# Vortex shedding characteristics of flow past two different diameters cylinders in tandem arrangement at low Reynolds number

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**Keywords:** Navier-Stokes equations; Finite element method; Vortex shedding characteristics; Tandem cylinders; Numerical simulation

**Abstract.** Flow vortex shedding from two circular cylinders of different diameters in tandem arrangement is investigated by means of numerical simulations. The two-dimensional Navier-Stokes equations are solved by a fractional step upstream finite element method at a relatively low Reynolds number Re = 100. The studied Reynolds number based on the diameter of the downstream main cylinder. The diameter of the downstream main cylinder was kept constant, and the diameter ratio between the upstream control cylinder and the downstream one was varied from 0.1 to 1.0. The gap between the control cylinder and the main cylinder ranged from 0.1 to 4.0 times the diameter of the main cylinder. It is concluded that the gap ratio and the diameter ratio between the two cylinders have important effects on vortex shedding characteristics from two cylinders of different diameters in a tandem arrangement.

## Introduction

Fluid-dynamic interaction between two circular cylinders immersed in a stream is of fundamental importance in fluids engineering, such as chimney stacks, off-shore structures in deep seas, tube bundles in heat exchangers, overhead power-line bundles, bridge piers and chemical-reaction towers, and adjacent skyscrapers. A tandem arrangement of two circular cylinders is a basic example of an array of multiple structures. Most of the reported studies on two-cylinder configurations were concerned with two cylinders of an identical diameter(Ishigai et al.1972; Bearrman and Wadcock1973; Zdravkovich1977,1987; Igarashi1981, 1984; Williamson 1985; Mittal et al. 1997; Sumner et al. 2000; Lin et al. 2002; Alam et al. 2003; Sharman et al.2005.) Zdravkovich (1977,1987) identified three flow patterns for cylinders of equal diameters in 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). (i) For 1<L/D<1.2-1.8, the extended-body regime, where two cylinders are so close to each other that the free shear layers separated from the upstream cylinder overshoot the downstream one, the cylinders behave as a single bluff body. (ii) For 1.2-1.8<L/D<3.4-3.8, the reattachment regime, the shear layers shed from the upstream cylinder reattach to the face of the second cylinder and vortex-shedding is observed only in the wake of the second cylinder. (iii) For L/D>4.0, the co-shedding regime, in addition to vortex-shedding from the downstream cylinder, vortex-shedding from the upstream cylinders is also observed.

In this paper, the flow past two circular cylinders of different diameters is investigated numerically. The aim of this study is to investigate the effects on vortex shedding from the two cylinders of different diameters in the tandem arrangement. The two-dimensional field

 

Navier-Stokes equations are solved by using a finite volume method. While the downstream main cylinder diameter D, is fixed, the upstream control cylinder diameter d, is varied from 0.1D to D. The Reynolds number based on the diameter of the downstream cylinder is 100 and 150. The gap G between the cylinders ranges from 0.1 to 4.0 times the diameter of the downstream cylinder D. The effects of the gap ratio G/D and the diameter ratio d/D between the two cylinders on vortex shedding from the cylinders are investigated.

## Governing equations and numerical method

The two tandem cylinders considered in this study are shown in Figure 1. The position of the upstream cylinder can be uniquely determined by the gap ratio *G/D* and the diameter ratio *d/D* between the two cylinders. The flow is in the positive direction of the x-axis, $\theta$ is an angle in the counterclockwise direction, starting from the positive direction of the x-axis, as shown in Figure 1.

The two-dimensional Navier-Stokes equations together with the continuity equation are solved by using a finite volume method. The temporal integration used in the present study is of second-order accuracy.

The Strouhal number is defined in terms of the cylinder diameter ($D$), the free-stream velocity ($U$), and the frequency ( $f$ ) of the oscillation of the lift coefficient as

$$S_t = fD/U \tag{1}$$

The Strouhal number predicted by the present model for *Re* =100 is 0.167, which is also identical to the numerical result by Baranyi(2004) and experimental result by Clift et al.(1978).

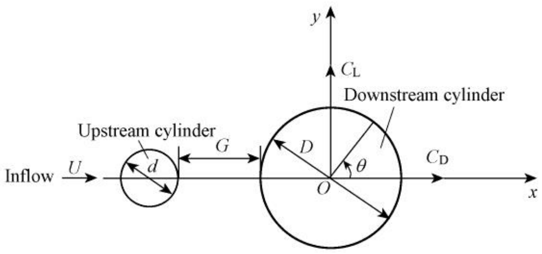

Figure. 1 Definition figure

## Vortex shedding form two tandem cylinders

The existence of the control cylinder induces significant variations of the mean drag, lift and the mean pressure distribution on the main cylinder. It is believed that these variations are the direct results of the interactions of vortex shedding from both cylinders. Therefore, the understanding of the vortex shedding characteristics from the two cylinders is of fundamental interests to both practitioners and scientists.

