Flow-induced vibrations of a circular cylinder interacted with another of different diameter

Md. Mahbub Alam[1] and Y. Zhou[1,2]

[1]Deparment of Mechanical Engineering and Automation
Shenzhen Graduate School, Harbin Institute of Technology, Shenzhen, China

[2]Deparment of Mechanical Engineering
The Hong Kong Polytechnic University, Hong Kong

In a real life architectural environment, most buildings and structures are not isolated and are in fact in close proximity of each other. Flow-induced vibrations of two interacting cylinders subjected to a cross flow have been the subject of intensive research because of relevance to engineering structural design and acoustic emission problems. A detail survey of research relating to flow-induced response of two cylinders suggest that previous investigations mostly were performed for (i) two cylinders of an identical diameter, (ii) two-dimensional model (spring mounted at both ends), (iii) single degree of freedom (either cross-flow or streamwise), and (iv) at a low mass-damping $m^*\zeta$ value (0.018~0.2). The literatures mainly clarified L/d range where vortex-resonance or galloping persists. There does not seem to have a systematic study on flow-induced response when upstream cylinder size (diameter) is changed. Hence a number of questions are still unanswered. Firstly, what is the effect of upstream cylinder diameter on flow-induced response of the downstream cylinder? Secondly, what would be the response of the cylinder if it is cantilevered mounted where the vibration amplitude is dependent on spawise location of the cylinder, three-dimensional model? Thirdly, is galloping or VE generated for a high value of $m^*\zeta$? Fourthly, how much forces on the structure base are induced when a structure experiences VE or galloping? Finally, what is the physics behind the generation of galloping for tandem cylinders, though galloping in general is not generated on an isolated circular cylinder (axis-symmetric body)?

The objectives of the present study are to experimentally investigate flow-induced response of a cantilever circular cylinder in the presence of an upstream cylinder of different diameters. The free end of the cantilever cylinder is free to move in two degrees of freedom. The cylinder had a $m^*\zeta$ of 3.95. The upstream cylinder diameter (d) is varied, with the downstream cylinder diameter (D) unchanged, so that the ratio d/D varies from 1.0 to 0.24. Two L/d = 1.0 and 2.0 are considered, and they are within

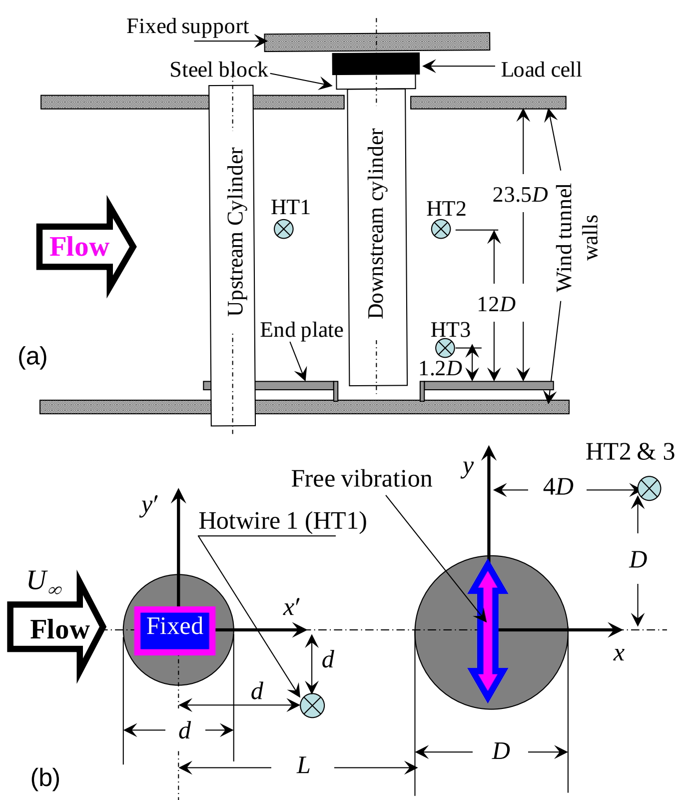

Fig. 1. (a) experimental setup, (b) definitions of symbols.

the reattachment regime. The flow-induced responses A_x and A_y in the x- and y-direction (where A stands for amplitude of vibration at the free-end of the cylinder), forces on the cylinder base C_D, C_{Drms}, C_{Lrms} and cylinder vibration frequency are systematically measured for U_r = 0.8 ~ 32. Furthermore, f_v behind the downstream cylinder and in the gap between the cylinders are examined.

