

## Wind Tunnel Tests of Flow Structures and Peak Pressures over a Low-rise Building: Building a Dataset for CWE Model Validation

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### Summary

To enable Computational Wind Engineering (CWE) models to function as an independent tool for predicting peak wind loads on low-rise buildings, high-quality wind tunnel measurements of the three-dimensional flow field and corresponding surface pressures at high Reynolds numbers ( $Re$ ) are necessary. This work presents the conical vortical flow structures and rooftop surface pressure distributions over a 1:6 scaled TTU WERFL building model subjected to a 45° incoming wind, measured at the NHERI Wall of Wind (WOW) Experimental Facility at FIU. The roof-height Reynolds number  $Re_H$ , based on the wind speed at roof height, was close to those of full-scale tests, thereby reducing the scaling effects commonly encountered in conventional wind tunnel experiments. The dataset could serve as a test case for validating CWE models, particularly those aimed at accurately predicting peak wind loads under cornering-wind conditions.

**Keywords:** *CWE model validation, large-scale wind tunnel test, NHERI WOW EF, peak wind load, vortex structures*

## 1 INTRODUCTION

Thanks to rapidly increased computing power and improved numerical algorithms, substantial progress has been made in computational fluid dynamics (CFD) and computational wind engineering (CWE). However, the wind engineering community is still not ready to solely rely on CFD predictions for peak wind loading on low-rise buildings (Scott et al., 2023; Potsis et al., 2023). The main reasons include the following: (1) significant challenges are faced by even the most advanced CFD methods, such as Large Eddy Simulation (LES), in accurately simulating separated and vortex-concentrated turbulent flows at high  $Re$  (Bouffanais, 2010; Blocken and Gualtieri, 2012) and predicting localized peak wind pressures that induce substantial damage to Cladding and Components of low-rise buildings; (2) the study of the sensitivity of CFD modeling parameters and the verification and validation (V&V) procedure of the CFD models against qualified experimental data are still lacking. The essential first step to enable CWE modeling as an independent design tool for wind load entails robust CWE V&V, which is highlighted in Scott et al. (2023). This work reports a wind tunnel test case of flow structure and pressure measurements of a 1:6 TTU WERFL building model under cornering wind conditions, which could be used to validate relevant CWE models. Simultaneous turbulent flow and pressure measurements were conducted using volumetric Particle Image Velocimetry (PIV) to map the extent of three-dimensional flow and vortex structures, along with Scanivalve pressure measurements to capture peak pressure.

## 2 EXPERIMENTAL METHODS

### 2.1 ABL Flow Simulation in the Wall of Wind Experimental Facility

The NSF NHERI 12-fan Wall of Wind (WoW) Experimental Facility (EF) at Florida International University (FIU) simulated an ABL wind reaching a maximum speed of 71.5  $m/s$  (160  $mph$ ) in

the large test section of  $6.10\text{ m}$  (wide)  $\times$   $4.27\text{ m}$  (high). Incoming wind velocities were measured using a vertical rake of three TFI cobra probes at the turntable center at  $2000\text{ Hz}$ . At the roof height, the “High Speed” wind condition generates  $U_H = 22.12\text{ m s}^{-1}$ ,  $Re_H = 0.92 \times 10^6$ , and a turbulence intensity  $I_u = 13\%$ .

