ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Terrain-induced and large-scale turbulence effects on the performance of wind mitigation strategies for low-rise buildings

Mokhtar O. Nasreldin [1], Pedro L. Fernández-Cabán [2,3], Sifat R. Khan [3]

[1]*FAMU-FSU College of Engineering, Tallahassee, FL, USA, nasreldin1.mokhtar@famu.edu*
[2] *FAMU-FSU College of Engineering, Tallahassee, FL, USA, plfernandez@eng.famu.fsu.edu*
[3] *FAMU-FSU College of Engineering, Tallahassee, FL, USA, sifatraihan.khan@fsu.edu*

SUMMARY:
Wind-induced damage to roof components of low-rise buildings is predominantly attributed to extreme suction (i.e., uplift) loads caused by vortices that develop when the oncoming wind flow impinges on the building envelope, resulting in flow detachment near roof corners and edges. Wind mitigation strategies for reducing roof suction loads (e.g., porous parapets, spoilers, etc.) have been experimentally evaluated and have shown promising results in alleviating uplift pressures for a limited number of idealized wind flow conditions. However, it is well-established that both the magnitude and spatial distribution of peak loads near separated flow regions are strongly linked to the small- and large-scale turbulent eddies embedded in the oncoming wind flow. This study leverages a novel flow-control instrument at the University of Florida (UF) NHERI Experimental Facility to modulate large-scale turbulent features of atmospheric boundary layer flows in the wind tunnel and better understand their impact on the intensity and distribution of wind loads on low-rise buildings. The instrument works in conjunction with an automated roughness grid, which enables precise adjustment of small-scale turbulence. Preliminary flow measurement experiments demonstrate how active control of the FFM can assist in the injection of large-scale (low-frequency) fluctuations into traditional BLWT flows.

Keywords: wind pressures, low-rise building, large-scale turbulence

1. INTRODUCTION

Wind-induced damage to roof components of low-rise buildings is predominantly attributed to extreme suction (i.e., uplift) loads caused by vortices that develop when the oncoming wind flow impinges on the building envelope, resulting in flow detachment near roof corners and edges. Wind damage mitigation approaches have primarily centred on retrofitting and strengthening roof components (e.g., installing additional fasteners or utilizing stronger adhesives) to protect the integrity of the building envelope against wind hazards (e.g., Prevatt et al., 2013; Datin et al., 2011; Henderson et al., 2013). However, the lifecycle of low-rise civil infrastructure brings about many unknowns associated with aging and deterioration of roof connections and components that can compromise their long-term performance. Therefore, resilience efforts must also incorporate wind load reduction strategies aimed at disrupting the flow structure around the building envelope to reduce the intensity of localized peak pressure extremes.

2. MOTIVATION

In the past several decades, wind tunnel researchers have tested and identified effective and relatively inexpensive methods to dramatically alleviate peak wind pressures developed in high suction roof zones (i.e., hot spots) of low-rise structures. Most of these methods are passive in nature and entail the inclusion of minor geometric alterations near roof edges/corners to disrupt the formation of strong conical vortices and mitigate wind-induced uplift loads. Some common mitigation strategies include parapet walls (solid, porous, cylindrical), spoilers (straight and curved), barriers, air foils, and others (e.g., Bitsuamlak et al., 2013; Aly and Bresowar, 2016; Azzi et al., 2020). Work performed in (Banks et al., 2000; Banks et al., 2001) reported reductions in peak suction forces exceeding 50% near roof edges when integrating spoilers or perforated parapets to a scaled model of the Wind Engineering Research Field Laboratory (WERFL) test building. However, it is well-established that both the magnitude and spatial distribution of peak loads near separated flow regions are strongly linked to the small- and large-scale turbulent eddies embedded in the oncoming wind flow (e.g., Li et al., 2018; Hillier and Cherry, 1981; Li and Melbourne, 1995; Saathoff and Melbourne, 1997; Tieleman, 2003).

2. METHODS

This study integrates a novel flow-control instrument, termed Flow Field Modulator or FFM (Figure 1), to modulate large-scale turbulent features of atmospheric boundary layer (ABL) flows in the BLWT. The instrument works in conjunction with an automated roughness grid (Terraformer), which enables fast and precise adjustment of small-scale turbulent properties. The FFM and Terraformer constitute the two primary flow conditioning devices of the BLWT at the University of Florida (UF) Natural Hazard Engineering Research Infrastructure (NHERI) Experimental Facility (EF - Award No. 2037725; see Catarelli et a., 2020).

