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Airfoils in Turbulent Inflow

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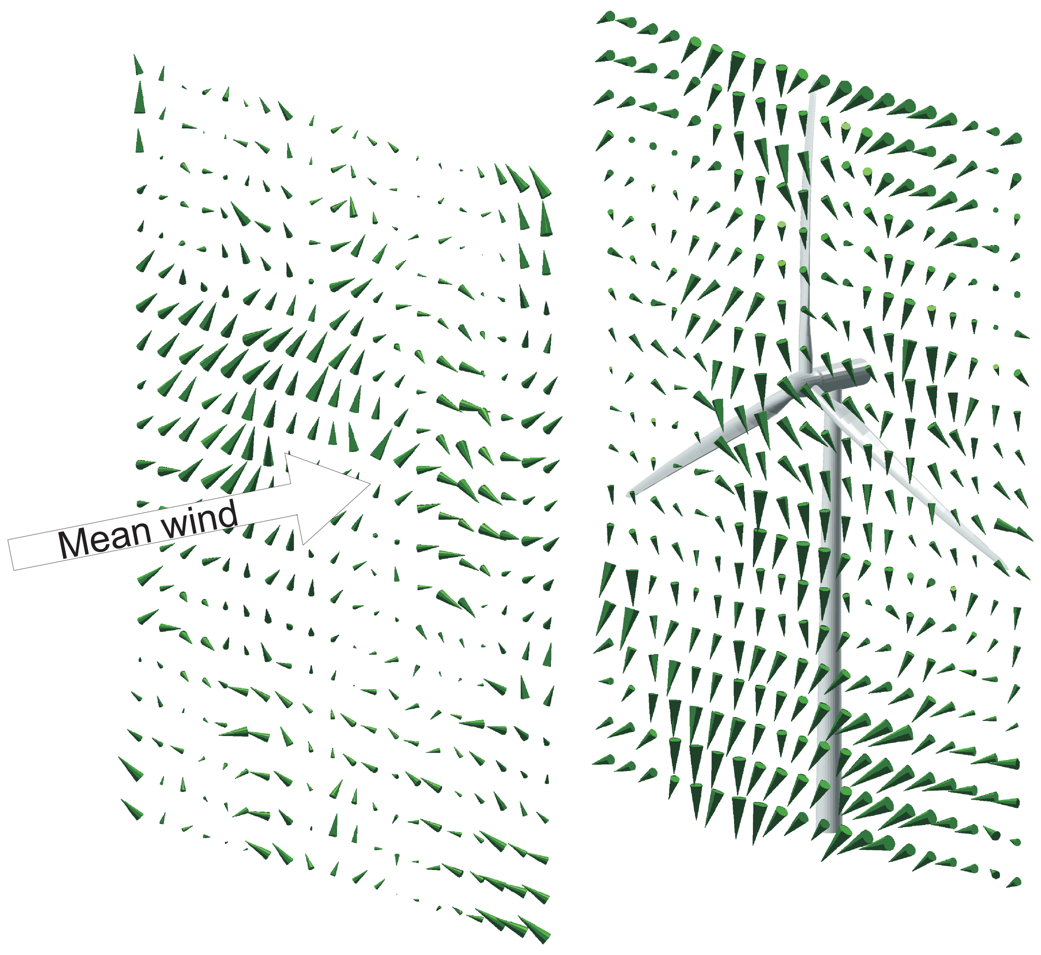
Introduction

The aim of the project is to analyse the influence of turbulence on the performance of airfoils used for wind turbines. The problem of a turbine blade in a turbulent flow will be analyzed numerically using Large Eddy Simulation (LES) and Detached Eddy Simulation (DES).

