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Large Eddy Simulations of an Airfoil in Turbulent Inflow

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ABSTRACT

Wind turbines operate in the turbulent boundary layer of the atmosphere and due to the rotational sampling effect the blades experience a high level of turbulence [1]. In this project the effect of turbulence is investigated by large eddy simulations of the turbulent flow past a NACA 0015 airfoil at Reynolds number 1.6 million. The effect of increasing the turbulence intensity is investigated and the results are compared to measurements from a wind tunnel. By including the inflow turbulence the agreement with measurements is improved for some angles of attack. The results indicate that the free stream turbulence may trigger separation of the flow at angles of attack close to stall.

KEYWORDS

Wind Turbine, Airfoil, Large Eddy Simulation, Turbulence, Wind Tunnel

1 INTRODUCTION

When designing an airfoil for a wind turbine blade the performance of the airfoil can typically be predicted by experiments and two-dimensional steady Reynolds Averaged Navier-Stokes (RANS) simulations. For low angles of attack RANS predicts the lift and drag with high accuracy because the flow is two-dimensional and steady [2]. For high angles of attack near or after stall the flow is three-dimensional and unsteady which leads to poor accuracy of RANS. These effects can be captured by a detached eddy simulation (DES) where the largest eddies in the separated area are resolved.

Detached eddy simulation (DES) is a hybrid of RANS and large eddy simulation (LES) [3]. It was developed for airfoil flows and has been successfully applied to different airfoils at a great range of angles of attack [4, 5]. In a typical DES the inflow turbulence cannot be resolved because the grid is very coarse in the upstream part of the domain. This is not the case for a LES.

In the present paper LES will be applied to airfoil flows in a wind tunnel. The effect of inflow turbulence will be investigated and the lift, drag and pressure distribution on the airfoil will be compared to experimental results.

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2 COMPUTATIONAL SETUP

The RISØ-DTU/DTU flow solver EllipSys3D is used in all computations presented in the following. The code is developed by the Department of Mechanical Engineering at the Technical University of Denmark and The Department of Wind Energy at Risø National Laboratory, see [6-8].

The computational setup is shown in Figure 1. The geometry of the setup is chosen to match the layout of the wind tunnel. The airfoil is a NACA 0015 with chord c. The outlet is placed 25c downstream from the airfoil and the domain is 1.5c in the spanwise direction. The wall boundary layer at the profile is modelled by the DES-technique. The Reynolds number is 1.6 million and the resolved domain contains 21 million cells.

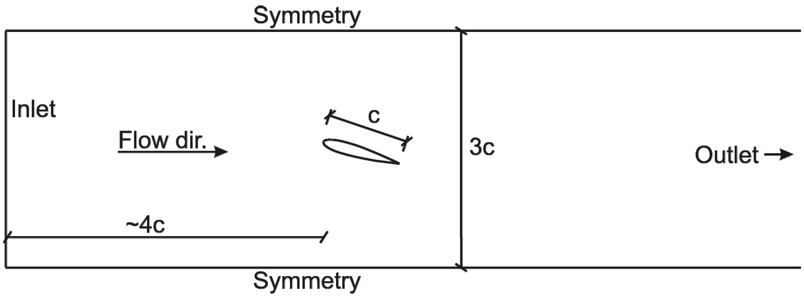

Figure 1: Computational setup

The inlet boundary condition is a mean velocity superposed by a turbulence field. The turbulence is generated synthetically and run through a precursor simulation.

3 RESULTS

The experimental results are reported in [6]. In Figure 2 the lift and drag coefficients are shown for different turbulence intensities. The turbulence intensity in the wind tunnel is approximately 0.1 %. The length scale of the turbulence in the simulations is roughly 0.25c.

The Figures 3 and 4 show the time averaged pressure distribution for 14° and 16° angles of attack.

