Numerical and experimental investigation of a streamwise oscillating cylinder wake in the presence of a downstream cylinder

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Extended Abstract

Structural failure may result from synchronization between the fluid excitation force and the system natural frequency in the streamwise as well as in the lateral direction. The problem of streamwise oscillation could be particularly severe when a lightly damped cylindrical structure is used in water. Previous studies have uncovered many important aspects of physics associated with the wake of an isolated streamwise oscillating cylinder. Five modes (Ongoren & Rockwell 1988; Xu et al. 2002) of the flow structure have been identified, depending on the combination of A/d and f_e/f_s, where f_e is the excitation frequency and f_s is the natural vortex shedding frequency of a stationary cylinder, A and d are the oscillation amplitude and the diameter of cylinder, respectively. However, flow-induced vibration often involves multiple structures in engineering. It is of both fundamental and practical significance to understand how a neighbouring cylinder would affect interactions between flow and an oscillating cylinder. This work investigates numerically and experimentally the flow around a streamwise oscillating cylinder in the presence of a downstream stationary cylinder.

Experimental investigation was conducted in a water tunnel (Zhou et al. 2001) and a wind tunnel (Zhou et al. 2002) using laser-induced fluorescence (LIF) flow visualization, particle image velocimetry (PIV) and hotwire techniques. The wake was generated by two tandem circular tubes of identical diameter, the upstream cylinder being forced to oscillate harmonically in the streamwise direction at A/d = 0.2 ~ 0.67 and f_e/f_s = 0 ~ 1.8. The Reynolds number, *Re,* and the cylinder center-to-centre spacing, L/d, were 150 ~ 1000 and 2.5 ~ 4.5, respectively. The numerical technique employed is the lattice Boltzmann method (LBM), as introduced by Chen and Doolen (1998). LBM is characterized by a clear picture of the physics of fluids, the natural parallelism, and ease to handle interactions between fluids and structures. The reliability and efficiency of LBM have been well demonstrated by a number of studies in various fields. Numerical simulations are carried out in a two-dimensional space for the same flow configuration as the experimental investigation. A/d, *Re* and f_e/f_s investigated were 0.2 ~ 0.5, 150 ~ 300 and 0.2 ~ 1.8, respectively. The computational domain was a $40d\times20d$ rectangular area.

Both numerical simulation and experimental data indicate that the flow structure is largely dependent upon the combination of A/d and f_e/f_s, not so much on L/d and Re. Three distinctive flow structures have been identified. The vorticity contours (Fig 1) from the numerical simulation exhibit a flow structure in excellent agreement with that measured using flow visualization and PIV (not shown), indicating that the LBM technique can be used to calculate reliably the flow field around two inline cylinders, one of which vibrates. For $1.6\leq f_e/f_s \leq 2$, vortices shed from the upstream cylinder are symmetrically arranged; each structure embraces a pair of counter-rotating vortices (binary vortices). The flow behind the downstream cylinder is characterized by a symmetric binary vortex street. In comparison, For $0.8 \leq f_e/f_s < 1.6$, alternative vortex shedding occurs from both cylinders. The flow structure behind the downstream cylinder is characterized by two rows of vortices: one consists of single vortices, and the other consisting of counter-rotating vortex pairs. As f_e/f_s reduces to 0 ~ 0.8, alternative vortex shedding occurs for both cylinders. The flow structures are distinctive from those behind an isolated streamwise oscillating cylinder (Xu et al. 2002; Xu 2002) at approximately the same combination of A/d and f_e/f_s. The drastic variation in the flow structure has a profound effect on the mean and fluctuating drag and lift coefficients (not shown) on both cylinders. Expectedly, the coefficients are significantly different when compared with those on an isolated streamwise oscillating cylinder. A more detailed analysis of both experimental and numerical data is under way and may further improve our understanding of flow-structure interactions of a streamwise oscillating cylinder in a cross flow in the presence of a neighbouring cylinder.

