CORRELATION BETWEEN ACTIVE GRID EXCITATION AND GENERATED WIND FIELD

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Abstract Turbulent wind fields play an important role for wind energy converters. Lift force fluctuations are strongly influenced by the statistics of the ambient turbulent wind field [1, 2] and lead to loads with similar characteristics. For realistic wind tunnel investigations, e.g. on wind turbine models, an active grid was build [3], which allows the dynamical generation of wind fields with comparable characteristics to those in the atmospheric boundary layer (ABL). In this work a new approach is presented, which describes the interaction between the active grid excitation and the resulting wind tunnel flow field. With this approach we are able to estimate synthetic velocity time series for grid excitations and predict their statistics. Statistical comparisons between synthetic time series and experimental data show a fairly good agreement. The goal of this approach is to find, by means of an optimization process, excitation protocols for the active grid, which generates particular flow cases of the ABL within the wind tunnel.

EXPERIMENT

The active grid consists of seven horizontal and nine vertical axes with 126 square flaps (7.4×7.4cm^2) mounted to the axes, see also [4]. The distance between the axes is 0.11m, which we call mesh size. Each of these axes is connected to a step motor and can be controlled individually with a frequency of 100Hz. All axes can be moved at a maximum rotational speed of 900°s^{-1} and with an angular precision of 0.07°. The excitation protocols describe the position in time of the active grid axes and flaps, respectively. Furthermore, the protocols are responsible for the stochastic properties of the resulting turbulent flow field. The challenge is to find excitation protocols for the active grid [5], which result in realistic flow fields, e.g. like fields with heavy intermittency, which is one of the major properties of the ABL.
For the design of new excitation protocols a correlation matrix between the active grid excitation and the resulting flow field was developed. Therefore, characterization experiments have been realized for almost all possible excitations of an active grid, with simultaneously movements of all axes. The adjustable parameters in this investigation were the angle of attack ($\alpha = 0 - 360°$) and the rotation speed of the active grid flaps ($\dot{\alpha} = \pm 90,\ \pm 225,\ \pm 450$ and $\pm 900° s^{-1}$), the wind tunnel inflow wind speed ($u_\infty = 5$, 10 and 20m/s) and the downstream position x (sixteen positions from one till twenty-four mesh sizes were selected). To record the resulting flow field three 1D-hot-wire probes were used. The sampling frequency was 20kHz and a lowpass filter was set at 10kHz. The hot-wires (HW) have a length of 2.5mm. The frequency response from the Dantec-Streamware standard square wave test was about 27kHz at 10m/s. The HW-probes were positioned in the wake of one of the active grid flaps, close to the test section centerline. One of the HW-probes is located at the tip of the flap, another at the center of the flap and one between both. The measurements show the dependency between the flow field dynamics and the wake positions.

RESULTS

A postprocessing of the recorded data finds the connection between the measured velocity time series and the experimental inflow adjustments of the active grid ($\alpha(t)$ and $\dot{\alpha}(t)$) and the wind tunnel inflow velocity (u_∞). After a sorting process an interaction matrix $\Gamma = \Gamma(u(t)|x, \alpha, \dot{\alpha}, u_\infty)$ is created, which is called VIDE (Velocity field - Inflow adjustments - DatabasE). Inside VIDE more than 400,000 velocity time series are stored, which enable to create new velocity time

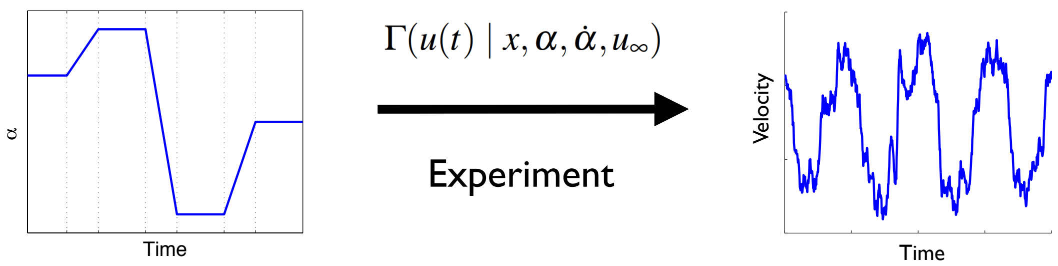
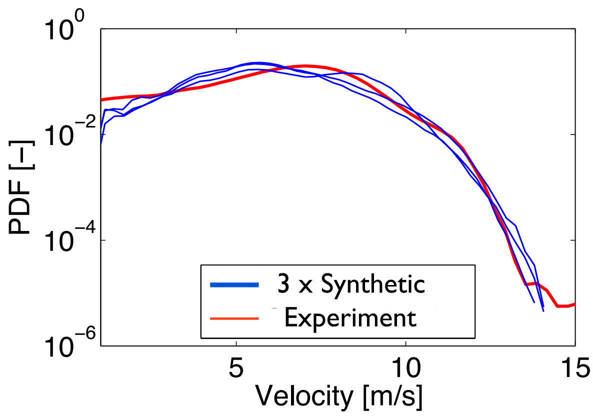