Experiments were conducted in a low-speed, close-circuit wind tunnel with a test section of 600 mm in width, 600 mm in height and 2400 mm long. The upstream cylinder of diameter d was solid and fixed-mounted at both ends. The downstream cylinder of outer diameter D = 25 mm was hollow, inner diameter 21 mm, 700 mm in length, and cantilever-mounted on an external rigid support detached from the wind-tunnel wall. d was 25, 20, 15, 10 and 6 mm, respectively, and the corresponding d/D was 1.0 ~ 0.24. U_∞ was varied from 0.5 to 20 m/s, corresponding to variation of U_r from 0.8 to 32, Reynolds numbers (Re) of 825 to 3.3×10^4 based on the downstream cylinder. Two hotwires were used to measure the frequencies of vortex shedding from the cylinders. A three-component strain-gauge load cell (KYOWA Model LSM-B-500NSA1). Free end vibration displacement of the cylinder was measured by using a standard laser vibrometer.

The results obtained from the experiments can be summarized as follows

(i) The downstream cylinder experiences violent vibration when the upstream cylinder diameter is d/D = 0.24 ~ 0.8 for L/d = 1 (Fig. 2) and d/D = 0.24 ~ 0.6 for L/d = 2. Meanwhile, C_{Lrms} is greatly amplified, increasing by a factor of more than 40 at U_r = 25.5. Compared with that for d/D = 0 or for a fixed cylinder, C_{Lrms} increases.

(ii) Vortices behind the vibrating cylinder appeared at two dominant frequencies corresponding to the natural vortex shedding and the cylinder vibration. While the vortices associated with the natural vortex shedding frequency decay rapidly and those associated with the vibration frequency persist.

(iii) Decreasing d/D is prone to generate vibration. At a small d/D, the upstream cylinder wake narrows, and the shear-layer reattachment position on the downstream cylinder approaches the front stagnation point, and hence the high-speed slice of the shear layer could flow alternately along the two different sides of this cylinder, thus exciting the downstream cylinder.

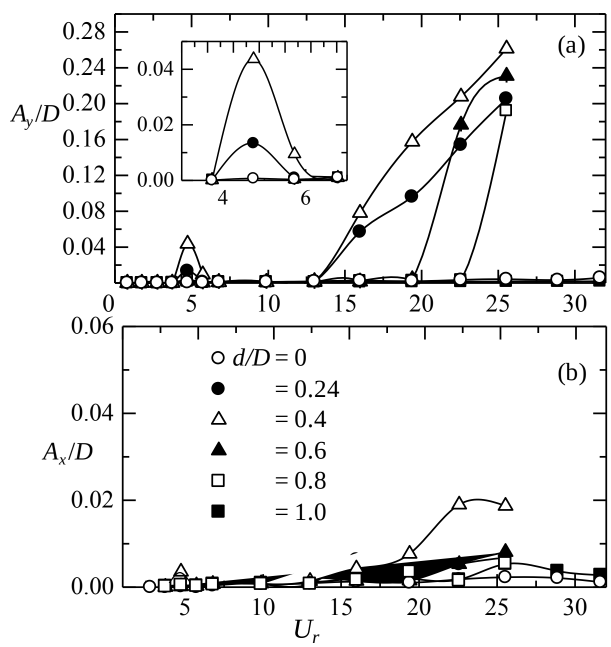

Fig. 2. Normalized vibration amplitude A_y/D and A_x/D at L/d = 1.