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Characteristics and Performances of a Newly-Built Actively-Controlled Multiple-Fan Wind Tunnel

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Abstract

An actively controlled wind tunnel with 120 fans has been recently built in Tongji University, China, in order to reproducing the atmospheric boundary layer more accurately for wind-resistant designs. Design parameters of the wind tunnel were described. Static and dynamic performances of the generated flows were investigated, including the verification of the uniformity of the uniform flow, the reproduction of the shear flow, the frequency responses of the sin wave flow, and the response of a sudden gust. All the investigations showed that this specially designed wind tunnel can properly reproduce the atmospheric boundary layer, especially for the specific wind flows that may cause severe wind-induced disasters.

Introduction

With the development of refined wind-resistant theory and design methodology and recent attention of wind engineering community on non-synoptic wind effects [1, 3], a new type of wind tunnel, called multiple-fan actively-controlled wind tunnel, has been developed to generate a turbulent flow with controlled characteristics [2, 4]. There are two distinctive features of this type of wind tunnel: (1) it can more accurately reproduce turbulent flows with high turbulence intensity and large integral length scale, as well as other special wind flows like strong shear flows and transient flows; and (2) it can generate time-varying flow fields by controlling the rotation speed of the fans with the input of wind velocity time histories. As a country with many severe wind events and largest-scale infrastructure constructions in the world, China has recently built its first multiple-fan actively-controlled wind tunnel. The present paper describes the design of this wind tunnel, investigates static and dynamic performances of flow fields to verify its quality.

Design of the multiple fan wind tunnel

The present facility (TJ-5 wind tunnel), designed by and located at the State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji Unviersity, is an open-circuit wind tunnel and composed of a multiple fan section, a settling chamber (including honeycomb and damping meshes), and test section with several movable sections, as shown in figure 1. The size of the test section is 1.5 m wide, 1.8 m high and 10 m long and the length can be adjusted by removing or inserting movable sections, depending upon the purposes of various experiments. The power system of this wind tunnel is composed of 120 fans arranged in a grid-like pattern (10 wide by 12 high arrays), as shown in figure 2. Each fan is driven by an AC servomotor of high quality through a computer and its rated power and speed are 550 W and 6000 rpm, respectively.

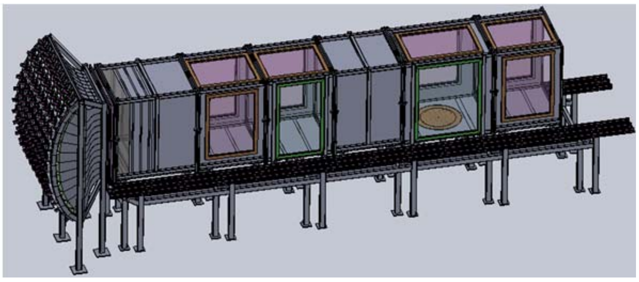


Figure 1. Sketch of TJ-5 wind tunnel.

Figure 2. TJ-5 wind tunnel.

Through the control system shown in figure 3, output of the motor, rotation speed, power and torque of the motor were displayed, and each fan can be individually controlled by setting control parameters on the interface or loading time histories.

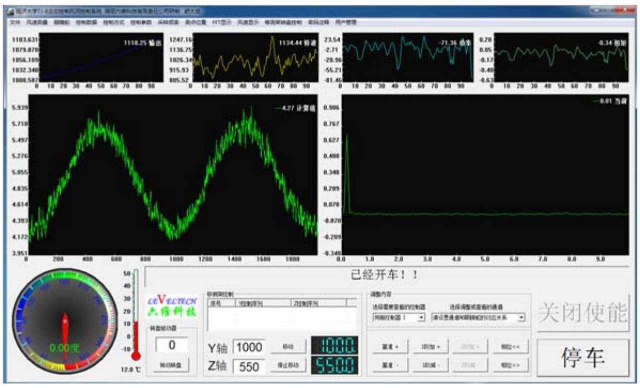


Figure 3. The operator interface of control system.

