2nd Symposium on Fluid-Structure-Sound Interactions and Control (FSSIC2013)
Hong Kong and Macau, May 20-23, 2013

Reynolds number effect on flow classification behind two staggered cylinders

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Introduction

The study of aerodynamic interference between multiple slender structures is of both fundamental and practical importance. Flow behind two staggered cylinders in close proximity is by far more complicated than that behind an isolated cylinder, depending on the angle (α) between incident flow and the line through the cylinders, and the cylinder centre-to-centre pitch P^*, in addition to the Reynolds number *Re*. In this paper, asterisk denotes normalization by d and/or U_∞. Naturally, flow classification in terms of α and P^* is crucial for a thorough understanding of the flow and has received considerable attention in the literature (e.g. Sumner [1]).

Hu and Zhou [2] investigated the flow structures and their downstream evolutions in the wake of two staggered cylinders for $P^* = 1.2 \sim 4.0$ and $\alpha = 0^\circ$ to 90° ($Re = 7.0\times10^3$). However, their flow structure classification suffered from a relatively coarse resolution in their measurement grid, ΔP^* and $\Delta\alpha$, which were 0.5 and 10°, respectively. Therefore, the first objective of this work is to provide an improved resolution in identifying the flow mode in the P^*-α plane. The increment $\Delta\alpha$ in the measurement grid of this work is reduced to 5° and the P^* range examined is 1.2 ~ 6.0, larger than that (1.2 ~ 4.0) in Hu & Zhou [2]. Zhou *et al.* [3] and also Xu *et al.* [4] have demonstrated that a variation in *Re* could result in a qualitative change in the flow structure. For instance, a single vortex street behind two side-by-side cylinders may change to two, one narrow and one wide, as *Re* increased from 450 to 1000 [4]. The dependence of flow classification on *Re* was however not addressed in Hu and Zhou [2]. As such, the second objective of this work is to provide insight on how flow classification may be influenced by *Re*. This is achieved by comparing the dependence of the flow mode on P^* and α at $Re = 7.0 \times 10^3$ with that at $Re = 1.5\times 10^3$ and 2.0×10^4.

Experimental Approach

Measurements were performed in a closed circuit wind tunnel with a working section of L × W × H = 2.4 m × 0.6 m × 0.6 m. The free-stream longitudinal turbulence intensity was approximately 0.4% for the *Re* range examined. The test models were two identical brass cylinders of $d = 12.5$ mm. Both cylinders spanned the full width of the working section and were mounted symmetrically with respect to the mid-plane, 0.2 m downstream of the exit plane of the contraction section of the wind tunnel. The length-to-diameter ratio of the cylinder was 48. Figure 1(a) shows the arrangement of the cylinders and the definitions of P and α. The x- and y-axes are defined along the free-stream and lateral directions, respectively, with their origin at the midpoint between the two cylinder centres, while the z-axis (not shown) is normal to both x- and y-axes, following the right-hand system.

Two single hotwires (Pt-10% Rh) of 5 μm in diameter and about 1 mm in length were used to measure simultaneously the streamwise velocity fluctuation u behind each of the two cylinders at $x^* = 2.5$, 5, 10 and 15, and $y^* = \pm1.3 \sim \pm3.0$, depending on the arrangement of the cylinders. Hotwire probes 1 and 2 [Fig. 1(a)] were placed in the downstream- and upstream-cylinder-generated streets, respectively. The power spectral density function E_u of u was calculated using a fast Fourier transform. The *Re* range investigated was $1.5\times10^3 \sim 2.0\times10^4$. The measurement grid covers $\alpha = 0^\circ$ to 90°, with an increment $\Delta\alpha$ of 10° and $P^* = 1.2$, 1.5, 2.0, 2.5, 3.0, and 4.0 for $Re = 1.5 \text{ x } 10^3$ and 2.0×10^4; $\Delta\alpha$ is reduced to 5° and $\Delta P^* = 0.5$ up to 6.0 for $Re = 7.0 \text{ x } 10^3$, as shown in [Fig. 1(b)].

