Intermittency of vortex shedding in the near wake of a finite-length square prism

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The flow around a wall-mounted finite-length cylinder is characteristics by the interaction between free-end downwash flow, spanwise shear flow and possible upwash flow. Based on PIV, HWA and flow visualization results, Wang & Zhou (2009) proposed a model to describe the near wake structure of a wall-mounted finite-length cylinder. They suggested that the spanwise shear layers are connected with each other by the shear layer from cylinder free end and form an over-all arch-type vortex structure. Kawai et al. (2012) found direct evidence for this claim utilizing high frame-rate 3D PIV technique. Both symmetrical and anti-symmetrical spanwise vortices were observed throughout cylinder span (Wang & Zhou 2009), similar observation was also reported by Sattari et al. (2011).

Considering the connection between flow around and aerodynamic forces on a bluff body, the occurrence of anti-symmetrical or symmetrical vortices may have profound effects on the drag and lift on the cylinder. Based on the condition-averaged results, Wang & Zhou (2009) found the vortex formation length for symmetrical vortices is far larger than that for anti-symmetrical ones, suggesting the drag coefficient (C_d) for the former is significantly smaller than the latter. A number of investigations (e.g. Sarode et al. 1981; Okamoto & Sunabashiri 1992) found that the C_d of a finite-length cylinder is smaller than its counterpart of 2D cylinder. This observation was attributed to the occurrence symmetrical vortex shedding in finite-length cylinder wake, which corresponds to a smaller C_d (Wang & Zhou 2009). More recently, Sattari et al.(2012) observed two flow regimes according to the pressure measurement on prism side faces. Regime A corresponds to a high-amplitude fluctuation of pressure coefficient (C_p), and is associated with consistent well-organized, alternate shedding of counter-rotating vortices. On the other hand, Regime B is observed during low-amplitude fluctuation of C_p, and is characterized by the co-existence of two-counter rotating vortices throughout the shedding cycle. Obviously, these two regimes correspond to the anti-symmetrical and symmetrical spanwise vortices proposed by Wang & Zhou (2009).

The present paper reports a large eddy simulation (LES) for the flow around a wall-mounted finite-length square prism with H/d=5, at Re_d =3900. It aims to reveal the relation between these two flow regimes and their effects on the aerodynamic forces, and also the effects of vortex shedding processes on the pressure fluctuation for these two regimes, respectively.

Figure 1 presents the time tracers of C_d and C_l. The time-frequency spectrum of C_l is also shown for comparison. The variation of C_d corresponds well with the behavior of C_l. Specifically, the local maximum value of C_d occurs when C_l fluctuates periodically with large amplitude, as indicated by Mode1 in figure 1; while, the local C_d minimum presences when there is no periodic fluctuation in C_l, as indicated by Mode2. As shown in figure 1, C_d =1.55~1.6 for Mode 2, while its maximum value is about 1.85 for Mode1. The later is about 20% larger than the former. The C_d values of both Mode1 and Mode2 are far smaller than that of a 2D square prism (0.21). Both Mode1 and Mode2 occur randomly and intermittently in time, correspond well with the energy distribution in the time-frequency spectrum of C_l. Although, the spectral energy concentrates at f^* = 0.105, it is not continues in time, as shown in figure 1(*c*). For example, the two pronounced

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energy peaks in the time-frequency spectrum correspond to Mode1; while no energy peak presences when Mode2 occurs.

Figure 2 presents the two typical instantaneous vortex structures for the two modes. For Mode1, alternating spanwise vortex shedding occurs in the near wake, similar to that in a 2D cylinder wake. However, under the effects of free-end downwash flow, the near wake structure of finite-length cylinder is more complicated relative to that of a 2D cylinder. The spanwise vortex shedding in Mode1 results in the large amplitude fluctuation of C_l and the higher value of C_d. While for Mode2, the periodic vortex shedding does not exist. That is, the alternating spanwise vortex shedding occurs intermittently in the finite-length cylinder near wake, which results in the two typical modes in the behaviors of C_d and C_l.

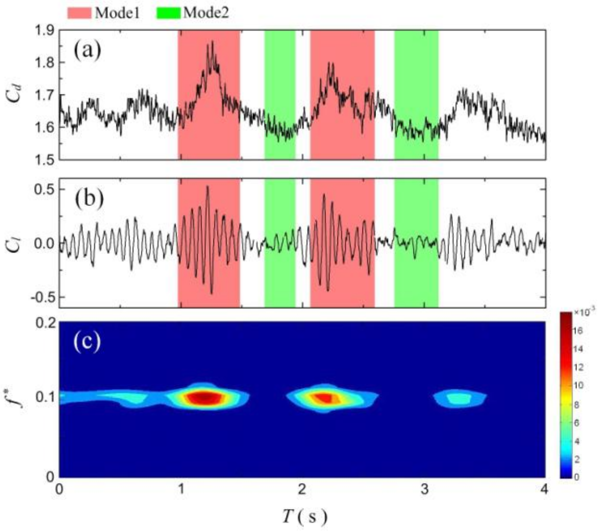

Figure 1. Time tracers of C_d and C_l (a, b), and the time-frequency spectrum of C_l (c).

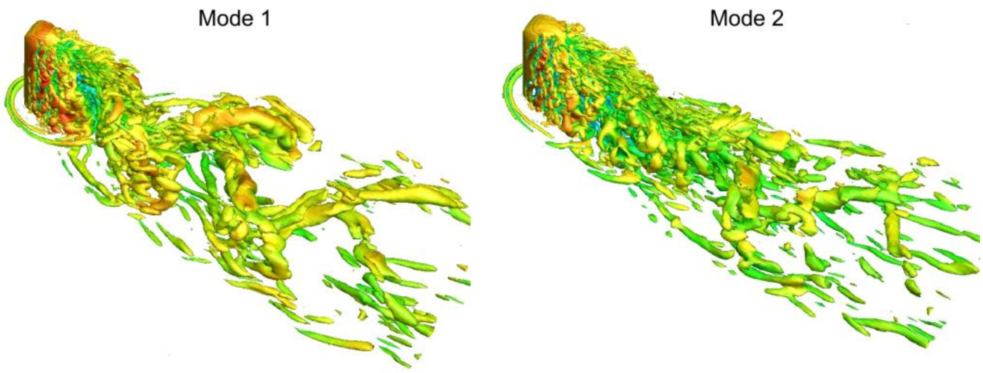

Figure 2 Typical instantaneous vortex structures for Mode1 and Mode2.

References

Wang HF，Zhou Y. 2009 The finite-length square cylinder near wake. J. Fluid Mech., 638: 453-490

Kawai H, Okuda Y, Ohashi M. 2012 Near wake structure behind a 3D square prism with the aspect ratio of 2.7 in a shallow boundary layer flow. J. Wind Eng. Ind. Aerodyn., 104-106: 196-202

Sattari P, Bourgeois JA, Martinuzzi RJ. 2012 On the vortex dynamics in the wake of a finite surface-mounted square cylinder. Exp. Fluids, 52(5): 1149-1167.

Sarode, R. S., Gai, S. L. & Ramesh, C. K. 1981 Flow around circular- and square-section models of finite height in a turbulent shear flow. J. Wind Engng Ind. Aerodyn. 8: 223–230.

Okamoto, T. & Sunabashiri, Y. 1992 Vortex shedding from a circular cylinder of finite length placed on a ground plane. J. Fluids Engng 114: 512–521.