Static performances of the flow field

Conventional calibrations for the static performances of the flow field were carried out to verify the flow quality of the wind tunnel, including the maximum wind speed, stability of the dynamic pressure, static pressure gradient along the test section, uniformity of the wind velocity field and the wind direction field, the distribution of the turbulence intensity.

Table 1 summarizes the calibration results with and without damping meshes. The results validate that the damping meshes can significantly improve the can static wind quality. Besides the uniformity of velocity field, all the parameters related to static performances meet the requirements of design values and standard values in Chinese codes. During the calibration process, the power and control systems work well in the rated power range, which indicates the serviceability of the wind tunnel.

Static wind parameters	with damping mesh		without damping mesh
	target value	calibration value	calibration value
maximum wind speed	18	>18m/s	>24m/s
stability coefficient of dynamic pressure	/	≤1.0%	≤5.0%
uniformity in velocity field	≤1.0%	≤2.0%	≤3.0%
uniformity in direction field	/	$\lvert\Delta\alpha\rvert$<0.5° $\lvert\Delta\beta\rvert$<0.5°	$\lvert\Delta\alpha\rvert$<0.6° $\lvert\Delta\beta\rvert$<0.6°
turbulence intensity	≤1.0%	≤1.0%	≤3.0%
static pressure gradient	/	≤0.005/m	/

Table 1. Calibration results for the static performances.

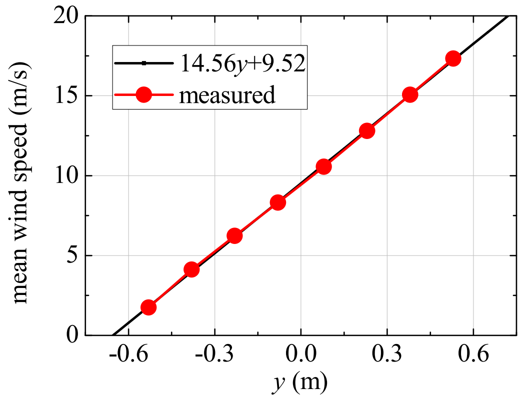
Dynamic performances of the flow field

Unlike conventional boundary layer wind tunnels, the multiple fan actively controlled wind tunnel is intended to simulate complicated wind velocity characteristics in the atmospheric boundary layer, such as severe shear flows, sudden accelerations and decelerations of wind velocities, flows with high turbulence intensity. For this wind tunnel, more attention should be paid on dynamic performances of the flow fields related to above special flow phenomenon, compared to static calibrations. Serials of tests on dynamic performances were carried out to evaluate the quality of the wind tunnel in reproducing special turbulent flows, including linearity tests of velocity gradient for shear flows, tests of sudden accelerations and decelerations in wind velocities, frequency response tests of sinusoidal wave flows and generation of wide-band wind velocity histories.

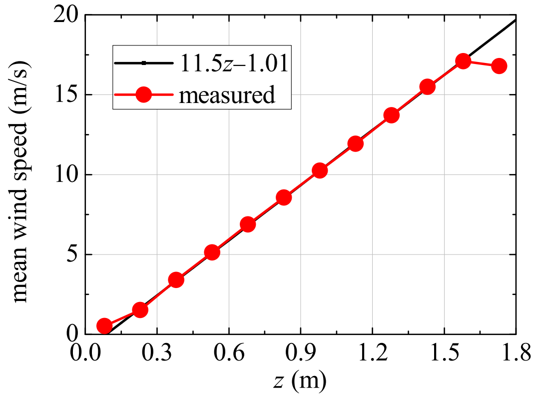
Simulation of shear flows

For special wind phenomenon such as tornadoes and downbursts, severe shear flows with very high velocity gradient exist within the height of the boundary layer (about 80~100m). By adjusting the rotation speed of each fan separately, this wind tunnel can be used for generalizing such shear flows conveniently.

Figure 4 gave an example of mean wind speed distributions when the rotation speeds of fans were linearly increased from 0 to 4000 rpm for different columns (figure 4a) and rows (figure 4b). The results of mean values of each column (figure 4a) and row (figure 4b) show good linearity of the shear flow in both horizontal and vertical directions, except the two measurement points near the wall of the tunnel.



