TEXAS TECH UNIVERSITY

Wake detection and management using downwind LIDAR measurements

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

Sponsors:

Sandia Blade Workshop 2018

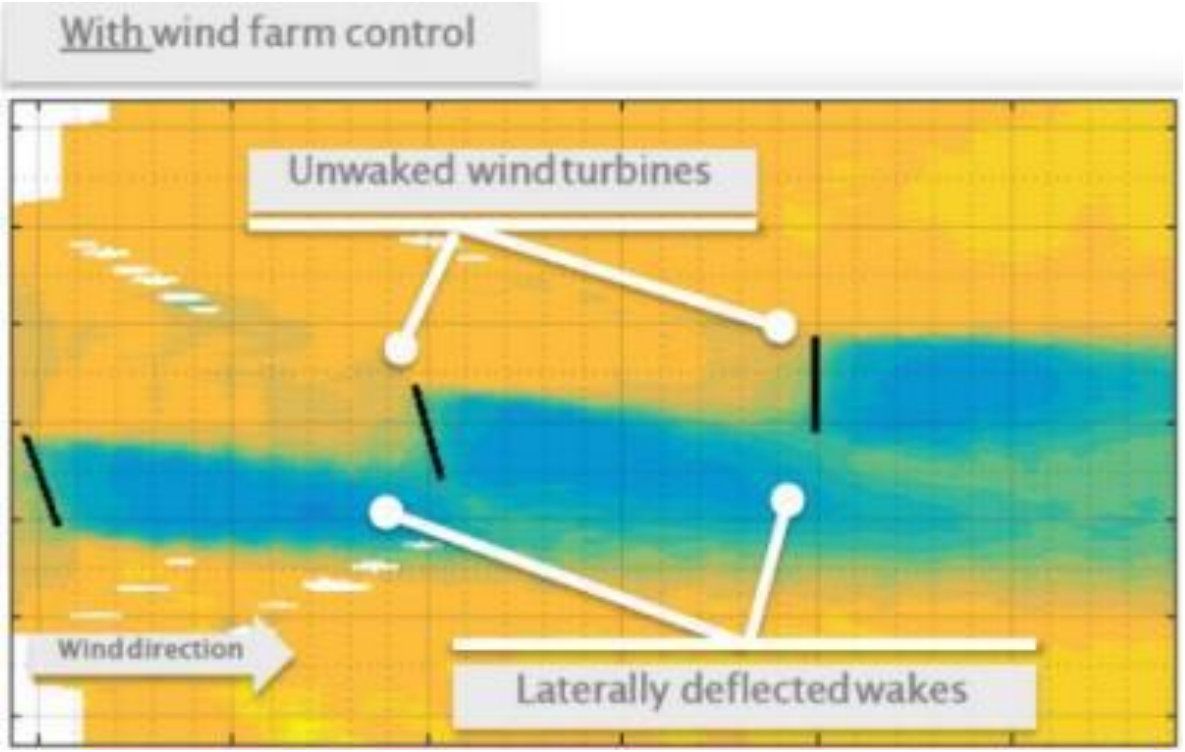
Collaborators

- 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:

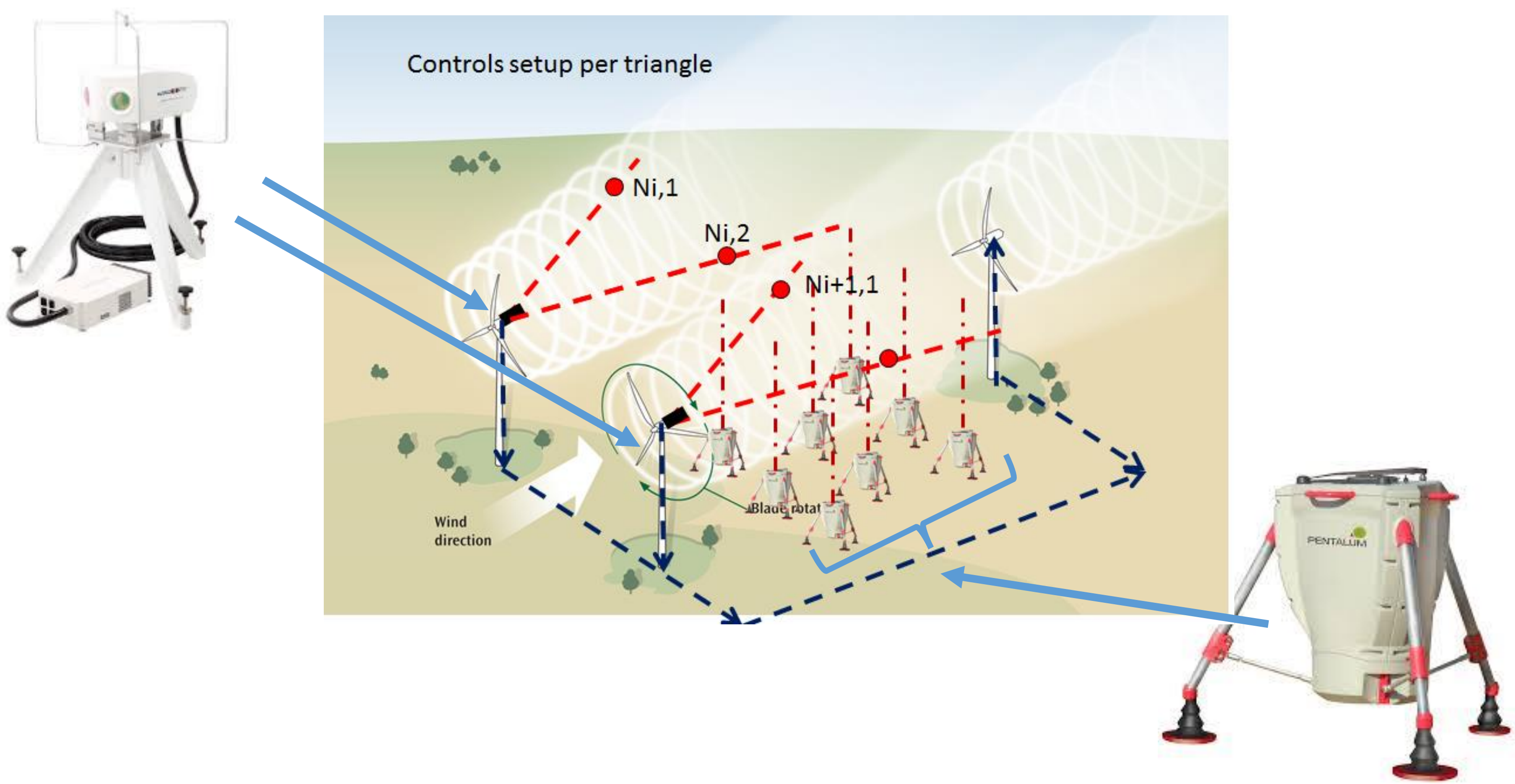
- Nacelle-mounted
- Downwind-facing

Pentalum SpiDAR:

- Ground-based
- Profile-measuring

R&D Questions

1. LIDAR Wake Detection: Simple-design, Inexpensive



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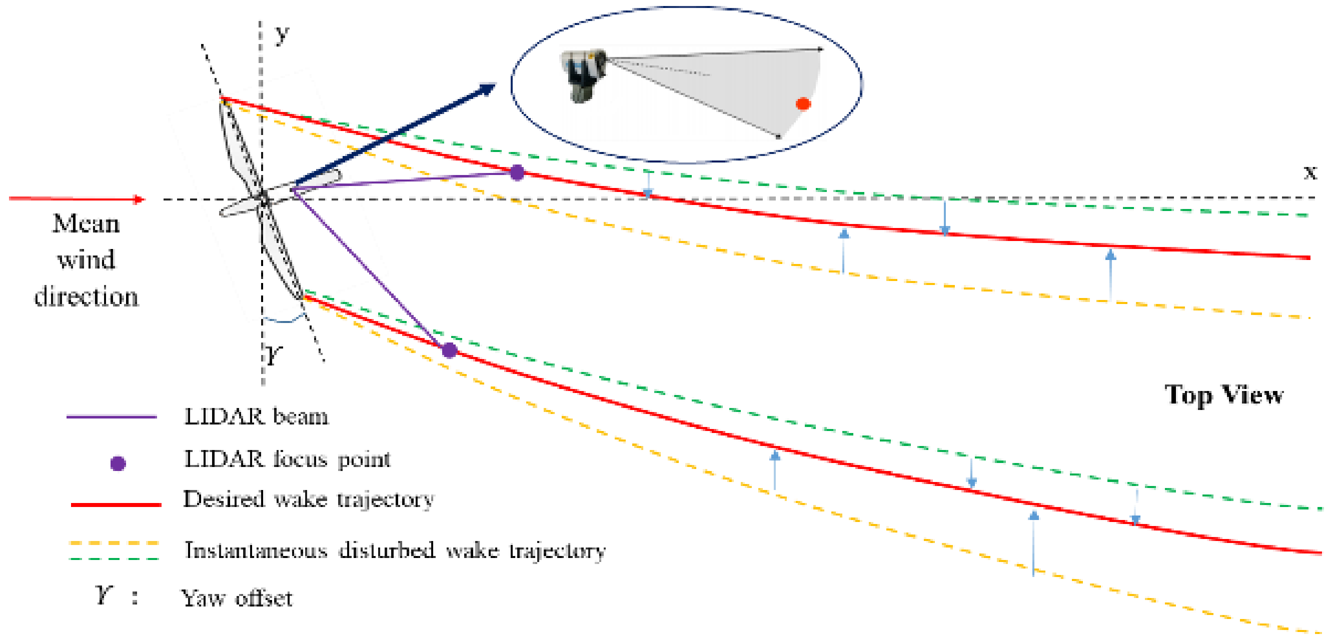
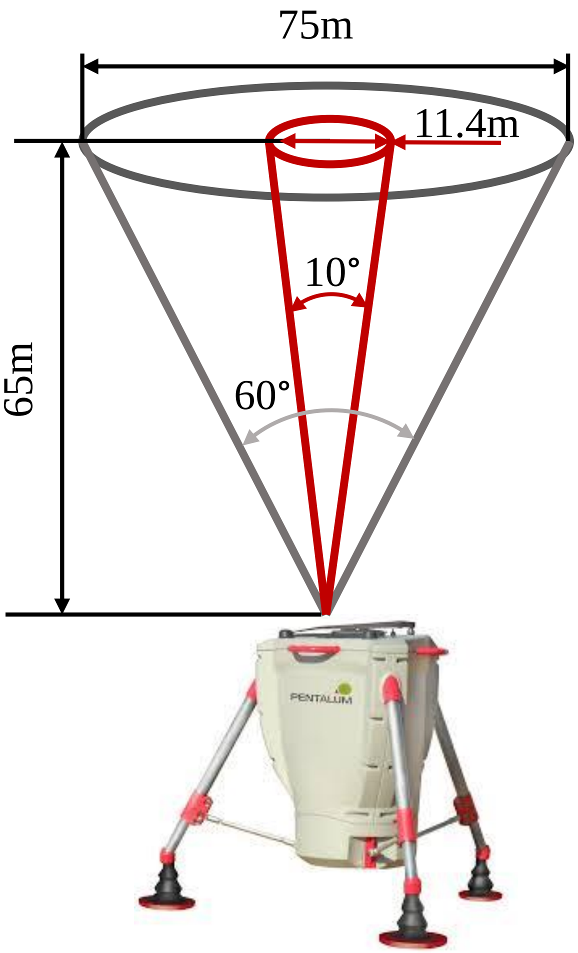


Outline

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

Ground-based LIDAR

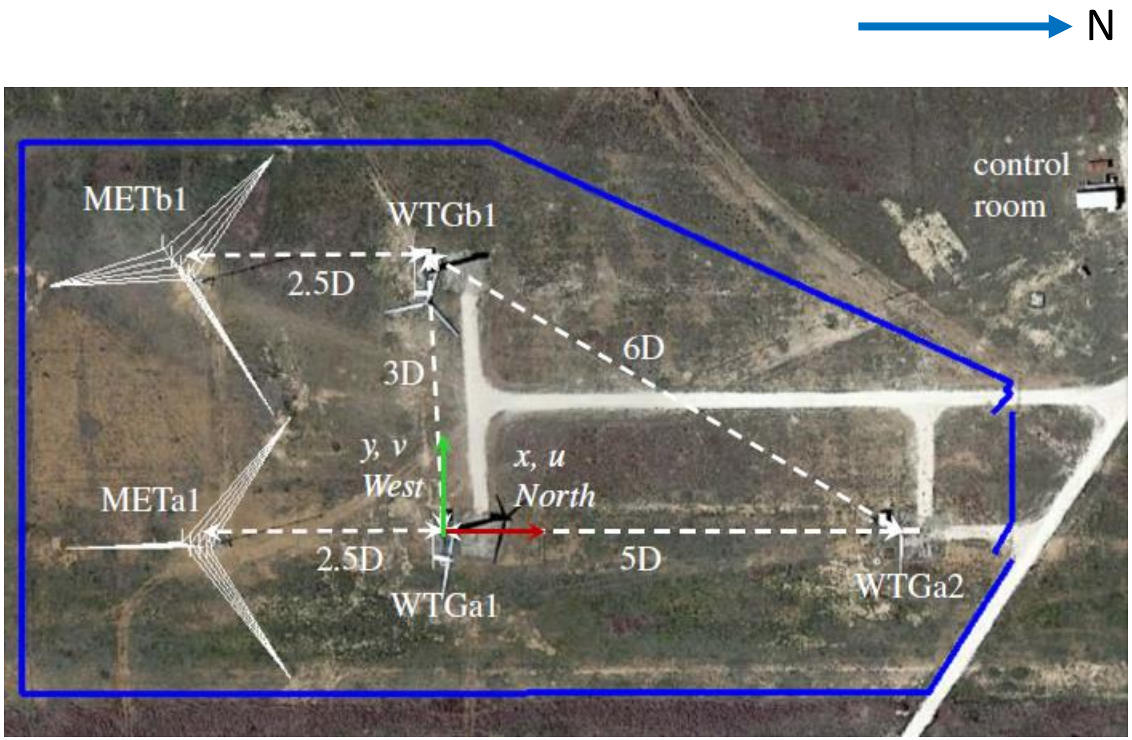


Pentalum SPIDAR

- non-Doppler, correlation-based
- Instantaneous profile

The figure is adapted from Eikill (2016)

SWiFT Deployment

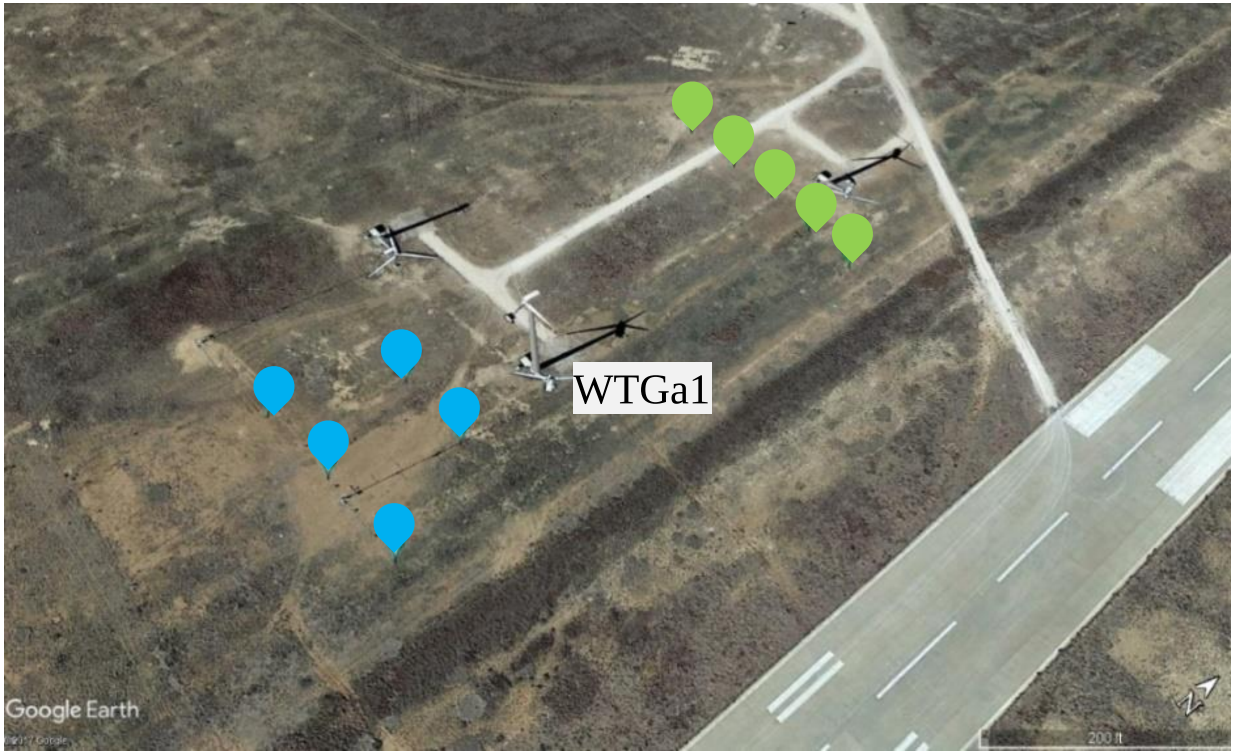


(Herges et al., 2017)

