WAKE MEANDERING AND ITS RELATIONSHIP WITH THE INCOMING WIND CHARACTERISTICS: A STATISTICAL APPROACH APPLIED TO LONG-TERM ON-FIELD OBSERVATIONS

E. Torres Garcia¹, S. Aubrun², M. Boquet, P. Royer, O. Coupiac and N. Girard

SMARTEOLE funded by Agence Nationale de la Recherche (ANR-14-CE05-0034)

¹eulalio.torres-garcia@univ-orleans.fr
²sandrine.aubrun@univ-orleans.fr
I. Context and objectives

II. Experimental set-up

III. Methods

IV. Results

V. Conclusions & perspectives
I. Context and objectives

II. Experimental set-up

III. Methods

IV. Results

V. Conclusions & perspectives
Context and objectives

- **SMARTEOLE: Smart Rotors to Improve Wind Energy Efficiency and Sustainability**
  - French National Project
  - 42 months
  - Total budget 2M€, funding 800k€
  - 6 partners (2 industrials, 4 research org.)

- Apply innovative control strategies at blade, rotor and farm scales

- Wake tracking for closed-loop wind farm control
Context and objectives

- **Characterization wake meandering based on incoming wind conditions**
  - Wake interactions
  - Wake meandering

- **Wind tunnel proofs of concepts**
  - Muller et al., Exp Fluids (2015) 56:53

- **Provide a database base for model calibration**
I. Context and objectives

II. Experimental set-up

III. Methods

IV. Results

V. Conclusions and perspectives
Measurement campaign settled in the North of France, in the west limits of Ablaincourt-Pressoir municipality.
Measurement campaign focuses on area surrounding WTs (SENVION MM82) SMV5 and SMV6.
115 measurement points along a Line Of Sight (LOS)
Acquisition range gate 25 m, total of 3000 m

30 LOS form a Plan Position Position Indicator (PPI)
Sweeping the azimuth angle of the LOS 1°, at 2°/s acquisition rate, holding elevation, 1 PPI every 15 s

3 elevation angles to cross the wake at different heights
2.5°, 3.8° and 5.2°
- 115 measurement points along a Line Of Sight (LOS)
  Acquisition range gate 25 m, total of 3000 m
- 30 LOS form a Plan Position Position Indicator (PPI)
  Sweeping the azimuth angle of the LOS 1°, at 2°/s acquisition rate, holding elevation, 1 PPI every 15 s
- 3 elevation angles to cross the wake at different heights
  2.5°, 3.8° and 5.2°
Experimental set up

- 115 measurement points along a Line Of Sight (LOS)
  Acquisition range gate points 25 m, total of 3000 m
- **30 LOS form a Plan Position Indicator (PPI)**
  Sweeping the azimuth angle of the LOS 1°, at 2°/s acquisition rate, holding elevation, 1 PPI every 15 s
- 3 elevation angles to cross the wake at different heights
  2.5°, 3.8° and 5.2°
Experimental set up

- 115 measurement points along a Line Of Sight (LOS)
  Acquisition range gate points 25 m, total of 3000 m
- 30 LOS form a Plan Position Indicator (PPI)
  Sweeping the azimuth angle of the LOS 1°, at 2°/s acquisition rate, holding elevation, 1 PPI every 15 s
- 3 elevation angles to cross the wake at different heights
  2.5°, 3.8° and 5.2°
Outline

I. Introduction

II. Experimental set-up

III. Methods

IV. Results

V. Conclusions and perspectives
Large database of LiDAR Measurements (821000 PPIs)

Classification according to:

- 1) Neutral atmosphere corresponding to $|L| \geq 1000$ m
  WT wake recovers more slowly than in unstable/convective conditions
- 2) Three wind directions ($WD$) associated with three different wake patterns
- 3) Two wind speeds ($U$) at different WT operational set points
1) Neutral atmosphere corresponding to $|L| \geq 1000$

Modern-Era Retrospective analysis for Research and Applications (MERRA2) $^1$

Numerical simul. based on space observations

- Wind direction ($WD$)
- Wind velocity ($U$)
- Pressure
- Temperature
- Monin-Obukhov Length $^2$ $|L|$

Bilinear interpolation between the 4 points gave no change in stability periods.