(a)



(b)

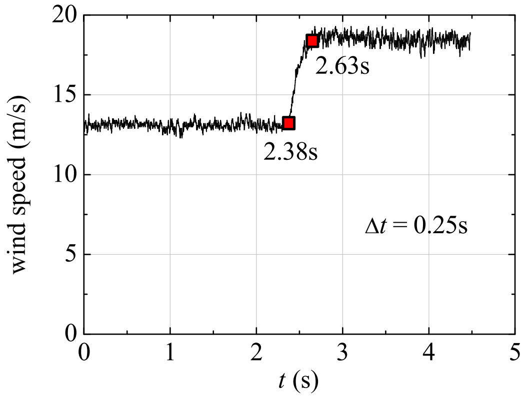
Figure 4. Linearity of shear flow in (a) horizontal and (b) vertical direction measured at 1m downstream from the damping meshes.

Simulation of a sudden velocity change

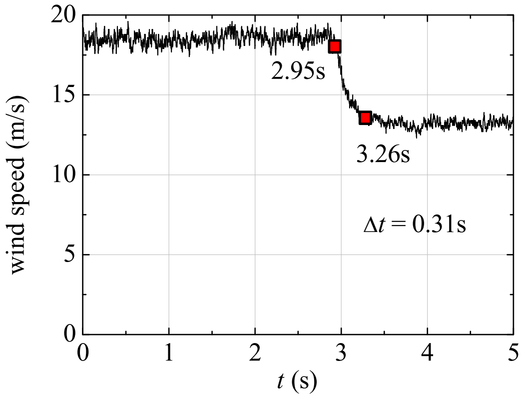
One of the advantages of multiple fan actively controlled wind tunnel is that the fan system, with small size, small inertia fore and fast response, can ope rate by the input signals in terms of time histories. Therefore, the rapidly varying flow field can be reproduced through the fan control of operation under severe acceleration and deceleration wind flows, and transient aerodynamic effects can be investigated accordingly. The performances of the wind tunnel under suddenly accelerated and decelerated wind flows were tested, focusing on the index of the time duration to respond such changes. The time duration of the velocity change for the input signal was shorter than 0.01s.

Two representative outputs were provided in figure 5 and 6, corresponding to the results at the same measurement location with different length of the test section: only one movable test block was assembled for figure 5 field and all assembled for figure 6. The results show that it takes 0.3s and 0.6s to accomplish the wind speed change from 12m/s to 17m/s at 1m downstream from the damping meshes, corresponding to the two test section assembling cases. The shorter the test section, the shorter time for responding the wind speed change. Moreover, compared to the input, the response time of the measured output is much longer.

More results with different background wind speeds were summarized in table 2, including both values for only one movable test block and all blocks assembled. Although the increase/decrease values in wind speed changes are same, the response time for the changes with high background wind speeds is far shorter than that for low background. The time durations for sudden accelerations are slightly shorter than those for decelerations and such discrepancy is significant when the background wind speeds are low.

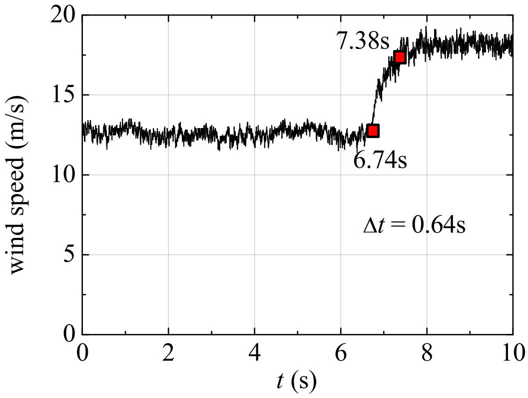


(a)

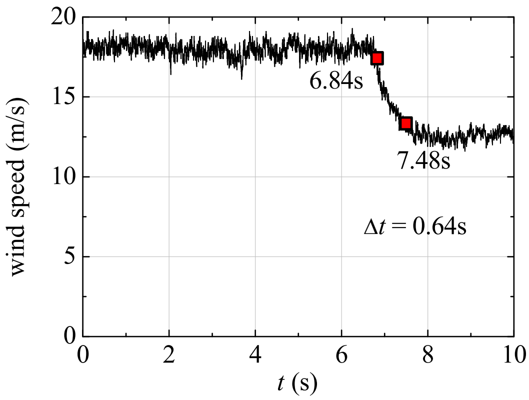


(b)

Figure 5. Velocity time history with a sudden velocity (a) increase and (b) decrease measured at 1m downstream from the damping meshes (only one movable test block was assembled).



