Wind Turbine Blade: LES with Natural Inflow Turbulence

Optimization of Aerodynamic Profiles for Wind Turbine Blades by Means of Numerical Simulation with Natural Inflow Turbulence at High Reynolds Numbers

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In Short

- Generation and insertion of synthetic wind with atmospheric turbulence into the flow domain.
- LES simulation for the detection of transition on wind turbine blades at high Reynolds numbers.
- Optimization of the aerodynamic design of wind turbine blades.

The reduction in cost of wind energy is in part due to the load-specific optimization, that is, material saving of individual components. The rotor blades are the determining component for both performance and loads. To obtain a high efficiency [1], there is an increased use of special aerodynamic profiles which have large areas of low-resistance, which means laminar flow is maintained. In order to design such profiles using computational fluid dynamics and achieve a comparably good agreement with experiments, such as in the wind tunnel [2] or in the free atmosphere [3], it is necessary to include the laminar-turbulent transition in the 3D simulation of wind turbine blades.

With the completion of phase three of the MexNext [4] project in 2017, the first comparisons between measurements and simulations were carried out and documented on a rotor model with a diameter of 5m in a wind tunnel. During the course of the MexNext project, transition was also successfully detected from the collected experimental data [5]. Measurements on a rotor blade 15m in length was carried out in the free atmosphere to study the behavior of the boundary layer within a specific zone on the suction side at different operational states as seen in [3]. In July 2018, microphone and pressure sensor measurements to study transition on a blade 45m in length were collected [6]. For these measurements, large-eddy simulations (LES) shall be carried out.

In consultation with the Helmut-Schmidt University of Hamburg, the $\mathcal{LESOCC}$ (Large-Eddy Simulation on Curvilinear Coordinates) code developed by Breuer [7] is used. $\mathcal{LESOCC}$ is a CFD code for the simulation of complex turbulent flows using either direct numerical simulations (DNS), large-eddy simulations (LES) or hybrid RANS-LES methods such as the detached-eddy simulation (DES).

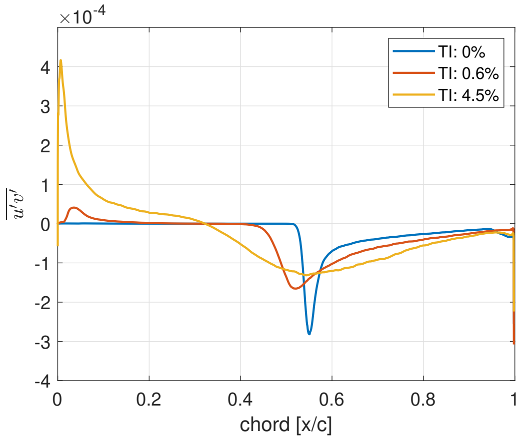
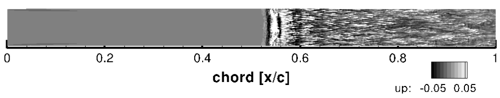
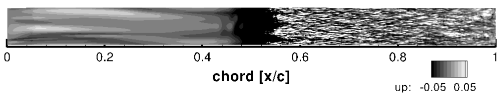


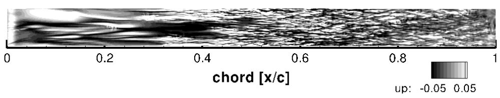
Figure 1: *Reynolds shear stress $\overline{u'v'}$ at the second cell normal to the airfoil wall on the suction side.*



a *TI = 0% No streaks, but the spanwise Kelvin-Helmholz roll on account of separation is seen before the flow turns turbulent.*



b *TI = 0.6% Formation of boundary layer streaks and a dark instantaneous separation region.*



c *TI = 4.5% high intensity formation of boundary layer streaks.*

Figure 2: *Snapshots of the instantaneous streamwise velocity disturbance u' for the visualization of boundary layer streaks. Slices are taken at a wall-normal height corresponding to the displacement thickness at 0.5% chord.*

The goal is to run wall-resolved LES for the detection of transition at high Reynolds numbers > $1E6$, preferably in comparison with experimental results [6] and to possibly determine a frequency range of inflow disturbances that influence transition for the particular case under consideration. For the resolution of the boundary layer at these high Reynolds numbers, the grid resolution leads to number of grid points in the order of hundreds of millions. Therefore, as planned, simulations at lower Reynolds numbers of around $1E5$ followed by $5E5$, an order of magnitude lower than the final goal were first run followed by cases with Re of 1 and $3E6$. There were a few reasons to do this:

1. Determine the level of coarseness of the grid that sufficiently resolves the boundary layer to observe laminar-turbulent transition.
2. Compare the effects of a change in the atmospheric inflow turbulence for various Reynolds numbers.
3. Determine the CFL number [8] for future runs.

Included here are results from the simulations at a Reynolds number of 1 million and at three different turbulent inflow conditions of 0%, 0.6%, and 4.5% to study the effect of turbulence intensity on transition. With added inflow turbulence it can be seen from Fig. 1 that the boundary layer is receptive to disturbances near the leading edge. See for example the peak at 4 % chord at a TI of 0.6 % in the plot of the Reynolds shear stress $\overline{u'v'}$ which indicates an exchange of momentum. With increasing turbulence the amount of energy penetrating and the length along the airfoil where disturbances penetrate increases (up to 10% chord at TI 0.6 % and 30 % chord at TI 4.5 %). This is in accordance to the principle of shear sheltering where low-frequencies penetrate the boundary layer to a larger extent and a thinner boundary layer (near the leading edge) is more receptive to external disturbances. As a response to the penetration of external disturbances, boundary layer streaks are formed. They are visible as elongated dark (slower than the mean flow) and light (faster than the mean flow) longitudinal regions of the flow.

WWW

https://www.fh-kiel.de/index.php?id=schaffarczyk

More Information

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Project Partners

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