Effects of Turbine Spacings in Very Large Wind Farms

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Overview

Motivation

Wake effects in Horns Rev 1. Photographer Christian Steiness.

As the size of wind farms continue to grow, there is an increasing demand for understanding and predicting wake effects.
The importance of wake effects are basically related to:

- Decreased production
- Increased loads.

Motivation

Wake effects in Horns Rev 1. Photographer Christian Steiness.

Increased understanding will enable engineers to:

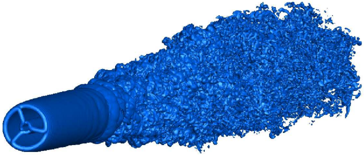
- Optimising farm layout, e.g. increased production.
- Optimising turbine design, e.g. lower material costs.
- Predicting power production, e.g. farm control.

Modelling a Wind Turbine and its Wake

Flow Solver + Turbulence Modelling

⇕

Turbine Modelling + Turbine Controller



Fully coupled LES and aero-elastic(Flex5) codes.

Further details in e.g. Sørensen, J. N. et al., Royal Society of London. Philosophical Transactions A, 2015. DOI: http://dx.doi.org/10.1098/rsta.2014.0071

Flow Solver

The flow solver EllipSys3D[1] is used to solve the filtered 3D incompressible Navier-Stokes equations:

$$\frac{\partial \overline{\boldsymbol{V}}}{\partial t} + \overline{\boldsymbol{V}} \cdot \nabla \overline{\boldsymbol{V}} = -\frac{1}{\rho} \nabla \overline{p} + \nabla [(\nu + \nu_{SGS}) \nabla \overline{\boldsymbol{V}}] + \frac{1}{\rho} \boldsymbol{f}_{WT} + \frac{1}{\rho} \boldsymbol{f}_{pbl} + \frac{1}{\rho} \boldsymbol{f}_{mf} + \frac{1}{\rho} \boldsymbol{f}_{turb}.$$

$$\nabla \overline{\boldsymbol{V}} = 0.$$

where a number of added forces are added to mimic various effects.
The velocity($\boldsymbol{V}$) is decomposed into a sum of the filtered velocity($\overline{\boldsymbol{V}}$) containing the large scales and the small scales($\boldsymbol{v}'$) modelled using a sub-grid scale(SGS) model:

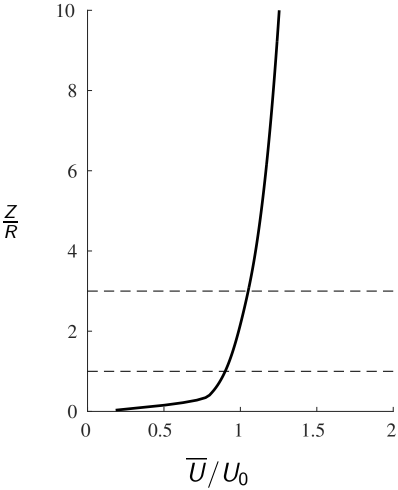
$$\boldsymbol{V} = \overline{\boldsymbol{V}} + \boldsymbol{v}'$$

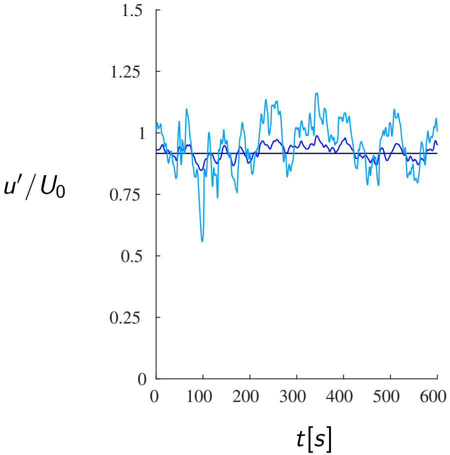
[1] Michelsen, AFM, 1992 and Sørensen, DTU, 1995

Inflow Conditions:

Shear exponent: $\alpha_{PBL} = 0.14$.

Same Mann turbulence[2] applied with different forcing.

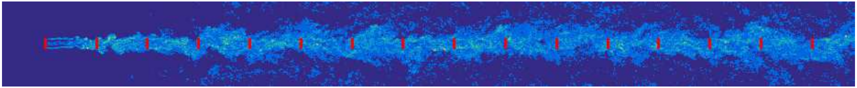




[2] Mann, 1994 and 1998.

