-shaped bluff body side plates. The slit-jet impinges the horseshoe surface of the target block. The horseshoe surface has a radius R originated from the point located on the symmetry axis at a distance h from the virtual vertex of the target block. The geometrical parameters of h, R, and b_{gap} along with the flow parameter Re_d determine the effective regime of design and operation. The flow oscillation process is made observable by using the smoke-wire technique. Streak photography is done via a high speed CCD camera of maximum framing speed at 8000 fps. Frequencies of the unsteady motions in the wake region are detected by a constant temperature hot-wire anemometer. The velocity and turbulence properties are measured by a two-component laser Doppler velocimeter. Evolution process of the jet/wake interaction is detected by PIV.

RESULTS AND DISCUSSION

Flow behaviors

Depending on the values of (h/d, R/d, Re_d), the flows in the cavity enclosed by the vee-shaped bluff body and the target block present different behaviors. For example, Fig. 2 shows the smoke-streak flow patterns at various h/d's as (R/d, Re_d)=(2.33, 339). In Figs. 2(a) and (b) which h/d=0 and 1.00, respectively, the slit-jet goes through the leading-edge slit, impinges the horseshoe surface of the target block, bifurcates into two streams, and forms two counter-rotating vortices. The impinging slit-jet does not oscillate. This flow pattern of bifurcation is usually observed at low values of h/d.

In the instantaneous pictures of Figs. 2(c) and (d) which h/d=1.67 and 2.00, respectively, the slit-jet is neither located at the neutral position, nor stayed at a fixed position. It actually swings back and forth continuously, periodically and proceeds with a self-sustained oscillation. In Figs. 2(e) and (f) for which h/d=2.33 and 2.67, respectively, the slit-jet in the horseshoe cavity is deflected from the central symmetry axis and attached to the inner wall of one of the vee-shaped bluff body walls. Most of the space in the cavity is occupied by a large vortex. No transverse oscillation of the jet is found. If the wind tunnel is restarted or if the jet is subject to a large perturbation, the deflected jet may attach toward the other side wall. This type of flow pattern is usually found at large values of h/d.

Turbulence intensities

The turbulence intensities at various Reynolds numbers increase from the inner region of the near wake, attain peak values, then decrease quickly in the outer region of the wake. Effect of "extra" vortex-stretching induced by the injection jets is apparent. The turbulence intensities in the wake of the fluidic-jet-injected vee-shaped bluff body are significantly high, about 80%, when compared with that of the close-tip vee-gutter, about 50%. Besides, the fluidic jet injection causes the high turbulence region of the jet-injected vee-shaped bluff body to be wider than that of the close-tip vee-gutter. At the downstream stages, the features of high turbulence intensities in the wake remain and the perturbed regions are widened.

Power spectrum, time scale, probability density function and integral length scale

The power spectrum density function in the wake shows two peaks: the shedding frequency of vortices and the oscillating jet. The frequency of fluidic oscillation in general is about 25 to 40 times higher than its counter part of vortex shedding, depending on the Reynolds number. The oscillation frequency of the presently developed oscillator is about 160 times larger than the previous results for enhancement of heat transfer and about 10 times larger than that of the fluidic flowmeter. The probability density function of the fluctuations displays a dual-peak pattern, which delineates the characteristics of the sinusoidal signals. The Taylor's integral length scale of the fluidic oscillation is about 5% of the large scale vortex shedding. With periodic injection of the jets, the integral turbulence length scales are drastically decreased by one order of magnitude. In view of Kolmogorov's energy cascade process, injecting the fluidic oscillating jets into the low frequency wake may increase the vortex-stretching evolution of the energy flow and play a role in enhancing the transport capability of the turbulence kinetic energy. The increased effect of vortex-stretching in the shear layer finally causes the integral turbulence length scale to reduce.

Evolution process of jet/wake interaction

Topological analysis applied to the PIV measured streak flow patterns in a water tank analogy apparatus shows evolution process of the jet oscillation and interaction between the jet and the wake vortices.

CONCLUSIONS

By inserting the horseshoe target block into the cavity of the vee-shaped guard plates, the slit jet can proceed self-sustained transverse oscillation under some designs of geometric parameters and Reynolds number. The present design pushes the oscillation frequency of the jet to significantly high values. The turbulence are significantly increased so that enhancement of mixing in the wake is expected.

REFERENCES

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[2] Uzol, O. and Camci, C.: Experimental and Computational Visualization and Frequency Measurements of the Jet Oscillation inside a Fluidic Oscillator. J. Visualization, **4**:88-96, 2002.

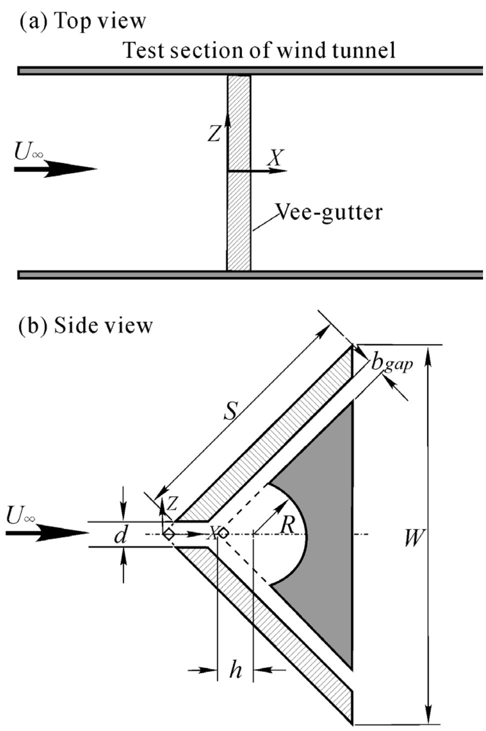

Fig. 1 Experimental setup. (a) vee-gutter in test section; (b) jet-injected vee-gutter.

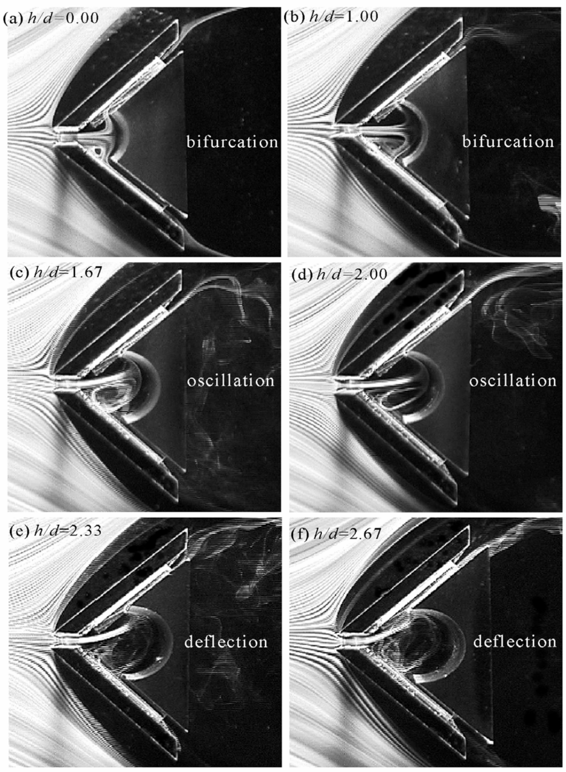

Fig. 2 Behaviors of slit-jet in oscillation cavity. Re_d=339, R/d=2.33, d=3mm, b_{gap}=2mm