References

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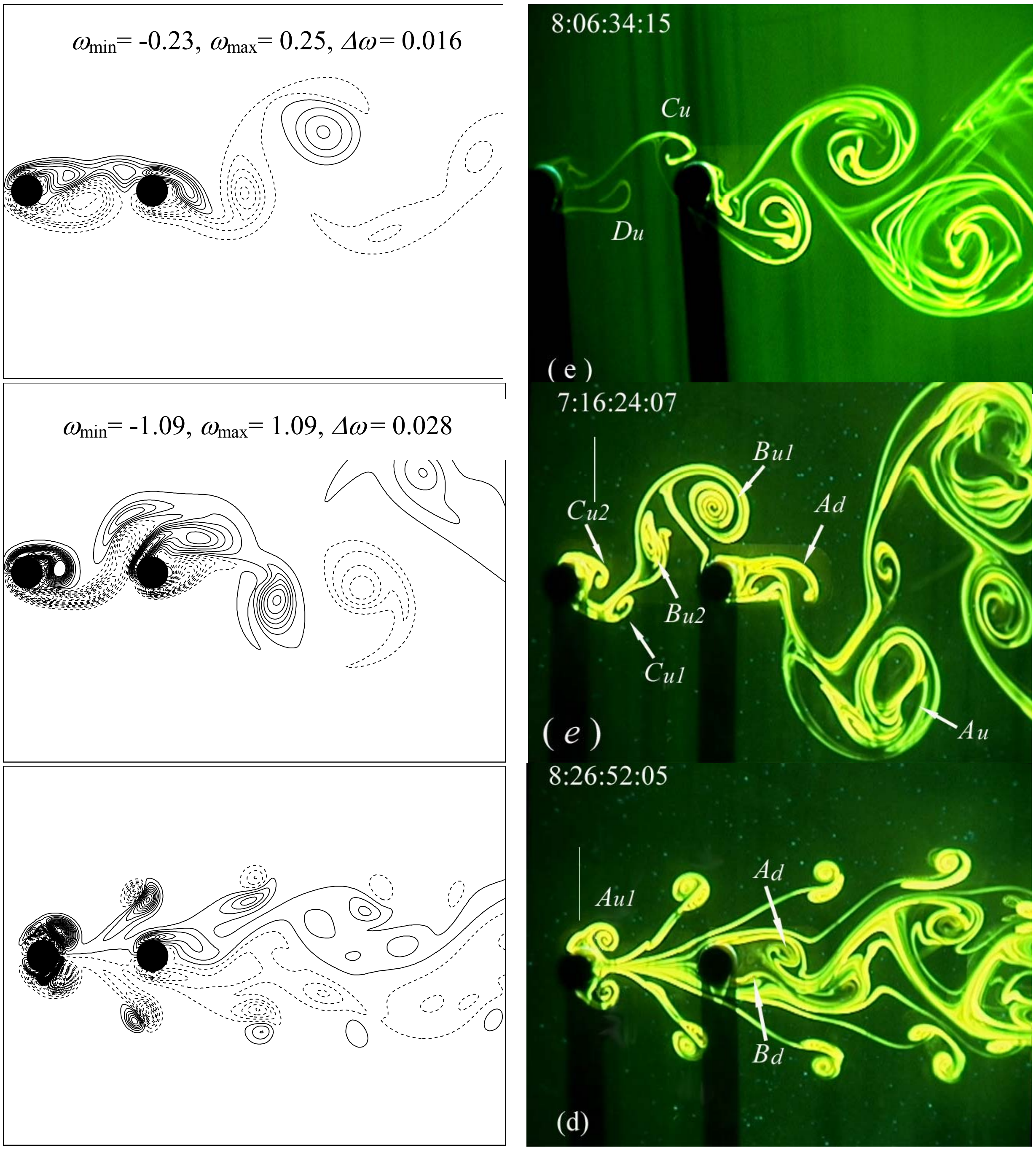

Figure 1 Left-hand side: vorticity contours from numerical simulation (Re=150); right-hand side: streaklines from flow visualization in a water tunnel using the LIF technique. A/D = 0.5, L/D = 3.5; f_e/f_s = 1.8 (Re = 300), 1.08 (300), and 0.5 (150) from top to bottom.