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Downburst Outflow Generation in Boundary Layer Wind Tunnel Using a Multi-Blade Flow Control Device

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SUMMARY:
This study focused on the generation of downburst outflows in the conventional boundary layer wind tunnel with a multi-blade flow control device. The installed device in the test chamber of the wind tunnel redirected the flow with the rotation of the blades to produce a transient gust front. The blades were controlled to be rotated in a flexible manner to obtain desirable wind velocity profile of downburst-like outflows with a larger scale for wind tunnel test. Following the rotation time history of the blades, the generated nonstationary wind velocity time history provided a reasonable input for characterizing transient aerodynamics effects on the high-rise buildings and bridge decks. The experimental results exhibited a similar profile and transient features to those of full-scale downburst events.

Keywords: downburst outflow, multi-blade flow control device, wind tunnel

1. INTRODUCTION

Downbursts characterized by intense, nonstationary wind fields are significant phenomena in wind engineering requiring further study. Recent researches indicate that the wind velocity fields generated from downbursts can impart high-intensity loads onto civil infrastructures (Le and Caracoglia, 2019). The replication of a downburst requires the advancements in wind tunnel technologies (Letchford et al., 2002). To tackle this objective, the special facilities for the simulation of downburst were constructed, in which the flow was expelled in a vertical direction to cause its impingement on a horizontal floor (e.g. Wood et al., 2001; Chay et al., 2006; Kim and Hangan, 2007). However, the wind scale generated from these facilities was limited, especially for the downburst-induced effects on the structure. Though a larger-scale WindEEE Dome was constructed for the simulation of nonsynoptic wind events (Hangan et al., 2017; Refan and Hangan, 2016; Elawady et al., 2017), the cost is extremely high. Alternatively, Butler and Kareem (2007, 2009) introduced a sloped flat plate in the conventional wind tunnel, which accelerated the flow near the floor for the generation of the downburst-like wind profile. Subsequently, Le and Caracoglia (2019) and Aboutabikh et al. (2019) used a multi-blade flow device to simulate the downburst outflows in traditional wind tunnels with the synchronous rotation of blades. An important merit of above technique is that it only requires a minor modification to the traditional wind tunnel.

Inspired by Le and Caracoglia (2019) and Aboutabikh et al. (2019), this study designed an apparatus that can be installed within the test chamber of a traditional wind tunnel to replicate the main features of the wind profile and wind velocity time history of downburst outflows. To obtain a desirable wind velocity profile of downburst-like outflows, the blades were rotated in a flexible manner. In addition, the nonstationary wind velocity time history could be generated for the experimental examination of transient aerodynamics effects on high-rise buildings and bridge decks by following the prescribed rotation time history

2. MULTI-BLADE FLOW CONTROL DEVICE

The small-scale boundary layer wind tunnel at Jiangsu University is shown in Figure. 1. The dimensions of the test chamber are 350×350 mm with maximum flow speed of approximately $20 \mathrm{m/s}$. The multi-blade flow device is inserted within the cross-section of the test chamber. Four equally spaced 340×78 mm flat blades are controlled by two servo motors that are mounted outside of the test chamber (Figure 2). The angular speed of rotation can be up to approximately $3\ \mathrm{rev/s}$. The wind speed measurements are obtained with multi-hole pressure probes (Cobra Probes) that simultaneously record wind speed time series in the along-wind and the cross-wind directions of the horizontal plane at a sampling rate of 1250 Hz.

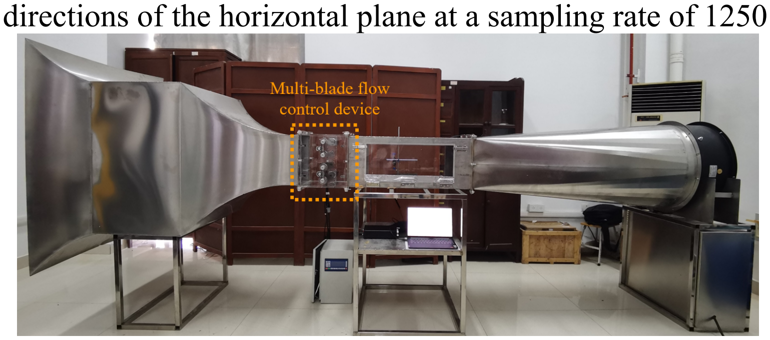

Figure 1. Wind tunnel with multi-blade flow control device.

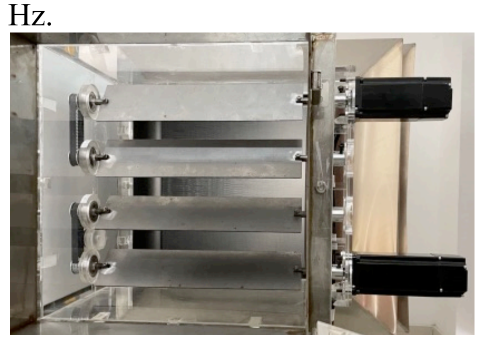

Figure 2. Multi-blade flow control device.

3. EXPERIMENTAL RESULTS

3.1. Vertical Profile of Horizontal Wind Speed

3.1.1. Wind profile with a constant rotation angle of blades

The downburst-like outflows could be obtained with redirection of the flow in the test chamber by the rotation of blades. The wind velocity profile of downburst-like outflows was presented in Figure 3. As shown in the figure, the downburst-like outflows present more significant nose-like features with larger rotation angle of all blades, resulting lower height (h_{max}) at which maximum wind velocity occurs. It is noted that the undesirable wind velocity profile with a small rotation angle could also be observed, which means the wind profile with high h_{max} would be hard to be obtained. The reason behind the observation may be that the flows failed to merge together as a unified flow due to slight redirection.