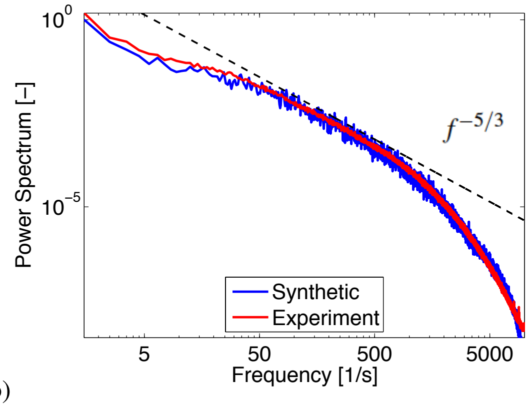
Figure 1. Sketch of the composing process of a time series. The left side plot is representative for the inflow conditions, it shows a time sequence of angles, which controls the active grid axes (excitation protocol). The arrow stands for the two ways of generating and composing, respectively, turbulent flow fields. The one way is the wind tunnel experiment, in which the inflow conditions generate a turbulent flow field. The other one is with VIDE ($\Gamma(u(t)|x, \alpha, \dot{\alpha}, u_\infty)$), thereby synthetic time series can also be generated, in contrast to the wind tunnel experiment composed on a computer.

series by rearranging the velocity times series from the database corresponding to an imposed inflow condition. Figure

1 shows the principle of the composing process. This new composed time series serve as an estimation of a flow field, which will be generated with the corresponding active grid excitation.
To show the quality of this method we compare an experimental and a synthetic generated velocity time series. Both composed with the same dynamical inflow conditions. The excitation protocol was generated with a Gaussian noise, the mean angle of the flaps to the incoming flow was $\langle\alpha\rangle = 45°$ and the standard deviation of the noise was σ =12.5°. Figure 2a) presents probability density functions (PDFs) of the velocity. The red line is the PDF of a time series recorded



a)



b)

Figure 2. Figure a) presents probability density functions (PDFs) of the velocity. The red distribution is a PDF measured in a wind tunnel experiment. The three blue curves are PDFs from synthetic time series. The composition of the synthetic time series based on the VIDE and the inflow conditions of the wind tunnel experiment. Figure b) shows a double logarithmic plot of two power spectra. The red curve is the power spectrum calculated from a time series measured in a wind tunnel experiment. The blue curve presents the power spectrum from a synthetic time series. The synthetic times series is calculated by the inflow conditions of the experiment.

in a wind tunnel experiment. The three blue lines are also PDFs from synthetic time series. Those series are composed on the computer with the specific inflow conditions from the experiment (red line) and the VIDE. The distributions of measured (red) and the composed (blue) time series are quite similar, but not equal. However, the composing process allows different realizations to the same inflow conditions, the three blue lines are some of those realizations. Also in the experiment we have to expect different flow field realizations for the same inflow conditions, because of imprecisions by the generation of flow fields and the chaotic nature of the turbulent flows. Many realizations of the synthetic time series show the range of possible deviations. This deviations serve as an uncertainty, which we also have to expect in the experiment.
Figure 2b) shows two power spectra, in red from the same experimental measured times series as above and in blue from a synthetic time series. Both spectra show a nearly equal shape over the hole frequency range. The inertial range is indicated with the dashed line, with the slope of $-\frac{5}{3}$. The only noticeable difference is the higher noise-level in the spectrum of the synthetic time series. This can be improved with longer time series in the VIDE, for that reason new measurements are planned. Not only one-point-statistics also two-point-statistics show the good validity of this method.
In the presentation the generation of VIDE and the composing of synthetic time series will be explained in detail. Also an iterative optimization of active grid excitation protocols will be shown. This iterative process generates synthetic time series for specific inflow conditions. The inflow conditions will be slightly changed until the resulting synthetic time series have the desired statistical properties. The basis for the optimization are the parameters $\alpha(t)$ and $\dot{\alpha}(t)$. This manner will generate excitation protocols, suitable for a lot of particular application, e.g. optimized to intermittency on a certain time scale.

References

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