SWiFT Deployment

Phase 1

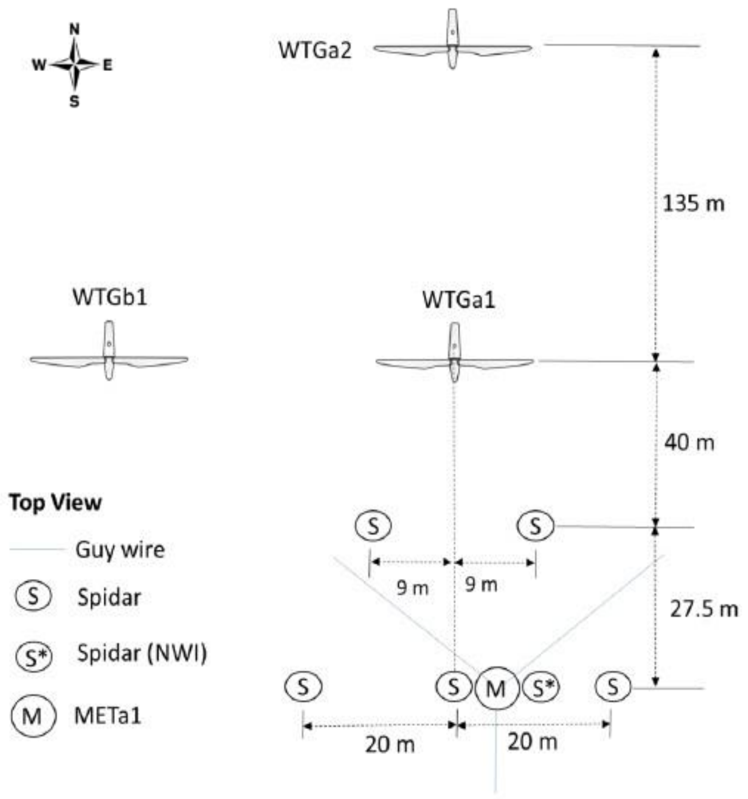
Phase 2



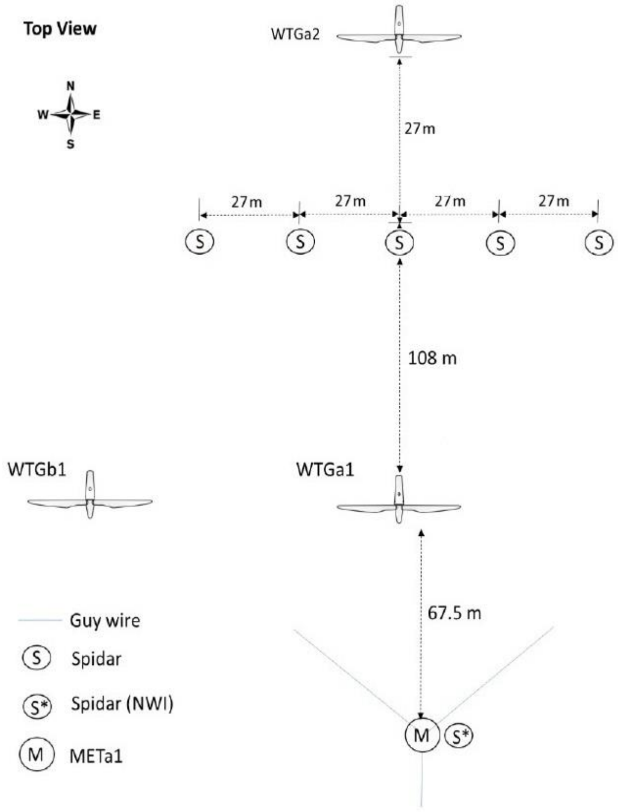
(Pereira, 2018)

SWiFT Deployment

Phase 1



Phase 2



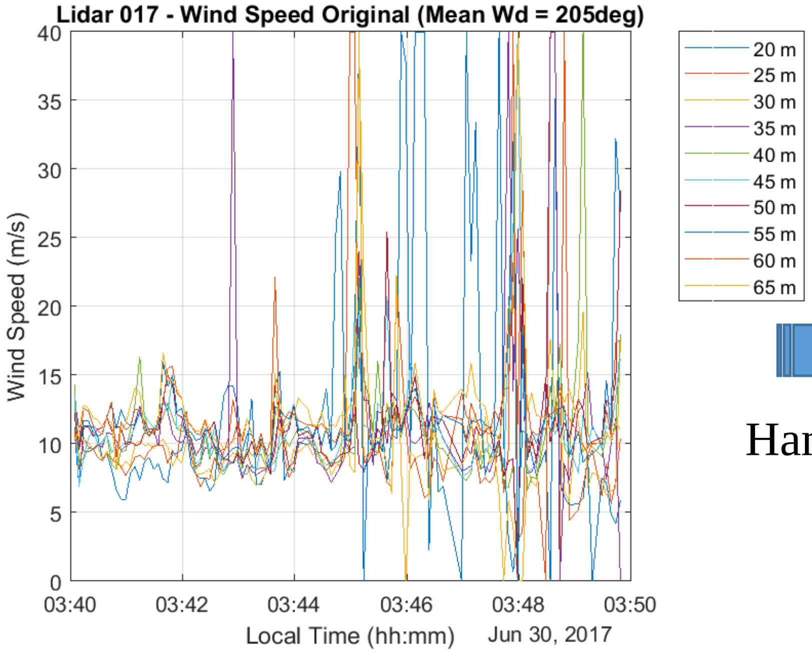
(Westergaard, 2016; Pereira, 2018)

Quality Control

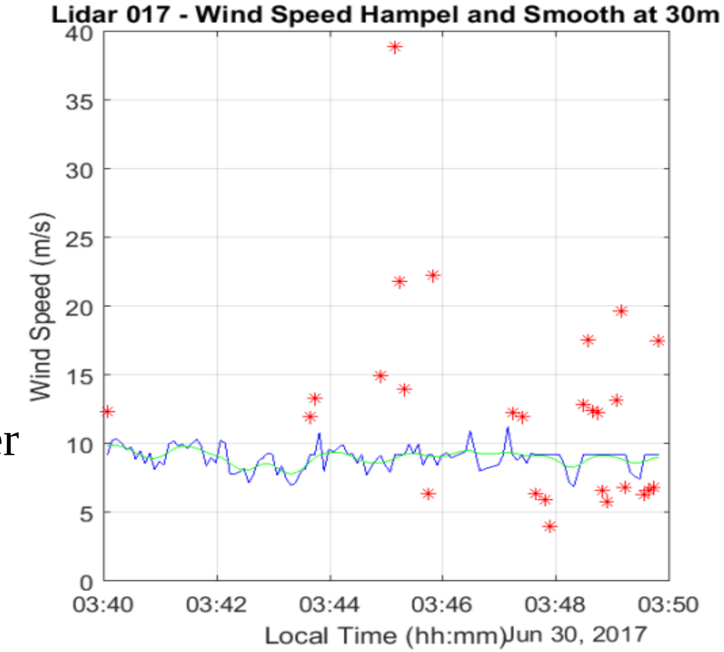
- Quality Score > 20% (Penatlum 2016) → Low data availability
- Clifton et al. (2018): practices and standards do not cover the entire range of LIDAR's potential
- Edward (1998): Consider data with and without outliers
- Sela (2012): Variable aerosol density leads to lower quality score
- Hampel Filter: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

(Pereira, 2018)

