EFFECT OF AN OSCILLATING CYLINDER ON A NEIGHBOURING CYLINDER WAKE

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Summary Vortex shedding from a neighbouring stationary cylinder in the presence of a neighbouring oscillating cylinder is numerically investigated using a newly developed Lattice Boltzmann technique. Other than reconfirming previous experimental finding that the oscillation of one cylinder can lock in vortex shedding from the stationary cylinder as well as from the oscillating one, the calculation documents the dependence on *T/d, A/d* and f_e/f_o of the lock-in phenomenon, typical flow structure and forces on the cylinders.

EXTENDED SUMMARY

Flow-induced vibration on a bluff body in crossflow has been extensively reported in the literature because of its practical significance. Nevertheless, our understanding of this problem is far from complete. For instance, how would an oscillating fluid-cylinder system influence a neighbouring cylinder wake? This question is relevant in engineering, where an oscillating fluid-structure system is frequently associated with the presence of a neighbouring structure such as heat exchanger tubes, a cluster of high-rise buildings, bundled transmission lines and piles of offshore structures. Lai et al. [1] investigated experimentally flow interference between one oscillating and one stationary cylinder and found that the frequency (f_s) of vortex shedding from the stationary cylinder could be modified by the oscillation of the other cylinder, resulting in the lock-in of f_s with the oscillation frequency (f_e). However, due to the limitation of experiments, many issues on this problem remain to be resolved. For example, the drag and lift forces on cylinders were not measured. There is insufficient information on how this type of lock-in depends on the cylinder centre-to-centre spacing, *T/d*, the cylinder oscillating amplitude, *A/d*, and the frequency ratio, f_e/f_o, where *d* is the cylinder diameter and f_o is the vortex shedding frequency when the oscillation is absent. The present work aims to investigate numerically how an oscillating fluid-structure system affects vortex shedding from a neighbouring stationary cylinder, thus complementing the experimental investigation.

The numerical technique employed is a recently developed lattice Boltzmann method (LBM), as introduced by Chen and Doolen [2]. 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 were carried out for a two-dimensional flow around two side-by-side circular cylinders, one oscillating laterally at $A/d = 0 \sim 1$ and $f_e/f_o = 0.4 \sim 1.6$. Three *T/d* values, i.e. 1.8, 2.2 and 3.5, were examined, which cover the asymmetrical and coupled street flow regimes when both cylinders are stationary (e.g. Zhou et al. [3]). The Reynolds number (*Re*) is 150. The computational domain is given by a rectangular area of 40d x 20d with a uniform grid of 640 x 320. Numerical results at T/d = 2.2 and 3.5 (not presented) show essentially the same flow structures as those observed experimentally at the same f_e/f_s and *A/d* by Lai et al [1]., thus providing a validation for the numerical technique presently used.

The numerical data reconfirm the experimental finding that the oscillation of one cylinder can lock in vortex shedding from the stationary cylinder as well as from the oscillating one. The hatched area in Figure 1 represents the region where vortex shedding from the lower stationary cylinder is locked in with the oscillation of the upper cylinder. The lock-in region for a single cylinder case is included in Fig. 1 for the purpose of comparison. The inserts in the figure show the iso-contours of spanwise vorticity, which display typical flow structures in the lock-in and non-lock-in regions. A number of interesting observations can be made based on the figure. Firstly, as *A/d* increases, the f_e/f_o range over which the locked-in response is observed grows, similarly to the single cylinder case. Secondly, for a larger *T/d*, the lock-in f_e/f_o range shrinks at a fixed *A/d*. This is expected since the oscillating influence impairs as the two cylinders are farther separated. Thirdly, at $T/d = 1.8$, the present lock-in region completely embraces that of a single cylinder, implying that the interference between the cylinders enhances the occurrence of lock-in. However, at $T/d = 2.2$, the oscillating influence on the stationary cylinder weakens and subsequently the lock-in f_e/f_o range at $A/d < 0.5$ retreats significantly for $f_e/f_o < 1$, even smaller than a single cylinder case. This retreat is substantially more evident at $T/d = 3.5$. For $f_e/f_o > 1$, the lock-in f_e/f_o range is always larger than a single cylinder case. Apparently, the oscillating effect is more persistent at a higher frequency ratio. Finally, it is worth commenting on the typical flow structures. In the absence of lock-in, the near-wake structure for $f_e/f_o < 1$ appears in-phased at $T/d = 1.8$ and 2.2 but anti-phased at $T/d = 3.5$. The flow structure is apparently different between $f_e/f_o < 1$ and $f_e/f_o > 1$ even at the same *A/d*. When the lock-in response is observed, vortex shedding from the two cylinders can be either in-phased or anti-phased and the flow structure further depends on *T/d*.