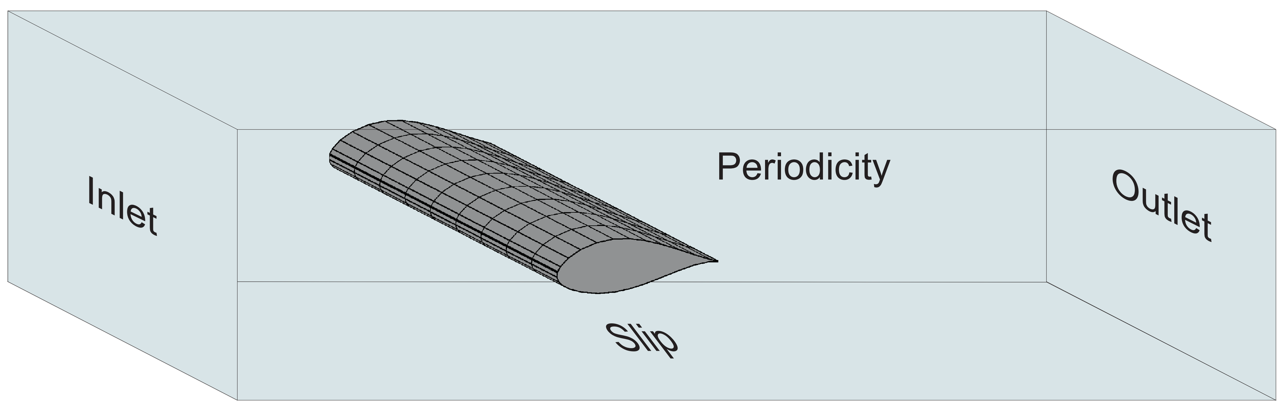
To the right an illustration of a wind turbine situated in a turbulent environment is shown. The arrows show the local velocity input at the current and the next time step of the computation.

Using the computer facilities of today it is not possible to analyze the illustrated problem by LES/DES. A simulation would require an overwhelming number of cells and time steps.

Alternatively the more modest problem of an airfoil in a wind tunnel-like computational domain is analyzed. From this problem some of the basic issues will be analyzed.



A sketch of the intended simulation is shown below. The scales in this simulation are several orders lower than in the setup above. The flow around an airfoil is simulated with the indicated boundary conditions.



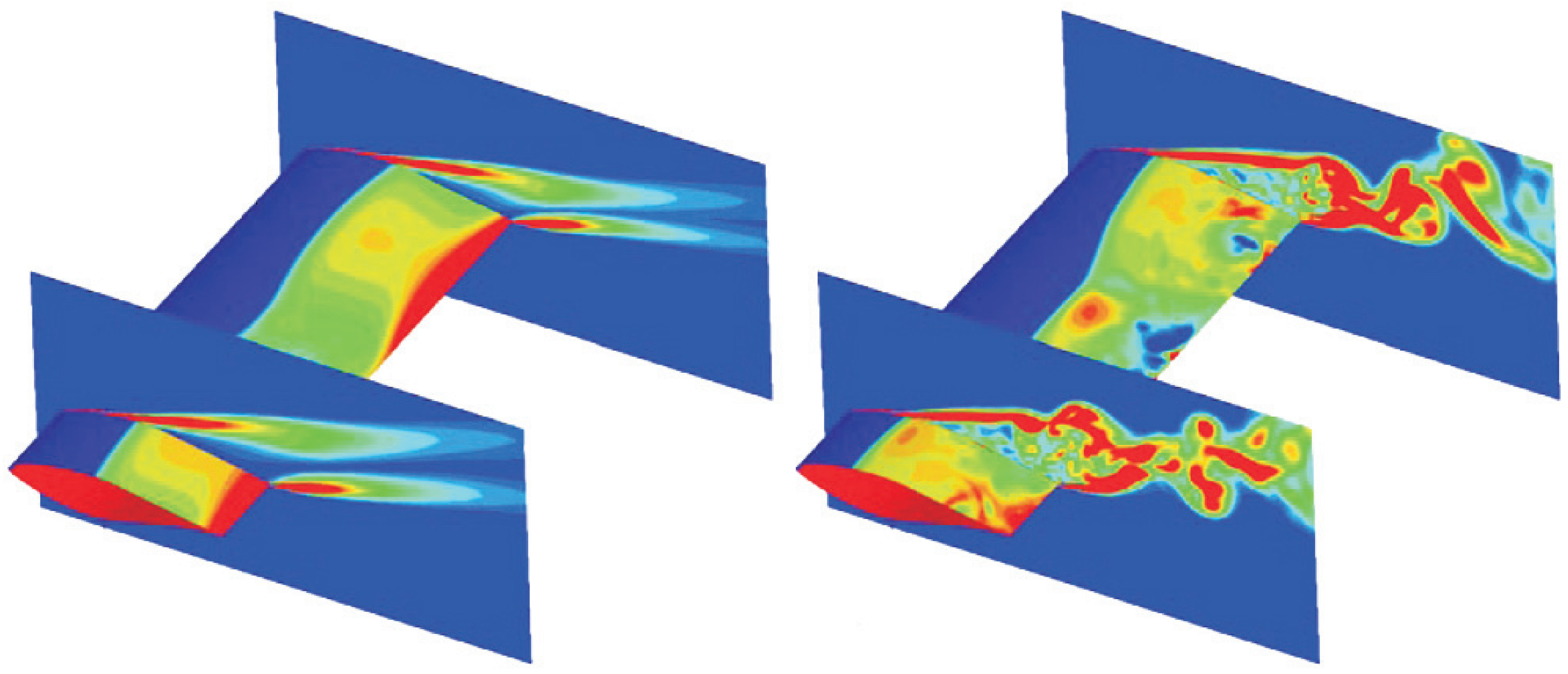
The anticipated issues of the project are:
- Generation of inflow and initial conditions
- Sustain turbulence from inlet boundary to leading edge of airfoil
- Maybe implement alternative formulations of LES/DES
- Parametric studies to identify parameters that make a substantial change to the flow

