Characterization of the SUMO turbulence measurement system for wind turbine wake assessment

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The remotely piloted aircraft system (RPAS) SUMO (Small Unmanned Meteorological Observer) has recently been equipped with a miniaturized 5-hole probe turbulence sensor with a temporal resolution of 100 Hz.
Due to it's small size SUMO is well suited for operations in wind farms as it will not impose any danger to the turbines in case of a collision.
The spectral response of the 5-hole probe has been investigated through laboratory- and environmental tests.

Measurement system

The RPAS SUMO is based on the fixed-wing model aircraft FunJet. It is a small and flexible system with a take-off weight of 600 g and length and width of about 80 cm (Fig. 1). More details can be found in e.g. Reuder et al. 2009.

The 5-hole probe micro Air Data System (ADS) consists of an Air Data Computer (ADC), a 5-hole probe and corresponding pressure transducers (Fig. 1). The probe is placed in the nose of the aircraft. Output for true airspeed (TAS), angle of attack (α), angle of sideslip (β) and altitude is given based on differential pressure measurements.

The 3-dimensional wind vector is calculated from 5-hole probe measurements of the flow approaching the aircraft after correcting for aircraft movement (e.g. Lenschow 1989).

Fig 1: The SUMO system and the 5-hole probe turbulence sensor.

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Wind tunnel tests of the 5-hole probe

Fig 2: The setup for the laboratory tests. Left: The test setup for the ADS; Right: The horizontal stick used to create turbulence in the flow. Pictures by Sebastian Wein.

The 5-hole probe was first tested in a parallel experiment together with a hot-wire anemometer (HW). Spectra of airspeed from the two systems can be seen in Fig. 3.

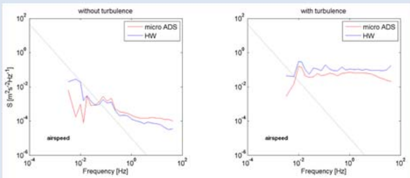

Fig 3: Spectra of airspeed from the HW and 5-hole probe parallel test.

- Both systems experience an energy shift between laminar and turbulent conditions
- The 5-hole probe react to the turbulence in a similar manner as the HW system in the relevant frequency range

The 5-hole probe was also tested with different tubing lengths between the probe and the ADC (15 cm, 30 cm and 90 cm). Spectra of TAS, α and β can be seen in (Fig. 4).

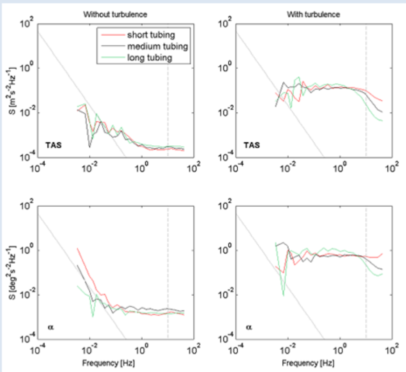

Fig 4: Spectra of TAS and α from the 5-hole probe for the different tubing lengths of 15 cm (red), 30 cm (black) and 90 cm (green).

- Little effect for laminar conditions
- With turbulence, some energy is lost for the highest frequencies
- The longer the tubing, the larger the loss by spectral damping.
- The system resolves turbulence appropriately up to a frequency of 20-30 Hz when using the shortest tubing

References:

Reuder et al, 2009: The Small Unmanned Meteorological Observer SUMO: A new tool for atmospheric boundary layer research. *Meteorologische Zeitscrift.*, **18**(2), 141-147.

Lenschow DH & Spyers-Duran P, 1989: Measurements techniques: Air motion sensing. *National Center for Atmospheric Research (NCAR) Bulletin* **23**

Environmental test of the 5-hole probe

To investigate the behavior of the 5-hole probe under atmospheric turbulence conditions, the spectral response of the u, v and w wind components from SUMO and a sonic anemometer was compared by driving with the instruments mounted on a car along the 2600 m long runway of Bergen airport Flesland (total of 12 legs with a speed of 20 or 25 m/s).

Fig 5: Setup for the test campaign at Flesland airport. From left to right: Gill R3-100 sonic anemometer, SUMO dummy with the 5-hole turbulence probe, Campbell CSAT3 sonic anemometer.

The resulting measurements of u, v, and w in the SUMO coordinate system by the 5-hole probe are shown in Fig. 6:

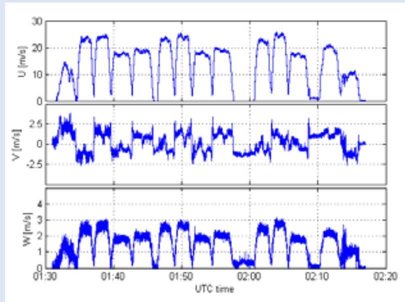

Fig 6: Time-series of u (in direction of the moving car), v (crosswind) and w (vertical) components of the measured flow vector.

First results of turbulence spectra for the u-component are presented in Fig. 7:

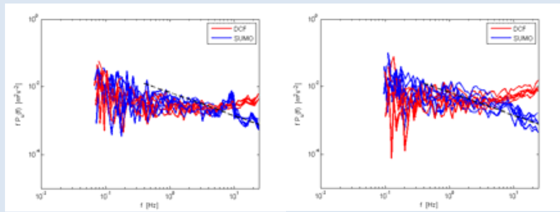

Fig 7: Spectra of the u-component for the legs with 20 m/s (left) and 25 m/s (right)

- The SUMO system measures spectra that are in general following the expected -2/3 slope expected from a Kolmogorov spectrum
- The peak at around 9 Hz is related to a vibration frequency of the SUMO mounting rod
- In the frequency range up to ca. 5 Hz, the 5-hole probe and the sonic anemometer show good agreement
- At higher frequencies the energy level of the sonic anemometer is distinctly enhanced, this can most likely be attributed to flow distortion at the edges of the mounting platform