Quality Control

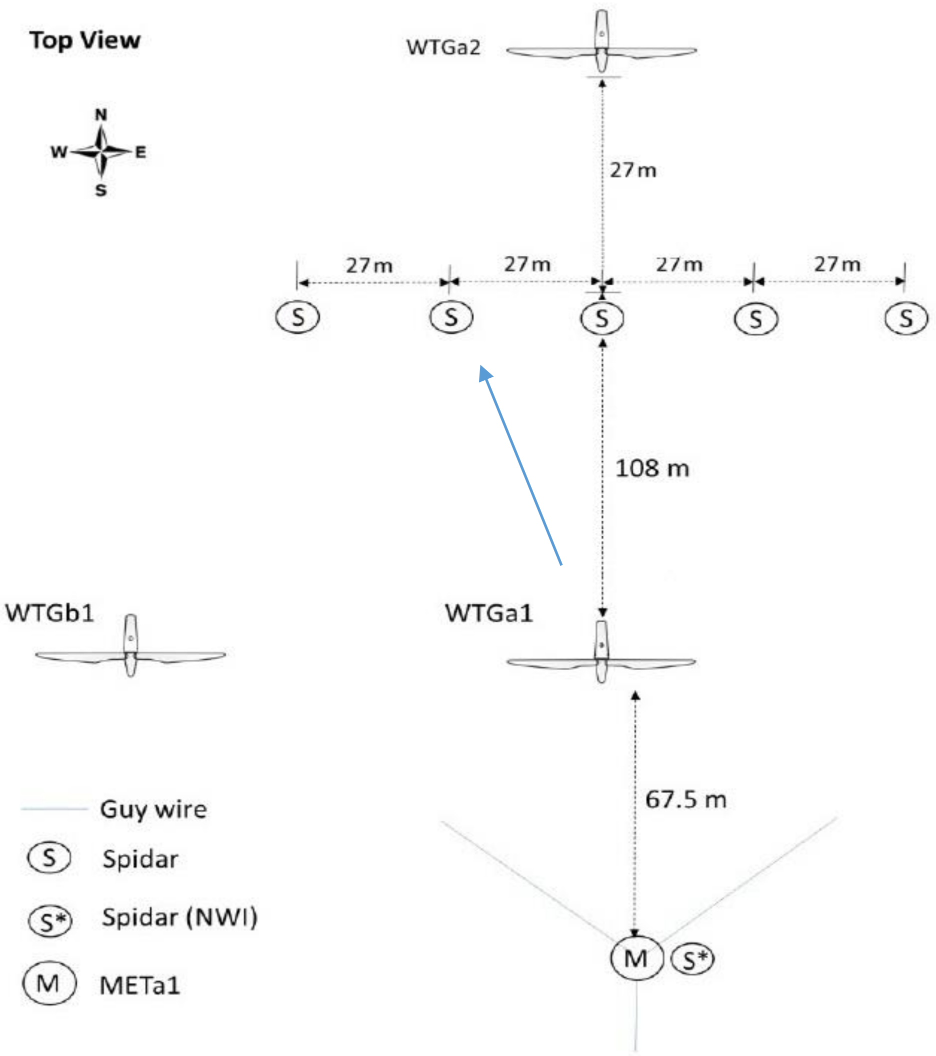


Hampel Filter

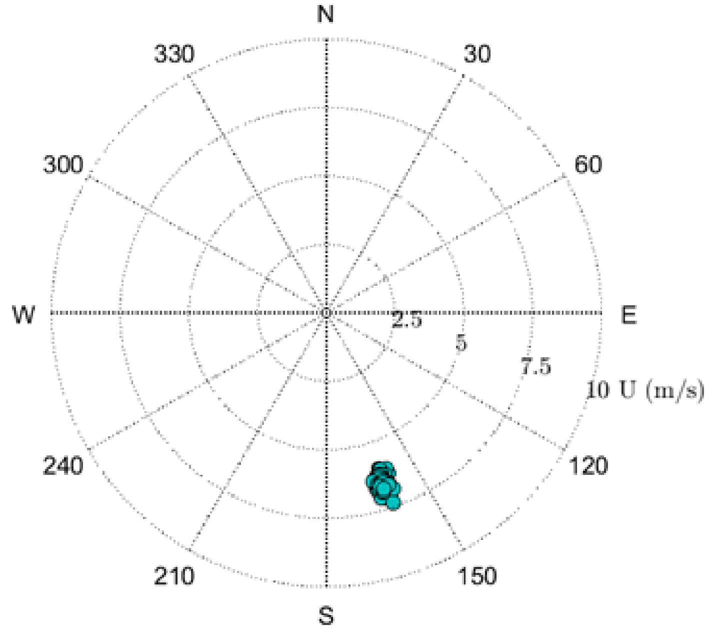


(Pereira, 2018)

Results: Phase 2

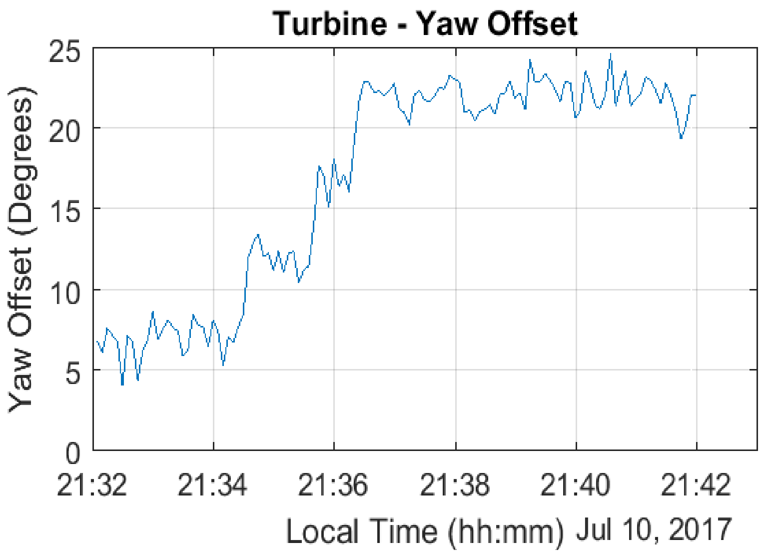


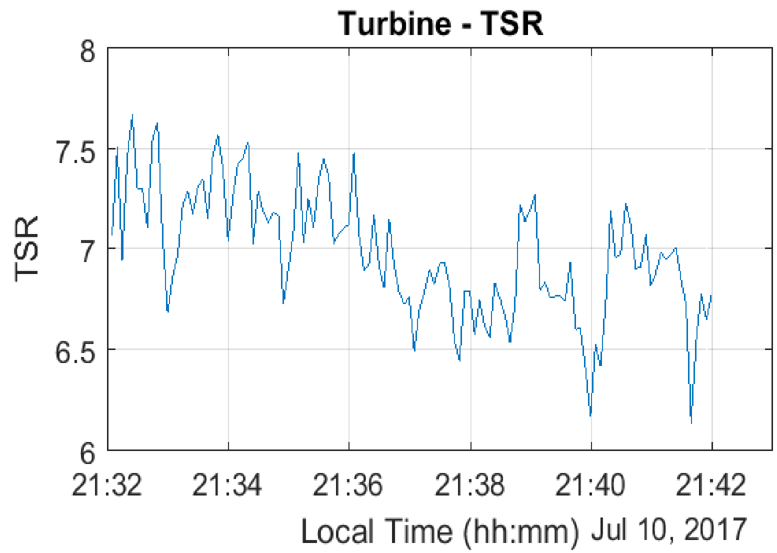
Weakly stable (21:32- 21:42 hrs.)
WS= 6.7 m/s at 32 m

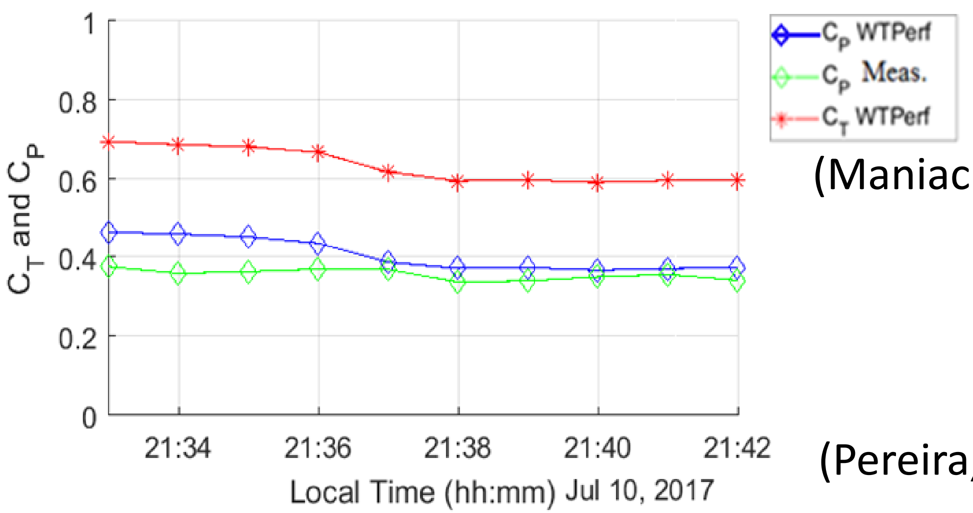


(Pereira, 2018)

Results: Phase 2



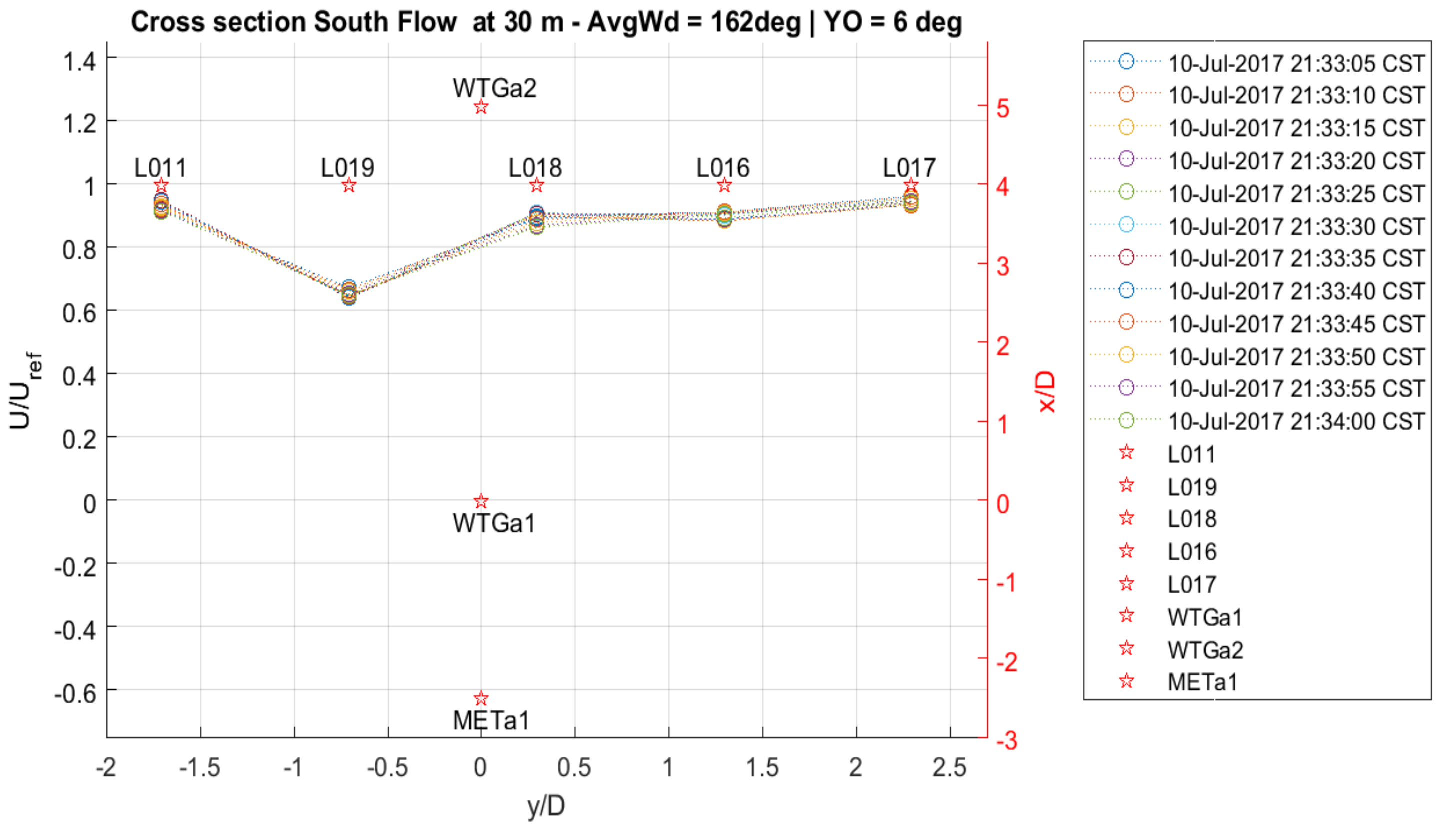




(Maniaci, 2011)

