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Transient aerodynamic forces of 2D rectangular prisms under accelerating and decelerating flows

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SUMMARY:
This study adopted the multiple-fan wind tunnel facility to generate accelerating and decreasing flows to investigate the transient effects of square and rectangular prism models with a 1:5 breadth/depth ratio. Static pressures at different locations inside the wind tunnel are measured to improve the estimation precision of aerodynamic parameters. Results show that the transient effects caused by the accelerating flow are more evident than those by the decelerating flow, which may be due to the different variation behaviors of the background static pressures. The contribution of the acceleration-induced transient effects to the unsteady drag force is more significant in the square prism case than in the 1:5 rectangular prism case. Although both prisms show two apparent drag gusts when the acceleration occurs, the two drag gusts in the 1:5 rectangular prism are better separated. On the other hand, less drag force variation is indicated in the deceleration cases. The transient effects of the unsteady lift force are similar to those of the unsteady drag force, except that only one noticeable lift gust is indicated during the flow transition. The added mass coefficient, obtained by normalizing the unsteady forces with the product of the air density and the prism cross-section, is found to be a time-variant parameter in this study.

Keywords: accelerating flow, decelerating flow, unsteady aerodynamic force

1. GENERAL INSTRUCTIONS

The non-stationary features of natural winds include sudden changes in wind directions and speeds. Such transient effects on bluff-body aerodynamic characteristics have been studied for decades. For the transient aerodynamic impact, earlier works, such as Sarpkaya and Kline (1982), Sarpkaya and Ihrig (1986), and Shirato et al. (2009), have discussed the aerodynamic coefficient variations of two-dimensional bluff bodies under accelerating or impulsively-started flows. Results showed that the transient effects on the drag or lift coefficients depend on the breadth/depth ratio of the immersed bluff bodies and the wind attack angles. Later, Takeuchi and Maeda (2013) conducted wind tunnel experiments to investigate a three-dimensional elliptic cylinder's drag and lift coefficients under accelerating flows when the attack angle is 45°. Yang and Mason (2019) discussed the transient effects of three two-dimensional rectangular prisms under several accelerating flows.

This study intends to investigate the transient effects on the aerodynamic characteristics of two-dimensional bluff bodies with the fundamental concept of the steady Morison equation. The multiple-fan wind tunnel at Tamkang University helps simulate accelerating and decelerating flows in this study. Since the drag and lift forces of the testing models are estimated from the surface pressures measured by the SCANIVALE equipment, it is essential to understand how the static pressure varies in steady and unsteady flows. Ground-mounted pressure tubes and two Pitot tubes are set up for static pressure measurements under steady or unsteady flows at various locations. The unsteady contribution induced by the flow transitions is calculated by extracting the pseudo-steady forces from the total measured forces. The added mass coefficients are then estimated by normalizing the unsteady contribution by the air density and the prism cross-section.

2. EXPERIMENTAL SETTING

Experiments were conducted in the multiple-fan wind tunnel (MFWT) at Tamkang University. The MFWT is an actively controlled blow-down tunnel with seventy-two individual motor-fan units, twelve in one column and six in one row. Each motor-fan unit comprises a servo motor and a 22-cm-in-diameter fan in its independent channel. The testing section has a sectional size of 1.32 m in width and height and 5.6 m in length downwind of the inlet entrance. Accelerating or decelerating flows are producible by modifying the rotational frequency of fans in each row, with some lateral variability in fan frequency introduced to promote mixing. Without finer screens, the inherent turbulence intensity of 3% is identified. Fig. 1 shows the ensemble-averaged wind speeds of accelerating and decelerating flows and their derived accelerations in this study. In an actively controlled wind tunnel with a short test section, the static pressures inside the tunnel chamber may differ from a suction-type one with a long test section. Pressure tubes are installed on the floor from upstream to downstream to measure the static pressures under steady or unsteady flows. Fig. 2 shows the ensemble-averaged static pressures at different locations corresponding to the geometries of the applied rectangular cylinders. Traditionally static pressures are measured less invariantly with time. However, for accelerating or decelerating flows, the reaction of static pressures at different locations may behave accordingly, leading to a bias when calculating aerodynamic parameters. To better describe the aerodynamics when flow transitions occur, this study considers a better calibration of static pressure inside the wind tunnel.

