Yawed Wind Turbines

An Experimental Study on the Far Wake Development behind a Yawed Wind Turbine

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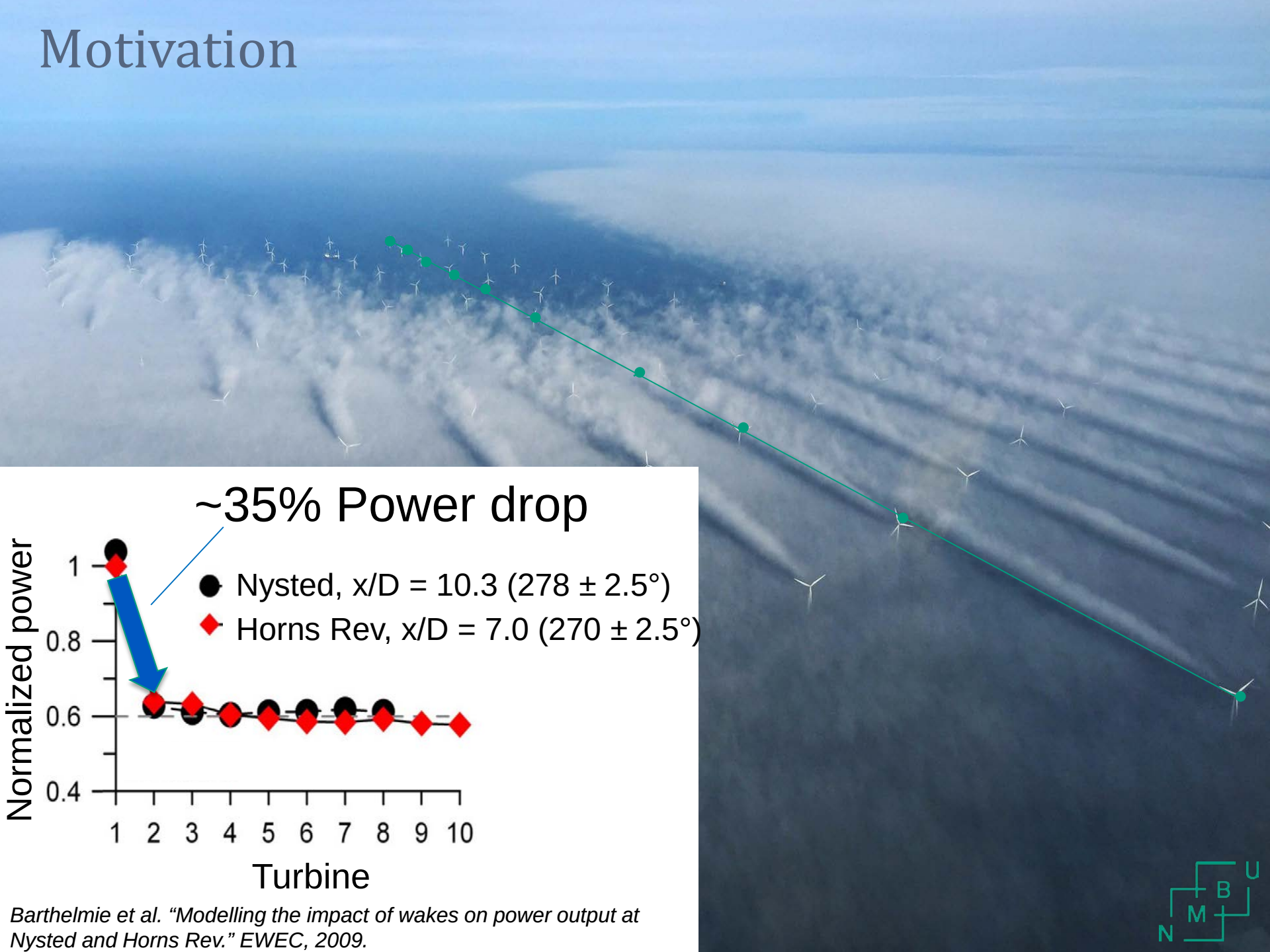
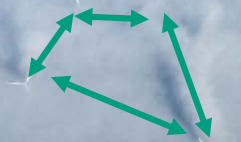
Motivation



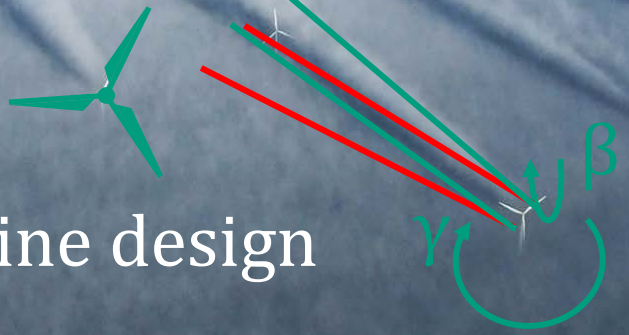
~35% Power drop

Barthelmie et al. "Modelling the impact of wakes on power output at Nysted and Horns Rev." EWEC, 2009.

