Wind Energy in complex urban environments

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CONTEXT

The need for reducing carbon emissions has put limelight on renewable energy sources for securing future energy supply. An interesting prospect is the installation of wind turbines in urban locations with significant local accelerations of the flow. They have an advantage of reducing electricity transmission losses as they are located closer to the consumption point. Studies have shown that vertical axis wind turbines (VAWT) are more adapted to turbulent environments with highly varying wind direction. The acceptance of wind turbines in urban and semi-urban locations involves two key hurdles. The first challenge involves reducing the uncertainty in **wind resource assessment** in order to justify operational efficiency and investment value. The second involves accurate turbine **noise prediction** to help reduce the noise generated to acceptable levels specified by regulations.

PROBLEM DEFINITION

The industrial practice for wind resource assessment involves conducting field measurements and calibrating a numerical model in neutrally stratified conditions. Studies have shown that the uncertainty in wind resource assessment can be reduced by a more realistic representation of atmospheric conditions such as the effect of *diurnal, synoptic and seasonal changing inflow conditions.*

The flow around VAWTs involve strong azimuthal variations of the blade angle of attack and the interaction of the blades with blade wakes. Noise is thus produced by VAWTs due to several phenomena such as unsteady loading noise at blade passing frequencies, dynamic stall noise and blade vortex interaction noise, in addition to other mechanisms also found in horizontal axis wind turbines such as tip vortex noise and blade self-noise. The situation is further complicated by the occurrence of flow non-uniformity such as encountered in the proximity of the building surface. Noise prediction from a VAWT can be improved by incorporating the *dynamic stall and blade wake interaction mechanisms* and providing realistic *inflow conditions.*

OBJECTIVES

The aim of this PhD is to develop numerical tools of industrial value that helps address hurdles facing adoption of urban wind turbines and provide deeper insight on the flow physics.

Wind resource assessment

- Developing a numerically stable atmospheric flow model that helps reduce the uncertainty in wind resource assessment.
- Analyzing the impact of including realistic inflow conditions such as from mesoscale simulations and synthetic wind fields.
- Studying the added value of incorporating humidity (moisture fluxes), variable heat fluxes and surface roughness maps.

Noise prediction for VAWTs

- Understanding the tonal noise generated by a VAWT under the influence of non-uniform inflow conditions obtained from the urban atmospheric flow simulations.
- Improving semi-analytical models for fast turbine noise prediction that includes the effects of noise generated by dynamic stall and blade wake interaction phenomenon.

METHODOLOGY

Microscale wind resource assessment

A steady Reynolds-Averaged Navier-Stokes (RANS) model is developed using OpenFOAM to be validated on a complex terrain case of Perdigão and later extended to an urban canopy test case. The non-neutral flow solver is based on the work of [2] and takes into account the buoyancy and Coriolis forces.

Noise prediction for VAWTs

A 2D Unsteady RANS model for VAWTs shown in Fig. 1 has been developed in OpenFOAM and coupled to an aero-acoustic solver based on the Ffowcs-Williams and Hawkings for the prediction of tonal noise. The model has been setup to match experimental conditions from [1] to validate the noise prediction chain.

