EXPERIMENTAL STUDY OF SYNTHETIC JET VORTEX RINGS IMPINGING ON A WALL

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Summary The process of vortex rings impinging on a fixed wall is experimentally investigated by using flow visualization and particle image velocimetry (PIV) methods. The vortex rings are generated by a synthetic jet actuator from a circular orifice. It is found that the vortex ring of the first period increases its diameter as it approaches the wall, while the vortex circulation decreases. In the following periods, as the vortex ring enlarges its diameter in the radial direction, it converges with the vortex rings formed during former periods, resulting in a larger-scale vortex concentration region. Thus, distinct differences in vortex trajectory and circulation are observed between the first period and the rest. However, such differences among different impingement periods decrease as more and more vortex rings impact the wall.

INTRODUCTION

Generally, the fan is used for equipment cooling by jet-like flows impinging on solid surfaces. However, it has been well known that the vortex ring is more efficient than a continuous jet since the vortex has a larger ability of fluid entrainment [1] and thus to enhance heat transfer [2]. Therefore, a number of investigations have been conducted to study the physics problem of vortex-wall interactions [2-5].

In these investigations, only a single vortex ring was concerned. However, the impingement of multi-period vortex rings with a solid surface is more significant in practical applications. This can be obtained by a synthetic jet actuator, which is a recently developed flow control technique [6]. This is also what this paper will present in the following.

EXPERIMENTAL SETUP

The experiment was conducted in a well-designed water tank with size 600×600×600 mm (see Fig. 1). The water was 500 mm in deep, and an “L” shape hollow circular cylinder was half-mounted in the water. The end of the vertical part was connected to a synthetic jet actuator by a pipe, while more details about this system can refer to Feng and Wang [7]. There was a circular hole with diameter D=10 mm arranged into the end of the horizontal circular cylinder as the exit of the vortex ring. Its distance to the side wall was fixed at 5D. In this study, the excitation amplitude and excitation frequency were adjusted to 5.5 mm and 0.2 Hz, respectively. The coordinate system is shown in Fig. 1, where the origin is defined as the intersection of the horizontal-cylinder axis with the impinging wall.

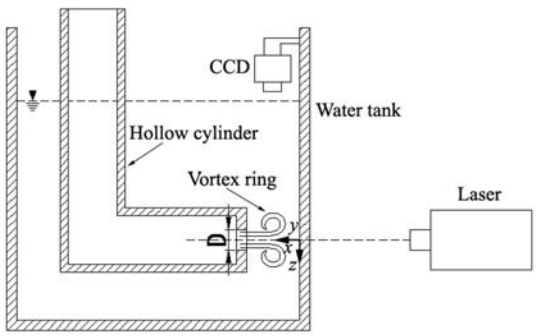

Fig. 1 Schematic of the experimental model.

A micro-PIV system was used to measure the flow field. The field of view was illuminated by a light sheet from an Nd: YAG laser, where the laser sheet was in the x-y plane. The particle images were captured by a CCD camera at sampling frequency 40 Hz. Then velocity fields were calculated based on the cross-correlation algorithm between two successive images. The sizes of the interrogation window and search window were set to 16×16 pixels and 8×8 pixels, respectively.

RESULTS AND DISCUSSION

Figure 2 presents four-period evolution of vortex ring impinging on the wall. A fully developed vortex ring is formed by the synthetic jet actuator at time t_0, which contacts with the wall surface at time t_0+0.3T. The vortex ring increases its diameter as it approaches the wall, while the vortex structure in cross section decreases, which is consistent with previous studies [2, 4]. During the second period, as the vortex ring enlarges its diameter in the radial direction, it converges with the vortex ring formed during the first period, forming a larger-scale vortex concentration region. The vortex ring from the second period is located inside of that from the first period, as shown at time t_0+2.15T. In the following periods, the vortex ring experiences the same process, resulting in a larger vortex structure, as shown at time t_0+4T.

The vortex trajectory during the impingement process is shown in Fig. 3. In order to present the differences in vortex trajectory between one single and multi-period vortex rings, three typical periods are selected. There nearly has no

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difference between vortex rings from different periods before they contact with the wall. However, after that, it is shown that subsequent vortex rings can reach up to a much larger radial position than the first period, approximately 0.4*D* beyond, and are much closer to the wall surface. However, period 2 and period 40 show a small difference.

