

PROPOSAL OF A PHD THESIS SUBJECT

Title: Towards realistic urban air mobility predictions using Vortex Particle Method and experimental measurements

Reference: **MFE-DAAA-2026-13**
(to be included in all correspondence)

Beginning of the PhD: October 2026

Application deadline : May 2026

Keywords: *Experimental study, Simulation, PIV, Propeller interaction, ambient turbulence, aeroelasticity, VPM*

Context

The shift toward aerial urban mobility relies on novel configurations of drones, air taxis, and rotating-wing aircraft. Unlike conventional-size airplanes or helicopters, these vehicles operate at low altitude within a dense urban environment where the airflow is heavily disturbed. The presence of an urban canopy with varied shapes and vertical surfaces creates an aerodynamic topology that generates heavily turbulent regions, sometimes amplified by hostile weather phenomena such as wind gusts, rain, or even hail. Under these conditions, the incoming flow field is no longer homogeneous; it exhibits velocity gradients and pressure fluctuations, which directly affect the performance of rotating wings, the structure of the wake, and the aero-elastic stability of the system.

ONERA has developed a high-performance code for the aerodynamic analysis of lifting surfaces based on the Vortex Particle Method [1]; however, when it is coupled with a lifting line, the velocity deficit observed in the wake disappears (see Figure 1). In reality, the boundary layer that develops

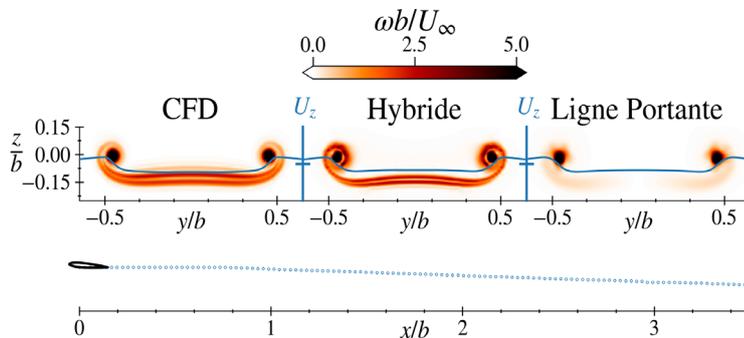


Figure 1 Wake velocity at 3.5 span.

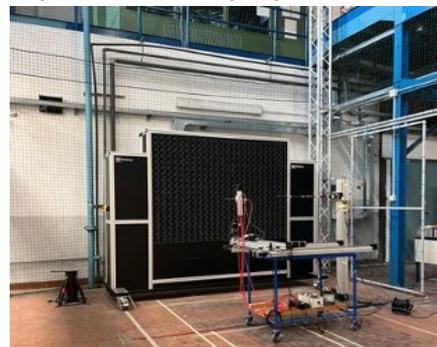


Figure 2 Flight arena of Politecnico di Torino.

on the pressure and suction sides of the airfoil generates two counter-rotating vortex sheets that overlap, causing a local deceleration of the flow. This phenomenon appears in URANS and hybrid simulations (URANS near-wall combined with VPM for the far field) whereas the lifting-line coupling does not capture it. Omitting this effect leads to erroneous predictions when assessing the interactions among multiple rotors, a main wing, and surrounding structures.

The lack of numerical reference databases linked to experimental campaigns is a major obstacle to validating new models. This thesis plans to carry out an experimental test campaign leveraging a range of facilities, including a flight arena (see Figure 2) and a large-scale wind tunnel (with PIV measurements, pressure data, and integrated loads) at Politecnico di Torino to provide the essential datasets for calibrating and validating the new implementations of the VPM solver. These experiments will not only confirm the relevance of the proposed models but also establish robust correlations between ambient turbulence intensity, wake structure, and aero-elastic responses, thereby laying the foundation for fast, reliable simulation tools for the design of future urban drones and helicopters.

Objectives of the PhD

First, the effect of atmospheric turbulence on rotors will be theorized and incorporated into ONERA's Lagrangian Vortex Particle Method (VPM). Second, the viscous-wake velocity deficit will be modelled by generating two counter-rotating vortex sheets derived from the airfoil. Third, rotor aerodynamic and aero-elastic behaviour will be examined as functions of Reynolds number, flow instability and rotor stiffness, focusing on loads, aerodynamic damping and aero-elastic stability. Fourth, the interaction between installed propellers and a fixed wing will be investigated to quantify how the double vortex sheet influences wing performance. Experimental campaigns in the flight arena and the D3M wind tunnel at Politecnico di Torino will provide a comprehensive dataset (velocity fields, pressure distributions, integrated loads) to validate and calibrate the numerical models and to delineate the limits of current approaches.

Activities of the PhD

The PhD thesis will begin with an experimental phase in a flight arena to measure ambient turbulence and the velocity fields in the wake of a rectangular wing. Subsequent tests on isolated rotors and rotors mounted on a fixed wing will be carried out in the D3M wind tunnel at Politecnico di Torino to evaluate various configurations. The PIV measurements, pressure data, and integrated loads will then be compared, primarily with the VPM and, for critical cases, with URANS.

These datasets will be used to formulate and implement a turbulence-injection module in the VPM, inspired by the work of the University of Le Havre [2]. In parallel, a double-vortex-sheet model will be developed based on [3] to correct the wake velocity deficit.

The goal is to enrich the current VPM solver so that it can rapidly simulate the structural and aerodynamic response of multi-rotor drones and urban helicopters interacting in realistic turbulent flows.

The results will be disseminated through peer-reviewed journal publications and presentations at conferences and doctoral-student workshops throughout the PhD.

References

- [1] Valentin, J. (2024). *Multi-Fidelity Vortex Particles Coupling with Lifting Line and Eulerian Methods for 3D Viscous Aeronautical Simulations* (Doctoral dissertation, Normandie Université).
- [2] Mycek, P. (2013). *Étude numérique et expérimentale du comportement d'hydroliennes* (Doctoral dissertation, Université du Havre).
- [3] Caprace, D. G. (2020). *Modeling of lifting-dragging devices for large eddy simulation of space-developing wakes: application to wings, rotors and formation flight* (Doctoral dissertation, UCL-Université Catholique de Louvain).
- [4] Grava, A., Serpieri, J., Bernardos, L., & Cafiero, G. (2025). *Multi-Fidelity Analysis of a Small-Scale Propeller Using VPM Against URANS and Experimental Data*. In AIAA Aviation Forum and ASCEND 2025.

Expected collaborations

The work will be carried out in Franco-Italian collaboration: experimental campaigns will be conducted at Politecnico di Torino, followed by numerical development and modeling at ONERA.

ONERA's center

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