CUSTOMIZED TURBULENT FLOW FIELDS

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Abstract A new approach is shown, which describes the interaction between an active grid excitation and a wind tunnel flow. With this approach we are able to find an excitation for the grid which reproduces an any turbulent flow field. Thereby we can bring free field measurements inside the wind tunnel. The presentation will show how the approach works and comparisons between reference data sets (outside measurements by ultrasonic anemometer) and wind tunnel flow fields generated by an active grid.

INTRODUCTION

Realistic wind fields are in the focus of fluid mechanic experiments, in particular for the applied research. To generate a realistic flow field, e.g. in a wind tunnel experiment, all flow characteristics (e.g. all dimensionless numbers) should be consistent with the "real world flow". In the predominant part of wind tunnel experiments the fulfillment of all characteristics is not possible. Therefore only the dominate characteristics are reproduced. This work is focused on reproducing changing flow conditions (turbulence). An important application of such flow fields are research on wind energy converters. Those machines work over many years ($\approx 20a$) in the heavy turbulent atmospheric boundary layer (ABL). Lift force fluctuations are strongly influenced by the statistics of the ambient turbulent wind field [1, 2] and lead to loads with similar characteristics.
To generate turbulent wind fields in a wind tunnel many approaches are used, e.g. diverse obstacles (like regular and fractal grids, cylinder etc.) or even boundary layer wind tunnels with a very long conditioning section in front of the test section. Those approaches map *one* turbulent flow condition, but in general the conditions change strongly over time. To overcome this problem we use a grid which excites the laminar flow to a turbulent one, by changing its blockage, which is controllable in time and in the grid plane. Its called active grid and is inspired by Makita [3]. However, generating the right turbulent flow field with an active grid is not trivial, because of the high dimensional excitation phase space.

MEASUREMENT OF A CORRELATION MATRIX

The active grid consists of seven horizontal and nine vertical axes with 126 square flaps (7.4×7.4cm^2) mounted to the axes. 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 grid is mounted on the wind tunnel nozzle and excites the laminar flow to a turbulent one by its *rotating* axes. Excitation protocols describe the position in time of the active grid axes and flaps, respectively. Therefore, the protocols are responsible for the characteristics of the resulting turbulent flow field [4].
The new approach, which finds the right excitation protocol, is based on a wind tunnel pre-experiment. In this experiment a correlation matrix between the active grid excitations and the resulting flow fields was measured. Therefore the excitation parameters, namely angle of attack of the flaps ($\alpha = 0 - 360°$), the rotation velocity of the axes ($\dot{\alpha} = \pm 90,\ \pm 225,\ \pm 450$ and $\pm 900° s^{-1}$), the wind tunnel wind velocity ($u_\infty = 5$, 10 and 20m/s) and the downstream position x (sixteen positions from one till twenty-four mesh sizes were selected), were successively changed. By measuring the corresponding wind fields the correlation matrix has been filled up.
Flow fields are recorded by three 1D-hot-wire probes. 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.

ACTIVE GRID EXCITATION PROTOCOLS

The correlation matrix served as a database, which shows us what velocity field can be expected when a certain set of inflow adjustment parameters is chosen. When the inflow adjustment parameters are changing the matrix provides a different flow field. It is possible to consider this in time: as the inflow parameters are changing over time, the corresponding flows (from the matrix) can be put together. This kind of building up synthetic velocity times series of various flows is a first approximation. The approximation is very good when the inflow adjustment parameters f vary slowly in time

$$\Delta T(f(\alpha, \dot{\alpha}, u_\infty) = const.)/T_{ref} \gg 1, \tag{1}$$

where T_{ref} is in the order of seconds ($u_\infty \approx 10m/s$) and depends on the velocity and velocity gradient. In general, condition (1) is not fulfilled and the approximation gets incorrect. To overcome this restriction the approach could be extended. Therefore the propagation velocity of the different flows is considered. Thus, a velocity times series build up of different flows will get gaps ($u = 0$) and overlaps ($u = u_1 + u_2$). Such gaps and overlaps are observed straight behind the grid, in the far field gaps get filled up with increasing downstream position and overlaps get washed out by turbulent diffusion. However, the extended approach with the consideration of varying propagation velocities change the shape of the synthetic velocity times series.