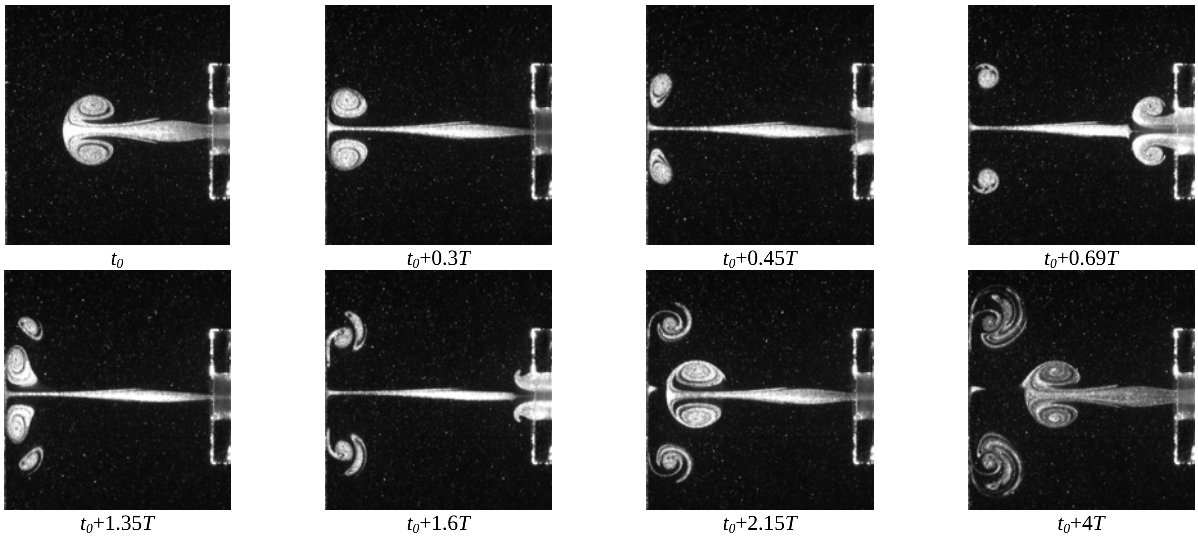

Fig. 2 Four-period evolution of vortex-wall interactions, where T is the excitation period and T=5 s.

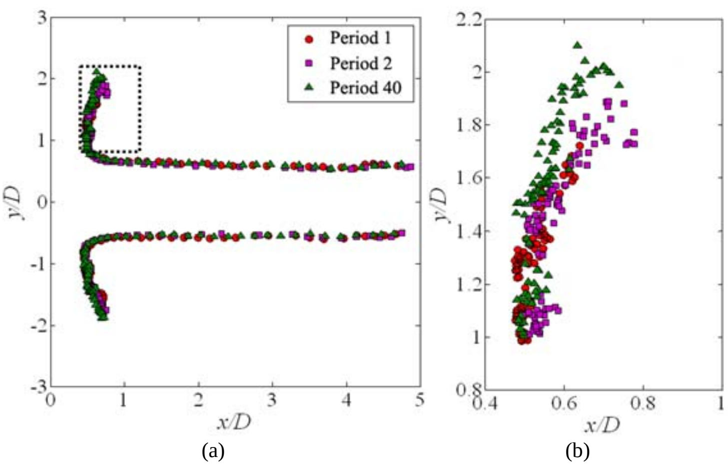

Fig. 3 Vortex trajectory, where (b) is the partial enlargement of (a).

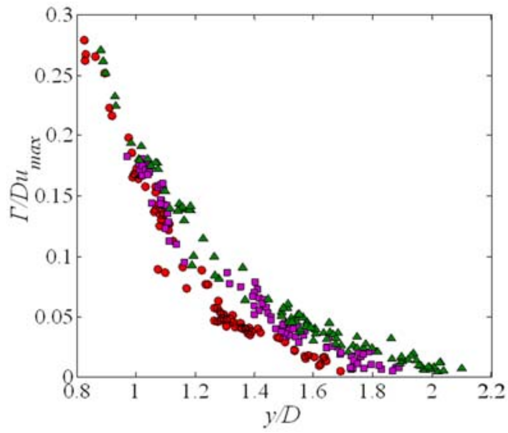

Fig. 4 Vortex circulation, where u_{max} is the maximum blowing velocity of the synthetic jet at exit.

Figure 4 shows the evolution of the vortex circulation, which decreases as the vortex ring approaches the wall. Besides, distinct differences are observed between the first period and the residual. As the period increases, the vortex circulation is enhanced due to the continuous vortex concentration among different periods, as has been pointed out in Fig. 2.

CONCLUSIONS

The problem of vortex rings impinging on a fixed wall is experimentally investigated. It is found that the vortex ring from the first period increases its diameter as it approaches the wall, while the vortex circulation decreases. In the following period, as the vortex ring enlarges its diameter in the radial direction, it converges with the vortex rings formed during former periods, forming a larger-scale vortex concentration region. Thus, distinct differences in vortex trajectory and vortex circulation are observed between the first period and the residual. However, such differences among different periods decrease with impingement period.

References

[1] Toyoda K., Hiramoto R.: *Fluid Dyn. Res.* 41:051402, 2009.
[2] Arévalo G., Hernández R.H., Nicot C., Plaza F.: *Phys. Fluids* 22:053604, 2010.
[3] Krishnan G., Mohseni K.: *Eur. J. Mech. B/Fluids* 29:269-277, 2010.
[4] Cheng M., Lou J., Luo L.S.: *J. Fluid Mech.* 660:430-455, 2010.
[5] Couch L.D., Krueger P.S.: *Exp. Fluids* 51:1123-1138, 2011.
[6] Glezer A., Amitay M.: *Annu. Rev. Fluid Mech.* 34:503-529, 2002.
[7] Feng L.H., Wang J.J.: *J. Fluid Mech.* 662, 232-259, 2010.