First wind turbine wake
the unmanned SUMO sy

Joachim Reuder, Professor and Line Båserud, PhD student, University of Bergen

Motivation

The accurate characterization of the structure and dynamics of turbine wakes is the key to understanding the wind field inside and behind a wind farm, and therefore of major interest and vital importance for wind farm designers and operators. The general wake features, a reduction of the average wind speed combined with an enhancement of turbulence, reduce the power output and increase loads and fatigue for down-stream turbines. Both effects have negative implications for the economy over the lifetime of a wind farm as they increase investments and reduce the revenue.

in atmospheric research over the last decade has now opened up for a novel airborne measurement approach to bridge and complements existing measurement techniques.

The SUMO system

The Small Unmanned Meteorological Observer (SUMO, see Figure 1) is a micro-RPAS of about 80 cm length and wingspan and a take-off weight of around 700 g. It has been developed in collaboration between the Geophysical Institute at the University of Bergen and the Lindenberg and Müller GmbH & Co KG in Germany. The system has since 2007 been subject to

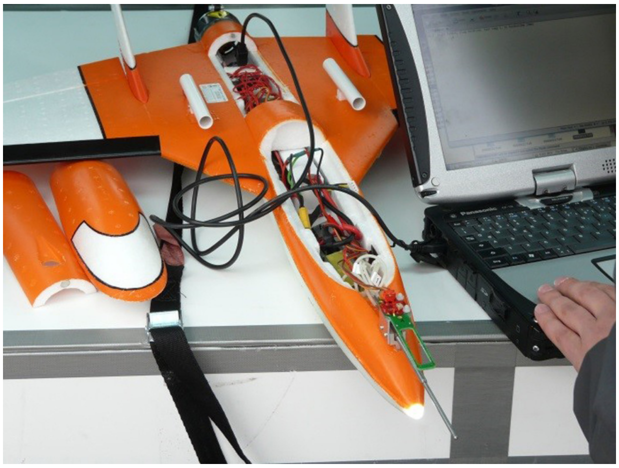

Figure 1: The SUMO system during the initialization before start (left). The 5-hole turbulence measurement probe is the grey tube mounted on the nose of the airframe. The picture on the right shows SUMO in operation in front of two of the NORDEX N80 2.5 MW test turbines at the ECN test site Wieringermeer. The 108 m meteorological mast can be seen in the lower left corner of this picture.

Full-scale wake investigations have during the last years mainly been performed in-situ by mast-based wind profile and turbulence measurements, or by the means of sodar and lidar remote sensing. The in-situ measurements from a mast can provide a good temporal resolution, but are limited to point measurements at the location of an available mast. Remote sensing, in particular by scanning lidar systems, gives a high flexibility with respect to spatial probing. However, these systems provide per definition volume averages instead of point measurements. The development and fast growing application of the Remotely Piloted Aircraft System (RPAS)

numerous improvements and is based on a slightly modified version of the commercially available model aircraft FunJet by Multiplex. Equipped with the open source autopilot system Paparazzi it is able to automatically fly preprogrammed flight missions. In addition to standard meteorological sensors for temperature, humidity and pressure, the SUMO system has also been equipped with a 5-hole flow probe for the measurements of the turbulent fluctuations of the wind with a sampling rate of 100 Hz. This allows for the calculation of relevant turbulence parameters, as e.g. the turbulence kinetic energy (TKE).

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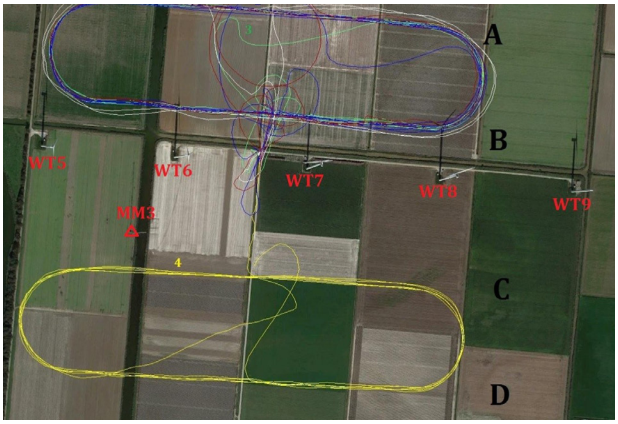

Figure 2: Location of the 5 NORDEX N80 2.5 MW turbines (WT5-WT9) and the meteorological mast (MM3) at the ECN test site Wieringermeer, together with the flight tracks of the 5 SUMO flights performed on May 10, 2014. The wind was coming from south-west, placing the flights # 1-3 and 5 downstream and the flight # 4 upstream of the row of wind turbines.

