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Journal of Visualization, Vol. 12, No. 3 (2009) 193-194

Short Paper

Bistable Flow Pattern for Cylinder Arrays with a Small Spacing Ratio

Zou, L.*1 and Lin, Y. F.*2

*1 School of Mechanical and Electronic Engineering, Wuhan University of Technology, Wuhan, 430070, P. R. China. E-mail: l.zou@163.com
*2 Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. E-mail: mmyflin@gmail.com

Received 24 November 2008 and Revised 12 January 2009

1. Introduction

Flow past cylinder arrays can be found in many engineering applications, such as heat exchanges, offshore structures, high buildings, and nuclear reactors, etc. A thorough understanding of the vortex structures could assist in alleviating problems associated with flow induced vibration. Differ from that of a single cylinder, the flow patterns behind cylinder arrays depend to a great extent on the spacing ratio of L/D (L is the center-to-center cylinder distant and D is the cylinder diameter) among many other parameters (Williamson, 1985). For example, for two side by side cylinders, two distinct vortex streets occur with a large spacing ratio. At a small spacing, however, the gap flow between the cylinders is deflected. It changes over intermittently from one side to another and is bistable (Kim and Durbin, 1988). Nevertheless, the physical mechanisms behind the formation and stability of a narrow and a wide wake remain unexplained. The present investigation is on laminar flow around four cylinders in an in-line square configuration with a small spacing ratio. It is hoped that this investigation will be helpful to comprehend the physical mechanisms why the bistable flow pattern occurs for cylinder array with a small spacing ratio.

2. Experimental and Numerical Methods

The experimental investigation was carried out in a low-speed closed-loop water tunnel with a working square cross-section of 0.3m×0.6m and a length of 2.4m. The four circular acrylic cylinders of diameter D=20mm were placed horizontally in it with L/D=1.6 and H/D=16 (H is the length of the cylinder). The Reynolds number is 200 based on the incoming flow velocity and the diameter of the cylinder. The flow patterns were obtained by using Laser Induced Fluorescence (LIF) visualization techniques (Wang et al. 2005). A SONY digital video camera (DCR PC120E) was used to capture the fluid motion into video tapes. Moreover, a Particle Image Velocimetry (PIV) system was also used to capture the detailed vortex structures (Kim et al. 2008). A Dantec control unit was used to synchronize the CCD camera with a Dantec Nd: Yag laser generator. A schematic description of the experimental setup is shown in Fig. 1. The finite volume method applied on unstructured grids was employed to calculate the 3D unsteady Navier-Stokes equations (Zou et al. 2008). The computational model and boundary conditions were specified to resemble the corresponding experimental conditions (refer to Fig. 2).

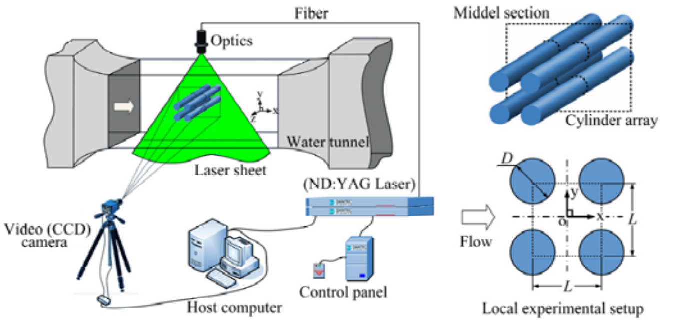

Fig. 1. Experimental setup.

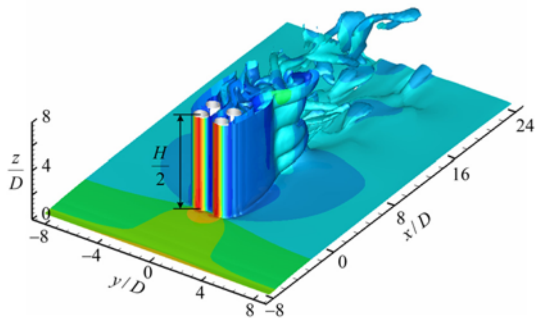

Fig. 2. 3D vortex structure.