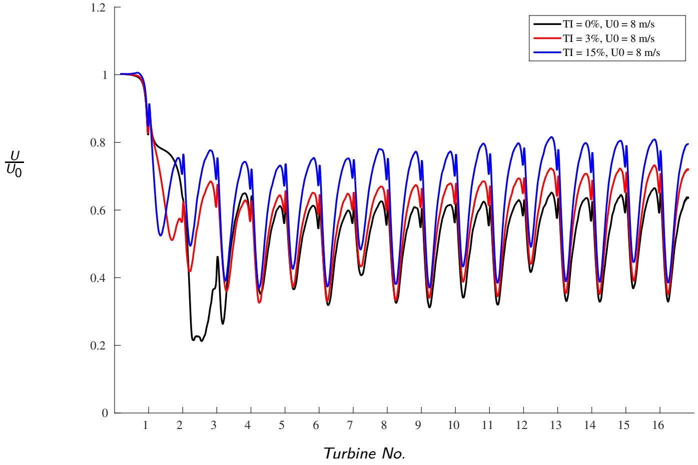
Table : Overview of simulations.

U_0	TI	Shear	Spacing/Domain ($S_X \times S_Y$)	Time
$8m/s$	0%	0.14	$12R \times 20R$	$60min$
$8m/s$	3%	0.14	$12R \times 20R$	$60min$
$8m/s$	15%	0.14	$12R \times 20R$	$60min$
$15m/s$	15%	0.14	$12R \times 20R$	$60min$
$8m/s$	0%	0.14	$12R \times 12R$	$60min$
$15m/s$	0%	0.14	$12R \times 12R$	$60min$
$8m/s$	0%	0.14	$14R \times 14R$	$60min$
$8m/s$	0%	0.14	$20R \times 20R$	$60min$



Further details in e.g. Andersen, S. J. et al., Journal of Physics. DOI: 10.1088/1742-6596/625/1/012027

Velocity distributions:



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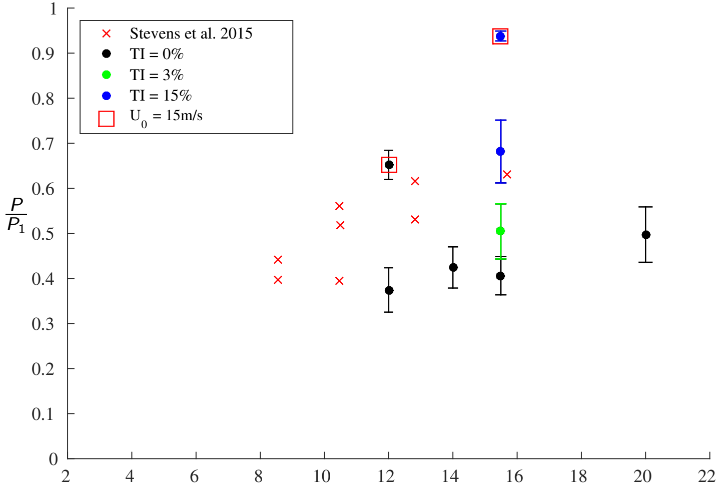
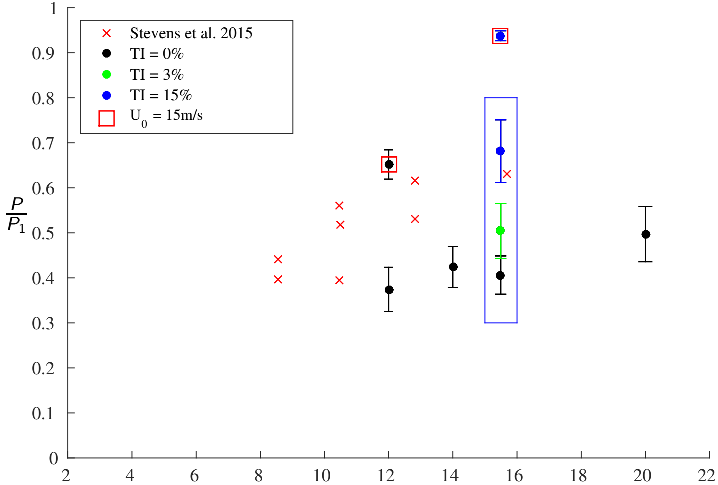
Power Production of 6th-16th Turbines:



