End-effects of a finite synthetic jet on flow control

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Abstract: Synthetic jet is one of the most efficient flow control techniques, which has been applied in various fields. The dimension problem is considered as one of the most important issues that potentially affects the global control results. For example, a two-dimensional synthetic jet interacts with a two-dimensional flow filed, which is usually the ideal situation. Since most of the flow fields in nature are highly three-dimensional, and sometimes the synthetic jet can not be considered as a two-dimensional one in comparison with the controlled flow. Consequently, the interactions between a finite synthetic jet and the flow around a two-dimensional circular cylinder are investigated experimentally in this study, where the particular attention is paid on the end-effects of the finite synthetic jet on the control effect.

The experiment was conducted in a recirculation water tunnel. The circular cylinder was horizontally mounted across the test section, and end plates were used in order to reduce the effects of the boundary layer developing on the test-section walls. The outer diameter of the circular cylinder was D = 30 mm, the inner diameter was d = 22 mm, and the spanwise length was L = 500 mm, giving an aspect ratio of 16.7. The synthetic jet was issuing from a slot with width h = 1 mm and length l = 50 mm, which was arranged on the external surface of the circular cylinder. The slot was located in the mid-span region of the experimental circular cylinder and paralleled to its axis. During the experiment, the slot was arranged at the front stagnation point of the circular cylinder. Since the ratio of the synthetic jet length to the cylinder's outer-diameter was only about 1.7, the present synthetic jet could be considered as a finite one. The origin of the coordinate was located at the cylinder center in the mid-span of the slot, while the x, y and z axes pointed to the streamwise, vertical and spanwise directions, respectively.

During the experiment, the free-stream velocity was fixed at U_∞ = 34.5 mm/s, corresponding to the Reynolds number Re = 800 of the circular cylinder and the natural frequency f_0 = 0.24 Hz (St = 0.21). The flow around the circular cylinder was belonged to the shear layer transition regime, where three-dimensional vortex structures developed in the wake. The synthetic jet was actuated at about twice of the natural frequency, namely f_e/f_0 = 2.08, with the equivalent momentum coefficient C_μ = 0.139. In order to study the end-effects of the synthetic jet on the control effect, six x-y planes of view from the mid-span to one of the slot end with identical interval 5 mm were measured using the two-dimensional time-resolved PIV system.

The objective is to find out how much the flow field near the mid-span is influenced by the three-dimensional end-effects of the finite synthetic jet. To address this issue, three aspects have been considered. Firstly, the characteristics of the statistical parameters at different x-y planes have been compared. Secondly, perturbation-diffusing path at different x-y planes, how the cylinder wake is synchronized by the synthetic jet, is investigated. Thirdly, the vortex dynamics under synthetic jet control at different x-y planes is analyzed. An example is shown in Figs. 1 and 2, exhibiting the time-averaged streamwise velocity for different x-y planes. It is shown that in the near wake region, the velocities at planes of z = 0, 5 mm, and 10 mm are nearly consistent with each other for the control cases, however, the

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velocities at planes of z = 15, 20 mm, and 25 mm exhibt some differences. Further analysis of the perturbation-diffusing path and vortex dynamics can also conclude similar suggestions.

To sum up, it is found that the end-effects of the finite synthetic jet have an apparent influence on the flow fields within half-cylinder-diameter distance from each end. However, it does not have a crucial influence on flow fields in the mid-span regions, namely -10 mm ≤ z ≤ 10 mm. In other words, the flow field in mid-span is independent of the slot length if it is longer than one cylinder diameter in this study.

