Aerodynamic characteristics of high-rise buildings under nose-like velocity profiles

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SUMMARY:
This study investigates the aerodynamic characteristics of high-rise buildings with various depth and aspect ratios under a nose-like velocity profile simulated in an actively controlled multiple-fan wind tunnel. The kinematic effect caused by such an inversely boundary layer flow is one of the essential factors in estimating the design wind loads of buildings in thunderstorm-prone areas. The experiments in this study are set up for two stages: (1) preliminary investigation of overall wind forces on the CAARC building and (2) detailed investigations of geometric dependence due to the aspect ratio ($H/\sqrt{BD}$) from 4 to 8, and the depth ratio (D/B) from 0.2 to 5. The preliminary results show that the nose-like profile has resulted in different pressure distributions on the sides and the leeward faces compared to the conventional boundary layer flow. When the approaching wind is normal to the broader windward face, the narrower side faces limit the development of the vortex and significantly lessen the across-wind force. On the contrary, the across-wind force is less invariant with the attack angle in the conventional boundary layer flow. The results in the second stage will further comprehend the essential roles of the depth and aspect ratios in the nose-like profile.

Keywords: Nose-like profile, multiple-fan wind tunnel, CAARC buildings

1. INSTRUCTION

Wind-induced damage to structures comes from various climatologic conditions. Among these conditions, thunderstorms are the dominant phenomenon in many parts of the world. The modern discussion on the thunderstorm structure can be traced back to the 1950s. Later in the 1980s, Fujita (1985) defined the formation of downbursts. Based on accumulated monitoring data from three projects: NIMROD (1978), JAWS (1982), and MIST (1986), Fujita (1990) further indicated the nose-like flow profile of the radial outflows from a downburst and its transient feature during a short time. A framework suggested by Kwon and Kareem (2009) categorized the overall dynamic effects of structures due to a thunderstorm wind into four elements: (1) kinematic effects, (2) rise-time effects, (3) non-stationary turbulence effects, and (4) transient aerodynamic effects. Among most works regarding the kinematic effects due to vertical profiles based on multiple-fan wind tunnels, only a few discussed the overall aerodynamic characteristics of structures immersed in a nose-like mean wind speed profile. Butler et al. (2010) employed a multiple-fan wind tunnel to investigate the kinematic and transient effects of variations within the boundary layer flow field on the pressures of three building models with different aspect ratios. Considerable differences were addressed when the short-time transition between the traditional boundary layer flow and the gust front profile. Although the mean and fluctuating pressure coefficients over the building surfaces have been illustrated, the overall aerodynamic effects, for example, in the across-wind or torsional directions, due to the nose-like profile, have not been examined in detail compared with the traditional boundary layer flow.

This study intends to investigate the kinematic effects of a steady nose-like profile flow on buildings with various depth ratios and aspect ratios. Experiments are arranged for two stages: (1) preliminary investigation of overall wind forces of the CAARC building under a steady nose-like profile flow and a steady conventional boundary layer flow, (2) detailed investigation of geometric dependence due to the aspect ratio ($H/\sqrt{BD}$) from 4 to 8, and the depth ratio (D/B) from 0.2 to 5. Due to the page limitation, the preliminary results in the first stage are introduced in this extended abstract. The results in the second stage will be detailed in the full paper or the oral presentation. Section 2 presents the experimental setting based on the multiple-fan wind tunnel at Tamkang University. Section 3 shows the vertical characteristics of the simulated flows. Section 4 presents the aerodynamic characteristics of the pressures over four faces and the base moments of the CAARC building. Finally, Section 5 concludes what was observed in the preliminary results and briefly introduces the geometric appearance of buildings in the second stage.

2. EXPERIMENTAL SETTING

Experiments were conducted in the multiple-fan wind tunnel (MFWT) at Wind Engineering Research Center 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. Various incidental velocity profiles 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 to smoothen the inherently generated turbulence, an average value of 3% turbulence intensity is identified for any cross-section in the second and third chambers. The building model in the first-stage experiments is the CAARC building with a 1/400 length scale, as shown in Figure 1. All pressure taps are distributed at 11 elevations and on the rooftop surface, totaling 384. The SCANIVALE micro-pressure scanning system simultaneously measured pressures over the surfaces of the model at a sampling rate of 300 Hz. An ensemble collection of one hundred and twenty runs of ten-minute sample records at the field scale was attempted to ensure statistical stability. Wind incidence is assumed to be 0 or 90 degrees to show the depth ratio effect on the aerodynamic forces.