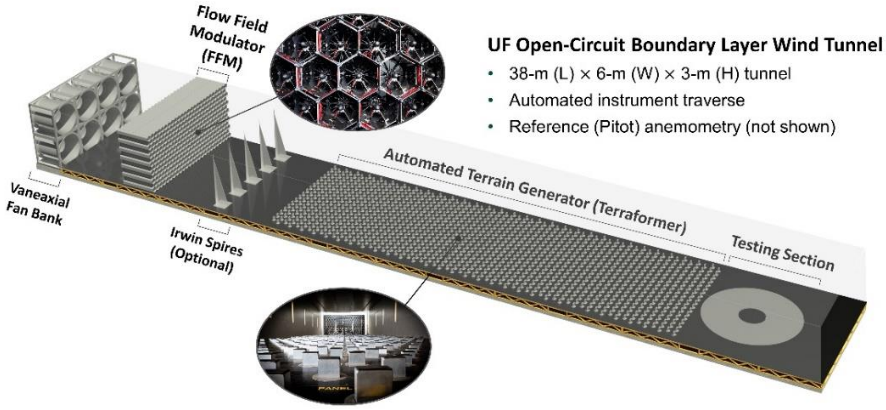

Figure 1. BLWT at UF EF depicting instruments generating small (Terraformer) and large-scale (FFM) turbulence.

The operation of the UF BLWT is fully automated, including the control of the FFM, Terraformer, and an instrument gantry system to collect velocity profile measurements. The large tunnel cross-section (6 m W × 3 m H) permits testing of large model scales to enhance spatial resolution of localized roof pressures, allow the inclusion of relatively small architectural features (e.g., parapets, spoilers, etc.), and test under higher Reynolds numbers than traditional BLWTs with negligible blockage effects. After proper calibration of the simulated wind field at the testing section, passive aerodynamic modifications will be introduced to the roof edges and corners of a baseline low-rise (WERFL) model. A series of aerodynamic (i.e., pressure) tests are planned to characterize the intensity and distribution of peak pressures near flow separation zones and their dependence on small- and large-scale turbulence (Figure 2).

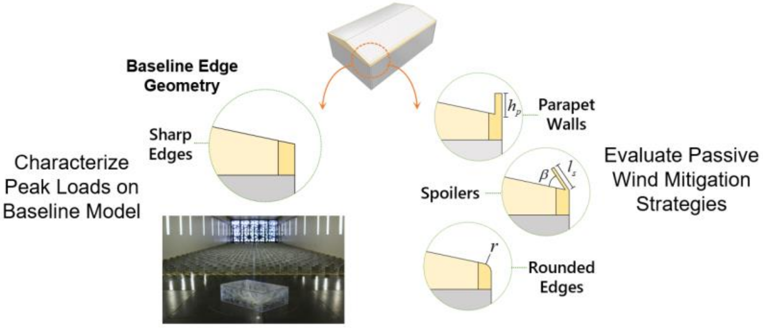

Figure 2. Roof edge/corner load mitigation strategies for the WERFL building.

3. PRELIMINARY RESULTS

Flow measurement experiments were recently conducted to benchmark the capabilities of the FFM for modulating large-scale turbulence structures in the BLWT. First, a constant velocity output was sent to all 319 cells and velocity measurements were taken immediately downwind of the Terraformer using Cobra probe sensors. The roughness elements were set to a uniform height of 30 mm for all the experiments. This first test represented the baseline case (i.e., traditional constant fan RPM). A 0.5 Hz (in-phase) sine wave signal was then fed to the controller of each individual fan to impart low-frequency velocity fluctuations. Finally, the 0.5 Hz sine wave was modified with a random phase to attenuate pronounced peaks at the dominant frequency. Figure 3 shows time histories of the longitudinal wind velocity and corresponding turbulence spectra measured at z = 650 mm above the tunnel floor. The measured spectra for the two sine waves reveal a broader distribution of turbulent eddies when compared to the baseline, with minimal effects on the inertial subrange. Further, these tests demonstrate how the low-frequency fluctuations are preserved as the flow travels over the 18.3 m Terraformer fetch.

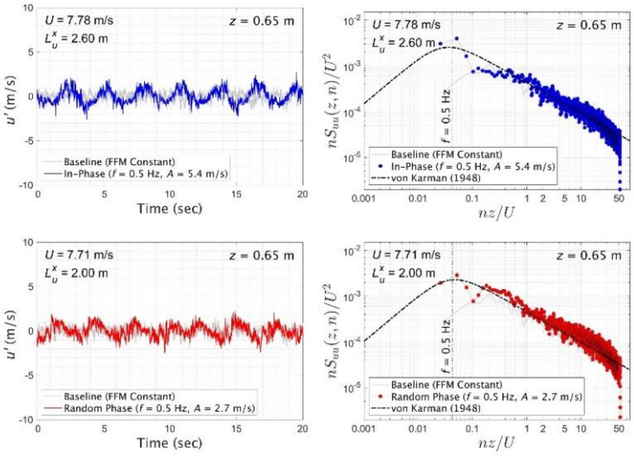

Figure 3. Time histories of wind velocity fluctuations and corresponding turbulence spectrum generated by the FFM and Terraformer roughness grid.

