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Brief Communication

The aerodynamics of a cylinder submerged in the wake of another

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ABSTRACT

Flow-induced fluctuating lift (C_{Lf}) and drag (C_{Df}) forces and Strouhal numbers (St) of a cylinder submerged in the wake of another cylinder are investigated experimentally for Reynolds number (Re)$=9.7\times10^3$–6.5×10^4. The spacing ratio L^* ($=L/D$) between the cylinders is varied from 1.1 to 4.5, where L is the spacing between the cylinders and D is the cylinder diameter. The results show that C_{Lf}, C_{Df} and St are highly sensitive to Re due to change in the inherent nature of the flow structure. How the flow structure is dependent on Re and L^* is presented in a flow structure map. Zdravkovich and Pridden (1977) observed a 'kink' in time-mean drag distribution at $L^*\approx2.5$ for Re $>3.1\times10^4$, but not for Re $\leq3.1\times10^4$. The physics is provided here behind the presence and absence of the 'kink' that was left unexplained since then.

1. Introduction

The flow over a circular cylinder is a classical case, studied extensively for over 100 years, as it contains a wide range of complex flow phenomena, despite its simple geometry. The flow displays different characteristics at different Re regime. The most famous is the formation of the von Kármán vortex street, where counter-rotating vortices are shed from the cylinder in a periodic fashion (Zdravkovich, 1997). This class of flow evolves in complexity when an additional cylinder is placed in the wake of the other (Alam and Meyer, 2013).

Slender structures appear in groups in many engineering applications, for example, chimney stacks, tube bundles in heat exchangers, cooling of electronic equipments, high-rise buildings, overhead power-line bundles, bridge piers, stays, and chemical-reaction towers. Naturally, some structures in a group are submerged in the wake of the others. Two inline cylinders may be considered as the basic element of multiple structures, where the leeward cylinder is in the wake of the windward cylinder (Fig. 1(a)). The knowledge of this flow is insightful for understanding the flow around structures in groups.

The in-line configuration of two cylinders involves shear-layer and cylinder interaction that is strongly dependent on Re and L^* (Zhou et al., 2009; Carmo et al., 2010; Wong et al., 2014). The characteristics of the flow around two cylinders has been extensively reviewed by Zdravkovich (1977) who has shown that vortex formation in the space between the cylinders

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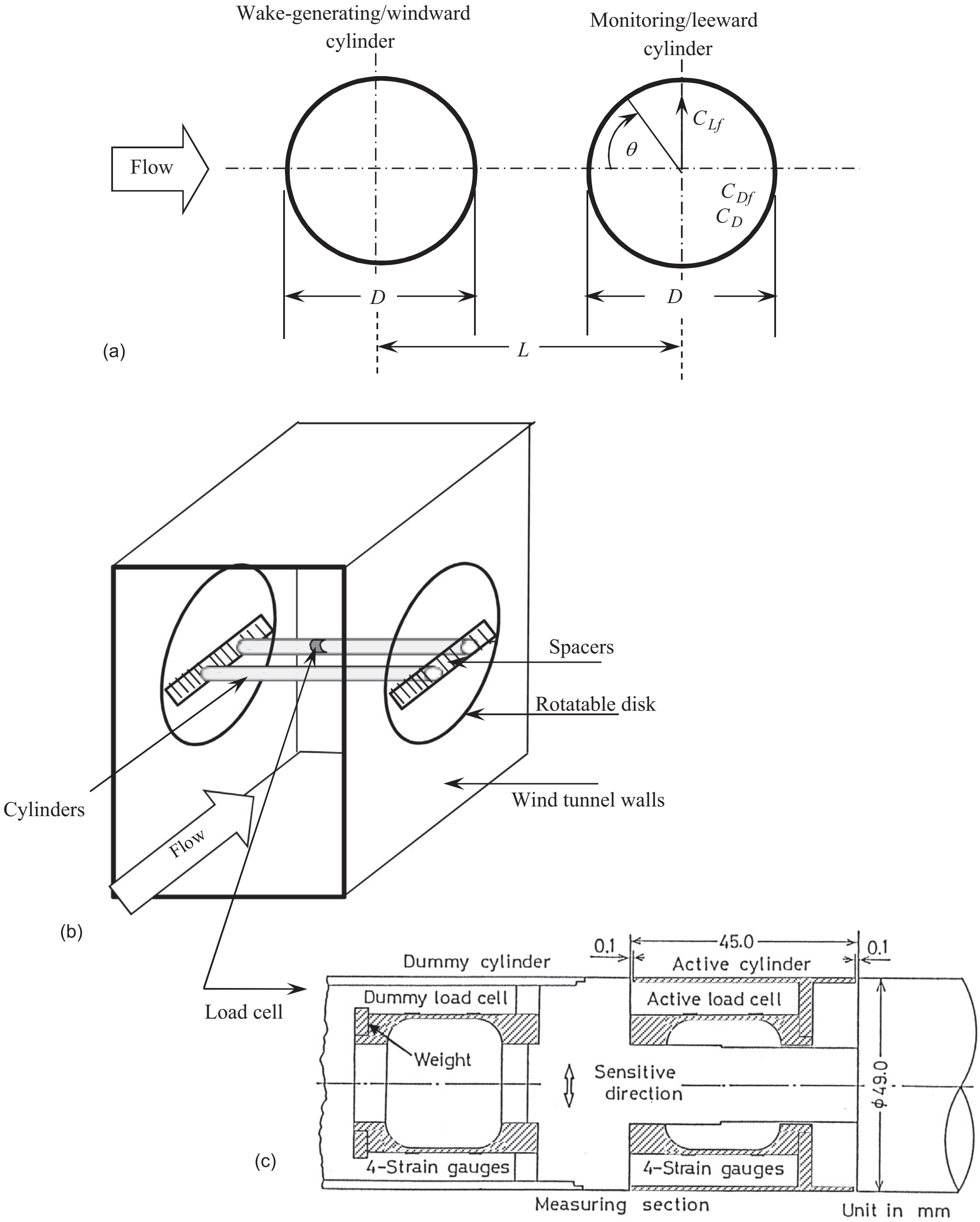

Fig. 1. (a) Notation of cylinder configuration, (b) a schematic of experimental setup, and (c) load cell details.

is only present when L^* is greater than about 4.0. A recent review of papers on two cylinders in cross flow has been made by Sumner (2010).

Biermann and Herrnstein (1933) measured time-averaged drag (C_D) on the two inline cylinders up to $L^*=8$ ($Re=1.05\times10^5$). Therefore, more investigation was needed to clarify the other parameters, such as, C_{Df}, C_{Lf}, St, surface pressures, wakes, boundary layers, etc. Time-averaged pressure measurements were conducted by Zdravkovich and Pridden (1977) at $Re=6\times10^4$ and Alam et al. (2003) at $Re=6.5\times10^4$. The results showed that for $L^*<3.5$ a negative pressure on the front surface of the leeward cylinder was generated instead of a positive pressure, exceeding that on the rear surface. In case of the windward cylinder, the pressure only on rear surface was affected by the presence of the leeward cylinder.