Models and perspectives of wake dynamics and turbulence

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Lidar measurements of wake turbulence: Setup

- Quasi-stationary for ca. 10 h
- Velocity $u_{los}$ with ca. 1 Hz
Lidar measurements of wake turbulence: Spectra

- Idea: Wake starts new turbulent cascade at $\approx D$

![Plot showing spectral decay of lidar measurements with and without wake effects.](image)

[Bastine e.a. 2015, J. Phys. Conf. Ser. 625]

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Lidar measurements of wake turbulence: Spectra

- Idea: Wake starts new turbulent cascade at $\approx D$
- Simplistic lidar correction using FINO I sonic

[Bastine e.a. 2015, J. Phys. Conf. Ser. 625]
Idea: Wake starts new turbulent cascade at $\approx D$

- Simplistic lidar correction using FINO I sonic
- $f^{-5/3}$ decay as in idealized turbulence
Lidar measurements of wake turbulence: Intermittency

PDF of $\Delta u = u(t + \tau) - u(t)$ show “heavy tails”
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Lower flatness in wake than in free flow
Lidar measurements of wake turbulence: Intermittency

- PDF of $\Delta_{\tau}u = u(t + \tau) - u(t)$ show "heavy tails"
- Lower flatness in wake than in free flow
- Flatness decay $F \propto \tau^{-\mu \cdot 4/9}$, $\mu \approx 0.27$
  \[ \Rightarrow \text{Wake core follows K62 idealized turbulence} \]
Reduced-order wake model using POD

Do we need another wake model?

Aim: Include wake structures and dynamics by “Proper Orthogonal Decompsition” (POD)
Reduced-order wake model using POD

Principle of POD: Decomposition into orthogonal modes

Original LES
Reduced-order wake model using POD

Principle of POD: Decomposition into orthogonal modes

- Reduce complexity of hi-fi LES flow field
Reduced-order wake model using POD

Principle of POD: Decomposition into orthogonal modes

- **Reduce complexity** of hi-fi LES flow field
- **Keep only few most energetic modes**
Reduced-order wake model using POD

Results for thrust at downstream turbine (FAST sim.)

6 modes

- First modes cover slow dynamics (only)

[Bastine e.a. 2018, Energies 11]
Reduced-order wake model using POD

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+ “added turb.”

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- Gaussian random field models effects of small scales

[Bastine e.a. 2018, Energies 11]
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- Gaussian random field models effects of small scales
- Models can be designed to match necessary complexity

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Option for efficient long-time studies

[Bastine e.a. 2018, Energies 11]
Wake tracking in lidar measurements

Question: Lateral movement of wake center?

[Trujillo e.a. 2017, EERA DeepWind]
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Wake tracking in lidar measurements

Disentangling of wake deficit and meandering

Fixed frame of reference

[Beck e.a., DEWEK 2015]
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Disentangling of wake deficit and meandering

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Moving “wake center” frame of reference

[Beck e.a., DEWEK 2015]

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Wake structure fully recovered from meandering flow

[Beck e.a., DEWEK 2015]
Wind tunnel wakes: Turbulence interaction

\[ D \approx 0.6 \text{ m} \]

\[ \langle u \rangle / u_{\text{ref}} \]

\[ TKE [m^2 s^{-2}] \]

\[ \chi^2 \propto \ln F \]

[Schottler e.a. 2018, WES 3]
Wind tunnel wakes: Turbulence interaction

\[ D \approx 0.6 \text{ m} \]

- High & homogeneous turbulence in wake
- Turbulence interaction \( \Rightarrow \) high intermittency
- Also in field campaign (not shown)

[Schottler e.a. 2018, WES 3]
Summary & Conclusions

- RAVE measurements lead to new insights in wakes
  - Structure of wake turbulence
  - Wake meandering: origin and measurement
  - Towards improved and efficient wake models

“Gigawatt Wakes” & other projects:

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- Benefit of complementary measurements
  - FINO 1 measurements
  - RAVE WEC measurements
  - Lidar campaigns

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Thank you for your attention!

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