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LES and WindEEE simulations of tornadic wind fields

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SUMMARY

Determining tornado-induced loads for design purposes requires simulating a wide range of tornado scenarios. Simulating all scenarios experimentally can be costly, making numerical simulations an attractive alternative for identifying the critical cases. To make this approach reliable, the numerical results must first be validated, which is the objective of the present work. In this study, a numerical simulation of a tornado-like vortex is validated against a counterpart experimental simulation conducted at the WindEEE Dome. The validation is performed by comparing instantaneous radial profiles of tangential velocity at the same height above the ground. The numerical and experimental profiles show a good agreement, demonstrating that the simulation accurately reproduces the key flow features of the laboratory vortex.

Keywords: tornado, LES, WindEEE, core radius, tangential velocity

1. INTRODUCTION

Wind hazards such as straight-line winds, tornadoes, and downbursts generate highly variable loads on buildings, and accounting for this variability is essential in structural design. Even for straight-line winds, the induced loads depend on factors such as ground roughness and the angle of wind attack. To capture this variability, structures are typically evaluated under multiple angles of attack and exposure conditions to determine the governing load case.

Tornado-induced loads are even more complex because additional parameters, such as the tornado's size, approach direction, and relative location with respect to the structure, can significantly influence the resulting wind field and loading. Capturing these effects experimentally across all relevant combinations of parameters is challenging, as tornado simulation in laboratory settings is both costly and time-consuming.

To address these challenges, computational fluid dynamics (CFD) has become an effective complementary tool (Gairola et al., 2024; Gairola & Bitsuamlak, 2019). CFD enables systematic parametric studies (Kuai et al., 2008; Verma & Selvam, 2021) that help identify the most influential variables and guide targeted experimental campaigns. However, the reliability of such parametric studies depends on the accuracy of the numerical model, which must be validated against experimental data before broader analyses can be undertaken.

This paper represents an initial step in a larger research effort aimed at performing a comprehensive parametric study of tornado-induced loading. Here, the focus is on validating a CFD simulation of a tornado-like vortex by comparing it with experimental results, thereby establishing confidence in the numerical model for subsequent parametric investigations.

2. METHODOLOGY

An experimental simulation of a stationary tornado-like vortex with radius of maximum winds equal to 25 cm was conducted at the WindEEE Dome. During this simulation, horizontal velocity components in a horizontal plane at z =10cm above the test chamber floor was measured using the PIV setup shown in Figure 1. In the numerical counterpart, Large Eddy Simulation (LES) is employed to reproduce a TLV with flow characteristics that match those of the experimental target. The simulation employed a cylindrical computational domain (Figure 2), consistent with the approach used by Gairola et al.(2023), Nasir & Bitsuamlak(2018) and Natarajan & Hangan(2012) featuring an inlet radius (r_o) of 1.6 m and an inlet height (h_o) of 0.8 m. The boundary conditions applied to the domain are illustrated in Figure 2a. Domain discretization is shown in Figure 2b, with mesh sizes detailed in Table 1. Finer meshes are used near the ground and the center to resolve regions of increased turbulence. Uniform radial and tangential velocities are prescribed at the

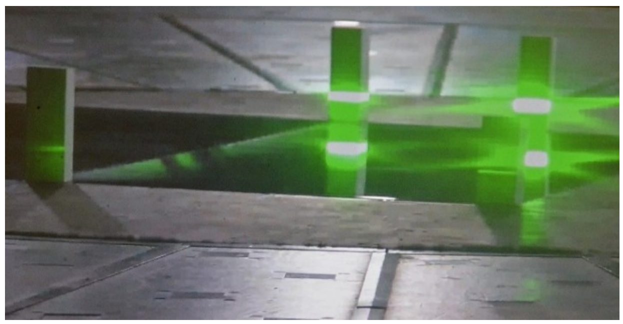
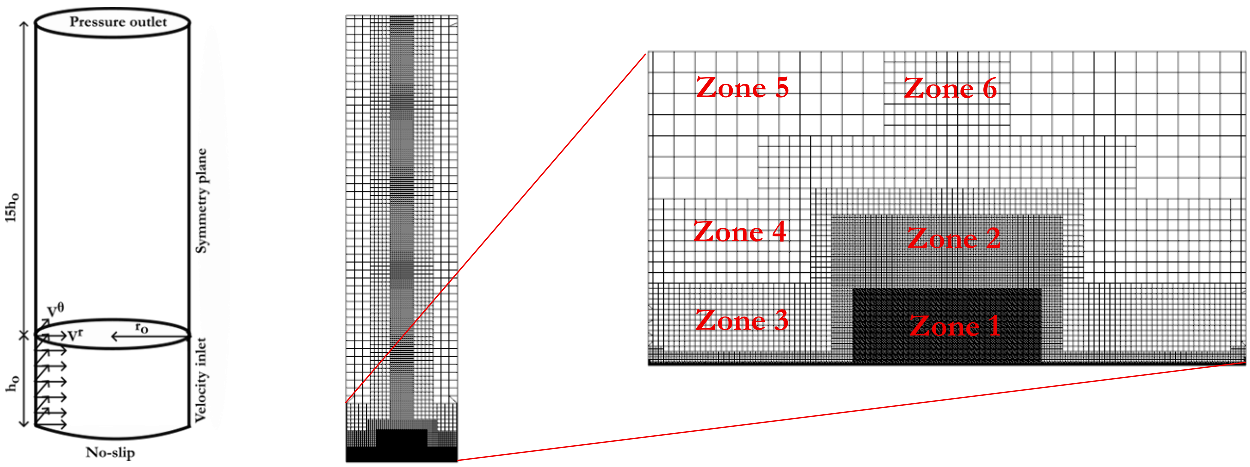


