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

Non-synoptic wind effects on buildings: Current perspectives on research and practice

Hatem Alrawashdeh [1], Theodore Stathopoulos [2]

[1]Department of Building, Civil, and Environmental Engineering, Concordia University,
Montreal, Quebec, Canada, hatem.alrawashdeh@concordia.ca
[2]Department of Building, Civil, and Environmental Engineering, Concordia University,
Montreal, Quebec, Canada, theodore.stathopoulos@concordia.ca

SUMMARY:
Based on recent non-synoptic wind research, experimental techniques and models were developed to study the effects of tornadoes and downbursts on buildings and structures. Specifically, the following aspects of non-synoptic winds are addressed in the paper: 1) laboratory modeling techniques of non-synoptic wind field from which design pressure coefficients are derived; 2) previous studies on low-rise buildings; and 3) development of provisions in current wind codes/standards.

Keywords: Non-synoptic, tornadoes, downbursts

1. GENERAL

Research on wind effects on structures has been mostly concerned with winds in large-scale storms, i.e., straight atmospheric boundary layer (ABL) winds. Non-synoptic winds are generally characterized by being of sub-synoptic scale (size < 1000 km, time < 1 day), higher wind speeds, and different recurrence intervals. In addition, the physics involved is much more sophisticated, with very complex flows.

The international wind codes and standards were developed for conventional wind conditions, i.e., straight ABL winds. Such presumption was not intended to embrace a simplified or idealized approach but to provide a more appropriate framework for design purposes satisfying the safety and economy of the design. Recently, however, spurred largely by (1) the awareness of the need to enhance the protection for life, socio-economic issues, infrastructure, and environmental considerations against non-synoptic windstorms for a better resilience, sustainability, and adaptation to climate change, and (2) research progress accompanied by better understanding of the tornados and downbursts via physical and computational studies, non-synoptic wind loads began to attract the substantial interest of the practicing profession, researchers, and wind code and standard committees.

2. LABORATORY MODELING FOR DOWNBURSTS AND TORNADOES

The complex behavior of a tornado vortex or a downburst and the physics involved, mainly being three-dimensional, transitionary, and non-stationary, posed many challenges to using the conventional scaling requirements and non-dimensional parameters adopted for atmospheric boundary layer wind tunnels (i.e., mean wind speed and Jensen number) for downburst and tornado simulators (Fujita, 1990). The variables of interest for scaling wind phenomena in physical laboratories primarily include the characteristic building dimension (D), the wind velocity (V), and time (T). The model scale (m) to the prototype (P) of these variables is defined as follows:

$$\lambda_L = D_m/D_P \tag{1}$$
$$\lambda_V = V_m/V_P \tag{2}$$

Based on the length (λ_L) and velocity (λ_V) scales, the time scale is determined as $\lambda_T = \lambda_L/\lambda_V$.

From a wind engineering perspective, where the ultimate concern is reliably duplicating the non-synoptic wind interaction with buildings, the use of these dimensionless numbers among the previous studies is discussed.

2.1 Downbursts

Two major types of simulation mechanisms have been developed in wind engineering to replicate the interaction between downbursts with buildings, including impinging jet (stationary and steady; stationary and transient; and translating with steady jet) and wall jet wind tunnel.

Most impinging jet simulations have a length scale defined as the ratio of the full-scale width of the downdraft flow to the width of the jet of the simulator and some other studies considered the height of the maximum velocity of the outflow as a reference dimension for the length scale. Adopting these variables has resulted in a wide spectrum of ratios among different simulators, as small as 1:3000-1:3500 (Mason et al, 2005) or as large as 1:700–1:1000 (McConville et al, 2009).

Several definitions also exist for what constitutes a reference velocity for λ_V in the downburst simulators, most used the maximum horizontal outflow velocity ($\lambda_V \approx 1{:}\ 1.7 - 1{:}\ 4$ in Mason et al, 2005) or the downdraft flow velocity ($\lambda_V \approx 1{:}\ 3.4$ in McConville et al, 2009). The most recent definition of the velocity scale based on the non-dimensional function $\gamma(t)$, introduced by Solari et al (2015), was adopted by WindEEE Dome. Based on the best similarity between the γ functions of full-scale and the simulator downburst, it was determined that the velocity scale and length scale are 2-4 and 100-500, respectively (Hangan et al, 2019; and Romanic et al, 2020).

2.2 Tornadoes

Many tornado simulators (or tornado vortex chambers) have been built to physically reproduce tornado-like vortices. Two types are distinct: Ward type (Ward, 1972) and IOWA State University Type Simulator (ISU) (Haan et al, 2008). The non-dimensional definition of the structure of tornado-like vortices in the laboratory is mainly governed by the swirl ratio (S). Other non-dimensional parameters also include radial Reynolds number (Re_r) and aspect ratio (a).

The paper will summarize the specifications and scales of the kinematic $(S,\ \lambda_V,$ and $Re)$ and geometric (λ_L) properties of the simulated tornadoes. That includes the various characteristic variables adopted for determining these quantities and the reference parameters for the simulation, considering (1) the three-dimensionality associated with the velocity of the tornadoes, (2) the physical simulator type and features, and (3) the reference field event adopted for modeling.

3. PROVISIONS IN CURRENT WIND CODES / STANDARDS

Most of the international wind codes and standards were originally developed for the conventional ABL flows because of their higher probability of occurrence compared to other types of extreme wind events. In the second last edition of the American Standard (ASCE/SEI 7, 2016), two methods were presented in the commentary to evaluate tornado-induced wind loads, namely the Extended and Simplified methods. The Extended Method basically involves the same procedure for wind pressures of conventional ABL flows, but the associated factors of the design velocity pressure and internal and external pressure coefficients are adjusted. In the Simplified Method, the changes on the equations and parameters used for conventional ABL flows are reduced into a single post-adjustment factor, identified as the “Tornado Factor (TF)”.