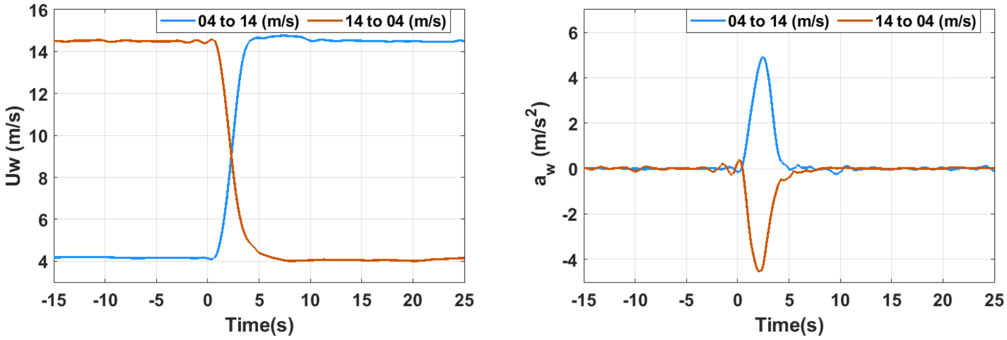

Figure 1. Unsteady windspeed variations (left) and derived accelerations (right)

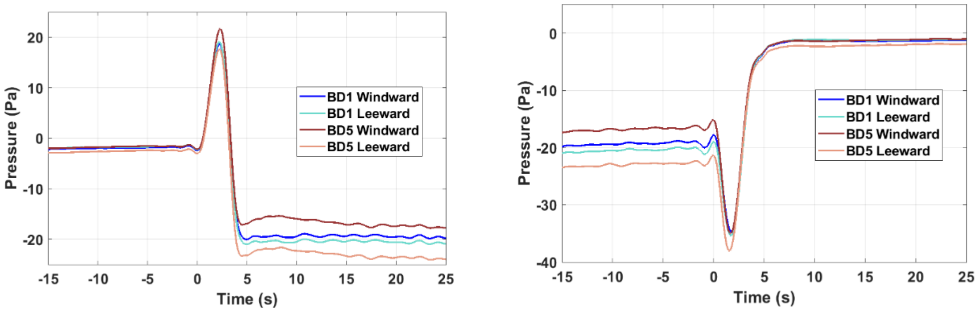

Figure 2. Static pressure variations of unsteady flows at specific locations: accelerating flow (left) and decelerating flow (right)

The testing models include one square and one rectangular prism model with a breadth/width ratio of 5. The wind attack angle remains 0 degrees for simplicity. Drag and lift forces are estimated by integrating all the circumferential pressures with their weighting lengths and extracting the corresponding static pressures in the background.

3. DISCUSSIONS

The Morison equation explains that when the bluff body is immersed in a flow with constant acceleration, the total drag or the lift force exerted on the bluff body can be estimated by the following equation by two components:

$$F_{total} = F_{steady} + F_{unsteady} = \frac{1}{2} C \rho A u^2 + C_M \rho V_M \frac{du}{dt} \qquad (1)$$

