

# Investigating interference effects on aerodynamic loading under tornado-like vortices: An LES study

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## SUMMARY

Over the last decade, tornadoes inflicted over \$1.1 billion of property damage and resulted in 50 deaths annually, indicating the importance of understanding the loading induced by this phenomenon. Recent literature has demonstrated the potential to model transient wind events using computational fluid dynamics (CFD), such as tornado-like vortices (TLVs), within a large eddy simulation (LES) framework by partially blocking the flow in a virtual wind tunnel. The TLVs generated using this method show similarities to vortices produced by tornado vortex generators (TVGs) and additionally exhibit realistic translation. Extension of this work has examined the aerodynamic loading induced on a building impacted by a translating TLV and attempted to compare the loading with real-world data. This abstract aims to build upon previous work by examining how the placement of surrounding structures affects loading on the building of interest, thereby simulating the loads experienced by a central building within a neighborhood.

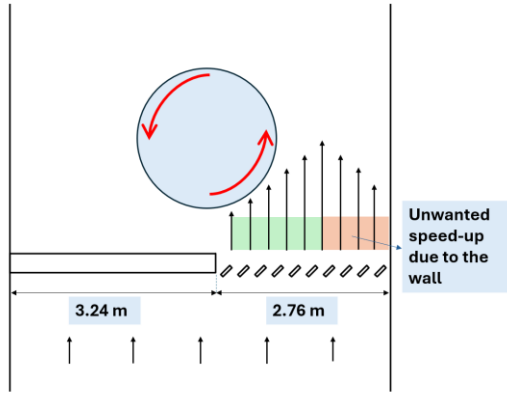
**Keywords:** *Sub-urban canopy layer, computational fluid dynamics, large eddy simulations, tornado-like vortex*

## 1. INTRODUCTION

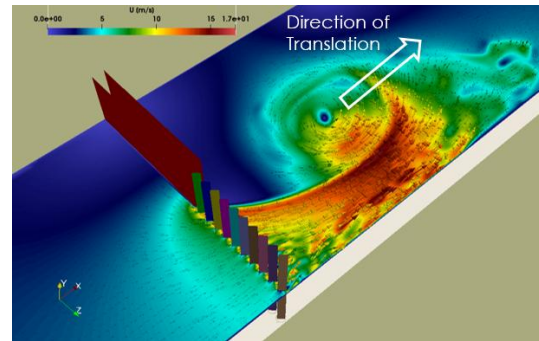
From 2015 through 2024, tornadoes were responsible for nearly \$11.5 billion in property damage in the United States and caused just under 6,000 injuries and 500 deaths (National Weather Service, 2025). As a result, a greater understanding of tornado-induced aerodynamic loading is critical to enhance the safety and resilience of the built environment. Studies following this line of research mainly focus on tornado-like vortex (TLV) characterization, meaning impacts and interactions of vortex-based wind systems with the built environment, are much less explored. For engineering applications, tornado-like vortices have been primarily simulated using tornado vortex generators (TVGs). However, TVGs generate pseudo-stationary or wandering TLVs, making them unable to reach kinematic similarity with full-scale tornadoes (Baker and Sterling, 2019). Some TVGs are also incapable of capturing the translatory nature of real-world vortices. Partially blocking the flow in straight line wind simulators by placing barriers, with a combination of walls and rotating louvers, inside straight-line wind tunnels address that concern as translating TLVs are formed (Figure 1 (a-c)), and the TLVs generated from this method have demonstrated the potential in achieving both geometric and kinematic similarity relative to the TLVs created by TVGs (Khaled et al., 2025). The proposed concept can be investigated using both numerical and physical simulations, including large eddy simulation (LES) and experiments in the University of Florida (UF) Boundary Layer Wind Tunnel (BLWT).

