Wake detection and management using downwind LIDAR measurements

Presenter: Suhas Pol Ph.D., Texas Tech University

Sponsors:

Sandia Blade Workshop 2018
Collaborators

• Graduate Students:
  • Tássia Penha Pereira (Graduated: August 2018)
  • Ricardo Castillo

• TTU Faculty:
  • Suhas Pol
  • Andy Swift
  • Archie Ruiz
  • Carsten Westergaard (Westergaard Solutions)

SNL:
  • Brian Naughton
  • Thomas Herges
  • Dave Mitchel
  • Geoff Klise
R&D Questions

1. LIDAR Wake Detection
2. Wake management

wind speed from 8 to 10mph → Double the Power Output
R&D Questions

1. **LIDAR Wake Detection:**

   - **Windar Photonics:**
     - Nacelle-mounted
     - Downwind-facing

   - **Pentalum SpiDAR:**
     - Ground-based
     - Profile-measuring
1. LIDAR Wake Detection: Simple-design, Inexpensive
1. LIDAR Wake Detection
2. Wake management
Outline

• Ground-based LIDAR
• Windtunnel-based wake detection and management
• Future work
Ground-based LIDAR

Pentalum SPIDAR
- non-Doppler, correlation-based
- Instantaneous profile

The figure is adapted from Eikill (2016)
SWiFT Deployment

(Herges et al., 2017)
SWiFT Deployment

Phase 1
Phase 2

WTGa1

(Pereira, 2018)
SWiFT Deployment

Phase 1

Phase 2

(Westergaard, 2016; Pereira, 2018)
Quality Control

- Quality Score > 20% (Penatllum 2016) → Low data availability
- Clifton et al. (2018): practices and standards do not cover the entire range of LIDAR’s potential
- Edward (1998): Consider data with and without outliers
- Sela (2012): Variable aerosol density leads to lower quality score
- Hampel Filter: Remove and interpolate outliers > $\pm 3 \times \text{median absolute deviation}$

(Pereira, 2018)
Quality Control

(Pereira, 2018)
Results: Phase 2

Weakly stable (21:32 - 21:42 hrs.)
WS= 6.7 m/s at 32 m

(Pereira, 2018)
Results: Phase 2

(Turbine - Yaw Offset)

(Turbine - TSR)

(Maniaci, 2011)

(Pereira, 2018)
Results: Phase 2

Cross section South Flow at 30 m - AvgWd = 162deg | YO = 6 deg

(Pereira, 2018)
Results: Phase 2

(Pereira, 2018)
Data: Conditional Sampling

- Atmospheric Stability

<table>
<thead>
<tr>
<th>Stability</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable</td>
<td>( z/L &lt; -0.05 )</td>
</tr>
<tr>
<td>Neutral</td>
<td>(-0.05 \leq z/L \leq 0.05)</td>
</tr>
<tr>
<td>Stable</td>
<td>( z/L &gt; 0.05 )</td>
</tr>
</tbody>
</table>

- Specific Wind Direction (North or South), Wind Speed, and Turbulence Intensity

- Turbine Operation (On or Off)

(Pereira, 2018)
Outline

• Ground-based LIDAR
  • PentalumSpiDAR
  • Wake detection with 5 sec. data
  • Requires quality control

• Windtunnel-based wake detection and management
• Future work
Outline

• Ground-based LIDAR
  • Pentalum SPIDAR
  • Wake detection with 5 sec. data
  • Requires quality control

• Windtunnel-based wake detection and management

• Future work
R&D Questions

1. LIDAR Wake Detection
2. Wake management
Experimental setup: Wind-tunnel test platform development

- Hyper Accelerated wind farm kinematic controlled simulator, “HAWKS”

Inflow $U_\infty$

4 Camera Array

This is how a test looks like
Experimental setup: Fully controllable model wind turbine development