Key words: flow control; finite synthetic jet; circular cylinder; end-effects

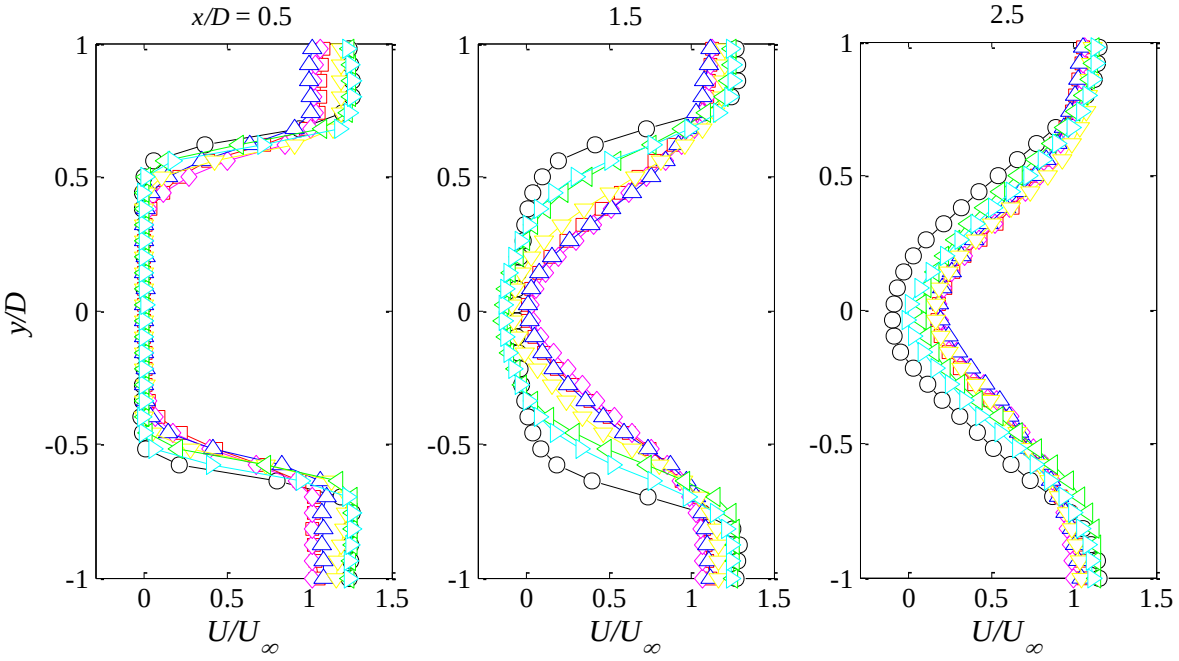

Fig. 1 Vertical-sectional distributions of time-averaged streamwise velocity U/U_∞ at x/D = 0.5, 1.5 and 2.5 for different spanwise planes for Re = 800, f_e/f_0 = 2.08, C_μ = 0.139. ○ Natural case; □ control case, z = 0; ◇ control case, 5 mm; △ control case, 10 mm; ▽ control case, 15 mm; ◁ control case, 20 mm; ▷ control case, 25 mm

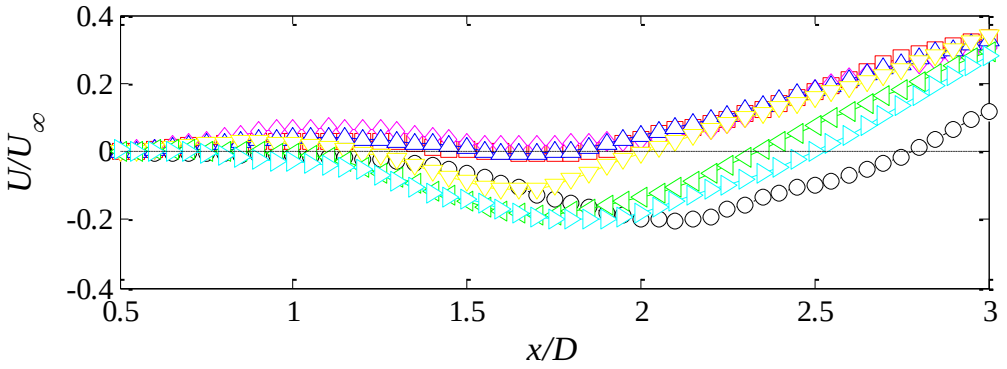

Fig. 2 Streamwise-sectional distributions of time-averaged streamwise velocity U/U_∞ at y/D = 0 for different spanwise planes for Re = 800, f_e/f_0 = 2.08, C_μ = 0.139. ○ Natural case; □ control case, z = 0; ◇ control case, 5 mm; △ control case, 10 mm; ▽ control case, 15 mm; ◁ control case, 20 mm; ▷ control case, 25 mm

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