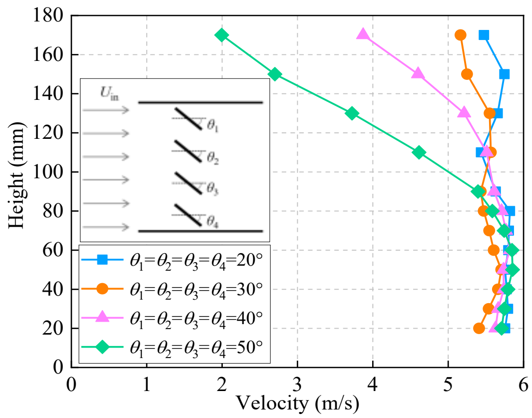

Figure 3. Simulation of wind profile with a constant ration angle

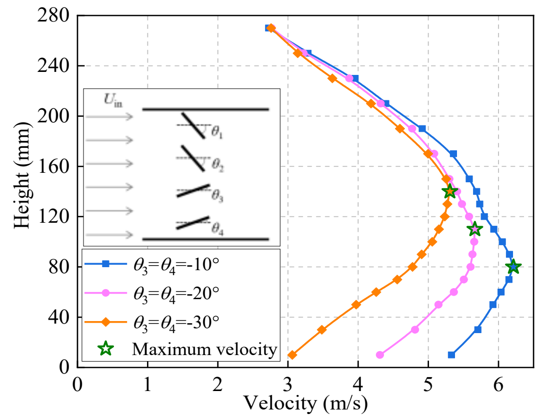

Figure 4. Simulation of wind profile with different rotation angles

3.1.2. Wind profile with various rotation angles of blades

To obtain a desirable wind velocity profile of downburst-like outflow with higher h_{max}, the blades were rotated in different angles to facilitate the misture of the flows. The wind velocity profile of downburst-like outflows was presented in Figure 4. The improved simulation performance and higher h_{max} of the simulated wind profile could be obtained with different rotation angles of blades.

3.2. Horizontal Wind Speed Time History

3.2.1. Wind speed time history for high-rise buildings

To produce a transient gust front, the blades of the flow device, starting from an initial position (horizontal blade), were rapidly angled downwards and then return to their original position. These actions produce a sudden variation trend in wind velocity. Following the rotation time history of the blades plotted in Figure 5, the wind velocity at the bottom of test chamber were measured (Figure 6). Clearly, the measured wind velocity time history presents significant nonstationary features, which are similar to the wind record of the AAFB downburst.

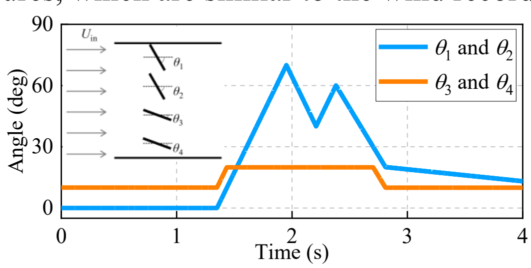

Figure 5. Rotation time history of blades.

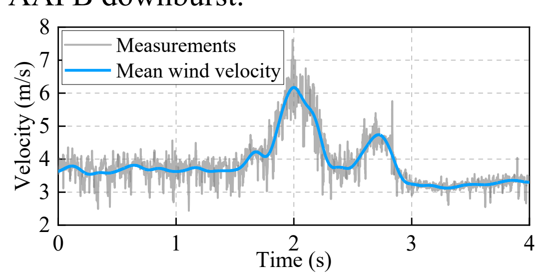

Figure 6. Wind velocity time history measured at the bottom of test chamber.

3.2.2. Wind speed time history for bridge decks

To investigate the transient aerodynamics effects on the bridge decks, the blades were controlled following the rotation time history plotted in Figure 7 to produce nonstationary wind velocity time history at the mid of test chamber. The wind velocity time history measured at the mid of test chamber was presented in Figure 8. Similar to the measurements at the bottom of test chamber, the measured wind velocity time history also presents significant nonstationary features, which also suggests that it can provide a reasonable input for the analysis of nonstationary wind-induced bridge deck response.

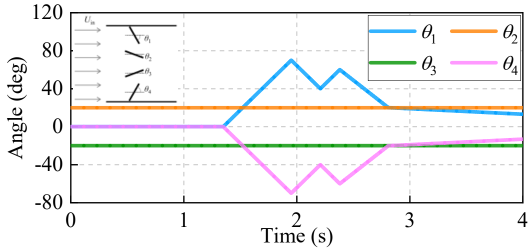

Figure 7. Rotation time history of blades.

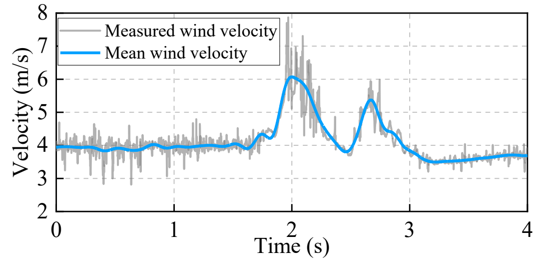

Figure 8. Wind velocity time history measured at the mid of test chamber.

4. CONCLUSIONS

With the implementation of a multi-blade flow device, a downburst-like outflow was replicated in a conventional wind tunnel in this study. The wind velocity profile of downburst-like outflows with high h_{max} was obtained by rotating the blades at different angles, which could provide reasonable wind input in larger-scale wind tunnel tests. In addition, the method to produce nonstationary wind velocity was proposed, aiming to investigate the downburst-induced effects on the high-rise buildings and bridge decks, respectively. The experimental results exhibited similar wind profiles and transient features to those of full-scale downburst events.

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