Figure 2 shows flow past two cylinder with different *G/D* for *d/D*=0.3 at *Re*=100. At this Reynolds number, the boundary layer around the cylinder is laminar. Flow patterns can be classified into two basic regimes: (i) For 0.1<*G/D*<1.5, the extended-body regime, where two cylinders are so close to each other that the free shear layers separated from the upstream cylinder attach to the shoulders of the downstream one, the cylinders behave as a single bluff body. (ii) For 2.0<*G/D*<4.0, the reattachment regime, the shear layers shed from the upstream cylinder reattach to the face of the second cylinder and vortex-shedding is observed only in the wake of the second cylinder.

It is expected that shedding of vortices from the cylinders has different modes, depending mainly on the gap between the two cylinders. Generally speaking, there will be two shedding processes from the upstream and downstream cylinders separately and the interactions between the shedding processes will be weak when the gap between the two cylinders is large. When the gap ratio is small enough, it is possible that two separate shedding processes will merge and the two cylinders behave as a single object. The strong shedding interactions are expected at intermediate gap ratios.

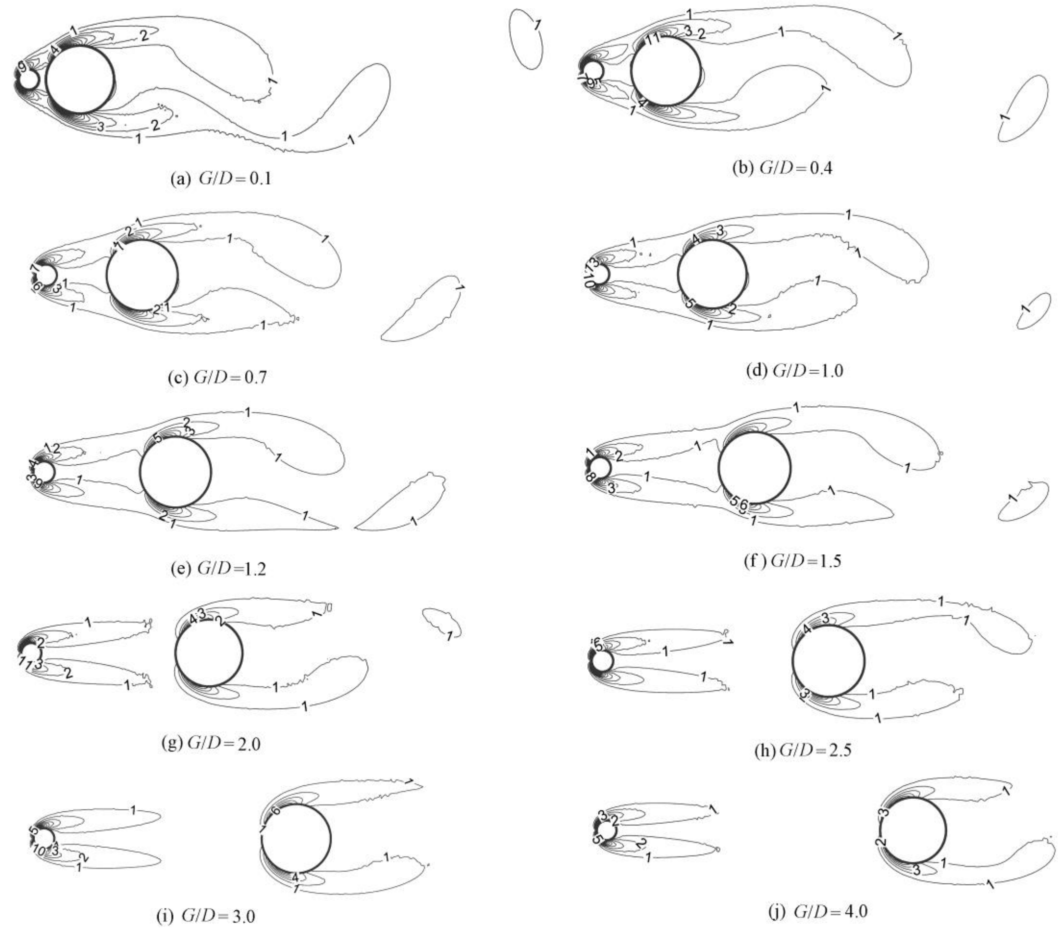


Figure. 2 Vorticity contours behind two cylinders with different $G/D$ values for $d/D$ = 0.3 and $Re$ = 100