In the latest edition of the ASCE/SEI 7 (ASCE/SEI 7, 2022), a new chapter “Tornado Loads” addressing tornado-induced wind loads was included. In fact, a new procedure for evaluating wind loadings was introduced. It almost differs from the case of conventional winds in terms of wind load coefficients and equations to accommodate the differences in tornadic wind speed (V_T). Accordingly, it necessitates that the buildings for risk category III and IV located in tornado-prone regions be designed for tornados of approximately EF2 intensity or less (i.e., wind speeds between 26 m/s and 135 m/s) depending on geographic location and the tornado speed relative to basic wind speed. Fig. 1 illustrates the criteria for establishing whether the tornado loads are required (ASCE/SEI 7, 2022).

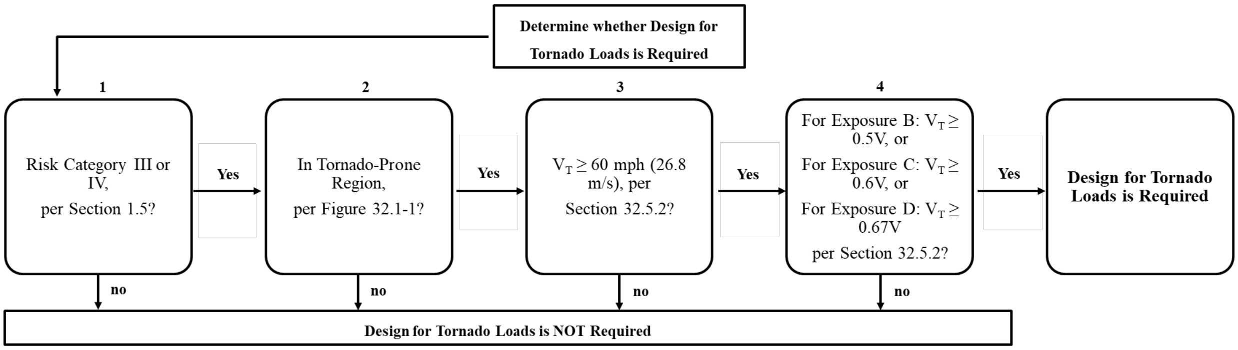

Figure 1. Flowchart of criteria for establishing whether the tornado loads are required (ASCE/SEI 7, 2022).

Generally, the wind loading design is dominated by tornado-induced loads for buildings designated as essential facilities/buildings with risk category III or IV, located in coastal areas typically exposed frequently to hurricanes (i.e., central, or southeast US), have large effective plan areas, and classified as “enclosed”. Conventional wind loads dominate over tornado-induced loads when the basic wind speeds are as large as one and a half of the tornado wind speed.

CONCLUSION

The perspectives are summarized as follows:

- Detailed literature review to be performed on laboratory modeling techniques of non-synoptic wind flows would be of significant benefit by providing the experimental and computational progress of the field.
- Most of the literature studies were devoted to understanding the structure of non-synoptic, i.e., tornadoes and downbursts wind fields, through physical and numerical approaches. More studies are still needed on subjects related to the interaction of such flows with the surface roughness and topography.
- The assessment of the newly proposed provisions for tornado-induced loads should be reviewed critically prior to further contribute to making recommendations towards downbursts.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the financial support by the Natural Sciences and Engineering Research Council of Canada (NSERC).

REFERENCES

ASCE/SEI 7. (2016). Minimum design loads and associated criteria for buildings and other structures. American Society of Civil Engineers, Reston, VA, USA.

ASCE/SEI 7. (2022). Minimum design loads and associated criteria for buildings and other structures. American Society of Civil Engineers, Reston, VA, USA.

Fujita, T. (1990). Downbursts: Meteorological features and wind field characteristics. Journal of Wind Engineering and Industrial Aerodynamics 36 (1-3), 75-86.

Haan, F. L., Sarkar, P. P., and Gallus, W. A., 2008. Design, construction and performance of a large tornado simulator for wind engineering applications. Engineering Structures 30 (4), 1146-1159.

Hangan, H., Romanic, D., and Jubayer, C., 2019. Three-dimensional, non-stationary and non-Gaussian (3D-NS-NG) wind fields and their implications to wind–structure interaction problems. Journal of Fluids and Structures 91, 102583.

Mason, M. S., Letchford, C. W., and James, D. L., 2005. Pulsed wall jet simulation of a stationary thunderstorm downburst, Part A: Physical structure and flow field characterization. Journal of Wind Engineering and Industrial Aerodynamics 93 (7), 557-580.

McConville, A. C., Sterling, M., and Baker, C. J., 2009. The physical simulation of thunderstorm downbursts using an impinging jet. Wind and Structures, An International Journal 12 (2), 133-149.

Romanic, D., Nicolini, E., Hangan, H., Burlando, M., and Solari, G., 2020. A novel approach to scaling experimentally produced downburst-like impinging jet outflows. Journal of Wind Engineering and Industrial Aerodynamics 196, 104025.

Solari, G., Burlando, M., de Gaetano, P., and Repetto, M. P., 2015. Characteristics of thunderstorms relevant to the wind loading of structures. Wind and Structures, An International Journal 20 (6), 763-791.

Ward, N. B., 1972. The exploration of certain features of tornado dynamics using a laboratory model. Journal of the Atmospheric Sciences 29 (6), 1194-1204.

Zhang, W., and Sarkar, P. P., 2012. Near-ground tornado-like vortex structure resolved by particle image velocimetry (PIV). Experiments in Fluids 52 (2), 479–493.