The time-averaged and root mean squared (rms) values of the drag and lift forces on the stationary cylinder are also tabled (not shown). Preliminary analysis indicates that the lock-in response does not affect to a great extent the time-averaged lift, drag and the rms drag but leads to an increase by 8 ~ 15% in the rms lift on the stationary cylinder. The result conforms to the increased vortex strength as lock-in occurs (not shown). The investigation indicates that LBM can be used reliably to calculate the flow field around two side-by-side cylinders, one vibrating. Further analysis will be focused on the classification of typical flow structures based on *A/d* and f_e/f_o at different *T/d*. The effect of the presence of the stationary cylinder on vortex shedding from the oscillating cylinder will also be examined.

References

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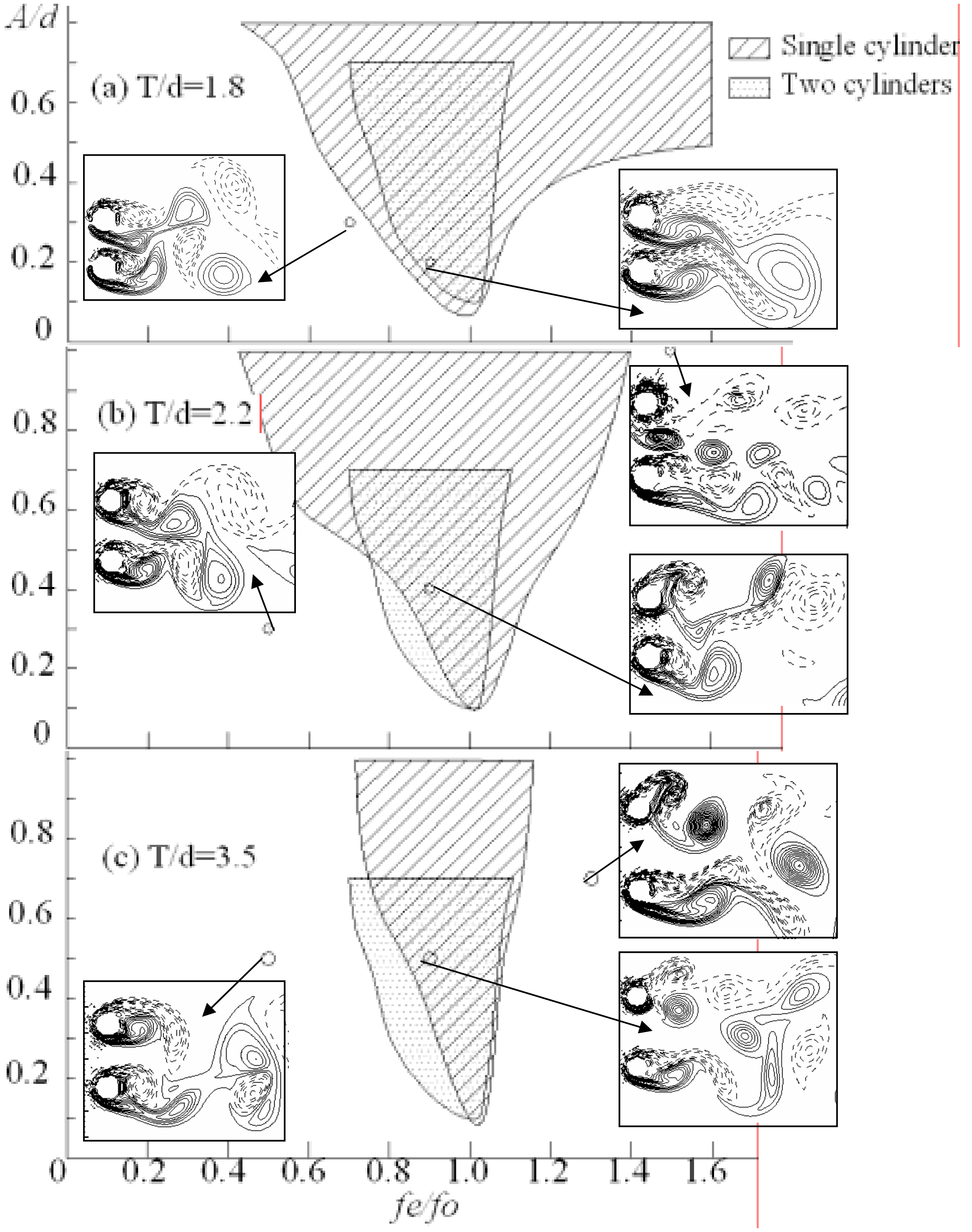

Figure 1 Region where vortex shedding from the lower stationary cylinder is locked in with the upper oscillating cylinder.