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Wake-induced vibration of tandem cylinders of different diameters

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A B S T R A C T

The wake-induced vibration (WIV) of the downstream cylinder of a tandem pair is investigated for different diameter ratios of $D_1/D_2=1/1$, $1/2$ and $1/3$, where D_1 and D_2 refer to the upstream and downstream cylinders, respectively. The streamwise separation between the cylinders was $L/D_1=3.5$, 7.0 and 6.5, respectively, measured from the centre of the upstream cylinder to the forward stagnation point of the downstream cylinder. Experiments with low mass-damping cylinders have been conducted in a water channel at around Re=25 000. The dynamic response showed that the downstream cylinder experienced WIV for all diameter ratios investigated, with displacement amplitudes reaching more than 1.5 diameters for higher reduced velocities beyond the vortex resonance range. The frequency response showed a similar behaviour for all three configurations, giving hints that a type of wake-stiffness mechanism might be governing the frequency of oscillation for all diameter ratios. The response was found to be dependent on both D_1/D_2 and L/D_1. In all cases, the static upstream cylinder was found to shed vortices as an isolated cylinder, not influenced by the presence or movement of the downstream body. Lift and drag coefficients as well as measurements of velocity fluctuations in both wakes are presented for all cases.

1. Introduction

When an elastic bluff body, like a circular cylinder, is immersed in the wake developed from an upstream body it will dynamically respond with *wake-induced vibrations* (WIVs). This hydroelastic mechanism has also been referred to as 'wake-induced galloping', 'interference galloping' or 'wake-displacement excitation' (Ruscheweyh, 1983; Bokaian and Geoola, 1984; Zdravkovich, 1988) and consists of the excitation of the downstream body by the interference of vortices developed in an unsteady wake generated upstream. The response of the downstream cylinder of a tandem pair is known to be severely increased by WIV when compared with that of an isolated cylinder under the resonant phenomenon of *vortex-induced vibration* (VIV).

Assi et al. (2010) reported on the effect of flow interference in the response of two identical cylinders aligned with the flow with centre-to-centre separations as large as 20 diameters. They have shown that vortices in the upstream wake play an essential role in driving the high-amplitude vibrations of the downstream cylinder. In fact, they performed an idealised experiment in which the unsteady vortex wake was replaced by a steady shear flow of equivalent mean velocity profile. They showed that the downstream cylinder immersed in that shear flow responded with a distorted type VIV but not with

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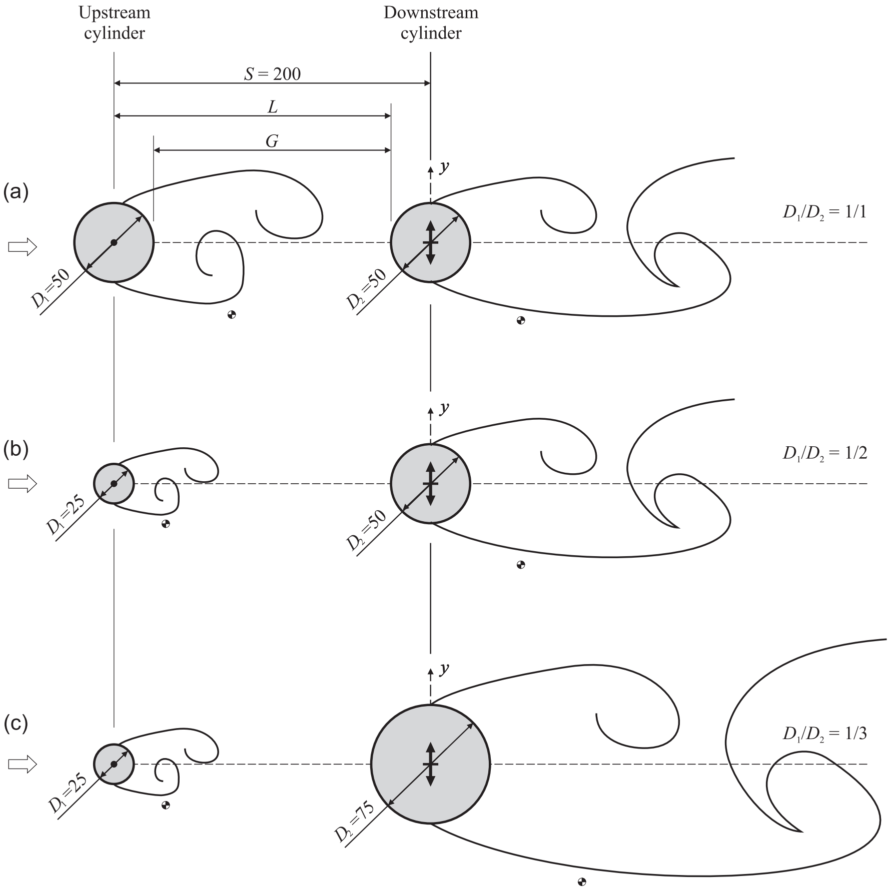

Fig. 1. Tandem configurations varying cylinders diameters. (a) $D_1/D_2 = 1/1$, (b) 1/2 and (c) 1/3. Dimensions are in millimetres. Sketches drawn to scale.

high-amplitude WIV. Their conclusion was that the unsteady interaction of coherent and periodic vortices from the upstream wake was necessary to input energy into the system and sustain the vibration.

The present work is a step further in the direction of understanding the vortex–structure interferences driving WIV of two bodies. This time we are concerned with varying the length and time scales of the wake involved in this kind of fluid–structure interaction. The downstream cylinder of a tandem pair is immersed in the wake developed from an upstream cylinder with smaller diameter. Consequently, the length and the time scales of the vortices that come from the upstream wake and reach the downstream cylinder vary proportionally. Three tandem configurations with the smaller cylinder positioned upstream are investigated in the present study, as illustrated in Fig. 1. The subscripts 1 and 2 will always refer to the upstream and downstream cylinders, hence D_1 and D_2 represent the respective cylinder diameters. Three diameter ratios of $D_1/D_2 = 1/1, 1/2$ and $1/3$ were chosen for the experiments and the centre-to-centre separation was kept constant at 200 mm in order to allow for the upstream wake to develop in the gap with no interference from the second body. As a consequence, the wake reaching the second cylinder will be proportionately different in each case due to the scale of the upstream vortex shedding mechanism and wake diffusion in the gap.

(*Note*: The subscripts in the non-dimensional numbers follow the same convention. Reynolds numbers (Re_1 and Re_2) take the diameter of the specified cylinder and Strouhal numbers are calculated employing the vortex shedding frequency (f_s) and the diameter of the referred cylinder, i.e. $\mathrm{St}_1 = f_{s1}D_1/U$ for the upstream cylinder and $\mathrm{St}_2 = f_{s2}D_2/U$ for the downstream cylinder.)

1.1. *Flow interference between cylinders*

Zdravkovich (1988) proposed a map of wake interference for two static cylinders with the same diameter arranged in several tandem and staggered configurations. The boundaries for each wake-interference zone clearly depend on the diameter of the two cylinders involved. It is expected that a smaller cylinder in the wake of a larger one will have to move many diameters across the wider wake before being free from any flow interference from upstream. The opposite might also happen for a larger cylinder moving across the narrower wake of a smaller body; the wake-interference zone might be reduced. Hence, the wake-interference map proposed by Zdravkovich (1988) will probably be different for each diameter

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