The intended outcome is:
- Knowledge of key parameters defining the turbulent inflow
- The importance of including turbulence in the inflow of LES/DES
- Guidelines concerning the design of airfoils for turbulent environments

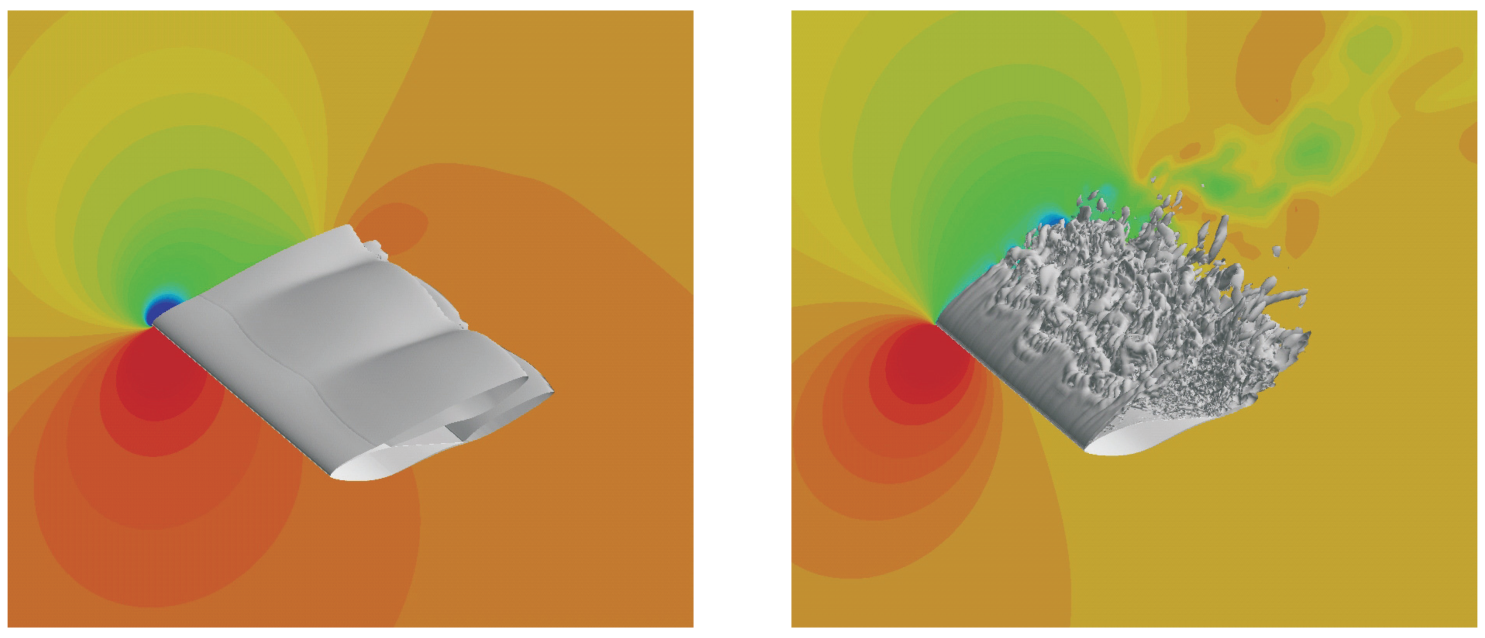
LES/DES Compared to RANS Simulations

The flow past an airfoil will be analyzed by use of LES and DES during the project. In LES and DES the effect of the small eddies is modelled. The large eddies are discretized and part of the solution. In RANS eddies of all sizes are modelled. Therefore LES/DES gives improved accuracy.

Below examples of the simulated flow around an airfoil is illustrated. The figures have been prepared at RISØ using EllipSys3D, which will also be used in the present project. To the left results from a RANS simulation are given and to the right results from DES. It is clear that DES gives a more detailed description of the wake.



The figures below show results from the same simulations. Here the unsteady flow in the separated wake is shown in three dimensions.

