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Vertiport Wind Flow Characterization and Simulation Validation Using WindShaper

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SUMMARY:
This paper aims to present the experimental characterisation of wind flow around the Rotor Tower at Politecnico di Milano (POLIMI) using the WindShaper facility for Urban Air Mobility (UAM) applications. A 1:150 scale model representing a 400×250 m urban area surrounding the tower, reproducing the local built environment, and the WindShaper system–comprising vertically stacked, independently controllable fans–will be placed in POLIMI's new rotor testing aerodynamic facility. Then, the WindShaper fans will be configured to generate the target atmospheric boundary layer inflow profile. The three components of the velocity field will be measured at selected locations around the tower using triple-wire hot-wire anemometry (HWA) and a 5-hole pressure probe at a sampling frequency of 50 Hz. Tests will be conducted for four reference wind speeds and approach directions to evaluate the sensitivity of the local flow field to varying inflow conditions. The resulting experimental dataset will also be used to tune and validate outcomes from a stochastic microscale wind model (SWM) simulation performed for the same area.

Keywords: Urban wind, Vertiport, Stochastic microscale wind model, WindShaper, Experimental testing, Urban Air Mobility

1. INTRODUCTION

Wind flow in urban environments is inherently complex, highly unsteady, and strongly influenced by the surrounding built environment. Buildings of varying sizes and geometries, street canyons, vegetation, poles, towers, and open spaces interact with the inflow wind, producing localized flow regions characterized by multi-scale turbulence and pronounced spatio-temporal variability (Britter and Hanna, 2003). Such conditions pose serious challenges for Urban Air Mobility (UAM) operations.

UAM represents an emerging mode of air transportation intended to transport passengers and goods at low altitudes, with take-off and landing typically occurring on or near buildings within dense urban areas (Federal Aviation Administration (FAA), 2023). Unlike conventional aircraft, UAM vehicles exhibit a wide range of configurations and are generally designed for vertical take-off and landing (VTOL). Thus, understanding the wind flow conditions in vicinity of buildings—where these vehicles are intended to operate —is critical for ensuring safety (Nithya et al., 2024a).

Traditionally, urban wind flow has been studied through computational fluid dynamics (CFD) simulations or experimental wind tunnel testing. However, both approaches have significant limitations: CFD simulations are computationally intensive, while wind tunnel experiments can be financially demanding. Similarly, acquiring observational wind data in real urban environments also involves considerable challenges. These include the need for deploying multiple sensors, the logistical difficulty of installing them across complex urban settings, and the associated financial costs, making such approaches largely impractical for studying wind conditions

Figure 1. POLIMI Vertiport on top of the Rotor Tower in the Bovisa Campus of Politecnico di Milano.

relevant to UAM applications (Nithya et al., 2024b). To address these limitations, this study aims to explore the use of a novel experimental facility for wind data acquisition based on WindShaper technology (Walpen et al., 2024), offering a potentially efficient and flexible alternative for urban wind characterization. The WindShaper system (see Figure 2) consists of an array of vertically stacked, independently controllable fans capable of generating tailored inflow conditions, including realistic atmospheric boundary layer (ABL) profiles representative of urban environments (Walpen et al., 2024). By precisely controlling the speed distribution of the fans, the system enables the reproduction of complex wind conditions in a controlled experimental setting for lower cost than traditional wind tunnel testing.

In this paper, the WindShaper facility is employed in conjunction with a scaled physical model of the urban area surrounding the Rotor Tower at Politecnico di Milano (POLIMI), where an experimental vertiport has been installed to allow vertical take-off and landing of large drones and small eVTOLs (See Figure 1).

The experimental campaign is designed to characterize the 3D wind field in the vicinity of and above the tower under 4 different inflow conditions. Measurements are performed using triple-wire HWA and a 5-hole pressure probe, enabling for detailed resolution of both mean flow and turbulence characteristics. Furthermore, the experimental data obtained from the WindShaper facility are used to support the development, tuning, and validation of a stochastic microscale wind model (SWM), a custom urban microscale wind data generator developed by the authors for UAM applications. SWM is based on Reynolds decomposition, where the total wind velocity is expressed as the sum of steady and unsteady wind components. Accordingly, SWM integrates a highly parameterized steady-state microscale wind solver, QUIC-URB (Brown et al., 2015), with a turbulence generator, TurbSim (Kelley and Jonkman, 2007). Although SWM may not achieve the same level of accuracy as computational fluid dynamics (CFD), one of its key advantages is the ability to generate quasi-non-stationary microscale wind data, $U(x,y,z,t)$, within seconds to minutes on a standard laptop. For further details on SWM, the readers are referred to (Nithya et al., 2025). On the whole, the objective of this work is to contribute to the advancement of reliable and efficient methodologies for urban wind characterization and simulation, with particular emphasis on applications in UAM, where rapid and accurate prediction of local wind conditions is essential for safe and effective UAM aircraft operations.

