CWE-8
June 7-11, 2026
London, ON, Canada

Numerical Simulation of WindEEE's Downburst

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Summary

Downbursts are intense, localized downdrafts that rapidly descend from a convective storm, strike the ground, and spread outward radially, generating high near-surface wind gusts capable of causing significant damage to structures and infrastructure. Unlike synoptic-scale winds, which extend over large spatial regions and persist for long durations, downbursts are highly transient and spatially localized, with characteristic timescales of only a few minutes and spatial extents on the order of hundreds of meters to a few kilometers. Understanding the downburst wind field is therefore essential for evaluating the associated structural loading. This wind field can be characterized using four primary approaches: full-scale field measurements, wind tunnel experiments, analytical formulations, and numerical simulations. However, because downburst events are rare, short-lived, and difficult to capture in real time, continuous and high-quality field measurements remain limited, unlike the more abundant synoptic wind records. Ongoing efforts such as those by the Northern Tornadoes Project Northern Tornadoes Project (2022) aim to track non-synoptic wind events, including tornadoes and downbursts, to build a comprehensive database across Canada. Given the challenges associated with full-scale measurements, increasing attention has been directed toward alternative methods such as controlled experimental studies and computational fluid dynamics (CFD). In this research, CFD simulations were validated against experimental measurements conducted at the Wind Engineering, Energy and Environment (WindEEE) Dome. This validation establishes a reliable computational domain for conducting multiple downburst scenarios and assessing structural loading under various conditions.

Keywords: *LES, CFD, WindEEE, Downburst, Aerodynamics, ABL winds, Turbulence*

1 INTRODUCTION

At any moment, approximately 2,000 thunderstorms are active across the globe (Zhang et al. 2024). Climate change is amplifying the frequency and intensity of these storms (Allen 2018) and (Rädler et al. 2019). Severe thunderstorms rank among the leading causes of global economic losses, exceeding USD $10 billion annually in property damage and claiming fatalities (Allen 2018). Notably, convective storms, including downbursts, accounted for 67% of wind-related damage in Ontario and Quebec from 2008 to 2021 (Hadavi et al. 2022). These trends underscore the urgent need for a PBD framework to enhance the structural resilience of buildings under wind loads produced by downbursts. Moreover, Kim and Hangan (2007) evaluated the behavior of the flow dynamics for impinging jet simulations and this study put the first model to estimate the downburst loading on buildings. In addition, Aboshosha et al. (2015) studied the turbulence characteristics of the downburst using LES and studied different terrain surfaces and the effect on the downburst flow. Canepa et al. (2022) conducted a comprehensive experimental investigation of near-surface flow dynamics in downburst-like wind fields using large-scale impinging jet experiments at the WindEEE Dome. The study analyzed an extensive database of transient velocity measurements obtained from repeated tests at multiple radial and vertical locations. The present study aims to investigate and replicate the WindEEE Dome flow field in order to generate downburst-induced wind loads on structures.

2 EXPERIMENT SETUP

The experiment was conducted at the Wind Engineering, Environment and Energy (WindEEE) Dome at Western University, Canada. The WindEEE Dome is equipped with 106 fans. WindEEE dome is the novel facility to simulate the tornadoes, downburst and ABL winds. Of these, 60 fans are used primarily for atmospheric boundary layer (ABL) simulation, while six larger fans located in the upper plenum generate downburst flows. The present study focused on a pure downburst configuration, operating the upper-plenum fans at 40% of their total capacity. The upper plenum functions by collecting and directing the airflow from the large fans to reproduce full-scale downburst behavior. Once directed, the plenum opens to create a downdraft that impinges on the chamber floor. The COPRA probes were positioned at various radial distances from the center, referenced to the bell-mouth diameter (D), which was selected to be 3.2 m (r/D = 0.4, 0.6, 0.8, 1, 1.2 and 1.4). The heights of the probes were placed at 0.025, 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 m to have a good resolution of the area of peak gusts of downburst.