(a)

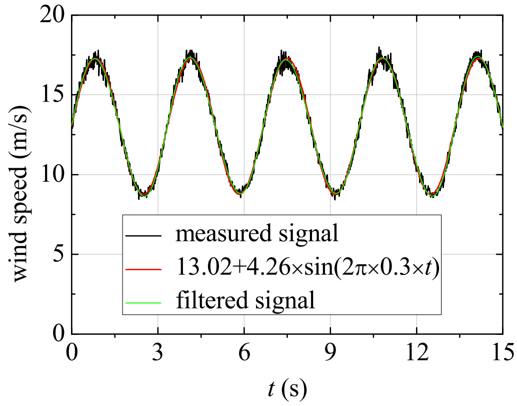


(b)

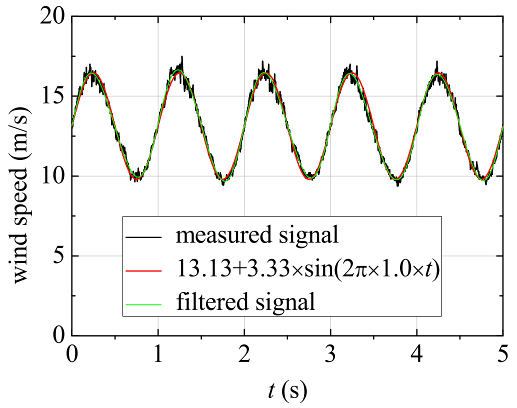
Figure 6. Velocity time history with a sudden velocity (a) increase and (b) decrease measured at 1m downstream from the damping meshes (all movable test blocks were assembled).

Velocity change	One section	All sections
0→5	1.16s	2.43s
4→9	0.51s	0.99s
8→13	0.38s	0.75s
12→17	0.25s	0.64s
17→12	0.31s	0.64s
13→8	0.51s	1.35s
9→4	0.82s	2.43s
5→0	1.60s	3.68s

Table 2. Response time for wind flows with a sudden velocity change.



(a)



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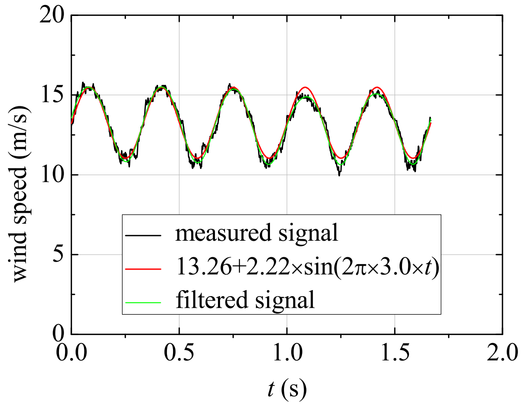


(c)

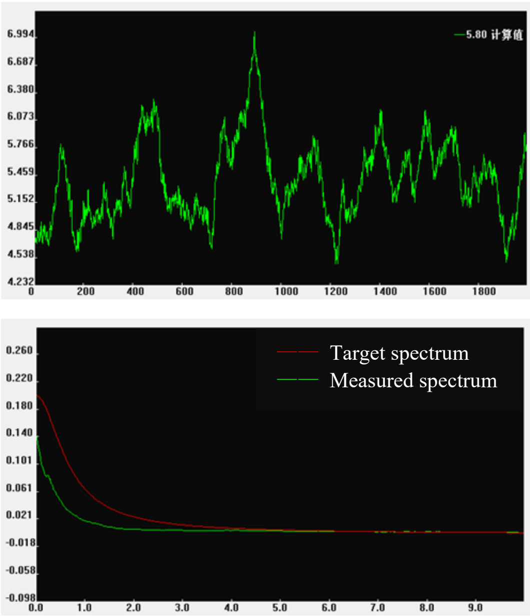
Figure 7. Velocity time history of the target sinusoidal wave flow with different circular frequencies: (a) ω = 0.3Hz; (b) ω = 1.0Hz; and (c) ω = 3.0Hz measured at 1m downstream from the damping meshes (only one movable test block was assembled).