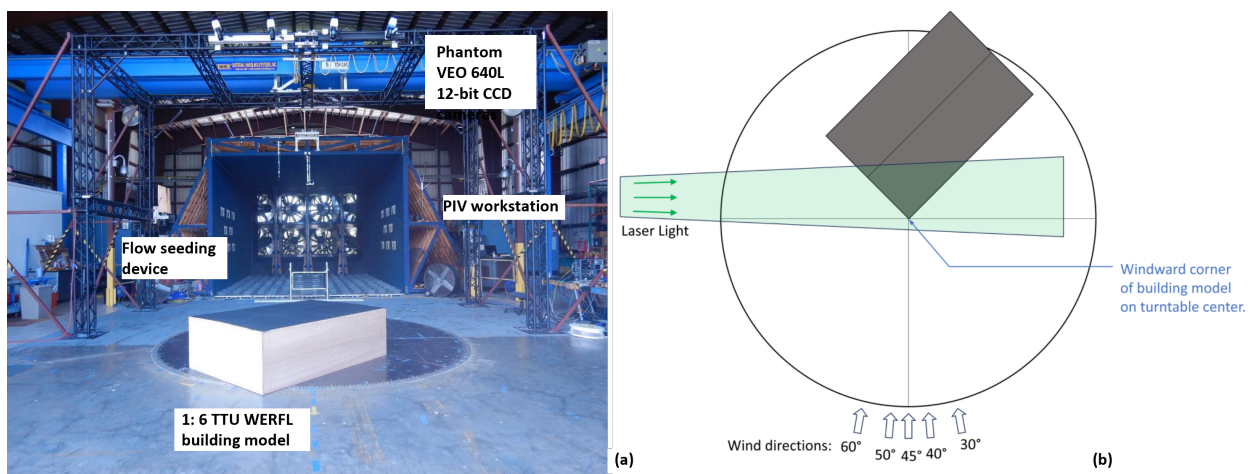
## 2.2 TTU WERFL Building Model

A 1:6-scale model of the Texas Tech University (TTU) Wind Engineering Research Field Laboratory (WERFL) building model was constructed with dimensions of  $L = 2.286\text{ m}$ ,  $W = 1.524\text{ m}$ , and ridge height  $H = 0.648\text{ m}$  (Fig. 1 (a)). In contrast to the 1:100 or 1:200 scaled building models, the 1:6 TTU building model allows for achieving near full-scale  $Re_H$ . The relatively large building model is also desirable for obtaining sufficient spatial resolution of pressure data by installing a high concentration of pressure taps at the corners and edges.

## 2.3 Synchronized Flow and Pressure Measurements

The wind pressure distribution on the roof surface was measured using a Scanivalve DSM4000 and ZOC33 pressure scanning system. A total of 228 pressure taps were installed on the model’s roof, with a higher tap density near the windward corner of interest.

Volumetric measurements of the rooftop flow field were conducted using a PIV system from LaVision, as shown in Fig. 1 (a). Flow seeding was generated by a Helium-Filled Soap Bubble (HFSB) Generator with a Linear Nozzle Array (LNA) system. Seeding particles were illuminated by the dual-head high-speed laser (Photronics Industries DM30-527H), with a wavelength of  $527\text{ nm}$  and an energy of  $2 \times 30\text{ mJ/pulse}$ . The volumetric optics projected light to the region above the windward roof corner of the building model on the turntable. Four Phantom VEO 640L 12-bit CCD cameras (with a spatial resolution of  $2560 \times 1600$  pixels) captured seeding particle images and were synchronized with the pressure measurement. Particle images were acquired with a field of view (FOV) of about  $1000 \times 1000 \times 200\text{ mm}^3$  (Fig. 1 (b)) using Tokina 100 mm F2.8 MACRO lens ( $f\# = 4$ ).

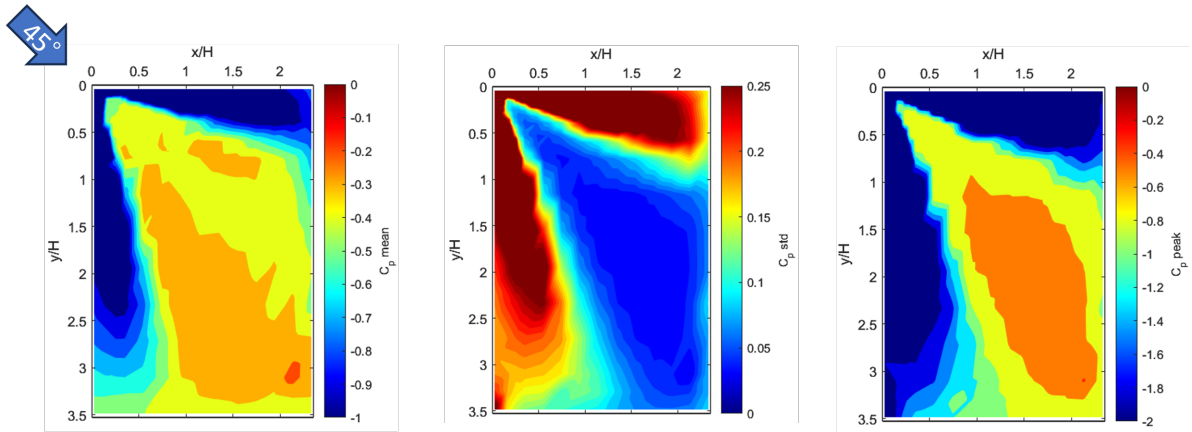


**Figure 1:** Experimental setup of volumetric flow measurement over the rooftop of the 1:6 TTU WERFL building. (a) Layout of instrument and data acquisition system; (b) Schematics of laser illuminated volume (top view from the upwind direction).