where C the aerodynamic coefficient depending on drag or lift; ρ the air density; A the projected area; u the wind speed; C_M the added mass coefficient depending on the shape of the bluff body; V_M the volume of the bluff body; and du/dt the derived acceleration. Fig. 3 shows the unsteady component $F_{unsteady}$ of Eq. (1) with respect to the normalized time. The total force F_{total} can be obtained by integrating the circumferential pressures with their weighting lengths. The steady component is estimated for the ensemble-average windspeed at each time instant by interpolating steady forces at each integral windspeed. In this study, we have conducted the steady force measurements of two prism models at steady wind speeds from 3 m/s to 15 m/s, guaranteeing the interpolation's efficiency. From Fig. 3, the transient effects caused by the accelerating flow are more evident than those by the decelerating flow, which may be due to the different variation behaviors of the background static pressures. The contribution of the acceleration-induced transient effects to the unsteady drag force is more significant in the square prism case than in the 1:5 rectangular prism case. Although both prisms show two apparent drag gusts when the acceleration is about to end, the two drag gusts in the 1:5 rectangular prism are better separated. On the other hand, less drag force variation is indicated in the deceleration cases. The transient effects of the unsteady lift force are similar to those of the unsteady drag force, except that only one noticeable lift gust is indicated during the flow transition.

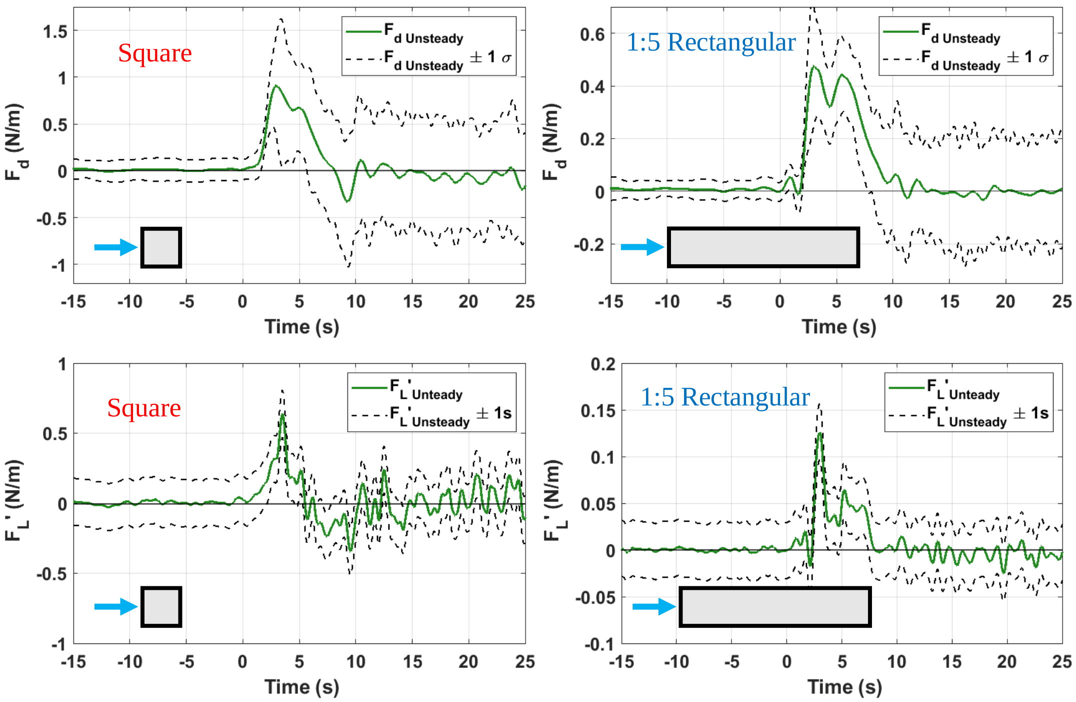

Figure 3. Unsteady contributions due to acceleration-induced transient effects: (top) mean drag forces and (bottom) fluctuating lift forces

4. CONCLUSIONS

This study indicates that the added mass coefficient, obtained by normalizing the unsteady forces with the product of the air density and the prism cross-section, is a time-variant coefficient, which is inconsistent with a constant of 1.51 (Blevins, 2001). The full paper or oral presentation will reveal more detailed information, including the CFD simulation results.

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