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Large Eddy Simulation of Vertical Axis Wind Turbine Wakes

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In this study, large-eddy simulation (LES) is combined with a turbine model to investigate the wake behind a vertical-axis wind turbine (VAWT) in a three dimensional turbulent flow. Two methods are used to model the subgrid-scale (SGS) stresses: (a) the Smagorinsky model, and (b) the modulated gradient model. To parameterize the effects of the VAWT on the flow, two VAWT models are developed: (a) the actuator surface model (ASM), in which the time-averaged turbine-induced forces are distributed on a surface swept by the turbine blades, i.e. the actuator surface, and (b) the actuator line model (ALM), in which the instantaneous blade forces are only spatially distributed on lines representing the blades, i.e. the actuator lines. This is the first time that LES is applied and validated for simulation of VAWT wakes by using either the ASM or the ALM techniques. In both models, blade-element theory is used to calculate the lift and drag forces on the blades. The results are compared with flow measurements in the wake of a model straight-bladed VAWT, carried out in the Institute de Méchanique et Statistique de la Turbulence (IMST) water channel. Different combinations of SGS models with VAWT models are studied and a fairly good overall agreement between simulation results and measurement data is observed. In general, the ALM is found to better capture the unsteady-periodic nature of the wake and shows a better agreement with the experimental data compared with the ASM. The modulated gradient model is also found to be a more reliable SGS stress modeling technique, compared with the Smagorinsky model, and it yields reasonable predictions of the mean flow and turbulence characteristics of a VAWT wake using its theoretically-determined model coefficient.

Keywords: Vertical-axis wind turbines (VAWTs); VAWT wake; Large-eddy simulation; Actuator surface model; Actuator line model; Smagorinsky model; Modulated gradient model