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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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1 Introduction

To obtain a high efficiency on wind turbine blades, 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 (CFD) and achieve a comparably good agreement with experiments, such as in the wind tunnel, it is necessary to include the laminar-turbulent transition in the 3D simulation of wind turbine blades.

In July 2018, microphone and pressure sensor measurements to study transition on a blade of 45 m in length were collected . For these measurements, accompanying LES simulations shall be carried out. Wall-resolved LES with modeled atmospheric inflow turbulence of appropriate length and time scales will be used for the occurring Reynolds number of several millions.

Most of the CFD codes assume that the entire boundary layer is turbulent and a majority of the turbulence models are developed under this assumption. In some cases they use simplified transition models for the laminar to turbulent transition prediction. This usually results in an over-prediction of the lift and an under-prediction of the drag . To overcome this issue, more advanced computational techniques are necessary.

To successfully resolve all scales of the flow around the blade, Direct Numerical Simulations (DNS) are required. But, due to the very fine grid resolution requirements, this method is computationally not feasible for high Reynolds number flows. Therefore, to reduce computational costs, LES is employed. Until today, to the knowledge of the authors, no wall-resolved LES studies at high Reynolds numbers ($> 10^6$) have been carried out for free atmospheric inflow turbulence.

2 Work Process and Output

It is planned to initially run the simulation at two different angles of attack and at two atmospheric inflow turbulence conditions, the specifications of which would be decided based on the experimental data analysis. Wall-resolved LES predictions would be carried out to simulate and then analyze the laminar-turbulent boundary layer transition phenomenon with a focus on the determination of the disturbances and their effect on transition.

The currently employed turbulence inflow generator was proposed by Klein et al. The necessary inputs are the Reynolds stresses, two integral turbulence length scales and one integral turbulence time scale. The calculated turbulence data satisfies the necessary one and two-point statistics. The Reynolds stresses will be, at least initially, defined for an isotropic inflow case. This approximately holds in cases where the flow to the wind turbine has had a sufficiently long distance of travel without physical disturbances.

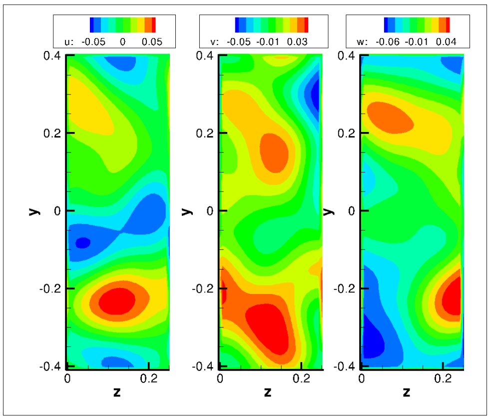

Figure 1: Cartesian velocity components of the instantaneous velocity fluctuations in a plane perpendicular to the inflow normalized bz u_∞ generated by the digital filter method for T.I = 2.8%

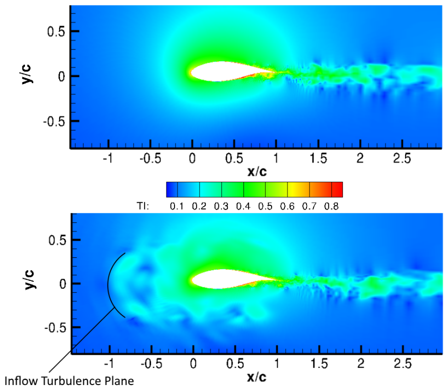

Figure 2: Top: No added atmospheric inflow turbulence. Bottom: Atmospheric inflow turbulence (TI = 2.8%) introduced one chord length upstream of the leading edge. This image is best seen on screen and not in print.

The length scales would be determined from the autocorrelation function of experimental data. Finally using Taylor's frozen hypothesis the corresponding time scale is determined.

The turbulence inflow generator by Klein et al. was extended by a source term formulation which allows to inject disturbances closer to the region of interest while maintaining the divergence-free condition.

Till date, simulations have been run at Reynolds numbers of 100,000 and 500,000 with and without added atmospheric inflow turbulence as we build up to the higher Reynolds numbers (in the order of a few million) to determine the best mesh resolution and CFL number combination for the optimum use of available resources.

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