Results and Discussion

Figure 2 presents flow classifications at $Re = 1.5\times10^3$, 7.0×10^3 and 2.0×10^4. Flow classification from the present measurement at $Re = 7.0 \times10^3$ is essentially consistent with the report by Hu and

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Zhou [2]. There is a departure in the border between different flow modes, which is partially ascribed to the different definitions of the border between different flow modes and partially the presently refined measurement grids. It is immediately noted that a change in *Re* from 1.5×10^3 to 7.0×10^3 or from 7.0×10^3 to 2.0×10^4 results in an appreciable variation in the border between different flow regimes.

In the full paper, the comparison of dependence of the flow mode on P^* and α with *Re* varies from 1.5×10^3 to 7.0×10^3 and 7.0×10^3 to 2.0×10^4 will be presented. The observation connected to the *Re* effect on the generic features of a two-cylinder wake such as flow separation, boundary layer thickness, gap flow deflection and vortex formation will be provided.

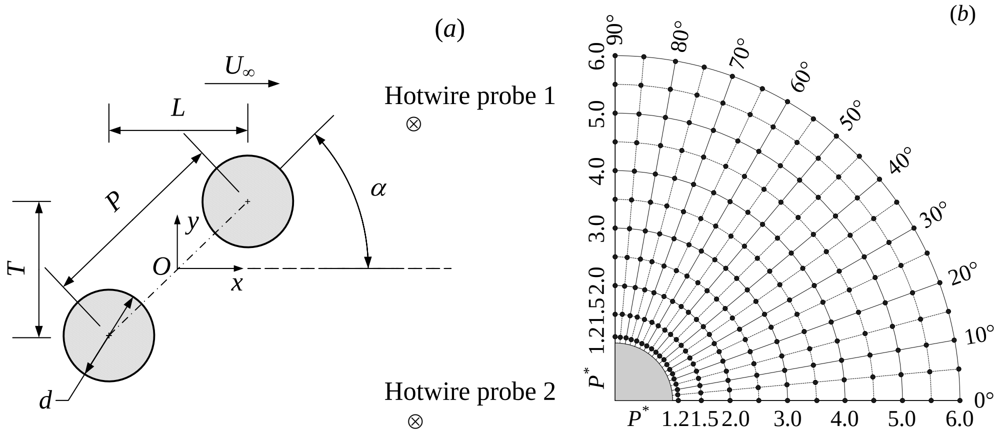

Fig. 1: (*a*) Experimental arrangement; (*b*) hotwire measurement grid in the P^* - α plane at $Re = 7.0\times10^3$.

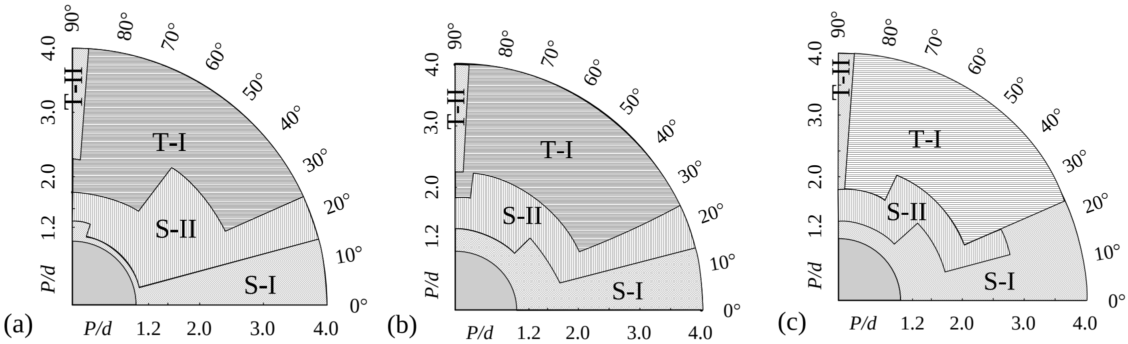

Fig. 2: Dependence of flow structures on P^* and α in the wake of two staggered circular cylinders: (a) $Re = 1.5\times10^3$; (b) $Re = 7.0\times10^3$; (c) $Re = 2.0\times10^4$.

References

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Keywords: two-cylinder wake, vortex structure, staggered cylinders, flow classification