Figure 1: Wind field profiling in the WindEEE Dome empty domain

3 NUMERICAL SIMULATION SETUP

Large-eddy simulation (LES) was employed for the numerical modeling of the downburst flow. The simulations were performed using an implicit unsteady solver with a fixed time-step of 0.0016 s. The Wall-Adapting Local Eddy-viscosity (WALE) sub-grid scale (SGS) model was selected to represent the unresolved turbulence. All computations were conducted using the STAR-CCM+ (Siemens) finite-volume solver. In addition, Prism layers were chosen to be 20 with growth stretch as 1.2 near the chamber floor where the maximum gust speeds are expected to occur. Figure 2 presents the empty computational domain adopted for the numerical simulations. Figure 3 illustrates the computational mesh, highlighting the different mesh refinement zones as well as the prism layer configuration.

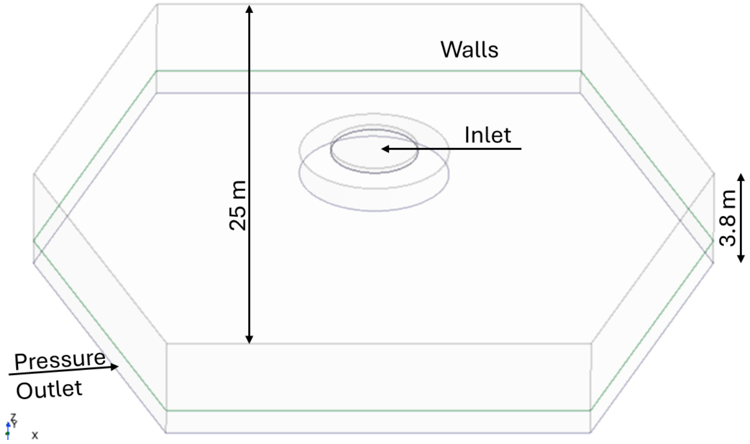

Figure 2: Computational domain of WindEEE dome

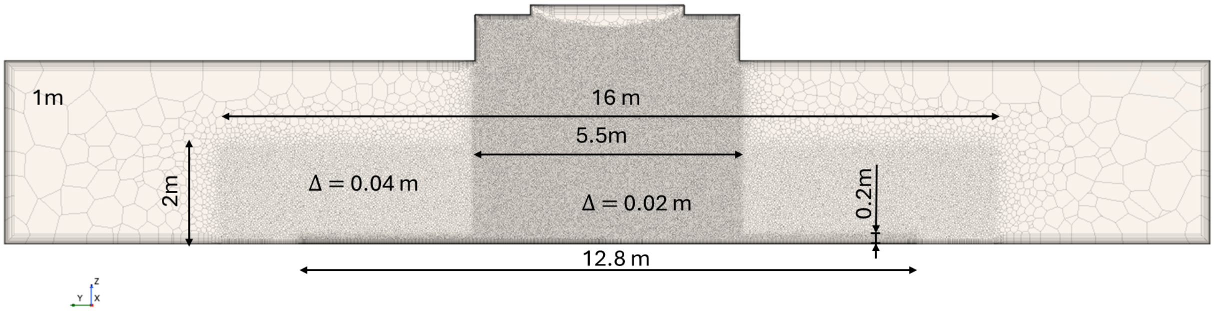

Figure 3: Meshing of the computational domain

The inlet jet velocity was defined as a time-dependent function reproducing the actuation sequence used in the WindEEE Dome experiments. The jet velocity (Vj) was held constant at 13.5 m/s during the first 4 s to represent the steady jet development phase, and then reduced linearly to 0 m/s over the subsequent 8 s, consistent with the shutdown characteristics of the physical nozzle system. Figure 4 presents the resulting inlet velocity profile applied in the simulation.

