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Numerical simulation of low-Reynolds number flows past two tandem cylinders of different diameters

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Abstract: The flow past two tandem circular cylinders of different diameters was simulated using the finite volume method. The diameter of the downstream main cylinder (D) was kept constant, and the diameter of the upstream control cylinder (d) varied from $0.1D$ to D. The studied Reynolds numbers based on the diameter of the downstream main cylinder were 100 and 150. The gap between the control cylinder and the main cylinder (G) ranged from $0.1D$ to $4D$. It is concluded that the gap-to-diameter ratio (G/D) and the diameter ratio between the two cylinders (d/D) have important effects on the drag and lift coefficients, pressure distributions around the cylinders, vortex shedding frequencies from the two cylinders, and flow characteristics.

Key words: *two tandem cylinders; vortex shedding; drag force; lift force; numerical simulation*

1 Introduction

Flow around two circular cylinders in a tandem configuration can be found in numerous engineering applications, such as chimney stacks, tube bundles in heat exchangers, overhead power-line bundles, bridge piers and chemical-reaction towers, adjacent skyscrapers, and offshore oil and gas engineering structures. A tandem arrangement of two circular cylinders is a basic example of an array of multiple structures. Therefore, it is of important, fundamental, and pragmatic significance to study flow around two tandem cylinders.

Most of the studies on two-cylinder configurations have been concerned with two cylinders of an identical diameter (Ishigai et al. 1972; Bearman and Wadcock 1973; Zdravkovich 1977, 1987; Igarashi 1981, 1984; Williamson 1985; Mittal et al. 1997; Sumner et al. 1999, 2000; Meneghini et al. 2001; Lin et al. 2002; Alam et al. 2003; Sharman et al. 2005). Zdravkovich (1977, 1987) identified three flow regimes for two cylinders of an identical diameter in a tandem arrangement based on the center-to-center spacing ratio L/D (where L is the distance between the centers of the cylinders and D is the cylinder diameter): (1) the

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extended-body regime, where $1.0 < L/D < 1.8$, two cylinders are so close that the free shear layers separated from the upstream cylinder overshoot the downstream one, and the cylinders behave as a single bluff body; (2) the reattachment regime, where $1.8 \le L/D \le 3.8$, the shear layers shed from the upstream cylinder reattach to the face of the downstream cylinder, and vortex shedding is observed only in the wake of the downstream cylinder; (3) the co-shedding regime, where $L/D > 3.8$, and vortex shedding from both the downstream and upstream cylinders are observed.

A small amount of studies have been carried out to investigate the flow characteristics behind two tandem circular cylinders of different diameters. For the ratio of the upstream cylinder diameter (d) to the downstream cylinder diameter (D) greater than 1, Igarashi (1982) observed four distinct flow regimes: complete separation, reattachment flow, bistable flow, and jumped flow. Dalton et al. (2001) investigated the suppression of vortex shedding or lift force on a circular cylinder when a smaller circular cylinder was placed next to it. Alam and Zhou (2008) showed that a decreasing d/D would narrow the width of the wake between the cylinders and increase the time-averaged drag force on the downstream cylinder. Zhao et al. (2005, 2007) performed numerical simulations of the flow around cylinders of different diameters with two values of the Reynolds number (Re = 500 and 5×10^4) based on a larger cylinder diameter. Both simulation results revealed that the relative position of the small cylinder had a significant effect on hydrodynamic forces and vortex-shedding characteristics of the cylinders.

In this study, the flow past two circular cylinders of different diameters was investigated numerically. The aim of this study was to investigate the effects of the two cylinders of different diameters in the tandem arrangement on the vortex shedding behind the two-cylinder system. The two-dimensional Navier-Stokes equations were solved using the finite volume method. While the downstream main cylinder diameter (D) was fixed, the upstream control cylinder diameter (d) varied from 0.1D to D. The studied Reynolds numbers based on the downstream cylinder diameter were 100 and 150. In this study, flow in the range of $40 \le Re \le 200$ was assumed to be two-dimensional and laminar. At a higher Reynolds number of about Re > 200, the flow became three-dimensional and turbulent. From the perspective of the main concern of this study, the two-dimensionality assumption is acceptable for numerically understanding the wake behind two tandem circular cylinders at low Reynolds numbers. The gap between the two cylinders (G) ranged from 0.1D to 4D. The effects of the gap-to-diameter ratio (G/D) and the diameter ratio between the two cylinders (d/D) on drag and lift coefficients, pressure distributions around the cylinders, vortex shedding frequencies from the two cylinders, and flow characteristics were studied.

2 Governing equations and numerical method

The two tandem cylinders considered in this study are shown in Fig. 1. The position of the upstream cylinder can be uniquely determined by the gap-to-diameter ratio (G/D) and the

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