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Testing of Frozen Turbulence Hypothesis for Wind Turbine Applications with a Staring Lidar

Juan Jose Trujillo (1), Davide Trabucchi (2), Oliver Bischoff (1), Martin Hofsäß (1), Jakob Mann (3), Torben Mikkelsen (3), Andreas Rettenmeier (1), David Schlipf (1), and Martin Kühn (1)

(1) Endowed Chair of Wind Energy, Universität Stuttgart, Stuttgart, Germany (trujillo@ifb.uni-stuttgart.de), (2) Politecnico di Milano, Milan, Italy, (3) Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Roskilde, Denmark

A pulsed lidar installed on the nacelle of a 5 MW wind turbine (116 m rotor diameter) is used to study Taylor's hypothesis of frozen turbulence over an open field. The measurements are performed staring upstream parallel to the turbine axis and at a height of approximately 102 m. At this height, the conditions which support Taylor's theory may fail due to the vertical wind shear and inhomogeneity. The scanning system provides upstream spatially filtered and temporally averaged wind data. These data should support the wind turbine control system in forecasting the arrival of gusts to the rotor in real-time.

Measurements taken simultaneously in a range between 0.4 and 1.2 rotor diameters upstream are used to search the wave-number region where the turbulent coherent structures move with the mean wind speed. By means of the coherence function it is possible to measure the correlation between turbulence measured at different points in wind direction; for the same data series, through the phase it is possible to evaluate the hypothetical time delay at each wave-number. According to Taylor's hypothesis the coherence should be one for all wave-numbers while the phase should be a straight line and its slope should be proportional to the speed of the turbulent structures.

Actually they evolve following the Kolmogorov cascade theory and the smallest structures vanish by conversion into thermal energy. Moreover the shear stress may stretch the turbulent structure. These factors cause a decay in the two points coherence and influence the frozen turbulence theory.

Measurement data are divided in bins according to their ten-minute statistics (average wind speed and turbulence intensity) and their spectra are evaluated with the Welch algorithm for bins with at least eighty minutes data. This choice reduces errors and gives a good frequency/wave-number resolution. The results show that the coherence of turbulence at 0.2 rotor diameter separation remains in average over 0.9 and 0.8 for wave-numbers of up to 0.025 rad/m and 0.045 rad/m respectively. With increasing separation, the coherence seems to be shifted down keeping almost the same shape. The phase suggests a good agreement of the experimental data with Taylor's hypothesis for a wider wave-number range. It oscillates slightly around a linear trend up to 0.01 rad/m. Sometimes, when the wave-number increases, the phase remains linear but its slope changes slightly. This evidences that not all the turbulent structures move at the same speed.