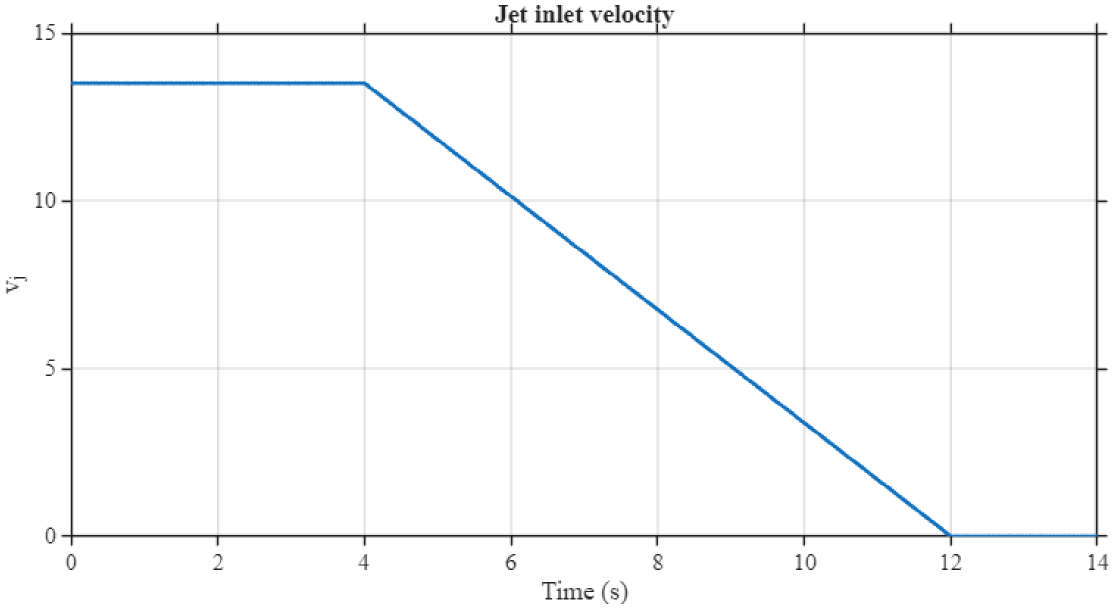

Figure 4: Inlet jet velocity

4 RESULTS

High-gust winds develop as the downburst interacts with the virtual chamber, as shown in Figure 5. The velocity vectors, normalized by the jet exit velocity, capture the temporal evolution of the flow from initial impingement to the establishment of the peak radial outflow after ground contact. Figure 6 further demonstrates the evolution of the outflow with nondimensional time at height of 0.1 m.

