# Numerical simulation of horizontal-axis wind turbine (HAWT)

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**Abstract:** The aim of this study is to estimate the wind power that can be extracted by an horizontal-axis wind turbine (HAWT) as a function of upstream wind. The incompressible Navier-Stokes equations are solved on a fixed cartesian mesh via a second-order accurate scheme in space and time. The turning blades and the mast are modeled by a penalization term in the governing equations within a collocated Chorin-Temam fractional time integration algorithm. The turbulence model is based on a large-eddy simulation model initially fitted on experimental data. This numerical procedure allows massive parallelization by using existing distributed linear-algebra libraries. The test case under consideration is the two blades NREL ametest wind turbine that has been intensively studied in wind tunnel.

*Keywords:* Wind turbine, Cartesian mesh, Immersed Boundary, Turbulence Modeling.

## 1 Introduction

The optimization of an horizontal-axis wind turbine (HAWT) is a real challenge for renewable energy purposes. The challenge is to find efficient blade shapes for a large spectrum of tip speed ratio (ratio between the velocity at the blade tip to the wind velocity). Hence, it is important to estimate the extracted power as a function of incoming wind. Several simple models exist in the literature for this purpose. For example, the model introduced by Sorensen and Myken [3] is based on an actuator disk model. Despite its simplicity (steady, axisymmetric), this model gives reasonable results in terms of integral quantities. Of course, it does not take into account three-dimensional effects that can significantly affect the flow especially near the wing tip and the hub. A full three-dimensional model can significantly improve the prediction of such phenomena. In this sense, we have developed a fully three-dimensional model based on the incompressible Navier-Stokes equations (§2). The main challenges are to compute the the solution past moving interfaces (the blades) and in this context, to conveniently model turbulence.

## 2 Modeling, numerical approach and preliminary results

The numerical simulation of HAWT is complicate because of the moving blades and their interaction with the mast and turbulence modeling. To our knowledge there exist very few numerical codes able to overcome difficulties linked to both moving interfaces and turbulence. The existing codes are usually based on body fitted meshes. For those codes it is necessary to regularly

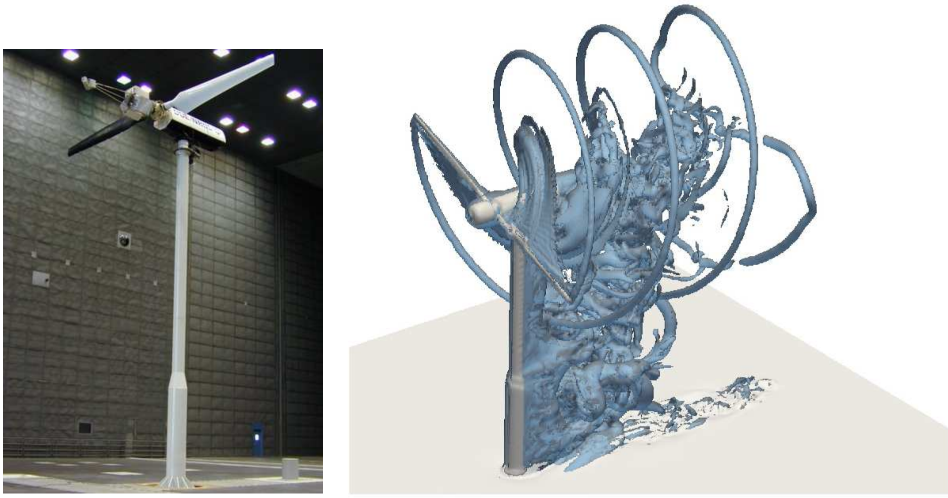

Figure 1: NREL turbine. Left, real turbine (http://www.nrel.gov/data/pix/Jpegs/17305.jpg). Right: numerical solution of the flow (norm of vorticity).

remesh for moving blades. For meshes with several millions of nodes, this can be very expensive or even unfeasible. To avoid this step, a fixed mesh method is then used in this study. The three-dimensional incompressible Navier-Stokes equation are discretized on a cartesian mesh. The fluid/structure interface, represented by the zero level set functions, is computed thanks to a second order penalization [1] similar to immersed boundary methods [2]. The turbulence is modeled using a SubGrid Scale model introduced by Vreman [4], where some parameters can be calibrated to fit experimental results. Figure 1 presents a numerical simulation of the real NREL ametest HAWT (blades lenght $\ell = 5m$, $\nu = 10^{-6}$, incoming wind= $10m/s$ and rpm= 72). After "calibration" of the eddy viscosity, the numerical extracted power is $P_{num} = 12.8kW$ is close to the experimental one $P_{exp} \approx 12kW$. The vorticity obtained is physically consistent. Indeed, the tip vortices as well as vortices generated by the mast are clearly visible.

## 3 Conclusion and Future Work

Although this work is still in progress, the results obtained using the numerical method presented in this paper are promising. The next step will be to compute the power for a large spectrum of incoming wind, and to contrast those results to wind tunnel data.

## References


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