---

$^1$ MERRA2 DB (Reanalysis of space observations of aerosols) [https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/](https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/)

2) Three wind directions (\(WD\)) 207°, 225° and 244°.

Field site
Wind turbines of interest: SMV5 and SMV6

PPI- velocity field for 22-12-2015 12:52:44
\(\alpha_3 = 5.2^\circ\)

Scanning time 15s
3) Two wind speeds \((U)\) at different WT operational set points
Methods

Acquired

Count data +80%
Interpolate values

Identify

$X_{LiDAR}$ [m]
$Y_{LiDAR}$ [m]
Test example: Average flow field for the 22 12 2015

Wind 207° rotation
Method for wind tunnel measurements
Muller et al., Exp Fluids (2015)

Instantaneous wake position deduced from a weighted space average

\[
Y_{\text{wake}}(X_{WD}, t) = \left( \sum_{i=1}^{N} \exp(Du_i (X_{WD}, Y_{WD}, t) \times Y_{WD,i}) \right) / \sum_{i=1}^{N} \exp(Du_i (X_{WD}, Y_{WD}, t))
\]
The mean and the standard deviation from the wake center location ($y_\omega$)

Cumulative standard deviation of the wake center position ($C\sigma_{y_\omega}$)

The statistical uncertainty convergence $\epsilon = 1.96 \cdot C\sigma_{y_\omega} / \sqrt{N}$

where:

- $C\sigma_{y_\omega}$ is the cumulative standard deviation of the wake center position
- $N$ the number of independent samples
- 1.96 for a confidence level of 95%
I. Introduction

II. Experimental set-up

III. Methods

IV. Results

V. Conclusions and perspectives
### Mean velocity field

Number of samples per case for $|L| \geq 1000$ m

<table>
<thead>
<tr>
<th>elev.</th>
<th>07207</th>
<th>11207</th>
<th>07225</th>
<th>11225</th>
<th>07244</th>
<th>11244</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_1 = 2.5^\circ$</td>
<td>284</td>
<td>248</td>
<td>155</td>
<td>255</td>
<td>121</td>
<td>149</td>
</tr>
<tr>
<td>$\alpha_2 = 3.8^\circ$</td>
<td>324</td>
<td>258</td>
<td>167</td>
<td>248</td>
<td>107</td>
<td>152</td>
</tr>
<tr>
<td>$\alpha_3 = 5.2^\circ$</td>
<td>242</td>
<td>184</td>
<td>131</td>
<td>258</td>
<td>105</td>
<td>153</td>
</tr>
</tbody>
</table>

![Image of velocity field plots for different cases showing varying elevations and number of samples per case.](attachment:image_url)
Statistical wake convergence

207° ±1°, accumulated 2 samples

PPI 3 $\alpha = 5.2^\circ$

PPI 2 $\alpha = 3.8^\circ$

PPI 1 $\alpha = 2.5^\circ$
Statistical uncertainty convergence

\[ \varepsilon \times 10^{-2} \]

\[ \alpha_1, \alpha_2, \alpha_3 \]

\[ \Sigma V_\omega, \Sigma V_\omega, \Sigma V_\omega \]

\[ U [m \cdot s^{-1}] \]
Mean and std. of wake centre

\[ U = 7 \text{ m/s} \]

\[ WD = 207^\circ \]

\[ WD = 225^\circ \]

\[ WD = 244^\circ \]
I. Introduction

II. Experimental set-up

III. Methods

IV. Results

V. Conclusions and perspectives
Conclusions and perspectives

- Large database for community use
- In Field data 100 samples are statistically significant
- Std of the wake center position is 0.19 at 3 D downstream
- A similar value was found in wind tunnel and field experiments, Aurbun 2012
- Show the influence of neighboring wakes

- Analyze velocity deficit
- Include RHI
- Include SCADA data
- Correlate wake behavior with wind turbine performance characteristics
THANK YOU FOR YOUR ATTENTION

E. Torres Garcia¹, S. Aubrun², M. Boquet, P. Royer, O. Coupiac and N. Girard

¹eulalio.torres-garcia@univ-orleans.fr
²sandrine.aubrun@univ-orleans.fr