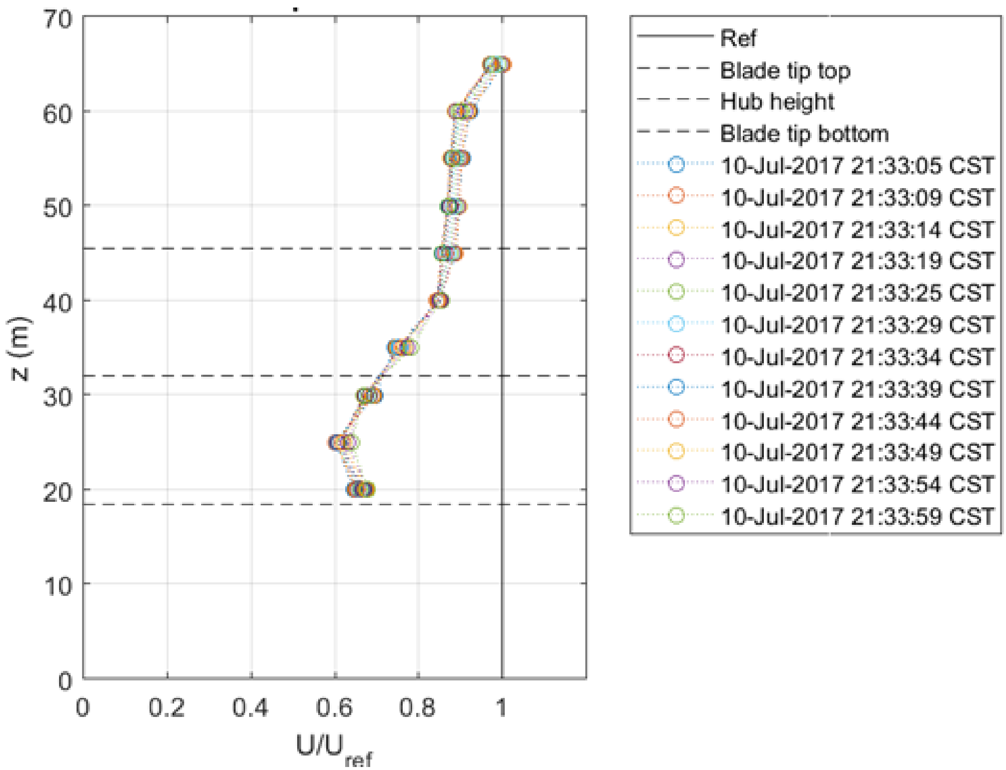
(Pereira, 2018)

Results: Phase 2



(Pereira, 2018)

Results: Phase 2



(Pereira, 2018)

Data: Conditional Sampling

- Atmospheric Stability

Stability	Criteria
Unstable	z/L < -0.05
Neutral	-0.05 ≤ z/L ≤ 0.05
Stable	z/L > 0.05

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

- Turbine Operation (On or Off)

(Pereira, 2018)

Outline

- Ground-based LIDAR
  - Pentalum SpiDAR
  - Wake detection with 5 sec. data
  - Requires quality control
- Windtunnel-based wake detection and management
- Future work

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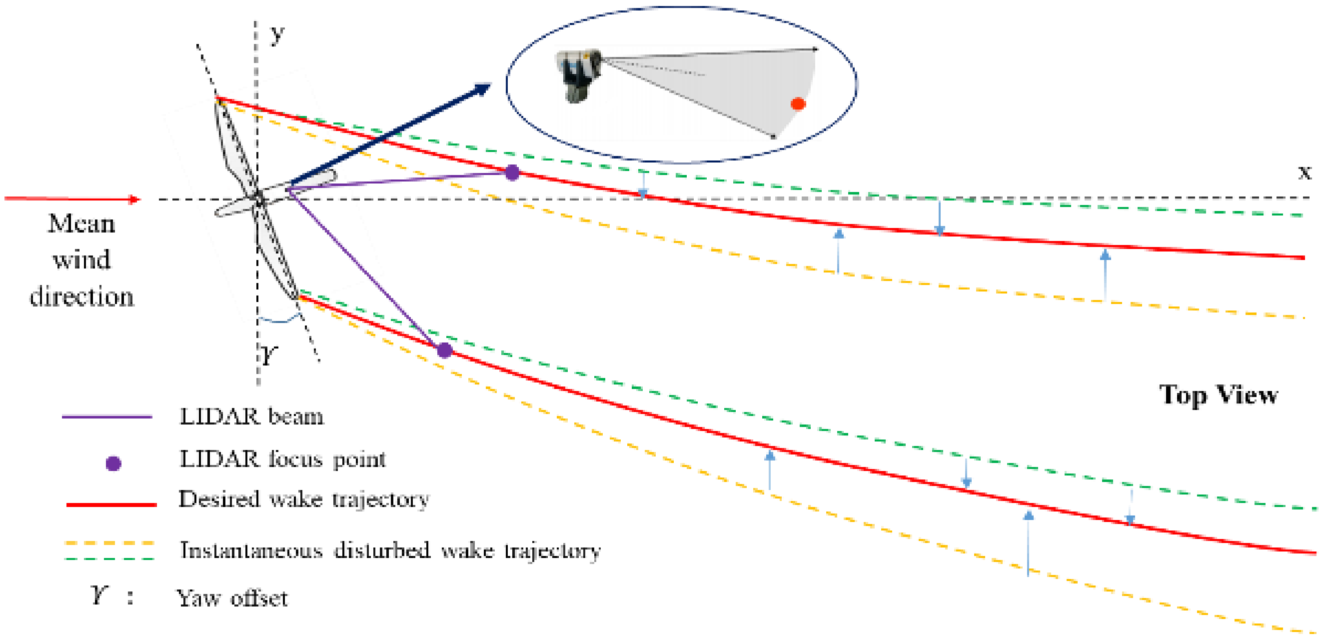
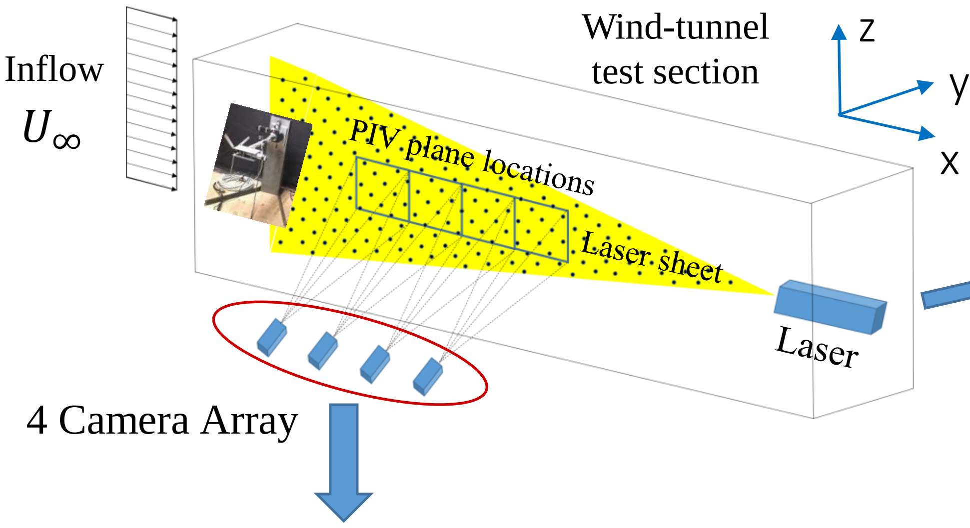
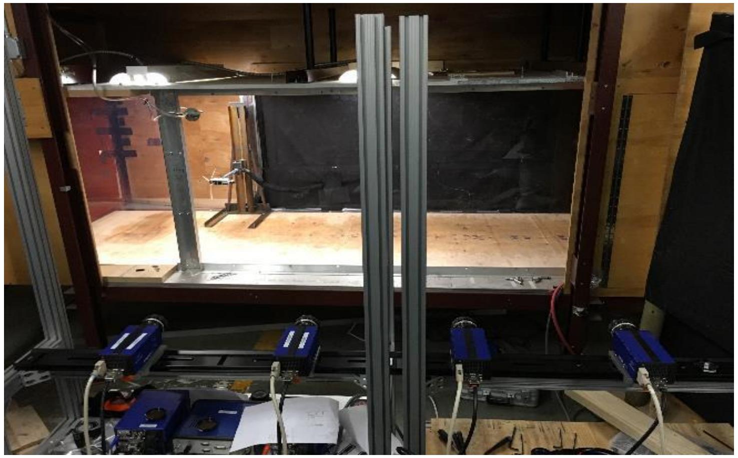
2. Wake management