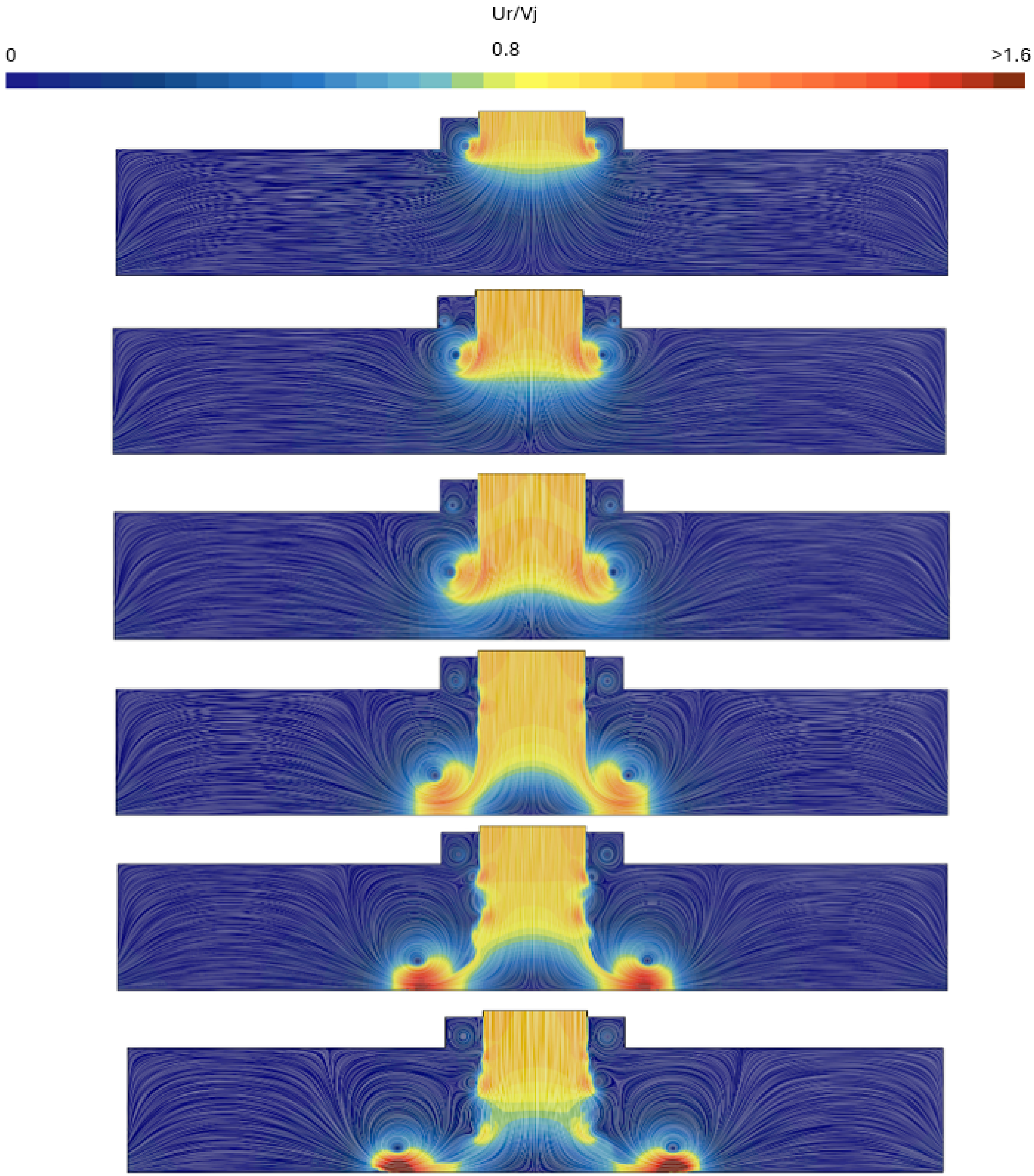

Figure 5: Velocity convolution of downburst flow at Tu = 0.05,0.1, 0.15, 0.2, 0.23 and 0.26 where Tu = T*D/Vj