Figure 1: PIV setup

velocity inlet boundary. The flow rate ($Q = 75\ \mathrm{m}^3/\mathrm{s}$) and inlet vane angle ($\theta = 25°$) from the experimental setup are used to calculate the inlet radial and tangential velocity components, as described by Equations 2a and 2b.

$$V^r = 2\pi r_o h_o Q \quad (1a)$$

$$V^\theta = V^r \tan\theta \quad (1b)$$



(a) (b)

Figure 2:a) computational domain b) meshing scheme

Table 1 : Mesh sizes used in each zone

Zone	1	2	3	4	5	6
Mesh Size (%B)	100/64	100/32	100/16	100/8	100/4	100/8

B = 0.45m

3. RESULTS

The validation is performed by comparing instantaneous radial profiles of tangential velocity obtained from both experimental and numerical simulations. Figures 3a and 3b present instantaneous contour plots of tangential velocity component from the experimental setup and the CFD simulation, respectively. The ordinates of the radial profiles shown in Figure 3c are tangential velocity values extracted from probe points shown by grey dots in Figure 3a. These profiles are normalized by their respective maximum tangential velocities.

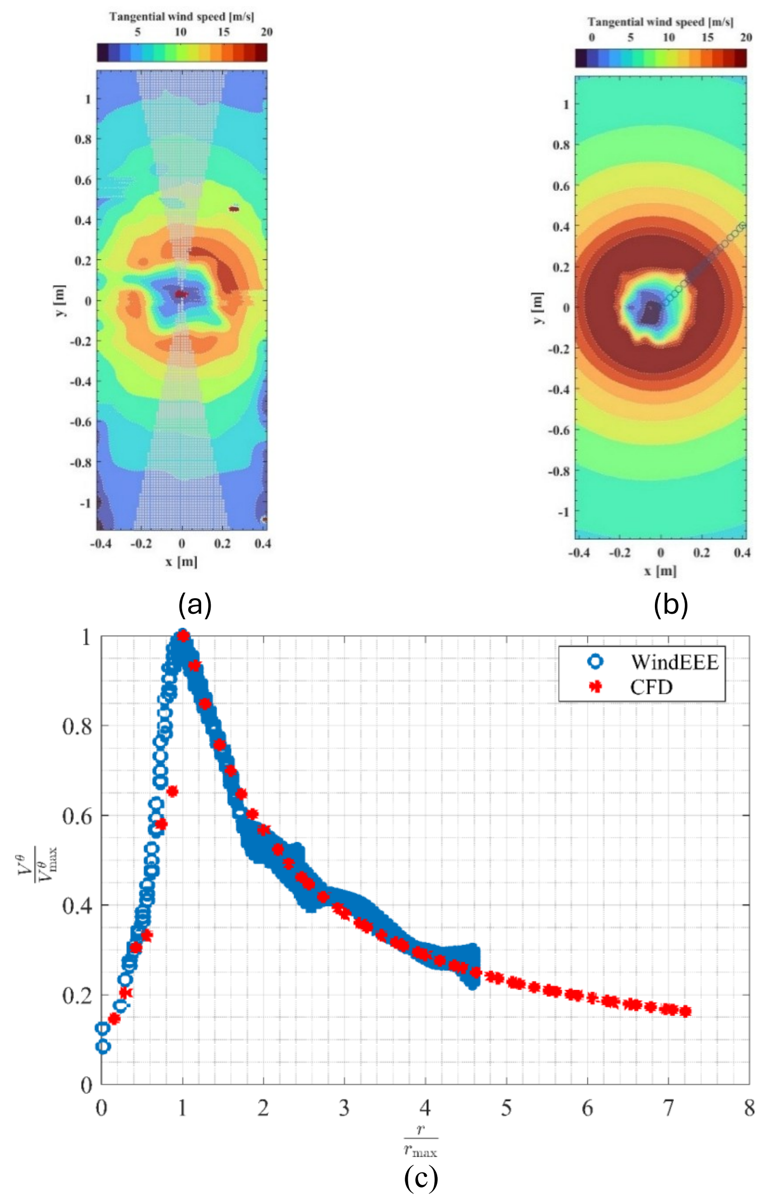


Figure 3: Instantaneous contour a) WindEEE, b) CFD, and c) radial profile of instantaneous tangential velocity

4. CONCLUSION

Validation of a numerical simulation of a tornado-like vortex against an experimental simulation has been carried out using data from the WindEEE Dome. The numerical model employed large eddy simulation. The validation was performed by comparing instantaneous radial profiles of tangential velocity at the same heights, and the results show very good agreement between the numerical and experimental profiles.

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