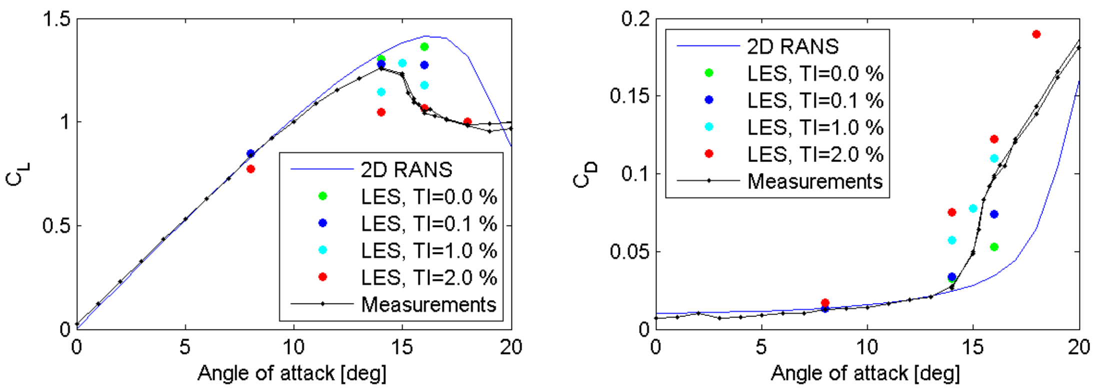

Figure 2: Lift and drag coefficients vs. angle of attack

The agreement between measured and experimental data is seen to be improved by including turbulence in the simulations. For 8° and 14° angle of attack a turbulence intensity of 0.0-0.1 % gives the best agreement with experiments. For 16° angle of attack 2% turbulence intensity gives better agreement. The pressure distributions for 15° at 1.0 % and 18° at 2.0 % turbulence intensity (not shown) are in good agreement with experimental results.

The two-dimensional RANS shows good agreement with measurements for low angles of attack but fails to predict the lift and drag close to and after stall.

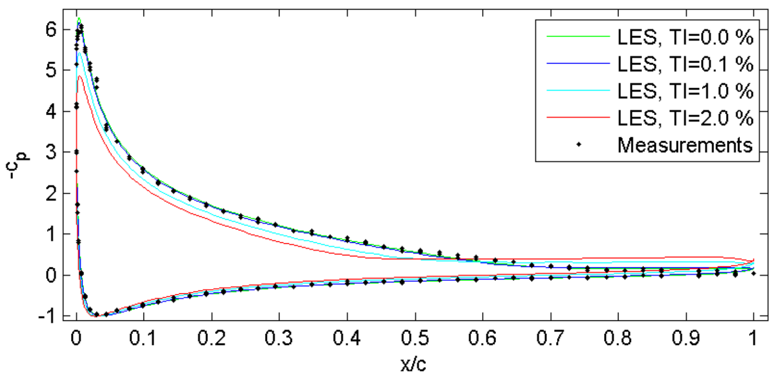

Figure 3: Pressure coefficient for 14° angle of attack

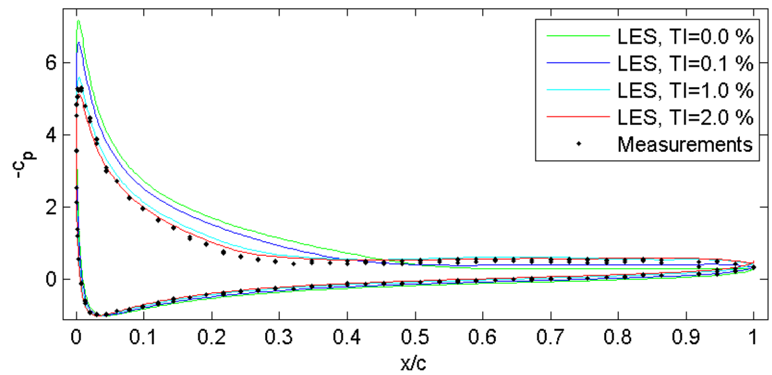

Figure 4: Pressure coefficient for 16° angle of attack

4 CONCLUSIONS

From the above results it is seen that the free stream turbulence has a large influence on the flow at angles of attack near stall. At these incidences the turbulence can cause the flow to separate.

The turbulence intensity that gives best agreement with measurements is not constant for different angles of attack. A reason for this could be that the turbulence intensity in the measurements may vary with the angle of attack due to increased loading of the fan or due to disturbances from the wake partially surviving the tour round the closed circuit tunnel.

Further work includes simulations with intermediate turbulence intensities and other angles of attack. These will form a base for the decision on whether or not further experiments are needed to determine the turbulence intensity and length scale in the wind tunnel more accurately.

ACKNOWLEDGEMENT

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