FLOW-INDUCED VIBRATIONS OF TWO TANDEM CYLINDERS IN A CHANNEL

by

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Short paper
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We numerically studied flow-induced vibrations of two tandem cylinders in transverse direction between two parallel walls. The effect of the horizontal separation between two cylinders, ranging from 1.1 to 10, on the motions of the cylinders and the flow structures were investigated and a variety of periodic and non-periodic vibration regimes were observed. The results show that when two cylinders are placed in close proximity to each other, compared with the case of an isolated cylinder, the gap flow plays an important role. As the separation ratio is increased, the fluid-structure interaction decouples and the cylinders behave as two isolated cylinders.

Key words: *vortex-induced vibration, two tandem cylinders, channel*

Introduction

Fluid-structure interaction is one of the most important problems in fluid mechanics, such as flow past cylinders [1, 2] and vortex-induced vibrations (VIV) [3-8]. For flow past an elastically mounted rigid cylinder, a significant phenomenon found in VIV is synchronization [4], when the vortex formation frequency is close to the natural frequency of the structure, the response amplitude of the cylinder has a significant jump. For the case of two elastically mounted cylinders in tandem arrangement, previous work indicated that the separation of two cylinders plays a significant role. Zdravkovich [5] found that all types of the fluid-elastic oscillations were related to the regions of interference and the response of cylinders were classified into three types. Papaioannou *et al.* [6] found that as the cylinders were brought closer to each other, the response curve became wider and the hysteresis effect that existing for the single oscillating cylinder was not observed. Prasanth *et al.* [7] found the response of the upstream cylinder to be qualitatively similar to that of an isolated cylinder, while the downstream cylinder undergoes very large oscillation amplitude. Borazjani *et al.* [8] observed larger amplitudes of motion and a wider lock-in region for the two cylinders case. Bearman *et al.* [9] studied flow past a stationary cylinder near a plane wall and found that when the gap was less than 0.3 *D*, strong regular vortex shedding was suppressed. For the case of a static cylinder between two parallel walls, a distinct characteristic in the vortex shedding regime is that the trajectories of the shed vortices cross each other and the final position is opposite with

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respect to the case of unconfined cylinder. In this paper, we numerically studied flow-induced vibrations of two tandem cylinders in a channel by lattice Boltzmann method. We focus on the effects of separation on the motion types of the cyliders and the flow structures.

Problem statement and numerical method

Figure 1 shows the flow configuration. Viscous incompressible flows past two tandem cylinders between two parallel walls were simulated. Each cylinder is thread by a shin smooth pole to keep it fixed in horizontal direction while can move freely in transverse direction through Newton's second law. The fluid motion is governed by the incompressible Navier-Stokes equation. The inlet flow velocity are given by a prescribed parabolic profile: $U(Y) = U[1 - (2Y/H)^2]$ where U is the centerline inflow velocity and H is the distance between two parallel walls. Such a system is governed by four non-dimensional parameters: the Reynolds number Re $= UD/\upsilon$, the blockage ratio $\beta = D/H$, the mass ratio $m^* = 4m/\pi\rho D^2$ (where m is the actual mass of the cylinder, and ρ is the density of fluid, and the horizontal separation between the two cylinders S/D.

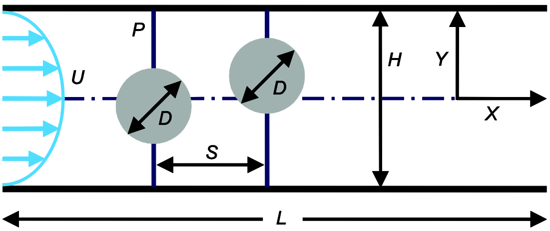

Figure 1. Schematic diagram of the flow configuration

Lattice Boltzmann method has been a promising numerical tool to effectively model complex physics [10-15]. The two-dimensional-nine-speed model [11] combining an extrapolation method [16] for moving curved boundary was adopted in the present study.

Results and discussions

We studied flow-induced vibrations with Re = 100, $\beta = ½$, and $S/D = [1.1, 10]$ for $m^* = 1$ and 0.1, respectively. Response vibrations were observed extensively in the present study. For $m^* = 1$, as $S/D \leq 3$, both cylinders oscillate periodically in a coupled frequency around the centreline of the channel at considerable amplitudes, while for $S/D \geq 4$, only a small-amplitude non-periodic vibration regime was observed. For $m^* = 0.1$, both cylinders always behave as periodic vibrations around the centreline of the channel. Figure 2 shows the non-dimentional peak-to-peak vibration amplitude A/D and vibration Strouhal number Stv = fD/U (where f is the coupled vibration frequency of the oscillators) *vs.* the separation. In fig. 2(a) the vibration amplitude of the rear cylinder is always larger than that of the front one. For $m^* = 1$, as $S/D \leq 2$, both cylinders vibrate at considerable amplitudes, while for $2 \leq S/D \leq 4$, the vibration amplitudes of both cylinders decrease rapidly, and for $S/D \geq 4$, both cylinders behave as small-amplitude non-periodic vibrations. For $m^* = 0.1$ and $1.1 \leq S/D \leq 10$, the cylinders always behave as a periodic vibration regime at considerable amplitudes, but as $S/D \approx 3$, there are sudden decreases of the amplitudes of both cylinders. As a comparison, the results of the isolated cylinder cases were also given. For $m^* = 1$, the cylinder oscillates around the centreline at a negligible amplitude and the wake flow is almost steady with two reserved stationary vortices. For $m^* - 0.1$, the cylinder vibrates periodically with $A/D \approx 0.8\ D$, and two reversed vortices are shed in a oscillation cycle. It is found that at large S/D, the behaviours of both cylinders just like two isolated cylinders for both the mass ratios. When the two cylinders are placed in close proximity, each cylinder has a significant effect on the other, especially for $m^* = 1$. Figure 2(b) shows that at $m^* = 1$, as S/D increases from 1.1 to 3, Stv increases, and for $S/D \geq 4$, both cylinders behave as non-periodic vibrations with negligible amplitudes. For $m^* = 0.1$, as S/D increases, Stv first increases and then decreases to form a valley at $S/D \approx 3$, and when $S/D \geq 4$, the coupled vibration frequency of tandem-cylinder system is close to the single cylinder case.