Frequency responses of sinusoidal wave flows

Frequency response performances of this wind tunnel were investigated through reproducing sinusoidal wave flows. Various waves were generated by changing the parameters such as the mean wind speed, the amplitude and the circular frequency. Frequency response tests were carried out for different test sections along the axis of the wind tunnel.

From the comparison of the outputs with different circular frequency inputs in figure 7, the measure amplitudes, which are the same for three inputs, decrease with increase in circular frequencies. The amplitude becomes one half of the target value when the circular frequency is 3.0Hz. For the mean wind speed value of 13m/s, the wave shapes maintain well with the circular frequencies of 0.3Hz and 1.0Hz, and distortion of the shape is found when the circular frequencies is 3.0Hz, while the mean wind speeds almost do not change accordingly.

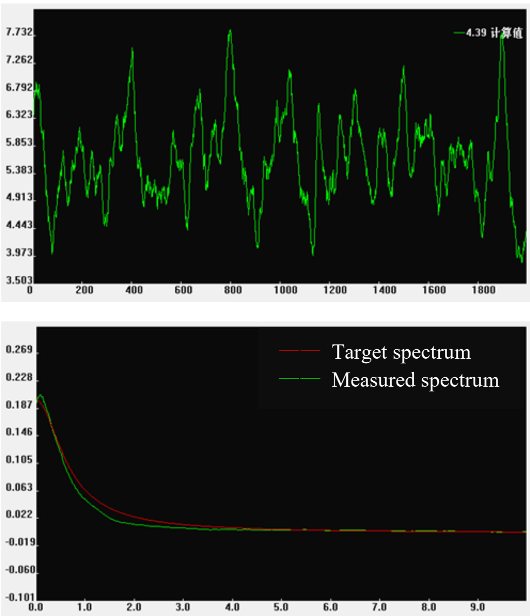
(a)



(b)

Figure 8. Generated (a) velocity history and (b) power spectrum without modification.

(a)



(b)

Figure 9. Generated (a) velocity history and (b) power spectrum after modification twice.

Reproduction of wide-band wind velocity histories

The process of reproducing a representative random velocity history with a wide-band power spectrum is same to that described by Cao et al. (2002). During the process, the modification of the input data of the fans through the modifications of the power spectrum and the phase was repeated until satisfied results are achieved. After setting the target statistical parameters such as mean velocity, turbulent intensity and integral length scale, the modification process can be automatically realized by the control system of this wind tunnel, including mathematically generating, modifying and judging the results. Moreover, this process can be displayed on the operator interface, as shown in figure 8 and 9.

Figure 8 and 9 provide one example of reproduced wind velocity history and its power spectrum without modification and after modification twice, respectively. The statistical parameters of the expected turbulent flow with von Karman spectrum were set as: U = 5 m/s, I_u = 10% and L_u = 0.1m. However, significant discrepancy can be found in figure 1(b) between the target and measured spectrum because of the response lag of the motors and the mass inertia of the air inside the wind tunnel. After modifying the input data twice, results shown in figure 2 achieve acceptable reproduction sicne the curve of the power spectrum of the measured flow agrees well with the target.

Conclusions

The first actively controlled multiple fan wind tunnel in China has been constructed in Tongji University, China, with 120 fans in total. In the rated power range, the power system and control system of the wind tunnel perform well. Through series of calibrations and tests on static and dynamic performances of the flow fields, the wind tunnel operates well after continual experiments. The test results indicate that this wind tunnel is applicable and serviceable for reproducing severe disaster-related wind flows with high turbulence intensity, strong shear, and rapid acceleration and decelerations.

Acknowledgments

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