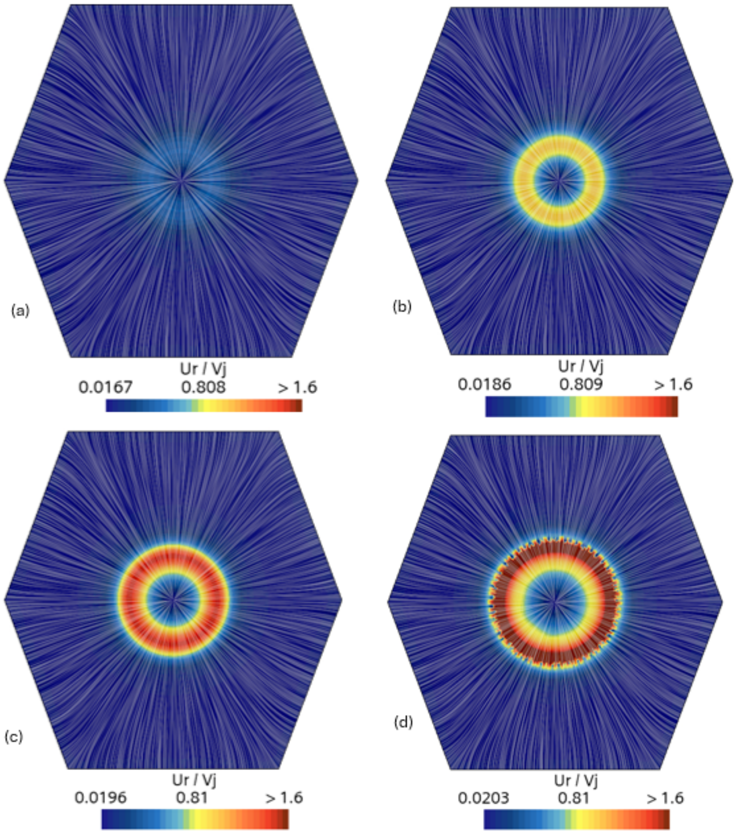

Figure 6: Plans of the radial outflow at a height of 0.1 m corresponding to selected nondimensional times, Tu = Time · D / Vj, with (a) Tu = 0.15, (b) Tu = 0.20, (c) Tu = 0.23, and (d) Tu = 0.26.

The proposed LES and experiment comparison is expected to provide comprehensive insight into the transient evolution of a laboratory-scale downburst. The velocity fields obtained from the simulation should clearly resolve the downward jet, the moment of impingement, and the rapid formation of the near-surface radial outflow. It is anticipated that the LES will reproduce the main coherent structures, most notably the translating vortex ring and the associated shear layers although with reduced small-scale variability relative to the experimental measurements.

The ensemble-mean experimental results are expected to show a higher level of fluctuation due to run-to-run variability, background turbulence, and sensor noise, whereas LES results should be smoother and more repeatable. Despite these differences, both approaches are expected to predict similar trends in the temporal evolution and spatial distribution of radial velocity, including the location of the radius of maximum wind and the decay of the wall-jet velocity with increasing radius.

Quantitative comparison between LES and experiment is expected to show reasonable agreement in key metrics such as peak radial velocity, time of peak arrival, turbulence intensity, and vertical velocity profiles. Minor discrepancies are anticipated due to uncertainties in inlet conditions, experimental repeatability.

REFERENCES

Haitham Aboshosha, Girma Bitsuamlak, and Ashraf El Damatty. Turbulence characterization of downbursts using les. *Journal of Wind Engineering and Industrial Aerodynamics*, 136:44–61, 2015. ISSN 0167-6105. doi:https://doi.org/10.1016/j.jweia.2014.10.020. URL https://www.sciencedirect.com/science/article/pii/S0167610514002220.

John T. Allen. Climate change and severe thunderstorms, 07 2018. URL https://oxfordre.com/climatescience/view/10.1093/acrefore/9780190228620.001.0001/acrefore-9780190228620-e-62.

Federico Canepa, Massimiliano Burlando, Djordje Romanic, Giovanni Solari, and Horia Hangan. Experimental investigation of the near-surface flow dynamics in downburst-like impinging jets. *Environmental Fluid Mechanics*, 22:921–954, 2022. doi:10.1007/s10652-022-09870-5.

Mohammad Hadavi, Lutong Sun, and Djordje Romanic. Normalized insured losses caused by windstorms in quebec and ontario, canada, in the period 2008–2021. *International Journal of Disaster Risk Reduction*, 80:103222, 2022. ISSN 2212-4209. doi:https://doi.org/10.1016/j.ijdrr.2022.103222. URL https://www.sciencedirect.com/science/article/pii/S2212420922004411.

Jongdae Kim and Horia Hangan. Numerical simulations of impinging jets with application to downbursts. *Journal of Wind Engineering and Industrial Aerodynamics*, 95(4):279–298, 2007. ISSN 0167-6105. doi:https://doi.org/10.1016/j.jweia.2006.07.002. URL https://www.sciencedirect.com/science/article/pii/S0167610506001139.

A.T. Rädler, P.H. Groenemeijer, and E. Faust. Frequency of severe thunderstorms across europe expected to increase in the 21st century due to rising instability. *npj Clim Atmos Sci*, 2(30), 2019. doi:https://doi.org/10.1038/s41612-019-0083-7.

S. Zhang, K. Guo, Q. Yang, and X. Xu. Review of wind field characteristics of downbursts and wind effects on structures under their action. *Buildings*, 14(9):2653, 2024. doi:https://doi.org/10.3390/buildings14092653.