LIDAR MEASUREMENTS OF FULL SCALE WIND TURBINE WAKE CHARACTERISTICS

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Outline

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  – Eliminate shear
  – Identify wake meandering
  – Resolve wake deficit in meandering frame of reference
  – Resolve inhomogeneous wake turbulence intensity characteristics
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Purpose

- Perform full-scale wind speed measurements in the wake of an operating 80m / 2.5 MW wind turbine.
- Resolve the wake meandering caused by the large scale part of the ambient turbulence field
- Resolve the wake characteristics in the meandering frame of reference, i.e.
  - Wake deficit
  - Inhomogeneous wake turbulence intensity characteristics

Reference project is EU-TOPFARM.
Site layout
Wake measurements with a horizontally shooting LiDAR (1)

NM80; 80m / 2.5MW; VP & VS
Wake measurements with a horizontally shooting LiDAR (2)

LiDAR Performance (Experimental QinetiQ ZephIR):

- PAN (horizontal) angle: $\pm 25^\circ$
- TILT (vertical) angle: $\pm 11^\circ$
- Scanning capacity (time resolution): 349 Hz
- Scanning capacity (spatial resolution): 1047 positions/plane (i.e. pr. 3 seconds)
- Focus limit maximum: 200m (= 2.5 x D)

LiDAR mode options:
1) Constant focus distance (40, 80, 120, 160 or 200m)
Preliminary measurements

• Measurements covers periods with moderate wind speeds and different flow direction.
• Low temperature operation (-10ºC – 0ºC).
• Wet and cloudy weather has reduced the data quality.
• Measurements includes single and double wake situations.
• Low wind speed measurements with mast in wake sector might be used for calibration?
• LiDAR is operating continuously during the next 2 months.
LIDAR sweep pattern during 3 sec.

Hub height
LIDAR shear; period = 3 sec.
LIDAR speed measurements; period = 3 sec.

- Raw measurements
- Shear corrected values

Wind speed (LiDAR) – m/s

Horizontal direction (y) [m]
Wake position identification based on a bivariate Gaussian least square fit method

\[ f(A, \mu_y, \mu_z, \sigma_y, \sigma_z) = \frac{A}{2\pi\sigma_y\sigma_z} \exp \left[ -\frac{1}{2} \left( \frac{(y_i - \mu_y)^2}{\sigma_y^2} + \frac{(z_i - \mu_z)^2}{\sigma_z^2} \right) \right] \]
Fitted speed deficit; ts=3 sec.

Flow direction

Horizontal direction - y

Vertical direction - z

Speed deficit - m/s
Wake at level $z_o = 3.6$ m

- Wind speed [m/s]
- Horizontal direction (y) [m]
Wake at Pan position; \( y_0 = 23 \text{ m} \)
Wake (meandering) tracking

Wind turbine is yawing appr. 11 deg.
Averaged speed deficit; ts = 30 x 3 seconds

Flow direction
Radial speeds using aligned wakes, 
$ts = 30 \times 3 \text{ sec.}$

Azimuth averaged 
wind speed
Average turbulence; $ts = 30 \times 3$ seconds

Wind speed St. dev. - m/s

$z$: Vertical direction - m

$y$: Horizontal direction - m
Radial distribution of turbulence based on aligned wakes, ts=3 x 30 sec.

Azimuth averaged turbulence
Time schedule for the wake measurements

- March–April 2009: Continuously wake measurements

- Spring 2009: Campaign measurement with experimental blade;
  1) Measure flow conditions in the rotor plane with 5 hole pitot tubes.
  2) Measure wake speed deficits and turbulence.
Conclusion

• The wake meandering dynamics has been resolved

• The wake deficit has been resolved in the meandering frame of reference

• The inhomogeneous wake turbulence intensity characteristics has been resolved in the meandering frame of reference
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Announcement

A EUROMECH colloquium will be organized 20–22 October 2009 in Madrid within the framework of TOPFARM. The theme for EUROMECH colloquium 508 is “Wind Turbine Wakes”.