The vortex generation method, using both a wall-only configuration and a combination of walls and louvers, has been validated through physical experiments conducted in the UF BLWT. A 1:20 scale replica of the Wind Engineering Research Field Laboratory (WERFL) building is placed inside the domain and the TLV translates over the WERFL model (Figure 1 (d)). This study included an isolated structure, so the next point of consideration involves how having structures

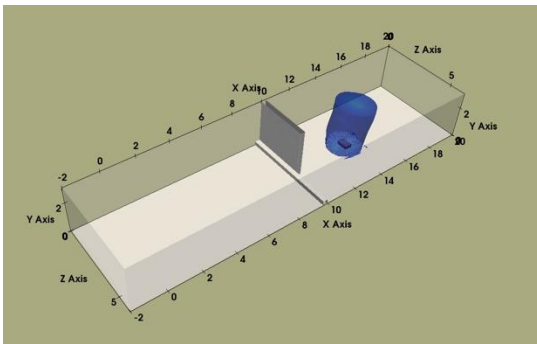
placed around the building of interest affects the induced loading on the central building. Canopy layer roughness has been shown to alter atmospheric boundary layer (ABL) wind flow (Zeng et al., 2024), and recent literature extended these studies to observe how the canopy layer impacts TLV wind fields and vortex structure (Sato and Takemi, 2025). However, the handful of such studies performed have relied on some type of a stationary TLV.



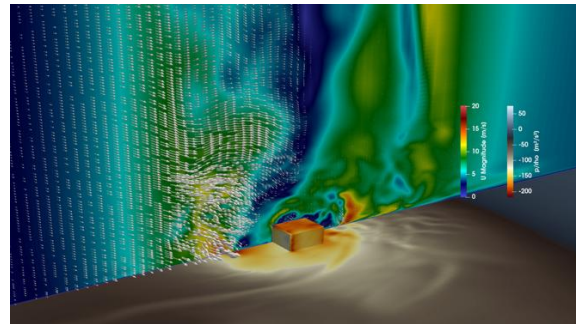
(a)



(b)



(c)



(d)

Figure 1. (a) Illustration of the concept of introducing horizontal shear instability by partial blockage, (b) translating TLV generation using the combination of a wall and louvers, (c) an isolated 1:20 scale WERFL building model under the TLV, and (d) velocity (domain) and pressure (building) contour as the TLV passes over the building.

This abstract aims to model TLVs in a wind tunnel environment using LES and have the vortex translate over a simple multi-structure orientation representative of a simplified version of a sub urban canopy layer. The LES simulation is expected to provide velocity and pressure data (of the entire domain) as the vortex passes over the neighborhood, and important wind loading parameters, such as surface pressures, are estimated to examine the impacts of the translating vortex. A secondary objective of this project is to determine how the structure of the translating vortex changes as the wind field interacts with the neighborhood.

## 2. METHODOLOGY

OpenFOAM, a powerful CFD numerical solver, is employed to run the LES simulations. The 30 m x 6 m x 3 m wind tunnel design by (Khaled et al., 2025) serves as the initial domain. A wall placed midway through the wind tunnel creates horizontal shear instability, leading to vortex generation (Figure 1 (a)). Initially, a single building is placed into the wind tunnel (Figure 2 (a)). Estimated wind loading will be calculated using the following formula for  $C_p$  shown in Eq. (1). The instantaneous  $C_p$  is calculated at the instant where the vortex core is tentatively on top of the building roof. The maximum tangential velocity at that instant is considered the reference velocity.

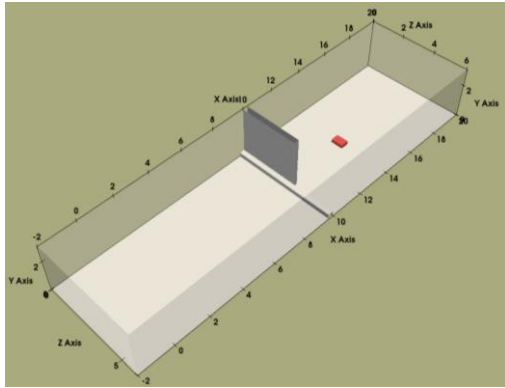
$$C_{p_{ins}} = \frac{p_{ins} - p_{ref}}{0.5\rho(U_{ref}^2)} \quad (1)$$