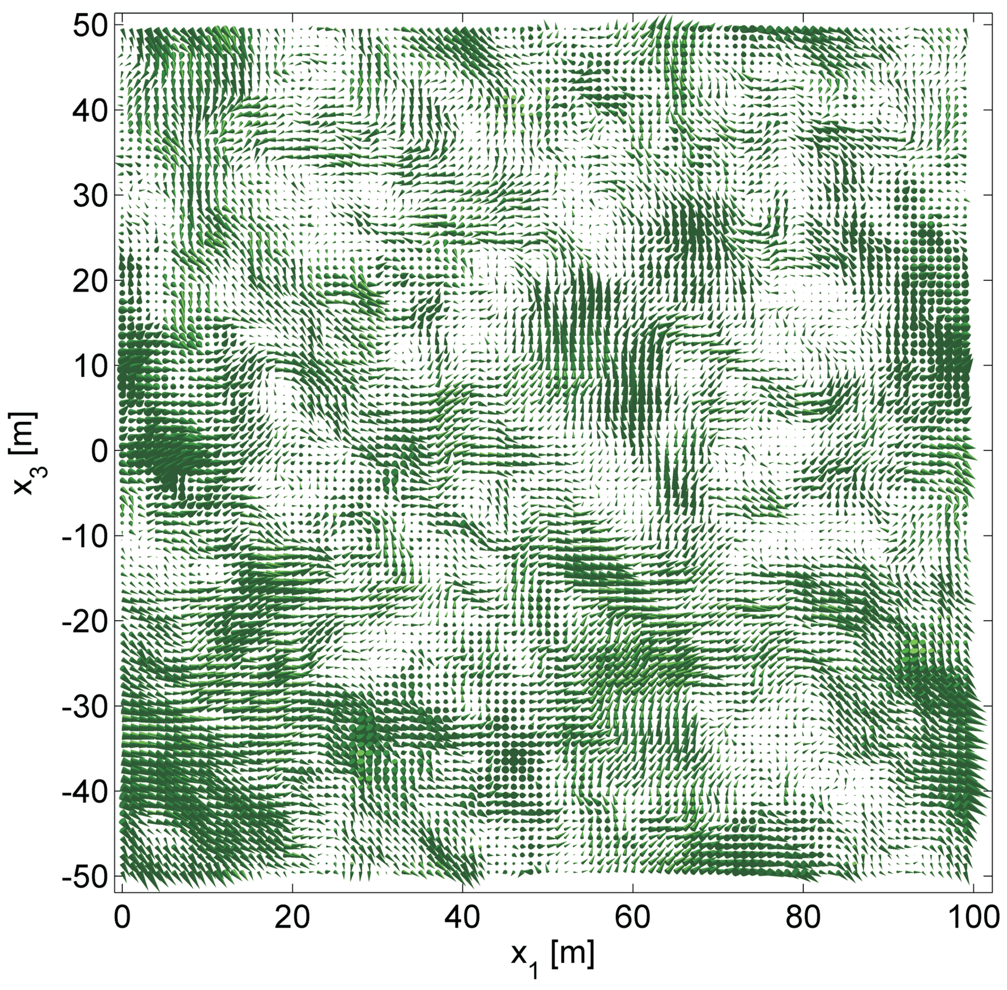


The results presented here from DES are generated with laminar inflow. For angles of attack where the flow is close to separation it is suspected that turbulence may trigger separation and change the character of the flow drastically.

The aim of this project is to analyze the effect of turbulent inflow by LES and DES.

Generation of Divergence-Free Synthetic Turbulence

The inflow of the LES/DES is a mean wind velocity field superimposed by synthetically generated turbulence. A three dimensional velocity field of