Both approaches (first approximation and the extension) are used to find an excitation for the grid. Therefore the problem gets inverted. A specific reference times series is given and the grid excitation is needed. For this, six steps have to be done, which will be explained in the presentation.

One preliminarily result is shown in figure 1. The figure presents two velocity measurements and standard deviations, one recorded outside at FINO (north sea measuring mast) by ultrasonic anemometer and the other recorded behind an active grid in a wind tunnel. The active grid excitation is generated by the first approximation. The figure shows that both velocity time series have nearly the *same* development in time. New experiments will show if the extended approach is able to reproduce the velocity development even better.

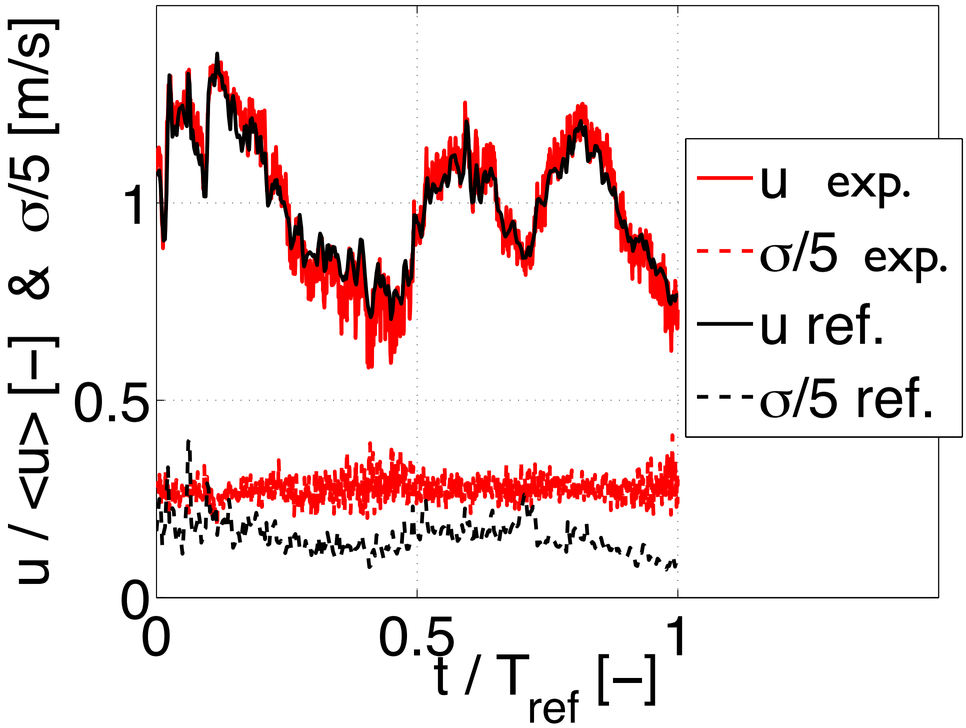

Figure 1. Reference, outside measurement at FINO performed by ultrasonic anemometer and reproduced velocity modulation by an active grid in a wind tunnel

References

[1] J. Schneemann, P. Knebel, P. Milan and J. Peinke. Lift measurements in unsteady flow conditions, *Proceedings of EWEC*, 2010

[2] Böttcher, F.; Renner, C; Waldl, H.-P. and Peinke, J.: On the Statistics of Wind Gusts. *Boundary-Layer Meteorology, 108, 163-73*, 2003

[3] Makita, H.: Realization of a large-scale turbulence field in a small wind tunnel. *Fluid Dyn. Res. 8, 53*, 1991

[4] Mydlarski L. and Warhaft Z. On the onset of high-Reynolds-number grid-generated wind tunnel turbulence *J. Fluid Mech. 320 331-68*,1996