Windflower

Figure 1: Rendering of Windflower probe

General

The Windflower measurement system was designed for autonomous operation while mounted at the nose cone of a wind turbine. The system consists of a probe and a connected data acquisition device, which is called VectoDAQ. Its ability to continuously operate under severe weather conditions has been validated during a test campaign lasting 80+ days. Of these days, 64 had rain and 35 had a minimum temperature below 0°C. The onboard heater of the system successfully prevents both, condensation, and icing during operation conditions. The system showed no damage or wear after disassembly at the end of the campaign and could have been operated for another couple of months without maintenance, validating the high degree of autonomy achieved by the system.

General	
Weight	~3 kg
Dimension probe	5-hole probe Head: 160 mm x Ø 9 mm, Boom: 1,580 mm x Ø 25 mm Mount: 260 mm Total length: 2,000 mm.
Materials	Head: Stainless steel Boom: CFRP Mount: PLA, Stainless steel VectoDAQ casing: Aluminum
Environmental Conditions	
Operating temperature	-20 ... 50°C (-4 … 158°F)
Operating medium	Air
Humidity	0 ... 95 %

Pressure Acquisition	
Pressure acquisition	5 differential pressure sensors
Pressure sensor accuracy	Max. +/- 0.25 % FSS (typical +/- 0.1 % FSS)
Temperature Control	
Measurement	Thermocouple or Pt100
Heater	24 V @ 2 A (= 48 W)

Operational Results	
Minimum velocity [m/s]	**Maximum velocity [m/s]**
5	25

Measurement Errors	
Flow angles[1]	< 1°
Velocities	< 1.0 m/s or < 1.0 %, whichever is greater
Temperature	< 1 K

[1] *Verified during a test campaign at TU Berlin*

Interface	
USB or CAN	Communication with Host PC for configuration (USB) and data acquisition (USB or CAN)
Power	5 V via USB or 7-36 V via CAN.
Pressure connection	Metal tube Ø 1.06 mm
Cable (included)	1.8 m LEMO (FGG.0B.307 to USB A)
Cable (optional)	1.8 m LEMO (FGG.0B.307 to D-SUB 9 for CAN)
Max. data transmission rate	16 Hz

Output	
Name	Unit
P_1…P_5 (differential pressure)	Pa
P_{abs} (absolute pressure)	Pa
T_{tc} (temperature at probe tip)	°C
Theta (cone angle)	°
Phi (roll angle)	°
Alpha (angle of attack)	°
Beta (yaw angle)	°
V_{mag} (velocity magnitude)	m/s
u, v, w (velocity components)	m/s
P_d (dynamic pressure)	Pa

P_s (static pressure)	Pa
ρ (air density)	kg/m³
T_{tot} (total temperature)	°C
T_s (static temperature)	°C
M (Mach number)	-
Yaw, Pitch, Roll (according to IMU)	°
Gyroscope (X, Y, Z)	rad/s
Accelerometer (X, Y, Z)	m/s²
Magnetometer (X, Y, Z)	Gauss
Av_Theta (cone angle averaged over one turbine rotation)	°
Av_Phi (roll angle averaged over one turbine rotation)	°
Av_Alpha (angle of attack averaged over one turbine rotation)	°
Av_Beta (yaw angle averaged over one turbine rotation)	°
Av_U, Av_V, Av_W (averaged velocity components over one turbine rotation)	m/s

Validation campaign

During a validation campaign at Danish Technical University (DTU) Windflower data was compared to data from a measurement mast installation at 118 m upstream of a test turbine and to data from a sonic anemometer placed on the nacelle of the test turbine in the downwash of the blades. Results of this comparison, as visualized in Figures 3 and 4, show the excellent performance of the Windflower system by means of accuracy and signal noise. Figure 2 moreover shows a picture of the probe mounted on the nose of the test turbine.

Figure 2: Picture of test turbine at DTU with Windflower system installed on the nose cone.

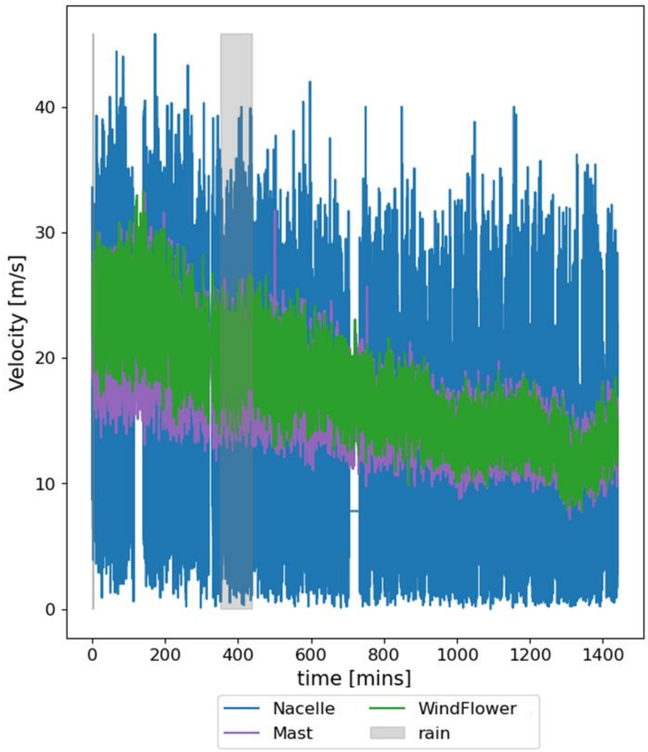

Figure 3: Velocity plot of a typical day during validation campaign at DTU. The grey area indicates rain detection.

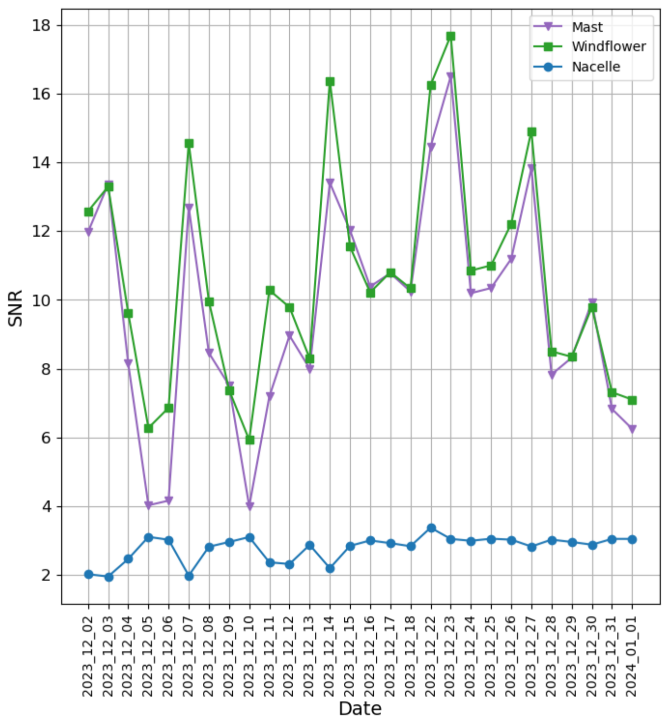

Figure 4: Averaged Signal to Noise ratio (SNR) per day for the signals from Windflower (green squares), the sonic anemometer upstream of the turbine (purple triangles) and the sonic anemometer on the nacelle (blue circles). The SNR was calculated for a data length of 3 seconds and averaged per day. Higher SNR implies less noisy signals.