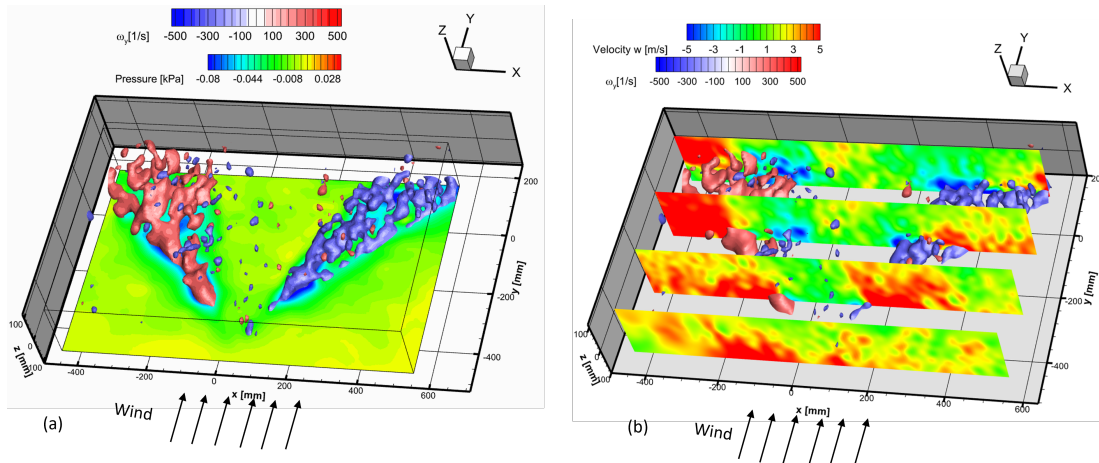
### 3 RESULTS AND DISCUSSION

Fig. 2 shows the statistics of surface pressure coefficients over the bare roof, which exhibit significantly stronger suction along the windward edges and roof corners induced by conical vortices. The region of dynamic vortices also has a higher standard deviation  $C_p'$ , as noted in Shelley et al. (2023). The baseline case shows a  $\overline{C_p}$  range of  $-4.43$  to  $-0.14$  and  $C_p'$  range of  $0.03$  to  $1.48$ . The peak pressure  $C_{p,peak}$  minimum is  $-8.74$ , which falls in the range of  $-4$  to  $-14$  in prior studies (Kopp et al., 2005; Moravej et al., 2024).

Counter-rotating conical vortices at the roof edges are depicted by iso-surfaces of vorticity component  $\omega_y = \pm 0.2$  1/s in Fig. 3 (a). Looking from upstream, conical vortices along the left roof edge rotate clockwise (*red color*), while those along the right roof edge rotate counterclockwise (*blue color*). The vortex strengths vary at the two roof edges and switch over time. Vertical slices of flow velocities are extracted in Fig. 3 (b), illustrating how the flow field varies from flow separation to vortex formation and, finally, to vortex breakdown.



**Figure 2:** Contour plots of mean pressure coefficient  $\overline{C_p}$  (left), standard deviation  $C_p'$  (middle), and peak pressure coefficient  $C_{p,peak}$  (right) over the bare roof at  $45^\circ$  wind and  $Re_H = 0.92 \times 10^6$ .



**Figure 3:** Rooftop vortical flows on the 1:6 TTU WERFL building at  $45^\circ$  wind and  $Re_H = 0.46 \times 10^6$ : (a) 3D instantaneous conical vortices indicated by  $\omega_y$ , and (b) extracted vertical slices of the flow field.

## 4 CONCLUSIONS

This work presents a wind-tunnel test focusing on the flow structures and surface pressures on a 1:6-scale TTU WERFL building model under 45° wind. The dataset of detailed inflow conditions, rooftop surface pressures and 3D flow structures can be used to support the validation of CWE models. To better serve as a comprehensive validation case or benchmark dataset, future improvements will include: (1) typical wind directions (0°, 45°, and 90°); (2) measurements of turbulent flow fields upstream of the building, along its sides, and in its wake; and (3) engagement with CWE modelers to co-design wind-tunnel experiments, ensuring complete inflow characterization and adequate spatial and temporal resolutions of the measured data based on the requirements of CWE models.

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