Campaign and SUMO missions performed

The SUMO flights presented here were embedded in the joint measurement campaign WINTWEX-W, performed between November 2013 and May 2014 in collaboration between NORCOWE and the Energy Center of the Netherlands (ECN) at the ECN test site Wieringermeer in the Netherlands. The main purpose of the campaign was the qualitative and quantitative description of single wind turbine wakes with respect to structure, propagation and persistency under various atmospheric conditions. The infrastructure of the test site relevant for this study consists mainly of a nearly east-west oriented row of five Nordex N80 2.5 MW research wind turbines (WT5-WT9 in Figure 2), with a hub height and rotor diameter (D) of 80 m. A meteorological mast (MM3) is located approximately 3 D upstream of WT6 for the main wind direction from south-west.

A suitable weather window in the afternoon of May 10 enabled 5 SUMO flight missions in the vicinity of the 5 test turbines. Figure 2 shows the corresponding race-track flight patterns. With a south-westerly wind of around 15 m/s four of the flights were located in the wake region downstream (flights #1-3 and #5) while flight #4 took place in the inflow upstream.

Results

Figure 3 presents the measurements of the east-west wind component **u** along the flight track given in UTM coordinates for the positions B (ca. 1.5 rotor diameters downstream) and D (upstream). The overall length of the x-axis presented is 1 km and the ticks are labeled every 100 m. The thin gray lines show the data from the individual legs (10 in the case of B and 4 in the case of D). The individual legs show a high inter-leg variability, while the average over all legs displays a rather homogeneous behaviour. The average background level of the wind speed is around 8 m/s for both positions. In the flight legs at B the wind turbines WT6 and WT7 both create a clear wake deficit that extends over about 150 m and reaches a maximum wind reduction of close to 4 m/s. Both the dimension and the amplitude of the effect measured by SUMO compare very well with results from static and scanning lidar wind measurements at the site.

The TKE calculated from the velocity variances measured by SUMO over the flight legs in position B (downstream) is plotted as function of the horizontal distance in Figure 4. Compared to the upstream conditions (not shown) it shows distinctly higher TKE levels as a consequence of the turbulence induced by the rotating turbine blades. At position B we can also see a clear signal from the individual wakes of the turbines WT5, WT6 and WT7 (denoted by the black arrows in the Figure). The one for WT5 is only captured partially. The fully probed wakes of WT6 and WT7 show the highest TKE level in the flanks of the wake while the TKE in the center is only slightly enhanced compared to the background TKE. Again the wake deficit extends over a horizontal distance of about 150 m.

Future work

After the successful proof of concept of SUMO's capability for wind turbine wake investigations, showing its potential of bridging and complementing mast and lidar measurements, a wide range of applications can be envisaged in the future. This includes the test of new flight strategies for future measurement campaigns, e.g. flying towards the wind turbine at different vertical levels and lateral displacement from the turbine centerline. This would result in rather low speed flights of SUMO over ground and therefore allowing the collection of longer time series of the 3-dimensional flow