3. VERTICAL CHARACTERISTICS OF SIMULATED FLOWS

Figure 2 shows the vertical profiles of two simulated flows – 1) a boundary layer flow with the mean velocity profile of a standard open terrain (terrain C specified in Taiwanese Wind Code) but with low turbulence intensity in the approaching winds (hereafter: ABL). and 2) a nose-shaped mean velocity profile, representative of a thunderstorm outflow-like wind field, exhibiting low levels of turbulence throughout its depth (hereafter: TS). The TS flow is designed to have the same maximum mean wind speed as the ABL. Besides, the ABL and TS flows are intended to have the same average value of all mean wind speeds over the building height range. These two assumptions are for the same comparison standard in the subsequent discussions. Nearly zero mean wind speeds are observed in the lateral and vertical directions. The simulated TS flow is also compared with the empirical models proposed by Vicroy (1991 and 1992) and Wood et al. (2001), giving the same assumption of the maximum wind speed and its corresponding height. Despite the slight difference in Figure 2, the authors consider the simulated TS flow acceptable since the accumulated field data of such a nose-like profile is still insufficient. The fluctuating wind speeds are almost uniformly distributed over the model height; therefore, the calculated turbulence intensities differ in the two flows due to the profile shapes of the mean wind speeds. Due to the page limitation, turbulent characteristics are provided in the full paper or the oral presentation.

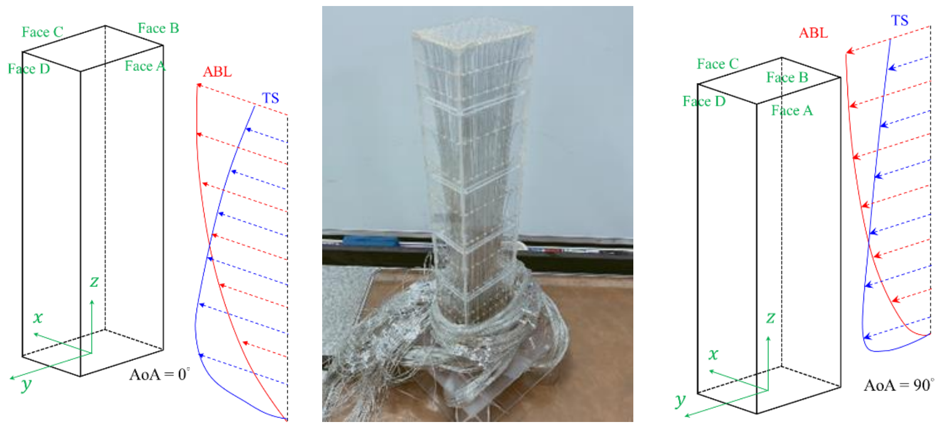


Figure 1. Diagram of the CAARC building model and its photo.