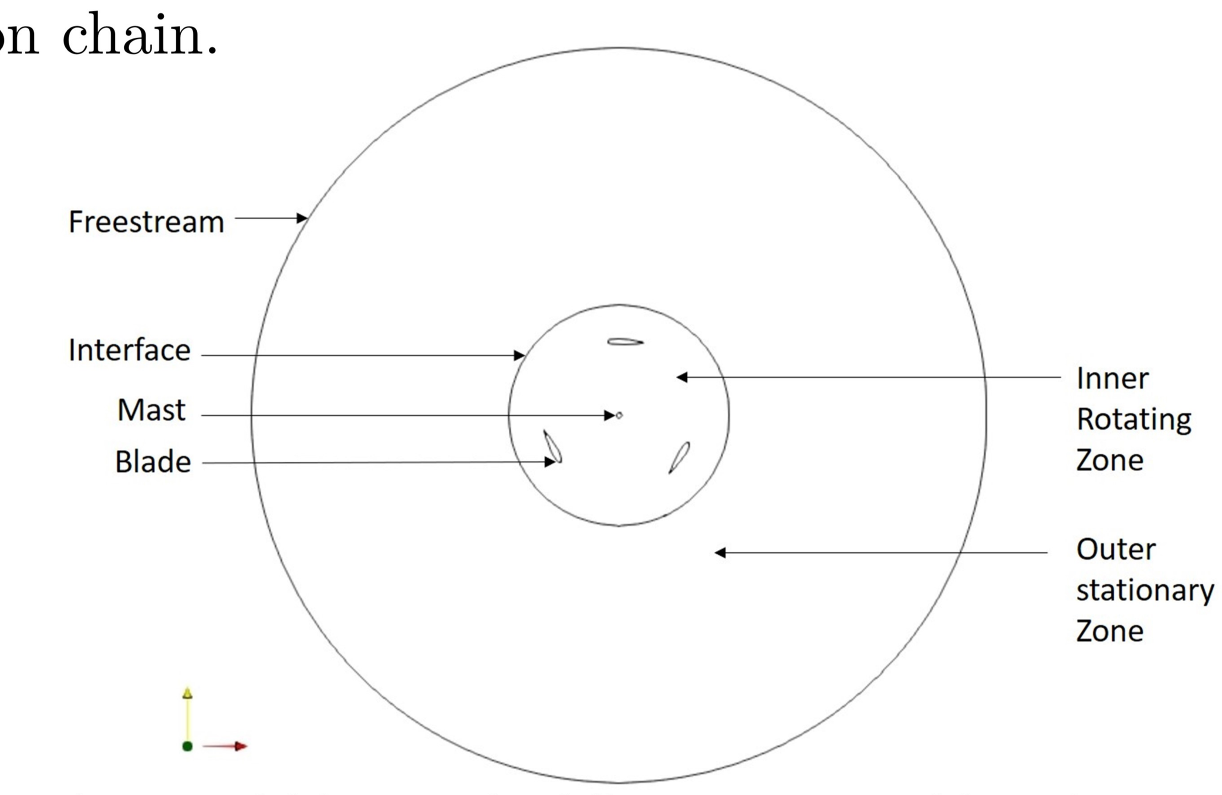

Fig 1. VAWT modelshowing the different regions and boundary conditions

PRELIMINARY RESULTS

Noise prediction for VAWTs

The flow around the VAWT is highly chaotic with the formation of leading and trailing edge vortices at the blades followed by vortex shedding and interaction between these shed vortices as seen in the velocity contours shown in Fig. 2. The sound pressure levels seen in Fig. 3 are favorably compared with experimental results of [1] at the blade passing frequency harmonics. The directivity patterns provide some insight about the noise-radiating phases of the blade trajectory. The blades experience impulsive loads due to interaction of the blade with the vortices shed from the other blades.