turbulence can be generated by Monte Carlo simulation by the method due to Jacob Mann. A velocity vector plot of a generated turbulence field is illustrated below.



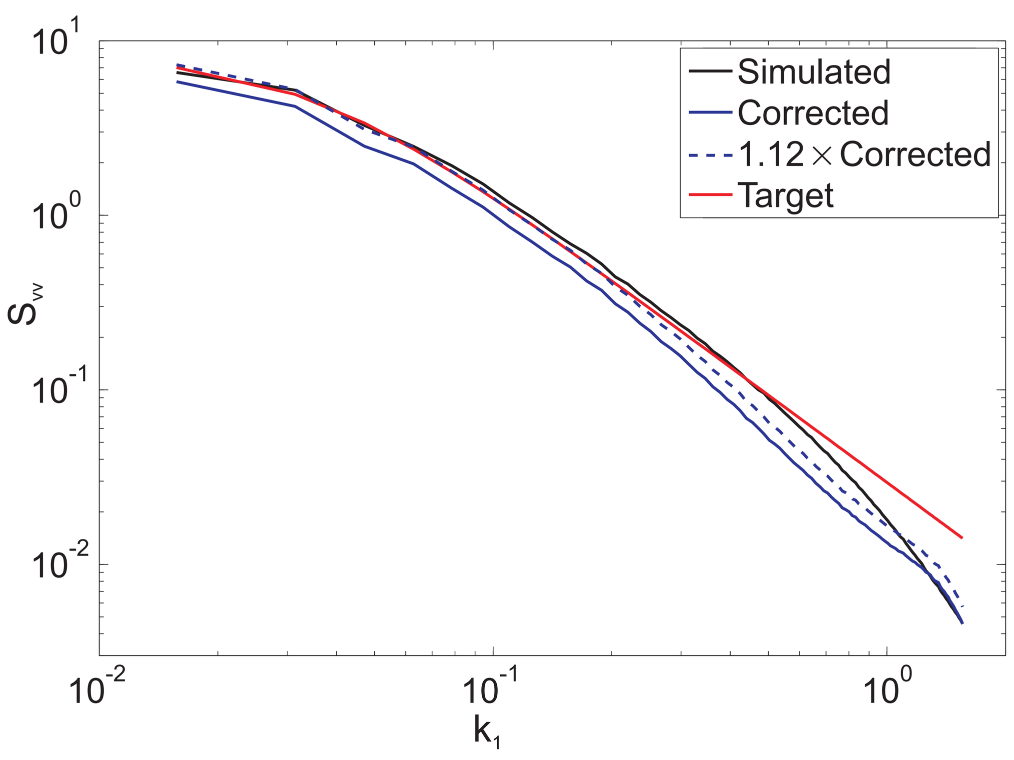
The discrete representation of the generated velocity field is not divergence-free. The reason is that waves with a wavelength on the same order of magnitude as the grid spacing are included in the inverse Fourier transform. These short waves can not be differentiated numerically with reasonable precision. Therefore the discretized field has non-zero divergence.