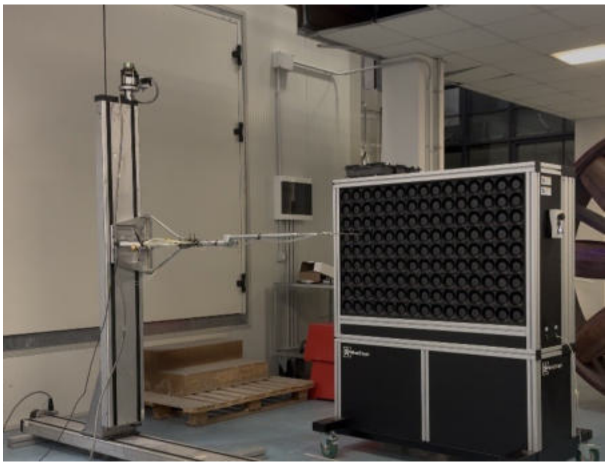

Figure 2. Picture of the WindShaper facility and an automated traverse system with a 5-hole pressure probe, as setup for characterization tests.

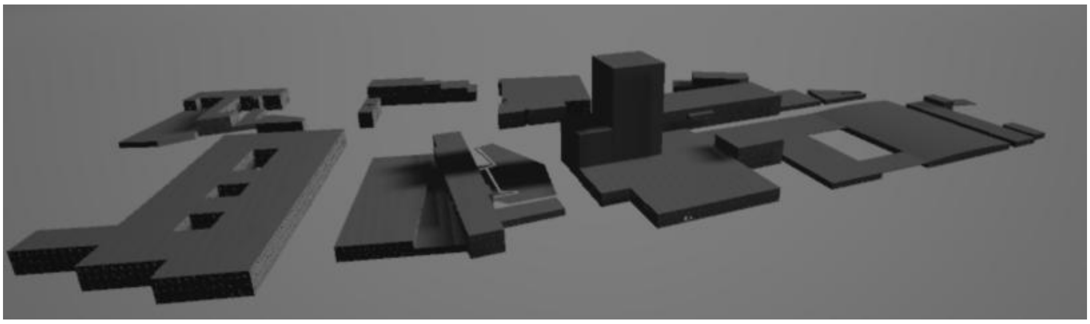

Figure 3. Downscaled 3D model of the built environment.

2. METHODOLOGY

To determine the wind speed and direction conditions for the experimental tests, historical wind data for the Bovisa area is analyzed using the OpenWeather API (OpenWeather Ltd., 2024). The daily maximum wind speed and direction at a height of 10 m are evaluated over the period from 1941 to 2025. From this analysis, four representative wind speed-direction combinations are identified: 2 m/s at 270°, 2 m/s at 285°, 3 m/s at 90°, and 2 m/s at 300°. These wind speeds are extrapolated to a height of 50 m using the logarithmic wind profile, assuming an urban terrain characterized by a roughness length, z_0, of 0.6 m (as per Wieringa, 1992) and a displacement height, d, of $0.7\bar{H}$ (according to Grimmond and Oke, 1999), where $\bar{H}$ is the average building height within the modeled area. Then, two extrapolated wind speeds, at 4 m/s and 6 m/s, are used as reference wind speeds, U_{ref}, at the scaled reference height, Z_{ref}, of 0.33 m for the experimental tests.

The 1:150 scale 3D physical model of the built environment surrounding the tower (see Figure 3), with dimensions of $2 \times 1 \times 0.3$ m, will be fabricated in polystyrene using laser cutting techniques. The tallest structure within the model, the rotor tower, reaches a height of 0.3 m. The model will be positioned 0.5 m in front of the WindShaper fan array. Subsequently, the rotor tower will be instrumented with pressure sensors, and 3-component wind velocity and turbulence intensity measurements will be taken using HWA and a 5-hole probe at specific locations on the rooftop of the rotor tower model, where the TLOF (Touchdown and Lift-Off Area) and FATO (Final Approach and Take-Off Area) are planned to be emplaced.

The experimental campaign will then be carried out by configuring the WindShaper fans to produce a uniform logarithmic wind profile defined as:

$$u_z = \frac{u_*}{k} \ln\left(\frac{z-d}{z_0}\right),$$

where u_z is the mean wind speed at height z, u_* is the friction velocity, and k is the Von Karman constant (Oke, 1987). The friction velocity is computed using the following equation

$$u_* = \frac{U_{ref} \cdot k}{\ln\left(\frac{z_{ref}-d}{z_0}\right)}.$$

Then, to translate the target wind speeds, u_z, into specific WindShaper fan throttle commands, the target wind speeds against WindShaper Fan's maximum throttle capacity.