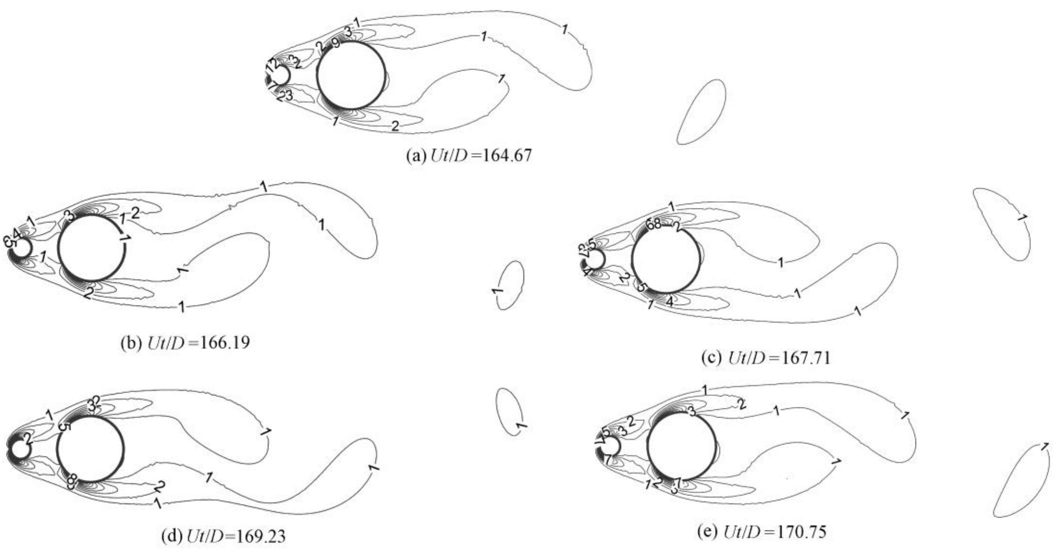


Figure. 3 Instantaneous vorticity contours behind two cylinders for $G/D$ = 0.4, $d/D$ = 0.3, and $Re$ = 100

Figure. 3 shows instantaneous vorticity contours behind the two cylinders for roughly one vortex shedding period for the case of *G/D*=0.4 at *d/D*=0.3 at *Re*=100. This is the single bluff body mode, A alternant vortex street can be seen behind the two cylinders. It can be also clearly noticed that the shear layers of the control cylinder attached to the front surface of the downstream main cylinder, and the shear layers of the upstream cylinder are symmetrical about the centerline of two cylinders.

## Conclusions

The numerical investigations of the effects of the gap ratio and the diameter ratio on the flow past two tandem circular cylinders at *Re* =100 are carried out. The instantaneous flow patterns and other quantitative information are obtained, which helps a better understanding of the complex flow characteristics around the cylinders in the tandem arrangement. The major results can be summarized as follows:

The shedding of vortices from two cylinders of different diameters in a tandem arrangement has different modes, depending mainly on the gap ratio and diameter ratio between the two cylinders. Generally speaking, there will be two shedding processes from the upstream and downstream cylinders separately. The interactions between the shedding processes will be weak when the gap between the two cylinders is large. When the gap ratio is small enough, it is possible that two separate shedding processes will merge and the two cylinders behave as a single object as far as shedding from them is concerned. Strong shedding interactions are expected at intermediate gap ratios.

## References


[1] Ishigai, S., Nishikawa, E., Nishimura, E., and Cho, K. 1972. Experimental study of structure of gas flow in tube banks axes normal to flow. *Bulletin of the Japan Society of Mechanical Engineering*, 15, 949–956.

[2] Bearman, P. W., and Wadcock, A. J. 1973. The interaction between a pair of circular cylinder normal to a stream. *Journal of Fluid Mechanics*, 61, 499-511.

[3] Zdravkovich, M. M. 1977. Review of flow interference between two circular cylinders in various arrangements. ASME. *Journal of Fluids Engineering*, 99, 618-633.

[4] Zdravkovich, M. M. 1987. The effect of interference between circular cylinders in cross flow. *Journal of Fluids and Structure*, 1, 239-261.

[5] Igarashi, T. 1981. Characteristics of the flow around two circular cylinders arranged in tandem (1st report). *Bulletin of the Japan Society of Mechanical Engineering*, 24, 323–331.

[6] Igarashi, T., 1984. Characteristics of the flow around two circular cylinders arranged in tandem (2nd report). *Bulletin of the Japan Society of Mechanical Engineering*, 27, 2380–2387.

[7] Williamson, C. H. K. 1985. Evolution of a single wake behind a pair of bluff bodies. *Journal of Fluid Mechanics*, 159, 1–18.

[8] Mittal, S., Kumar , V., and Raghuvanshi, A. 1997. Unsteady incompressible flow past two cylinders in tandem and staggered arrangements. *International Journal for Numerical Methods in Fluids*, 25, 1315-1344.

[9] Sumner, D., Price, S. J., and Paidoussis, M. P. 2000. Flow-pattern identification for two staggered circulation cylinders in cross-flow. *Journal of Fluid Mechanics*, 411, 263-303.

[10] Lin, J. C., Yang, Y., and Rockwell, D. 2002. Flow past two cylinders in tandem: instantaneous and averaged flow structure. *Journal of Fluids and Structures*, 16, 1059-1071.

[11] Alam, M., Moriya, M., Takai, K., and Sakamoto, H. 2003. Fluctuating fluid forces acting on two circular cylinders in a tandem arrangement at a subcritical Reynolds number. *Journal of Wind Engineering and Industrial Aerodynamics,*91, 139-154.

[12] Sharman, B., Lien, F. S., Davidson, L., and Norberg. C. 2005. Numerical predictions of low Reynolds number flows over two tandem circular cylinders. *International Journal for Numerical Methods in Fluids*, 47, 423-447.

[13] Baranyi, L., 2004. Numerical simulation of flow past a cylinder in orbital motion. *Journal of Computational and Applied Mechanics*, 5, 209–222.