The divergence does not cause problems for engineering load calculations. When used as inflow for an incompressible LES the divergence causes unnatural decay of the turbulence. Therefore a divergence correction is applied.

The divergence correction makes the discrete representation of the velocity field divergence free for a given differencing scheme. Unfortunately, the pressure correction dissipates energy. Below is an example of a power spectrum before and after the divergence correction.

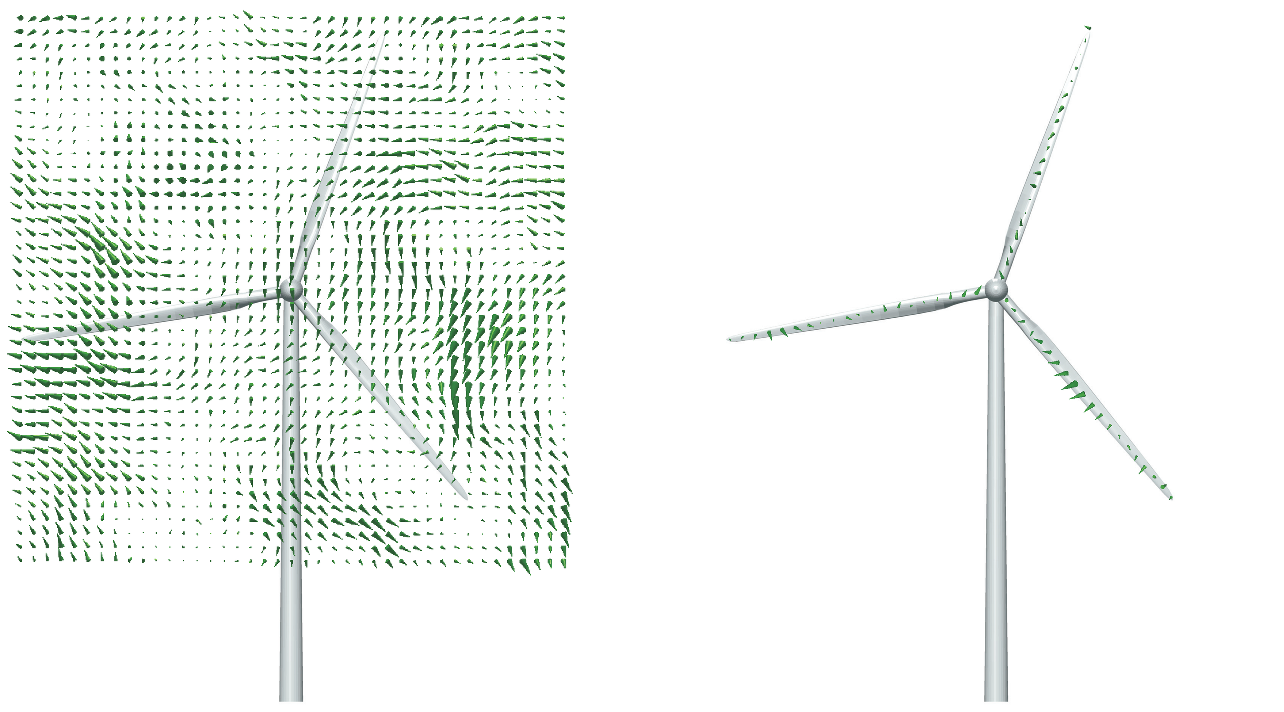
By scaling the velocity components by a common factor a fair approximation to the target spectrum can be obtained. If the approximation is found to be too poor the spectrum will be modified in wave number space before the inverse Fourier transform.

The divergence correction involves the solution of a Poisson equation. Different approaches for solving the linear set of equations are investigated in order to find an efficient method.