The three-dimensional model of the WERFL building is created in AutoCAD and transferred over to the computational domain in OpenFOAM. Unlike loading analysis in ABL winds, loading in TLVs involves greater variability. Some advanced-level factors to be considered include, but are not limited to, the location of the building relative to the vortex center and the size of the building relative to the vortex. In this study, these advanced-level factors are held constant: the building of interest is placed at the center of the vortex, and the fixed relative scale of the building and vortex is maintained. Neighborhood configurations are created by changing the layout and orientation of the structures to get a fully representative picture of how varying orientations affect wind loading and structure vulnerability. The first neighborhood setup features a 3 x 3 layout, with the target building located in the center. The two initial setups are displayed in Figure 2 (a-b).

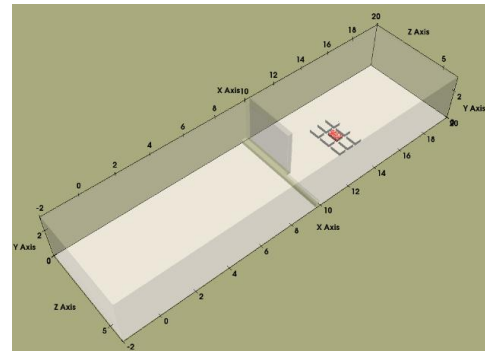
## 3. FINDINGS AND CONCLUSION

Straight-line vortex generation is a relatively new concept and is yet to become a widely endorsed TLV generation methodology. There have been somewhat conflicting findings reported in addressing the question of whether vortices are intensified or weakened due to the presence of structures or buildings in a neighborhood (Sato and Takemi, 2025). Established ABL studies report that when wind interacts with buildings, vortices are shed depending on the incident wind profile (Blocken, 2016). Preliminary studies involving an isolated structure indicate that building-generated vortices influence the TLV, which may contribute to the aerodynamic loading experienced by building models in the wake. LES detects the changes in the TLV structure in time and space as TLV interacts with the building models.

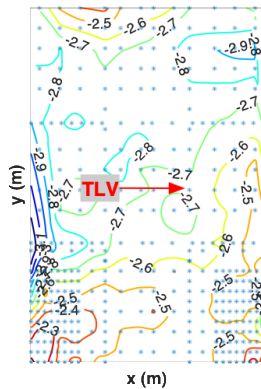
Figure 2 (c-d) presents the loading-induced pressure coefficient estimated on the roof of the test building under the single (Figure 2 (a)) and multi-structure (Figure 2 (b)) neighbourhood. In Figure 2, at the leading edge, the TLV is translating from the left to the right of the image and  $C_{p_{ins}}$  of nearly -3 is observed for the isolated building case. Whereas, in the multi-structure arrangement, the  $C_{p_{ins}}$  is nearly -2.1 near the leading edge, showing a clear drop in  $C_{p_{ins}}$ . A similar framework, which includes the choice of reference pressure and velocity, is used to calculate the  $C_{p_{ins}}$  for both cases. Hence, it can be concluded that the magnitude of pressure drop is less than that of a multi-structure arrangement. The reason could be attributed to the ‘slowing effect’ of the vortex due to the multi-structure arrangement. From previous simulations, it is found that the maximum tangential velocity and pressure drop are positively correlated. As the ‘slowing effect’ is more prominent in the multi-structure case, the pressure drop is also less. The preliminary findings indicate the need for further investigation before reaching definitive conclusions.



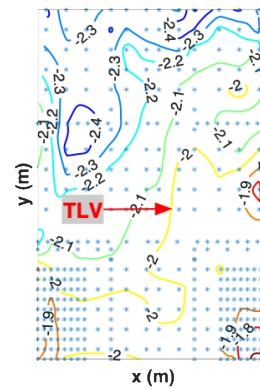
(a)



(b)



(c)



(d)

Figure 2. Visualization of (a) wind tunnel domain with single and (b) multi-structure setups. Estimated roof loading with sensor locations (dots) and  $C_p$  (contours) for the (c) single and (d) multi-structure case.

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