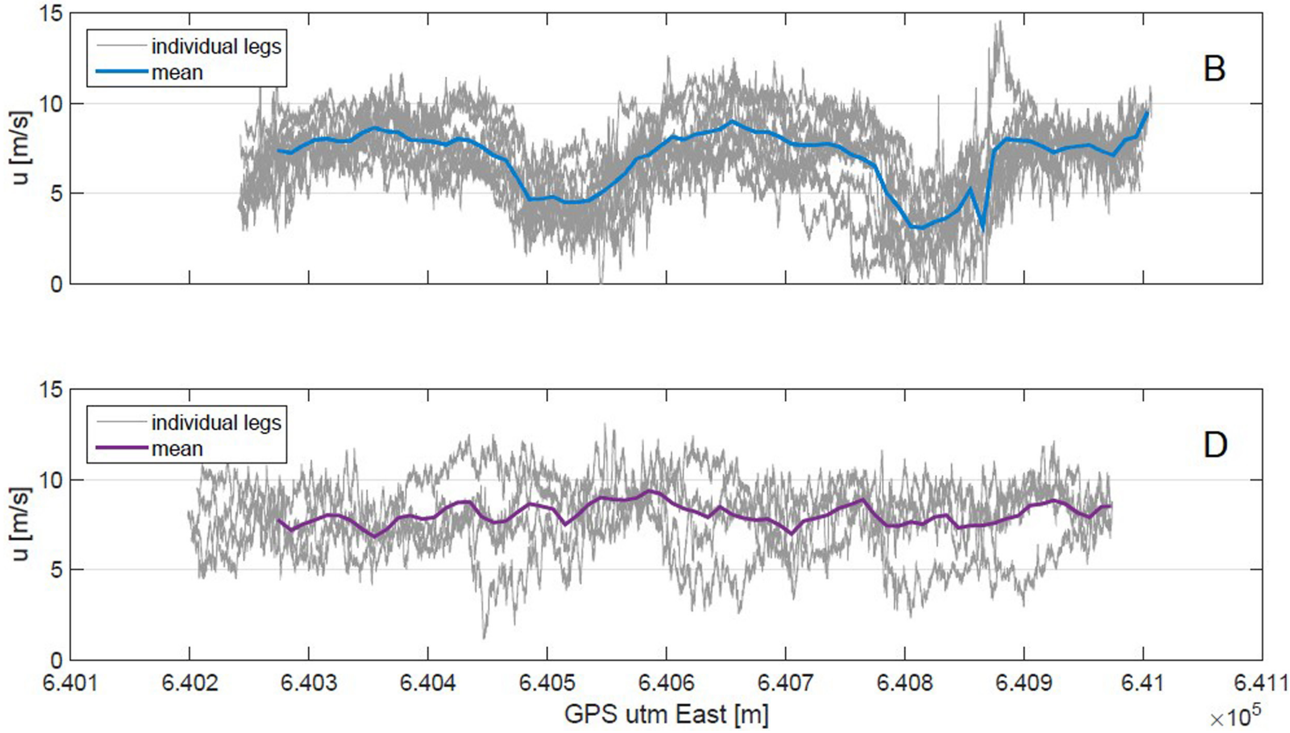

Figure 3: Wind speed measured by SUMO in positions B (ca. 1.5 rotor diameters downstream of the row of wind turbines) and position D (upstream). The thin gray lines show the data from the individual flight legs, while the thick colored line in each plot indicates the average over all corresponding flight legs at a given position.

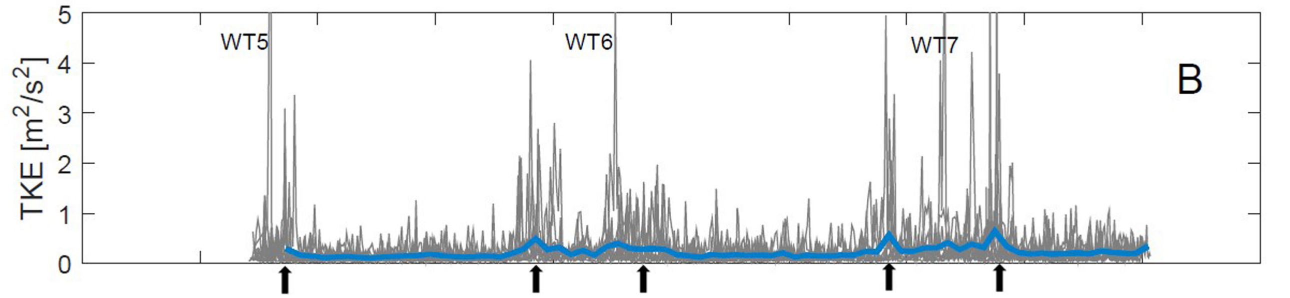

Figure 4: Turbulence kinetic energy (TKE) as function of the horizontal position as derived from the SUMO 5-hole probe turbulence measurements at position B. The thin gray curves show the data from the individual flight legs, while the thick blue line indicates the average over all corresponding flight legs. The black arrows show the extension of the wake signals.

vector, consequently increasing the statistics and robustness of the results. A new dimension of wake measurements will in the future be opened by the combination of fixed-wing (e.g. SUMO) and rotary-wing RPAS. The latter will, due to their hovering capability, be able to perform longer time series at fixed, but freely selectable positions. Two corresponding quadcopter systems with turbulence measurement capacity have recently been purchased by the Geophysical Institute and are at the moment in the test and validation phase.

References

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