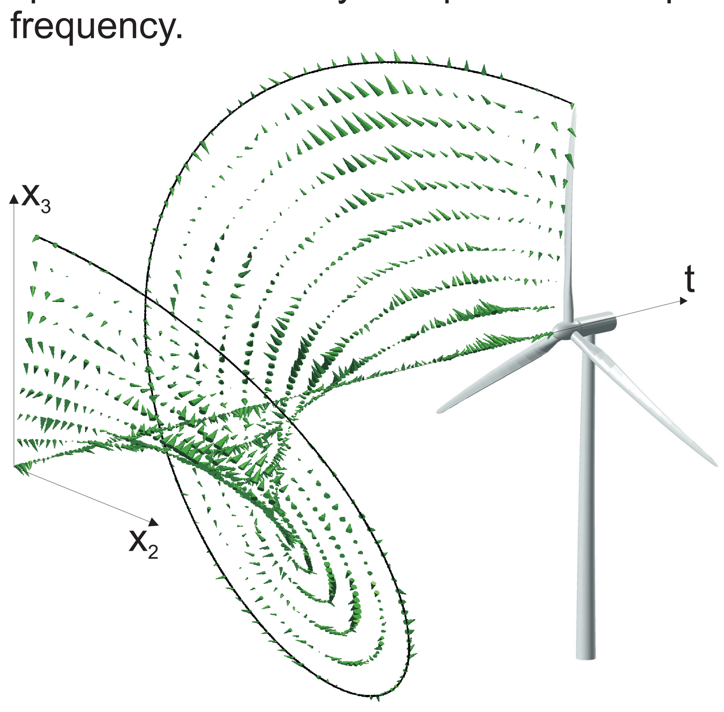
A New Approach to Generation of Turbulence for Load Calculations

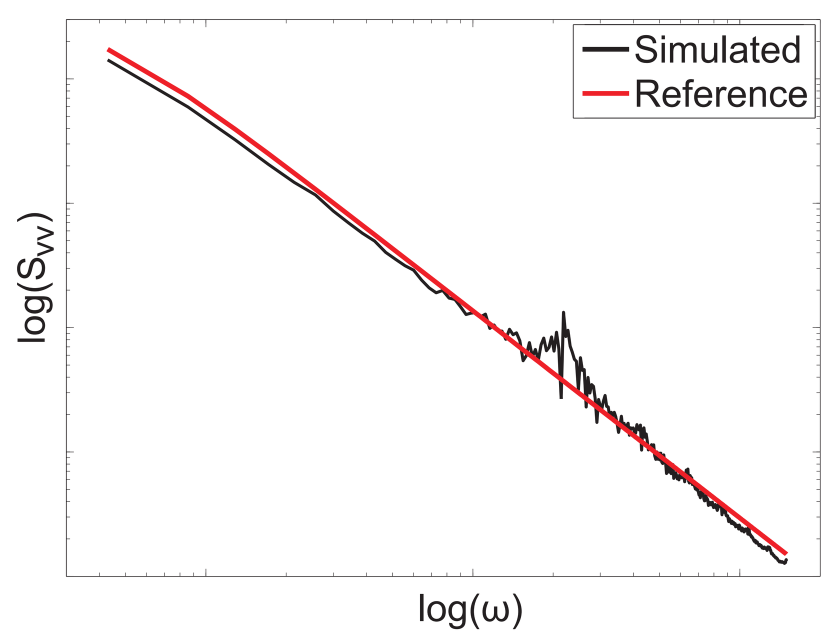
When simulating turbulence for engineering load calculations with the model due to Jacob Mann a velocity field covering the entire rotor plane at all time steps must be simulated. Only the velocities at the positions of the blades in each time step are needed, so a new method is developed where only these components are generated. The concept is illustrated below.



Field generated with existing method — Field generated with new method

The inflow for a single blade at consecutive time steps is shown below to the left. The simulated velocities form a spiral.
The method gives the correct auto-correlation and cross-correlation in the rotor plane. The power spectrum of velocity components sampled at the tip of a blade shows a peak at the rotational frequency.





The advantage over the existing method is that computational speed is improved. If a single realization is needed the computation time is comparable to the existing method. If more than one realization is needed the following realizations can be generated very efficiently.

The method will be presented in a paper written with Søren R. K. Nielsen.