- 1 ADC for voltage measurement
- 3 PWM signals for pitch control
- 1 PWM signal for yaw control
- 1 QEP for rotor RPM measurements
- DC Generator w/ embedded encoder
- Buck DC/DC converter
- Controller
- Hall effect sensor ACS271
- TI TMS320F28335 Control board

Wind

DC generator

Gate PWM

Buck DC/DC converter

Controller

SCI Communication

1 ADC for current measurement

• 1 ADC for voltage measurement
Wake vector field under dynamic yaw misalignment

Stream-wise velocity field, $\frac{U}{U_\infty}$

Vorticity: $\nabla \times \mathbf{u} = \frac{\partial V}{\partial x} - \frac{\partial U}{\partial y}$

Horizontal plane at hub height
Validation of HAWKS wake deflection measurements

Comparison of the HAWKS wake deflection $y_c/D$ at $x/D=7$ with different previous studies.

HAWKS setup for wake detection

• Hot-wire anemometry showed good agreement with LIDAR measurements (Van Dooren et al. (2017)).

• **Hot-wire system**
  - Dantec Dynamics 54T42 MiniCTA (Constant Temperature Anemometer) equipped with 55P16 hot-wire probe.
  - 16-bit NI 9215 DAQ

• **Power spectral density PSD analysis parameters**
  - Sampling frequency=20 kHz
  - Sampling time per window=0.1024 sec
Results Wake interface PSD analysis

- Comparison of PSD characteristics across the wake interface at x/D=3.

**Observations**

- The peaks at every position across the wake interface show that the dominant frequencies are multiple of the rotational frequency.
- The dominant peak across the wake interface is at 1P.
- Across the wake interface, the peak at 1P show a significant variation compared to the peaks at 2P and 3P.
Results: wake deflection vs rotor speed

Contours of the normalized mean stream-wise velocity ($U/U_\infty$) in the horizontal plane at hub height for several RPM at $\gamma = 20^\circ$.

Comparison of normalized mean stream-wise velocity ($U/U_\infty$) profile in the hub-height horizontal plane at $x/D=3$ for yaw angle $\gamma=20^\circ$.

Observations

- The wake velocity deficit is more pronounced with increasing rotor speed.
- The wake is shifted to the left with increasing rotor speed.
Results: wake deflection vs rotor speed

Comparison of measured wake deflection center $y_c(x)$ for $\omega=3000$, 4000, and 5000 RPM at yaw angle of $\gamma = 20^\circ$ with wake deflection given by DTU wake deflection model.

- HAWKS wake deflection was compared with DTU empirical linear wake deflection model (Guntur (2012)).
  \[
  \frac{y_c}{D} = 0.24 \frac{x}{D} C_T \tan(\gamma)
  \]
- $C_T$ exhibits a monotone behavior with $\omega$, and hence with $\lambda$. 

\[
\begin{array}{c}
\text{T} \quad \text{TX} \quad \text{DT} \\
\text{C} \quad \text{T} \quad \text{C} \quad \text{T} \quad \text{C} \quad \text{T} \\
\end{array}
\]

\[
\begin{array}{c}
\text{3000 RPM} \\
\text{4000 RPM} \\
\text{5000 RPM} \\
\text{DTU, } C_T=0.55 \\
\text{DTU, } C_T=0.66 \\
\text{DTU, } C_T=0.85 \\
\end{array}
\]
Outline

• **Ground-based LIDARtt**
  • Pentalum SPIDAR
  • Wake detection with 5 sec. data
  • Requires quality control

• **Windtunnel-based wake detection and management**
  • HAWKS testing platform
  • Wake detection: tip vortices
  • Wake deflection: yaw and or speed

• Future work
Future Work

• Ground-based LIDAR
  • V&V effort; LIDARs upstream
  • LIDAR array at 2D downstream
  • Rotor comparison

• HAWKS
  • Closed-loop control demonstration
  • HAWKS 2.0: 3 turbine setup
  • SWiFT test
Thank you!