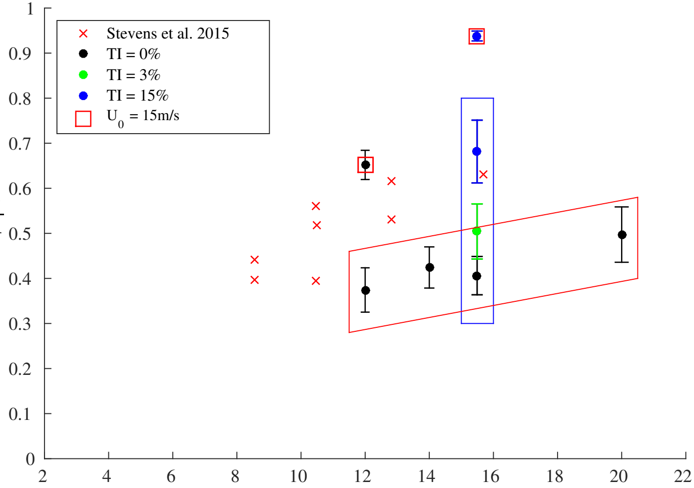
$$S = \sqrt{S_X S_Y}$$

Power Production of 6th-16th Turbines:



$$S = \sqrt{S_X S_Y}$$

Power Production of 6th-16th Turbines:

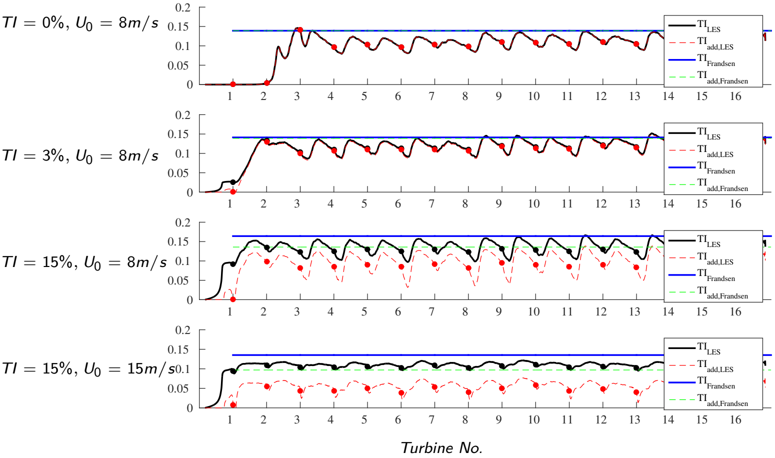


$\frac{P}{P_1}$

$S = \sqrt{S_X S_Y}$

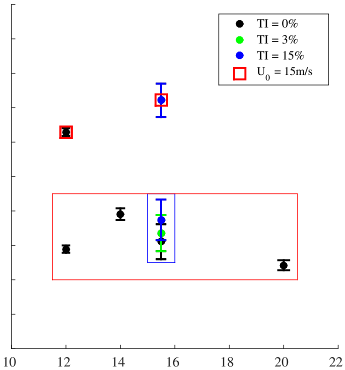
Added Turbulence:

Farm turbulence(Frandsen, 2005): $I^2_{T,wf} = I^2_0 + I^2_{add,wf}$, where $I^2_{add,wf} \approx \dfrac{0.36}{1+0.2\sqrt{\frac{s_X s_Y}{C_T}}}$



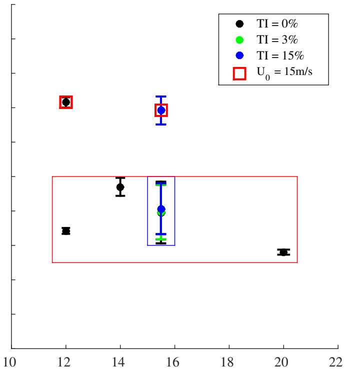
Equivalent Loads of 6th-16th Turbines:

Equivalent Flap Moments.



$$S = \sqrt{S_X S_Y}$$

Equivalent Yaw Moments.



$$S = \sqrt{S_X S_Y}$$

Conclusions and Discussion

- Converged velocity after about 4th turbine, but still large variations in power productions of individual turbines.
- Turbulence enhances the wake recovery.
- Streamwise spacing more important than transverse in terms of wake recovery.
- The standards appear to overestimate the added and total farm turbulence consistently at the turbines.
- Equivalent flap moment increase with increase in atmospheric turbulence(recovery), but yaw is unchanged.
- Equivalent loads highly dependant on spacing, decreases for large distances as the wakes breaks down.

Acknowledgements

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Thanks for your attention.