3. Results and Discussions

Figure 3 shows the instantaneous flow patterns at the middle section (in x-y plane, z/H=0.5) of the cylinder array. They were captured by both the LIF measurement and numerical simulation. It can be clearly observed that the downstream cylinders are completely shielded by the free shear layers from their corresponding upstream cylinders with a wide wake and a narrow wake generated intermittently switch with each other at different time instant. A bistable behavior evolves behind the downstream cylinders due to the effects of jet-like flow characteristics between the two row cylinders. However, this bistable nature of the wake flow appears to be completely random. Similar results were recorded by Sayers (1988), Lam and Zou (2007) and Zou et al. (2008) in high Reynolds number regime. It means that this bistable characteristic is nominally independent of the Reynolds number.

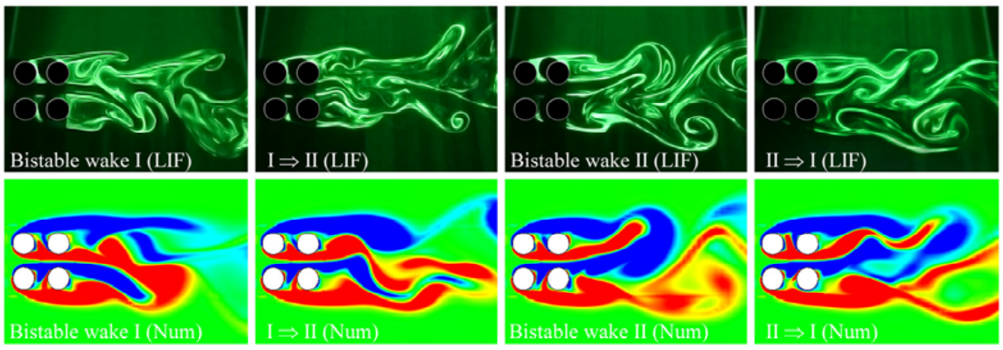

Fig. 3. Bistable flow pattern distributions at middle spanwise position.

As Fig. 4 shows, a non-uniform distribution of instantaneous spanwise vortex structures along the spanwise direction can be observed at the further downstream. Deflection angle of this biased flow appears to be sensitive. It varies in different spanwise locations (z/H) with an increasing trend from z/H=0.0625 position toward the middle section of the cylinders (refer to Fig. 2, 3D vortex structure colored by pressure distribution). Because of the bistable wake patterns at such small spacing ratio, between the upstream cylinders and the downstream cylinders, no evident vortex shedding occurs along the spanwise direction. It implies that the downstream cylinders are completely shielded by the free shear layers from their corresponding upstream cylinders in all spanwise positions. Furthermore, the present numerical results are in good agreement with those captured by LIF and PIV techniques. Such successful experimental and simulation results will establish the comprehensive database to further our understanding about the physical mechanisms of the bistable flow characteristics for cylinder arrays with a small spacing ratio.

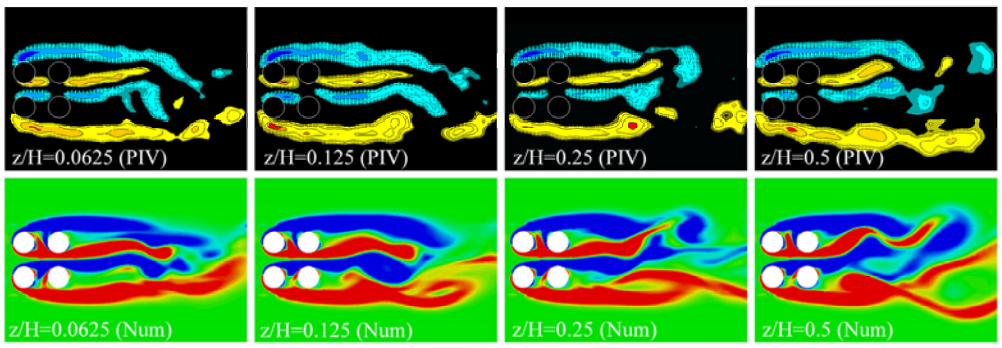

Fig. 4. Instantaneous flow patterns distributions at different spanwise positions.

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