Wind turbine wakes: Issues in modelling and measurements

Rebecca Barthelmie – University of Edinburgh/Risø National Laboratory

Sten Frandsen, Pierre-Elouan Rethore – Risø National Laboratory

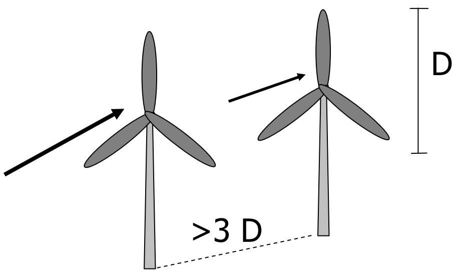
Martin Mechali, Leo Jensen – Elsam

Claus Perstrup – Energi E2

Funding: PSO F&U 4103, STVE 2104-04-0005, Edinburgh Research Partnership.
Thanks to Energi E2/Københavns Energi for Midd

What is a wake?

- Wake is the U decrease and TI increase behind a wind turbine
- Wind turbines should be placed >3 D apart



Wake issues

- Power loss
  - In large offshore wind farms wake losses 10-20% of total power output
  - Standard wake models validated for small wind farms offshore (k=0.05)
  - Modelling wake losses between large wind farms, esp. offshore
  - Wake modelling in complex terrain
  - Availability of data for wake research
- Loads
  - Wake generated turbulence also important for loads

Objective

Evaluation of wake models in order to optimise wind farm layout

What do we need to know?

- Overall wind farm wake losses
- Wake losses in rows
- Wake expansion
- Dependence on spacing, wind speed, turbulence

Why is this data comparison difficult?

- Identifying the freestream wind speed and direction
- Inaccuracy in the yaw angle
- Impact of different turbines
- Different ambient turbulence
- Different numbers of observations
- Quantify the uncertainty

What have we done so far?

1. Down the row losses
2. Wake width
3. Turbulence
4. Stability

RISØ

Data sources:

Horns Rev

- Vestas V80 2 MW h.h. 70 m , 80 turbines (8x10), distance 7 D

Middelgrunden

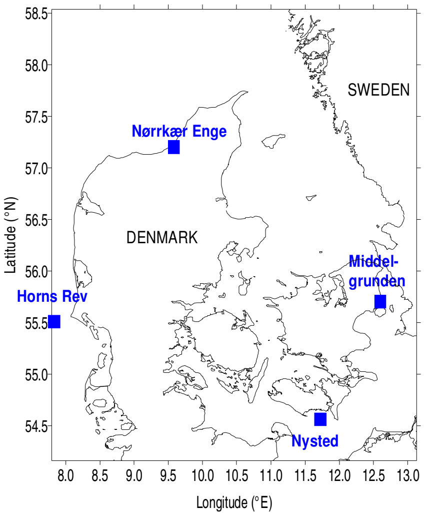
- Bonus 2 MW h.h. 67 m, 20 turbines, distance 2.6 D

Nysted

- Bonus 2.3 MW h.h. 69 m, 72 turbines (8x9), distance 5.6 D /10D

Nørrekær Enge

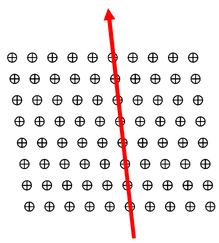
- Nordtank 300 kW h.h. 28 m, 42 turbines, distance 7-8 D

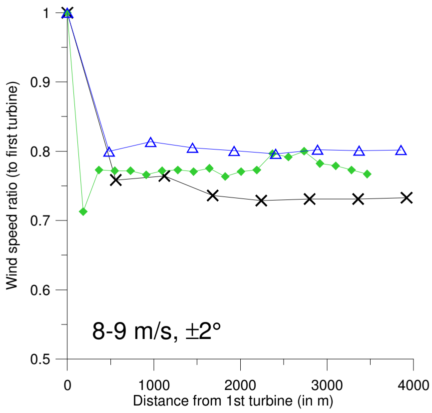


RISØ

1. Direct (down the row) wakes

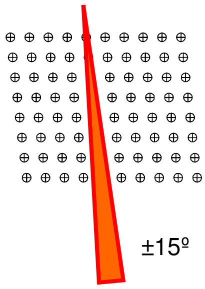
- For narrow wind speed and direction bins
- Limited # observations
- Are these wake losses different?