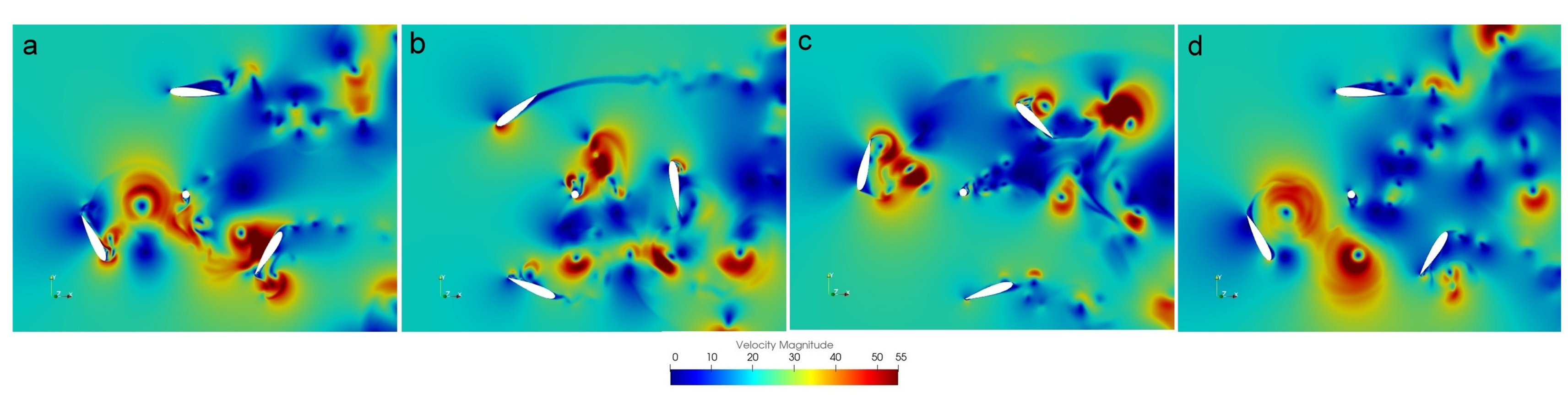

Fig 2. Velocity contours at different azimuthal angles a) 0° b) 40° c) 80° d) 120°

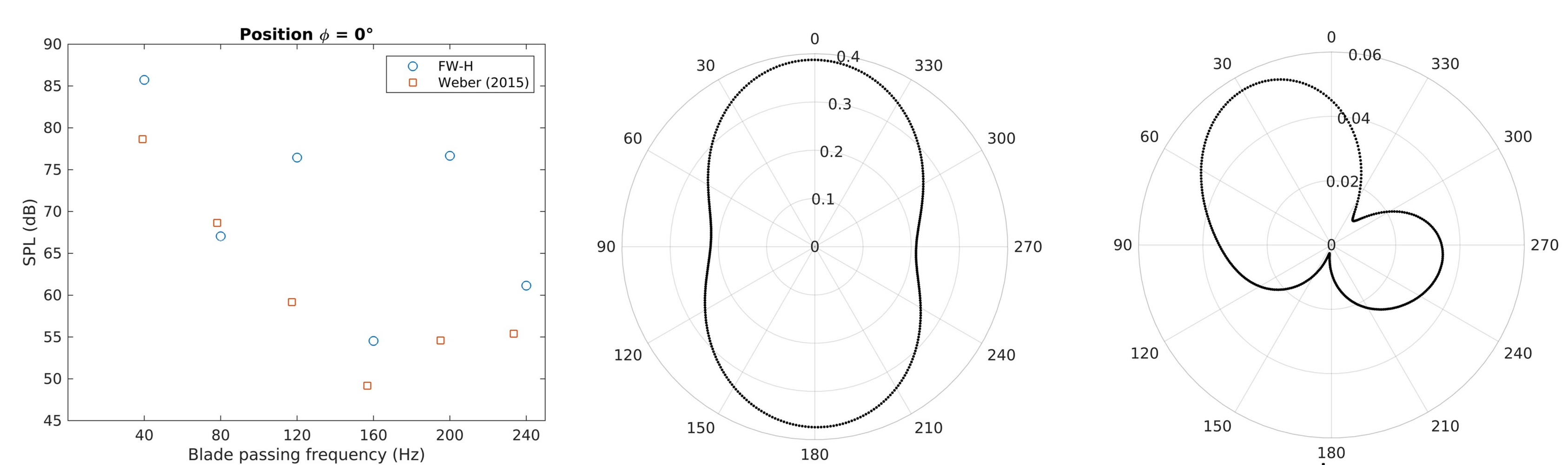

Fig 3, Left-Comparison of sound pressure levels with microphone measurements of [1], Right-azimuthal directivity patterns at first two blade passing frequencies a) 40 Hz and b) 80 Hz

[1] Weber, J., Becker, S., Scheit, C., Grabinger, J., and Kaltenbacher, M., "Aeroacoustics of Darrieus Wind Turbine,"International Journal of Aeroacoustics, Vol. 14, 2015, pp. 883–902.
[2] Temel, Orkun & Bricteux, Laurent & Beeck, Jeroen. (2018). Coupled WRF-OpenFOAM study of wind flow over complex terrain. Journal of Wind Engineering and Industrial Aerodynamics.

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