4. PRELIMINARY OBSERVATIONS AND FUTURE WORK

Preliminary flow measurement experiments demonstrate how active control of the FFM can assist in the injection of large-scale (low frequency) fluctuations into traditional BLWT flows. Initial observations indicate that, in some cases, integral length scales were doubled compared to the baseline case (i.e., no FFM-induced fluctuations). Additional flow measurements will be conducted to calibrate the flow at the downwind testing section and achieve autonomous convergence to target ABL spectra models. Following proper calibration of the approach flow conditions at the testing section, a series of aerodynamic tests performed on a low-rise (WERFL) building model are planned to map the effect of terrain-induced and large-scale turbulence of the extreme wind loading near flow separation zones.

ACKNOWLEDGEMENTS

This work is supported by the National Science Foundation (NSF) under Grant No. 2138414. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NSF.

REFERENCES

Aly, A. M., & Bresowar, J. (2016). Aerodynamic mitigation of wind-induced uplift forces on low-rise buildings: A comparative study. Journal of Building Engineering, 5, 267-276.

Azzi, Z., Habte, F., Elawady, A., Gan Chowdhury, A., & Moravej, M. (2020). Aerodynamic mitigation of wind uplift on low-rise building roof using large-scale testing. Frontiers in Built Environment, 5, 149.

Banks, D., Sarkar, P. P., Wu, F., & Meroney, R. N. (2001). A device to mitigate vortex induced rooftop suction. In Proceedings of the Ninth Americas Conference on Wind Engineering, Clemson University, Clemson, South Carolina (Vol. 10).

Banks, D., Meroney, R. N., Sarkar, P. P., Zhao, Z., & Wu, F. (2000). Flow visualization of conical vortices on flat roofs with simultaneous surface pressure measurement. Journal of Wind Engineering and Industrial Aerodynamics, 84(1), 65-85.

Bitsuamlak, G. T., Warsido, W., Ledesma, E., & Chowdhury, A. G. (2013). Aerodynamic mitigation of roof and wall corner suctions using simple architectural elements. Journal of Engineering Mechanics, 139(3), 396-408.

Catarelli, R. A., Fernández-Cabán, P. L., Masters, F. J., Bridge, J. A., Gurley, K. R., & Matyas, C. J. (2020). Automated terrain generation for precise atmospheric boundary layer simulation in the wind tunnel. Journal of Wind Engineering and Industrial Aerodynamics, 207, 104276.

Datin, P. L., Prevatt, D. O., & Pang, W. (2011). Wind-uplift capacity of residential wood roof sheathing panels retrofitted with insulating foam adhesive. Journal of architectural engineering, 17(4), 144-154.

Henderson, D. J., Morrison, M. J., & Kopp, G. A. (2013). Response of toe-nailed, roof-to-wall connections to extreme wind loads in a full-scale, timber-framed, hip roof. Engineering structures, 56,1474-1483.

Hillier, R., & Cherry, N. J. (1981). The effects of stream turbulence on separation bubbles. Journal of wind engineering and industrial aerodynamics, 8(1-2), 49-58.

Li, G., Gan, S., & Li, H. (2018). Wind pressure mitigation on gable roofs for low-rise buildings using spoilers. Journal of Structural Engineering, 144(8), 04018104.

Li, Q. S., & Melbourne, W. H. (1995). An experimental investigation of the effects of free-stream turbulence on streamwise surface pressures in separated and reattaching flows. Journal of wind engineering and industrial aerodynamics, 54, 313-323.

Prevatt, D. O., Shreyans, S., Kerr, A., & Gurley, K. R. (2014). In situ nail withdrawal strengths in wood roof structures. Journal of Structural Engineering, 140(5), 04014008.

Saathoff, P. J., & Melbourne, W. H. (1997). Effects of free-stream turbulence on surface pressure fluctuations in a separation bubble. Journal of Fluid Mechanics, 337, 1-24.

Tieleman, H. W. (2003). Wind tunnel simulation of wind loading on low-rise structures: a review. Journal of wind engineering and industrial aerodynamics, 91(12-15), 1627-1649.