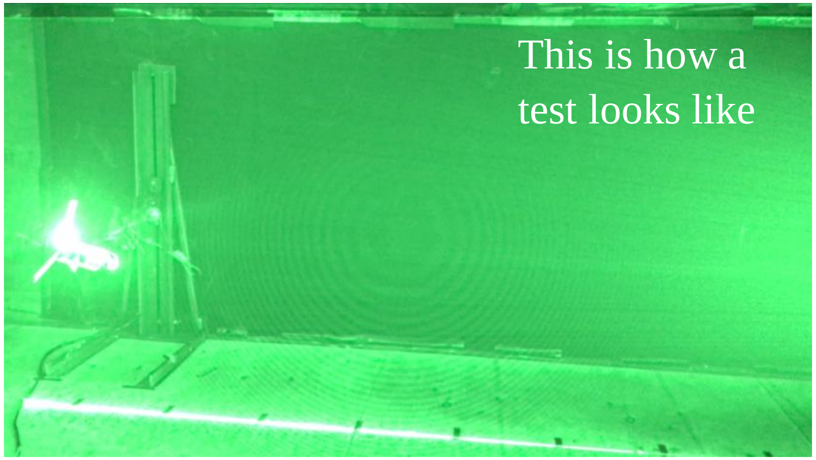


Experimental setup: Wind-tunnel test platform development

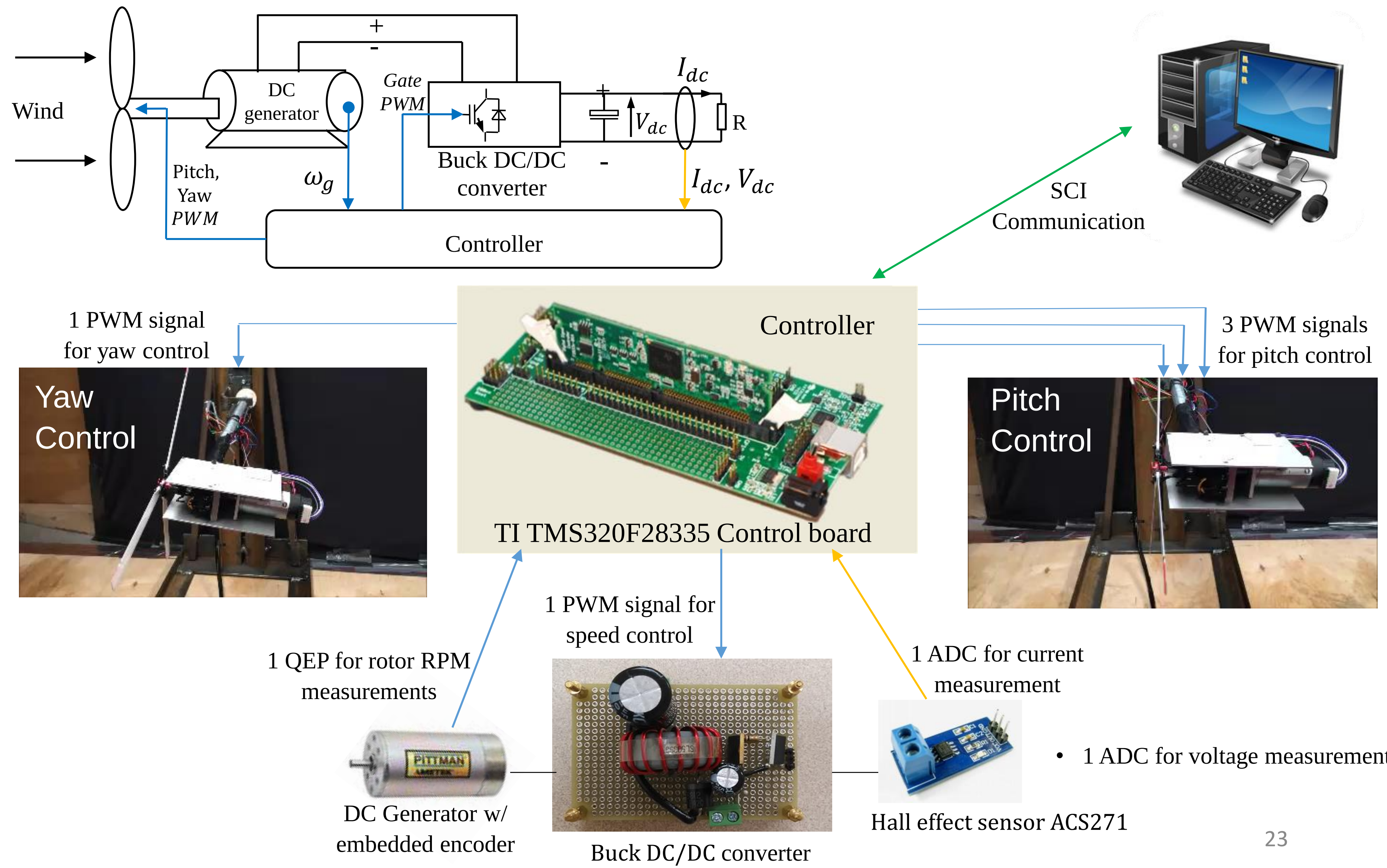
- Hyper Accelerated wind farm kinematic controlled simulator, “HAWKS”





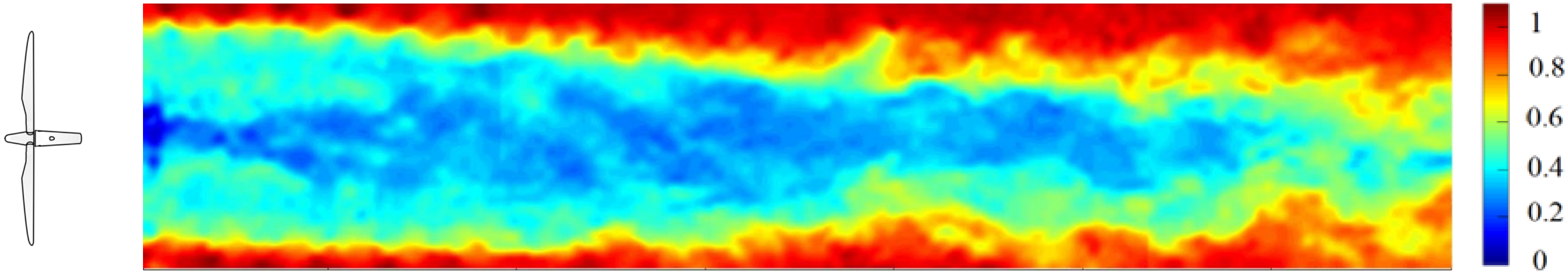


Experimental setup: Fully controllable model wind turbine development

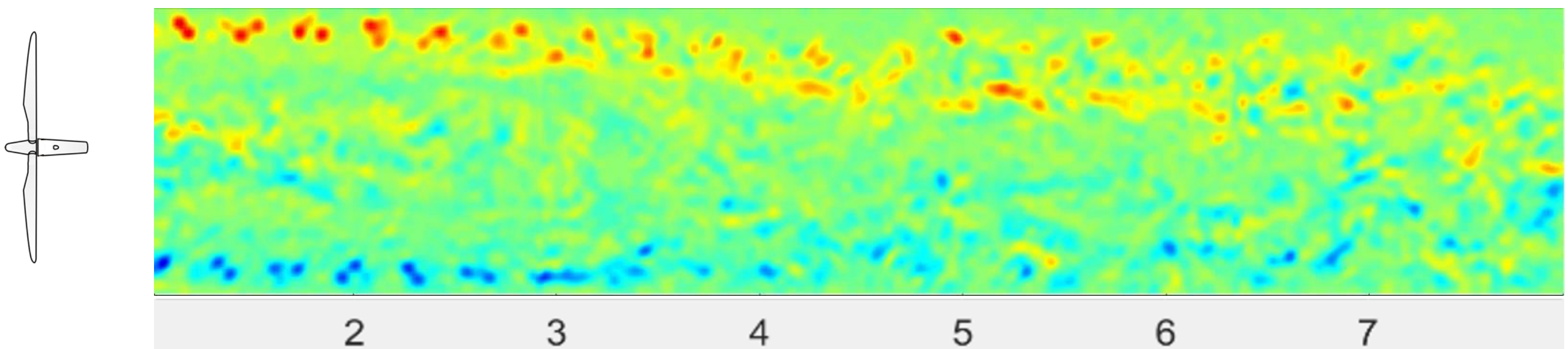


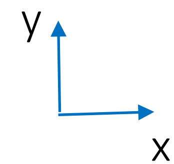
Wake vector field under dynamic yaw misalignment

