



Wind Tunnel Tests and Wake Effects of Pitch and Load Controlled Model Wind Turbines

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wind farms: interaction of turbines inevitable !

- power losses due to wake effects
- increased loads

W understanding of <u>interactions</u> necessary

[Barthelmie et.al. 2010]

[Crespo et.al. 1999]





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Field measurements:

expensive, changing boundary conditions, limited availability

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CFD:

often model-based, (computational) costs, **validation**?

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Experiments:

inexpensive, tunable boundary conditions, **upscaling**?

behind the rotor...

behind the rotor...

- **W** Decreased wind speed
 - power losses

Increased turbulence intensityhigher loads

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Model Wind Turbines

₩D=58cm

- variable pitch, variable speed
- ₩ automated control

 \forall measured variables: P, ω, β, T

▼vacuum-casted blades (SD7003)

Pitching Mechanism

▼ collective pitch ▼ closed-loop ▼ $\Delta\beta \le 30^\circ$

C A R L V O N O S S I E T Z K Y

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Pitching Mechanism

 \overrightarrow{v} collective pitch \overrightarrow{v} closed-loop $\overrightarrow{v} \Delta \beta \leq 30^{\circ}$

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Partial Load Control

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T2: independent partial load control - maximizing cp

 ∇ T1: systematic variation of γ, β

T2: independent partial load control - maximizing cp

 $\mathbf{\nabla}$ T1: systematic variation of $\gamma,~eta$

Results

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▼ two 'variable speed, variable pitch' model wind turbines
▼ tested partial load control

 \overline{W} two 'variable speed, variable pitch' model wind turbines \overline{W} tested partial load control

improved power output for yaw misalignment in tandem-configuration
 +6% for x/D=3 at 18° yaw misalignment of T1

▼ in good agreement with simulations!



Outlook







Active Grid



,custom' turbulence







,custom' turbulence





Active Grid





LiDAR measurements by Risø, DTU

Experiments: ,Smart Blades' Project, Nico Reinke,André Fuchs,Tim Homeyer. ForWind, University of Oldenburg



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Thank you for your attention!



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cpmax for different wind speeds and pitch angles



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Electrical Load Variation

U_{St} of the **maximal** c_P for each wind speed







Electrical Load Variation

 $\nu = const.$



U_{St} of the **maximal** c_P for each wind speed















change in pitch influences P2
for however: no gain in P_{tot}!
 $\beta_{P_{1,opt}} = \beta_{P_{tot,opt}}$



























































































 \overrightarrow{v} collective pitch \overrightarrow{v} "closed-loop" $\overrightarrow{v} \Delta\beta \leq 30^{\circ}$










































wake expansion II



$\overline{\mathbf{w}}$ wind tunnel: open test section - free stream





wake expansion II



$\overline{\mathbf{w}}$ wind tunnel: open test section - free stream



turbulent conditions at T2 for large x

























$$\vec{\nu}_{ind_1}(\theta) = \vec{\nu}_{ind_2}(\theta + 180^\circ)$$

 $\vec{\nu}_{res_1}(\theta) \neq \vec{\nu}_{res_2}(\theta + 180^{\circ})$

$$\vec{\nu}_{res} = \vec{\nu}_{ind} - \vec{\Omega} \times \vec{r} + \nu_{\infty}$$
$$\vec{\nu}_{res_1}(\theta) = \vec{\nu}_{res_2}(\theta + 180^\circ)$$

$$\vec{\nu}_{\infty}(\theta) \neq \vec{\nu}_{\infty}(\theta + 180^{\circ})$$

$$c_{T,1} = c_{T,2} \qquad \longleftarrow \qquad c_{T,1} \neq c_{T,2}$$

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