Experimental characterization of airfoil boundary layers for improvement of aeroacoustic and aerodynamic modeling

The present work aims at the characterization of aerodynamic noise from wind turbines. There is a consensus among scientists that the dominant aerodynamic noise mechanism is turbulent boundary trailing edge noise. In almost all operational conditions the boundary layer flow over the wind turbine blades makes a transition from laminar to turbulent. In the turbulent boundary layer eddies are created which are a potential noise sources. They are ineffective as noise source on the airfoil surface or in free flow, but when convecting past the trailing edge of the airfoil their efficiency is much increased and audible sound is radiated.

We performed measurements of the boundary layer velocity fluctuations and the fluctuating surface pressure field in two different wind tunnels and on three different airfoils. The first wind tunnel is the one of LM Wind Power A/S following the classic concept for aerodynamic wind tunnels with a hard wall test section. Acoustic far field sound measurements are not possible in this tunnel due to the high background noise. The second wind tunnel is owned by Virginia Tech University. The test section has Kevlar walls which are acoustically transparent and it is surrounded by an anechoic chamber. In this experiment the far field sound was measured with a microphone array placed in the anechoic chamber. The measurements were compared to predictions with an analytical model for trailing edge noise. The analytical model is divided into two steps. First the fluctuating velocity field is related to the fluctuating surface pressure field, then the far field trailing edge noise is related to the surface pressure field close to the trailing edge of the airfoil. The data base of measurements was used to evaluate the different parts of the original analytical trailing edge noise model and to improve it, because the predictions gave in general too low far field noise levels. Our main finding is that the acoustic formulations to relate the fluctuating surface pressure field close to the trailing edge of airfoil to the radiated far field sound give excellent results when compared to far field sound measurements with a microphone array and measured surface pressure statistics as input up to a frequency of about 2000-3000Hz. The fluctuating surface pressure field can be measured in a wind tunnel with high background noise due to the high level of the fluctuating surface pressure field. Hence, trailing edge noise can be evaluated by means of measured surface pressure field, even in cases where a direct measurement of trailing edge noise is not possible. This opens up great new vistas, i.e. by testing new airfoils in a standard industrial wind tunnel or by testing new wind turbine rotors in the field.

The main difficulty for trailing edge noise modeling is to predict the fluctuating surface pressure field correctly and one uncertainty of the original model was the assumption of isotropic turbulence. This was investigated in the present work and a new model to relate the boundary layer velocity field to the surface pressure field accounting for an anisotropic turbulence spectrum was proposed. The results were very similar compared to the original model and underestimated the measured one point surface pressure spectrum, even though the prediction of the one point velocity spectra was improved.

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