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A FINITE ELEMENT $K-\varepsilon$ MODEL FOR ONSHORE WIND FARM MODELLING

Matias Avila[1,*], Arnau Folch[2] and Guillaume Houzeaux[3]

[1] Barcelona SuperComputing Center (BSC), Gran Capità, Edifici Nexus I Of.204, 08034, Barcelona, Spain

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We present a Computational Fluid Dynamics (CFD) modeling strategy for onshore wind farms aimed at predicting the production of farms using a CFD model that includes complex terrain, wind turbine effects, and thermal effects inducing atmospheric stratification. The model involves the solution of the Reynolds-Averaged Navier-Stokes (RANS) and energy equations together with a $k-\varepsilon$ turbulence model specially designed for the Atmospheric Boundary Layer (ABL). The model is implemented in Alya, a High Performance Computing (HPC) multi physics parallel solver based on finite elements and developed at Barcelona Supercomputing Center.

The computational modeling of wind flows over complex topography requires an important amount of computational resources but also sophisticated models and numerical methods. For energy production it is not only important the wind speed prediction, it is very important to predict the turbulent kinetic energy field in order to prevent blade deterioration. The wake effects and the aerodynamic behavior of the wind turbines are described using the actuator disk model, upon which a volumetric force is included in the momentum equations.

The effect of the rotation of the Earth, given by the Coriolis term, is important when the area of interest goes beyond the surface boundary layer ($\approx$ 150 m), producing a turning of the direction towards the ground. When considering large wind farms with wind turbines at different heights Coriolis effects are important. The increasing size of modern wind turbines obligates to consider Coriolis effects also in wake studies over flat terrain.

Thermal effects are present in the form of buoyancy forces, affecting mean profiles indirectly through their effect on vertical turbulent fluctuations, which can strongly influence the vertical wind profile and wake effects.

In this work we compare several thermal stability corrections to the ABL $k-\varepsilon$ closure schemes for onshore wind resource assessment. The proposed models aim at providing a more realistic description of the average ABL structure in the wind turbine rotor area. The performance of the models are tested against measurements. The structure of the atmospheric boundary layer is modeled with the limited length scale k-ε model of Apsley and Castro [1] which has been previously shown to be effective at reproducing observations in both the neutral and stable atmospheric boundary layers while being quite elegant in its simplicity. This model is compared against other k-ε correction models, as [2].

The Navier Stokes and the k-ε equations are implemented using a stabilized finite element formulation based on the variational multiscale method (VMM) [3]. The Navier Stokes equations are discretized using the algebraical subgrid scale model (ASGS), as described in [4]. This method gives stable solutions when the Coriolis and inertial forces becomes important with respect to viscous effects.

Though mathematical results exist ensuring the well-posedness of the k-ε equations, the strong nonlinearities may interact with discretization errors in such a way as to instabilize computations. Crosswind dissipation terms need to be added to k-ε equations to prevent loss of positivity of k or ε. When considering complex terrain the convergence of the numerical solution becomes much harder. The VMM has demonstrated great potential for the numerical simulation of RANS flows, while the use of classical stabilization methods such streamline upwind Petrov Galerkin (SUPG) fails to converge over complex topography. A robust finite element implementation of the equations based on VMM is developed and described in this work. The proposed linearization and stabilization method is shown to achieve proper convergence and stable solutions over very complex topography.

As the integration of the model up to the ground surface is still not viable for complex terrains, a specific law of the wall including roughness effects is implemented which is consistent with the fully developed ABL inlet profiles. Two different wall law formulations for $k - \varepsilon$ equations, equivalent over flat terrain are presented and compared, obtaining different results over complex terrain.

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