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



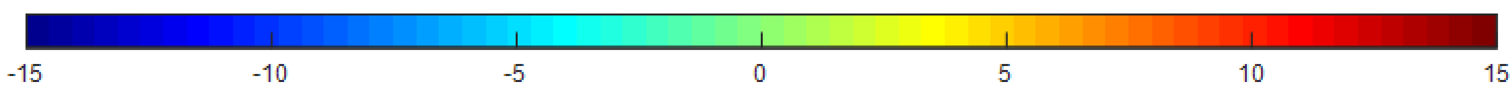
Vorticity: $\nabla\, x\, \boldsymbol{u} = \frac{\partial V}{\partial x} - \frac{\partial U}{\partial y}$





Horizontal plane at hub height

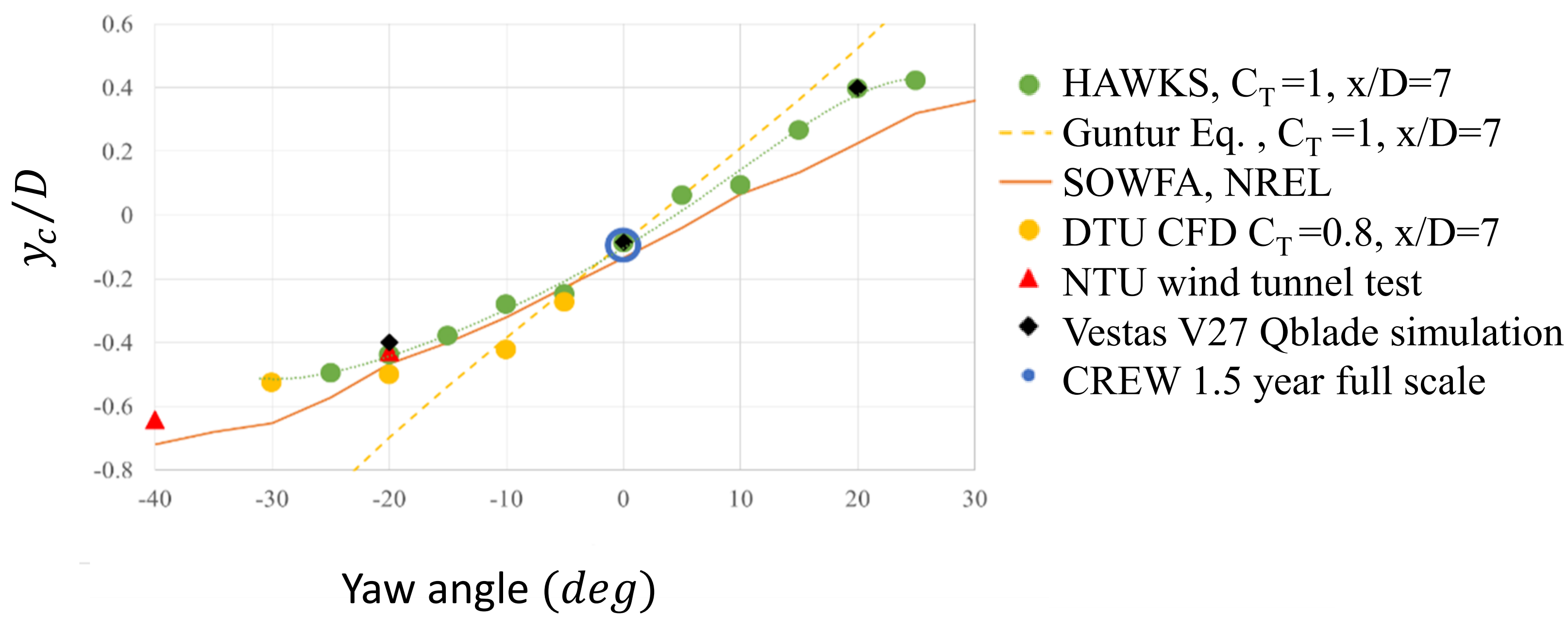
Downstream Distance, x/D



Rotations/sec

Validation of HAWKS wake deflection measurements

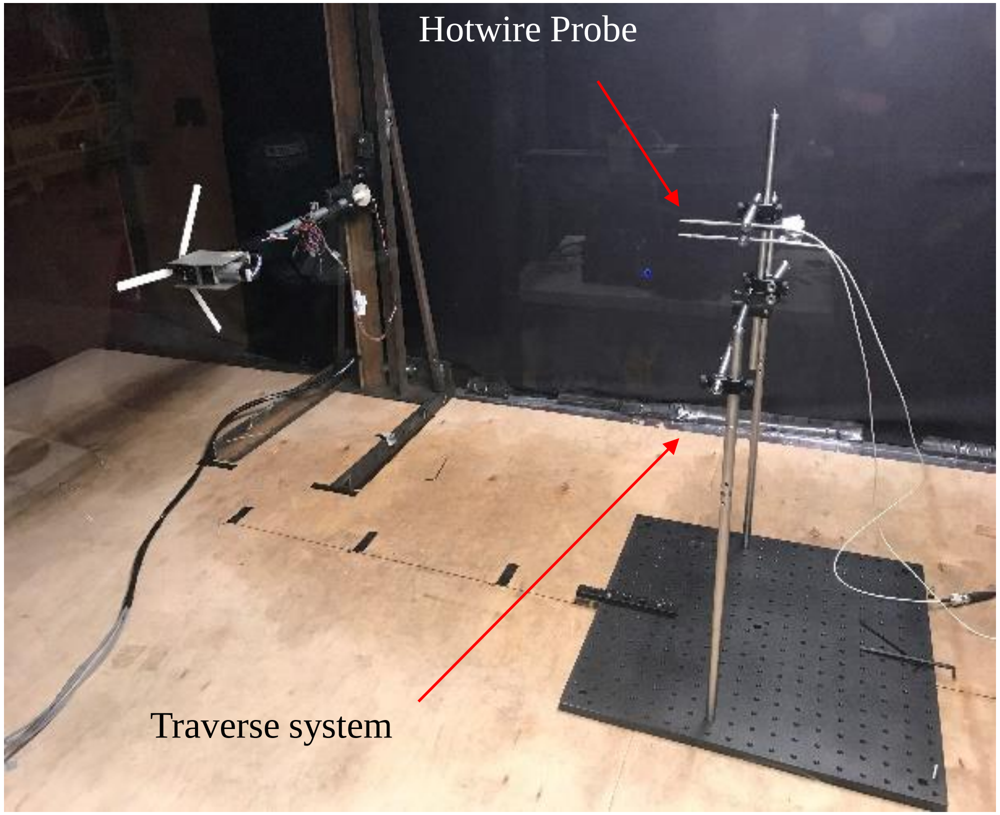
Comparison of the HAWKS wake deflection y_c/D at x/D=7 with different previous studies.



Castillo, R., et al. "PIV measurements in a real time controlled model wind turbine wake simulator." *Journal of Physics: Conference Series*. Vol. 753. No. 3. IOP Publishing, 2016.

HAWKS setup for wake detection

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

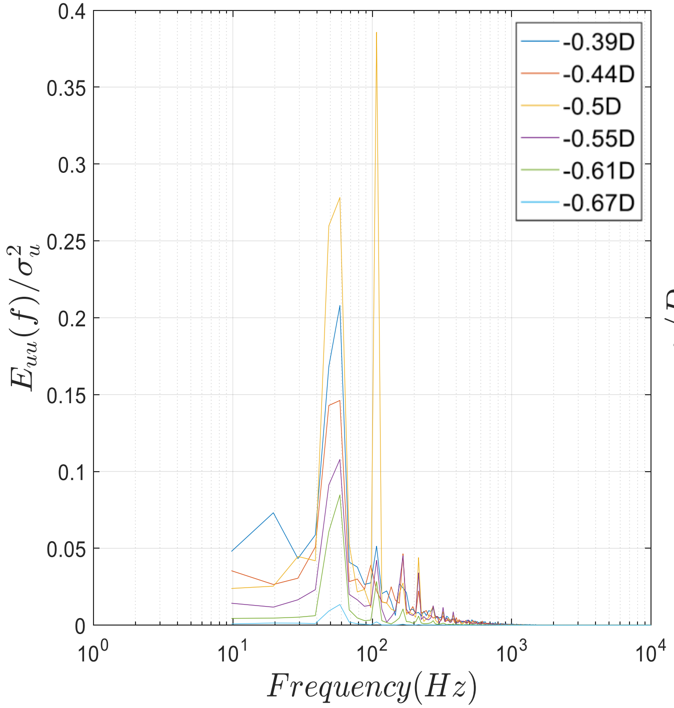


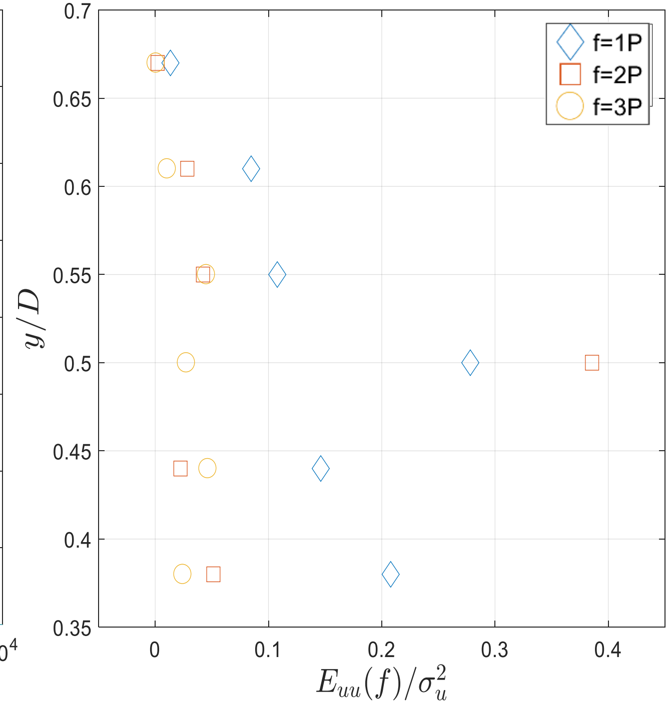
- **Hot-wire system**
  - Dantec Dynamics 54T42 MiniCTA (Constant Temperature Anemometer) equipped with 55P16 hot-wire probe.
  - 16-bit NI 9215 DAQ