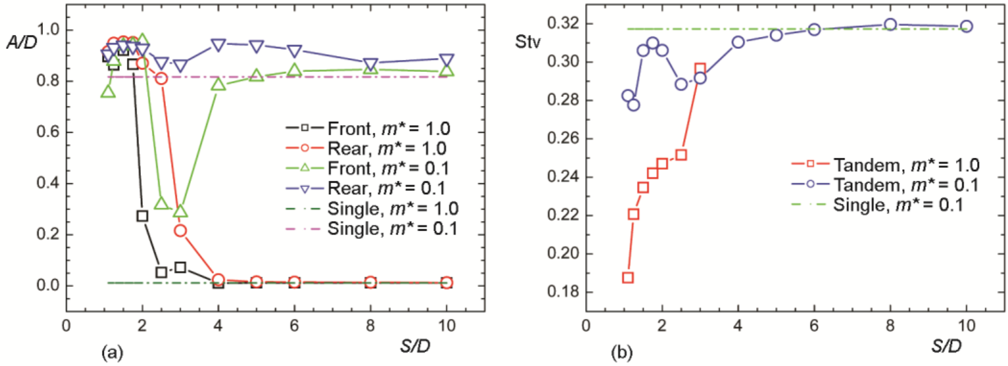

Figure 2. Vibration amplitude (a) and Strouhal number (b) as functions of separation

Figure 3(a) shows that at $m^* = 1$ and $S/D = 1.25$, both the cylinders vibrate at $A/D \approx 1$ after sufficient numerical time, and in the wake, two reversed vortices are shed in a vibration cycle.

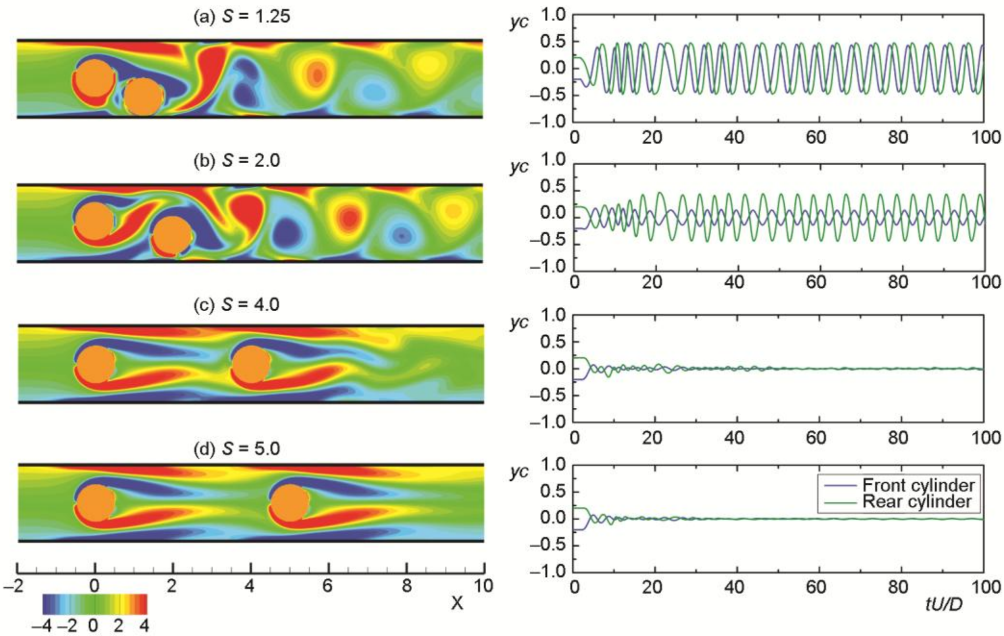

Figure 3. Instantaneous vorticity contours (left) and time evolution of transverse displacements (right) with Re = 100 and m^* = 1

As S/D = 2, as shown in fig. 3(b), the two cylinders still vibrate periodically, but the amplitude of the front cylinder is rather smaller than that of S/D = 1.25, and in the wake still a well-arranged vortex street is observed, but in the gap flow, we find that vortex core forms initially in the wake of the front cylinder. The formation of the vortex core is the reason that decouples the interaction between the two cylinders. As S/D = 4.0 and 5.0, as shown in figs. 3(c) and 3(d), both cylinders oscillate non-periodically at negligible amplitudes. At S/D = 4.0, only a wavy trail with no vortex shedding was observed, while for S/D = 5.0 the flow is almost steady and in the wake of each cylinder, only two reversed stationary vortices are formed, just like the case of an isolated cylinder.

Conclusions

Flow-induced vibrations of two tandem cylinders in a channel were studied by lattice-Boltzmann method. A variety of periodic and non-periodic vibration regimes with the corresponding flow structures were observed. A detailed study of the vibration amplitude and vibration frequency as functions of the separation demonstrates that the separation has significant effects on the cylinder motions in the proximity-wake interference regime and the cylinders behave as two isolated ones as they are kept apart.

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