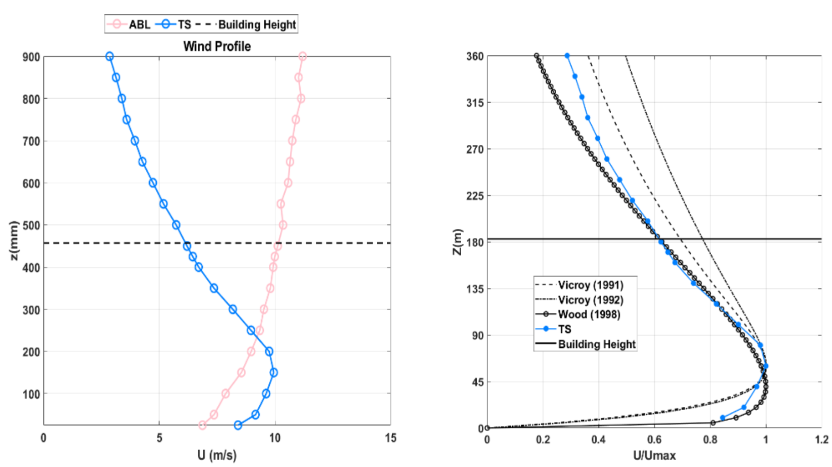
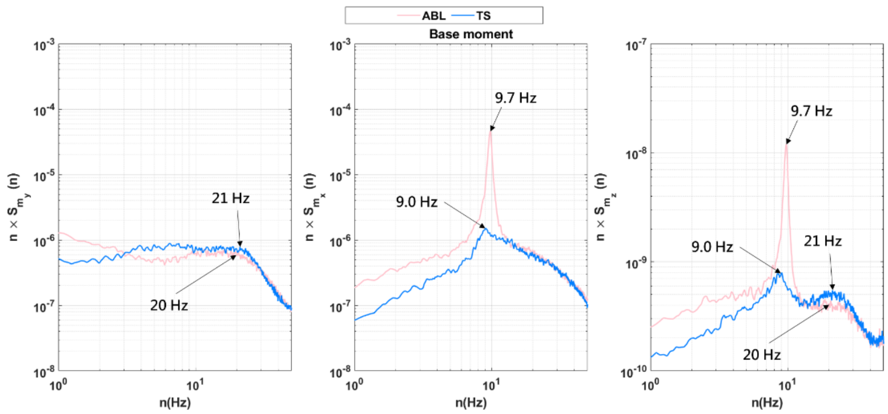


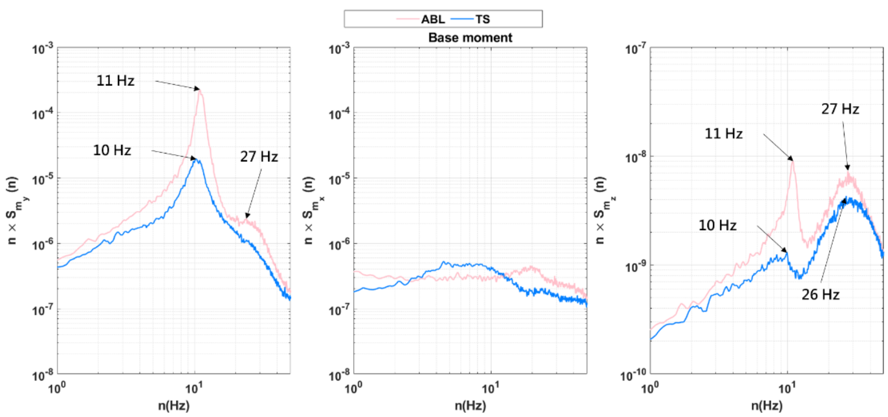
Figure 2. Mean wind velocity profiles of simulated ABL and TS flows.

4. AERODYNAMIC CHARACTERISTICS OF THE CAARC BUILDING

The spectra of the along-wind and across-wind forces in the TS flow show low spectrum areas when the attack angle is 0°, particularly the across-wind force spectrum. Compared to the sharp peak at 9.7 Hz in the across-wind force spectrum in the ABL flow, a relatively small spectral peak at 9 Hz is found in the TS flow. On the contrary, when the attack angle turns 90°, the spectral peaks in the across-wind force spectra are considerably sharp in both flows. Higher dependence on the depth ratio is confirmed in the TS flow rather than in the ABL flow. Further, the tendencies in the torsional spectra in the TS flow are also different from that in the ABL flow.



(a) AoA = 0°



(b) AoA = 90°

Figure 3. Base moment spectra for ABL and TS flows.

5. CONCLUSIONS

Except for the aspect ratios mentioned in Butler et al. (2010), the preliminary results based on the CAARC building in this study have also shown the high dependence of the depth ratio on the aerodynamic characteristics due to the shape effects of the nose-like profile flows. Detailed information regarding these two effects will be presented based on the second-stage experiments in the full paper or the oral presentation, including the depth ratios of 0.2, 0.25, 0.33, 0.5, 0.67, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0 and the aspect ratios of 4, 5, 6, 7, 8.

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