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

Results Wake interface PSD analysis

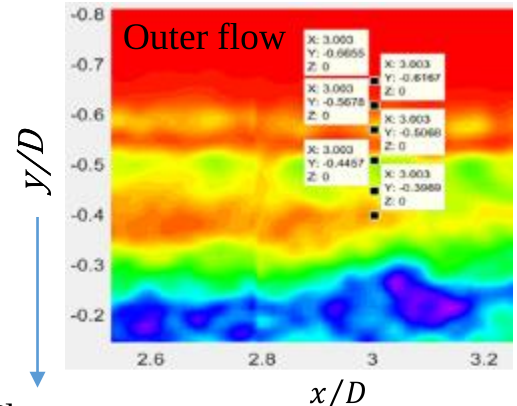
- Comparison of PSD characteristics across the wake interface at x/D=3.





RPM	1P	2P	3P
3000	50 Hz	100 Hz	150 Hz

Measurement points across the upper wake interface

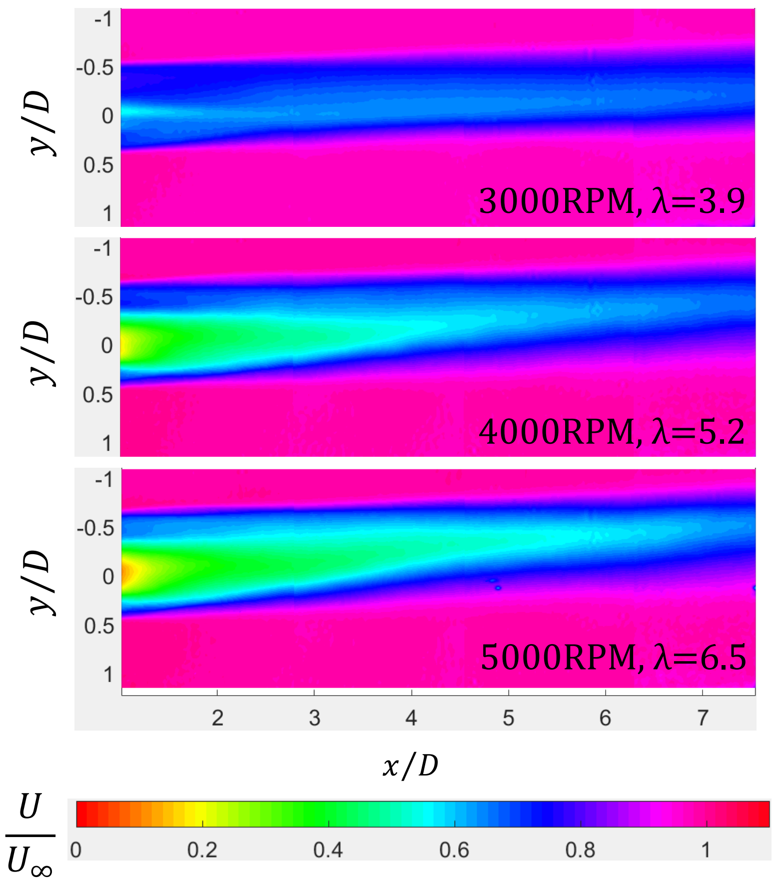


Closer to the rotor center y/D=0

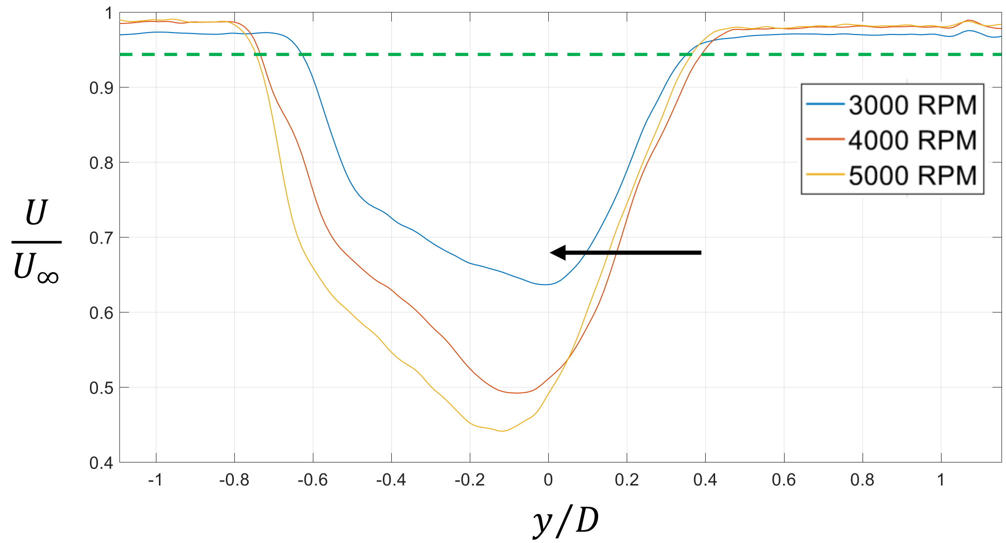
Observations

- ➢ 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_∞) in the horizontal plane at hub height for several RPM at $\Upsilon = 20°$.

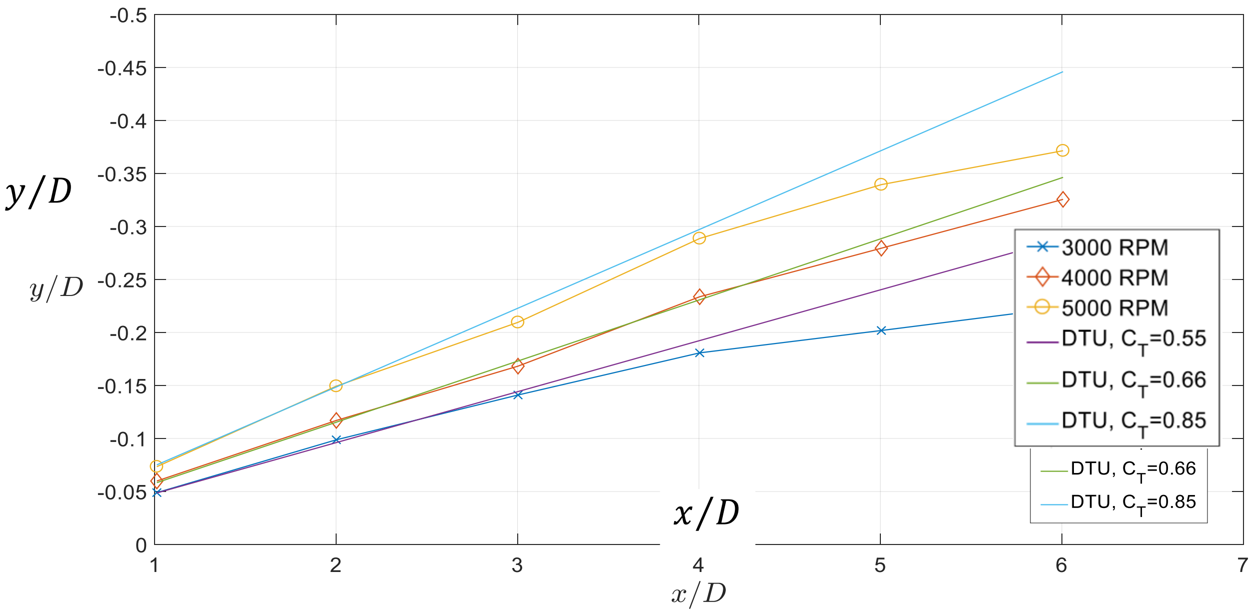


Comparison of normalized mean stream-wise velocity (U/U_∞) profile in the hub-height horizontal plane at x/D=3 for yaw angle ϒ=20°.

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 ω=3000, 4000, and 5000 RPM at yaw angle of $\gamma = 20°$ 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 ω, and hence with λ.

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!