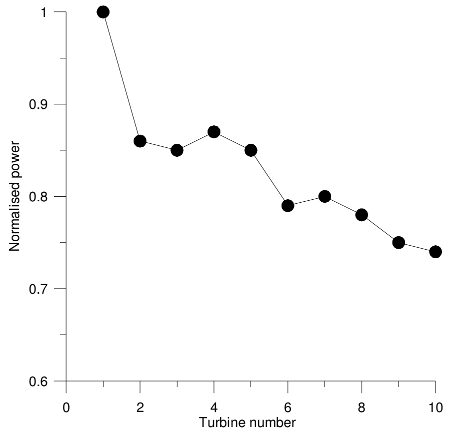




Indirect wakes

- As angle increases, power drop decreases
- So overall wake losses are a combination of direct and indirect wakes and are predicted to be 5-15%



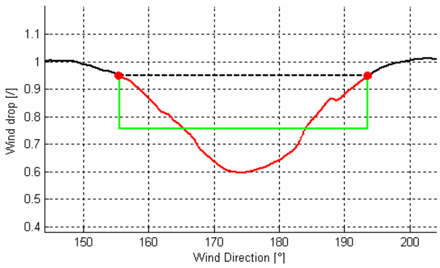


Frandsen et al. (COW 2005)

Rebecca Barthelmie

2. Wake width

- Part of model evaluation
- Defining wake width is subjective
- Depends on level of U ratio
- Not always a clear wake shape
- Wake widths calculated in U bins



Rebecca Barthelmie

RISØ

Model evaluation

Analytical model (Frandsen et al. 2006)

- Initial expansion

$$\frac{D_w}{D_0} = \sqrt{\beta_*}$$

- where

$$\beta_* = 0.5\frac{1+\sqrt{1-Ct}}{\sqrt{1-Ct}}$$

- Subsequent expansion

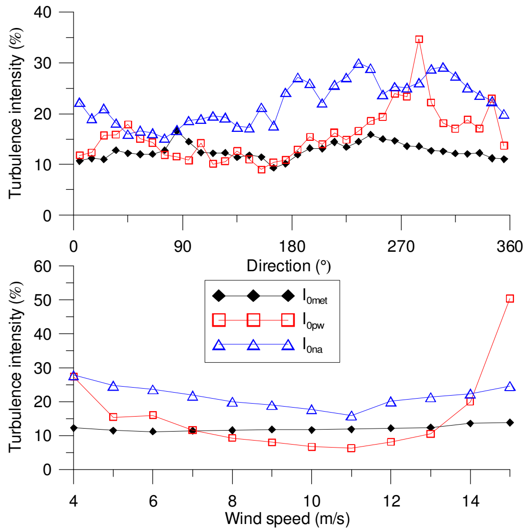
$$\frac{D_w}{D_0} = (\beta_*^{\,n/2} + \alpha_* . s)^{1/n}$$

- Evaluation of α, β, n and comparison with linear expansion in WAsP

Rebecca Barthelmie

RISØ

3. Turbulence: Middelgrunden



Rebecca Barthelmie

The turbulence model

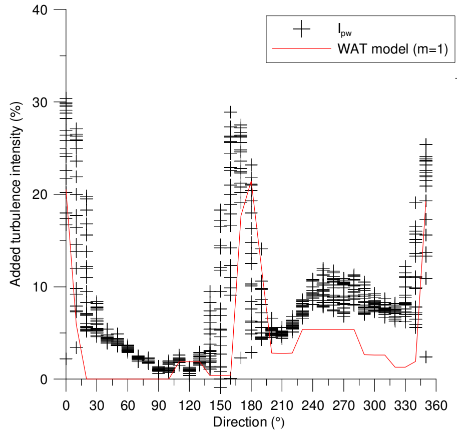
- Total turbulence

$$I_{T,wf}^2 = I_0^2 + I_{addwf}^2$$

- Turbine added turbulence (from Frandsen)

$$I_{addwf} \approx \frac{a\sqrt{C_t}}{b\sqrt{C_T}+\sqrt{s_f s_r}} = \frac{0.36}{1+0.2\sqrt{s_f s_r / C_T}}$$

- Implemented into WAsP Engineering=WAT model



Rebecca Barthelmie

4. Wake losses by atmospheric stability class

- Stability describes stratification of the atmosphere
- Use Monin-Obukhov length
- Needs accurate temperature profile
- Here using wind shear

Rebecca Barthelmie

RISØ

Wake model projects

- EU funded
  - Coordination Action: POW'WOW
  - Research project: UPWIND (Wp8, Flow)

- IEA Offshore Annex 23
  - Wake model comparison planned including power loss and loads

Rebecca Barthelmie

RISØ

Summary

1. Accurate prediction of wake losses is an important part of wind farm economy
2. For small wind farms (2 rows) wake models sufficiently accurate
3. For large wind farms, models need significant improvement
4. Wake losses in complex terrain need attention
5. Data are needed for wake model validation

Rebecca Barthelmie