The data obtained from the experiments will be used to validate the SWM-generated wind fields and calibrate its turbulence intensity parameters. Ultimately, this comparison seeks to demonstrate the effectiveness of the WindShaper and to establish the SWM as a reliable, computationally efficient wind simulation tool for UAM applications.

3. EXPECTED OUTCOMES AND PROGRESS OF THE WORK

The primary outcome of this research is the establishment of a high-fidelity experimental dataset characterizing the flow field around the POLIMI's Rotor Tower. Specifically, these data provide a detailed understanding of how subtle variations in wind approach angles influence the flow topology and turbulence intensity over the TLOF and FATO areas. Furthermore, the validation and tuning of the SWM establishes a computationally efficient and accurate wind simulation framework, essential for the safe integration and operation of UAM vehicles in dense urban environments.

So far, the historical wind data analysis, the mathematical framework for the WindShaper throttle control, the SWM simulations (see Figure 4), the calibration of the 5-hole probe, and the WindShaper have been completed. The 1:150 scale polystyrene model of the POLIMI rotor tower is under fabrication. The next phase of work involves the execution of the experimental tests across the 4 identified wind scenarios, followed by the comparative statistical analysis with the SWM simulated data and tuning of SWM.

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REFERENCES

Britter, R. and S. Hanna (2003). Flow and Dispersion in Urban Areas. Annual Review of Fluid Mechanics 35, 469–496.

Brown, M. J., M. D. Williams, M. A. Nelson, and K. A. Werley (2015). QUIC transport and dispersion modeling of vehicle emissions in cities for better public health assessments. Environmental Health Insights.

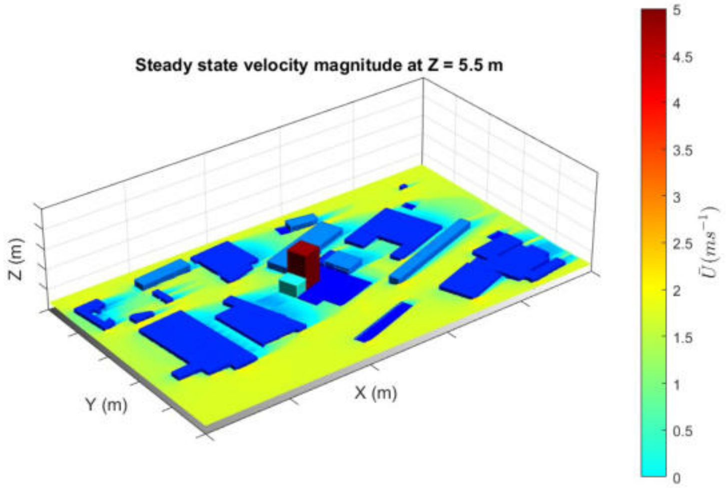

Figure 4. Steady state wind velocity magnitude field around the POLIMI rotor tower built environment as simulated by QUIC-URB in SWM for 2 m/s and 270°inflow wind condition.

Federal Aviation Administration (FAA) (2023). *Urban Air Mobility: Concept of Operations v2.0*. Tech. rep. Federal Aviation Administration (FAA).

Grimmond, C. S. B. and T. R. Oke (1999). Aerodynamic Properties of Urban Areas Derived from Analysis of Surface Form. Journal of Applied Meteorology 38, 1262–1292.

Kelley, N. D. and B. J. Jonkman (2007). *Overview of the TurbSim stochastic inflow turbulence simulator*. Tech. rep. National Renewable Energy Laboratory (NREL), Golden, CO, United States.

Nithya, D. S., F. Monteleone, G. Quaranta, M. Liang, and V. Muscarello (2025). Development and Validation of a Custom Stochastic Microscale Wind Model for Urban Air Mobility Applications. Drones 9, 56.

Nithya, D. S., G Quaranta, V Muscarello, and M Liang (2024a). Assessment of a highly parameterized steady-state microscale wind simulator for urban air mobility applications. Proceedings of 31st Congress of the International Council of Aeronautical Sciences.

Nithya, D. S., G. Quaranta, V. Muscarello, and M. Liang (2024b). Review of Wind Flow Modelling in Urban Environments to Support the Development of Urban Air Mobility. Drones 8.

Oke, T. R. (1987). Boundary Layer Climates. Methuen, London.

OpenWeather Ltd. (2024). *OpenWeather API*. `https://openweathermap.org/api`. Accessed: 2026-03-10.

Walpen, A., T. Govoni, J. Stirnemann, M. Ionescu, N. Bosson, G. Catry, and F. Noca (2024). Automated control of complex aerodynamic flows generated by Windshaper fan arrays. Proceedings of AIAA SCITECH 2024 Forum.

Wieringa, J. (1992). Updating the Davenport roughness classification. Journal of Wind Engineering and Industrial Aerodynamics 41, 357–368.