What can be done to limit wake effects?



Wind farm layout



Turbine design

Control strategies:

Yaw control

Pitch control

TSR control

Picture: Bel Air Aviation Denmark – Helocopter Services

Yawed Wind Turbine Project

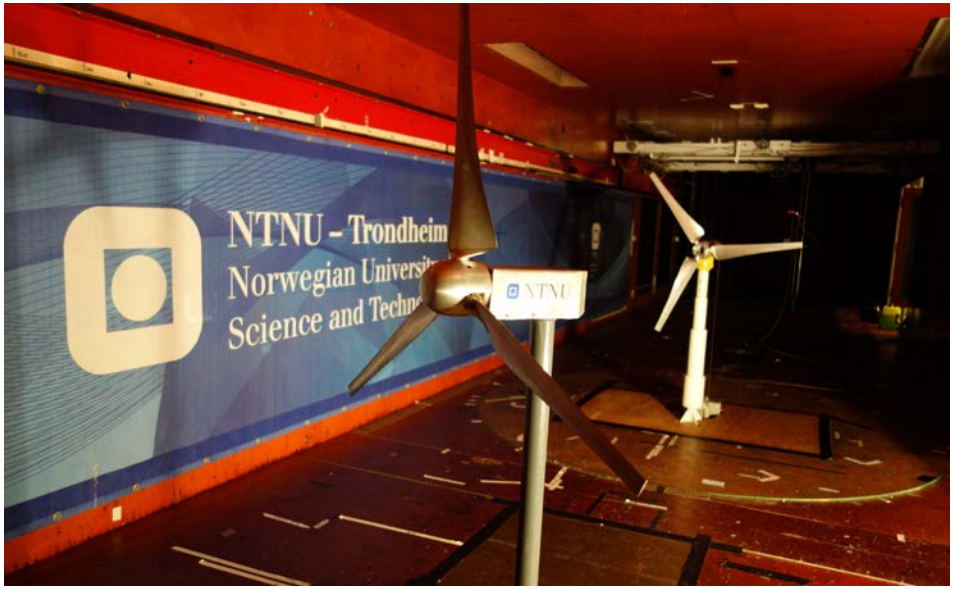
Influence of yaw misalignement on the wake developement

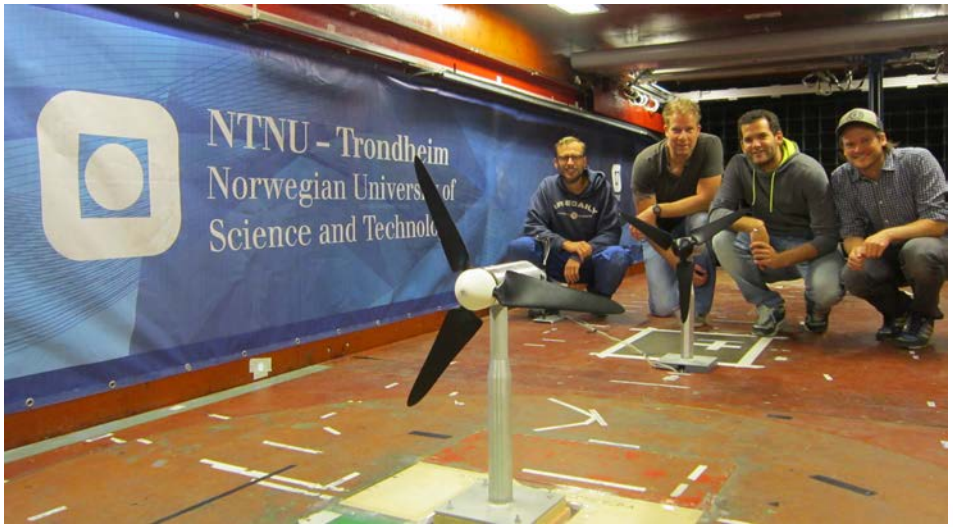
Collaboration project

Experimental Campaign

- Different rotor designs
- Same wind tunnel
- Single turbine and multiple turbine arrays

Yawed Wind Turbine Project





Model wind turbines

NTNU

D=0.89m
NREL S826
Small hub & tower
CCW rotation

Small NTNU

D=0.45m
NREL S826
Relative Big hub & tower
CCW rotation

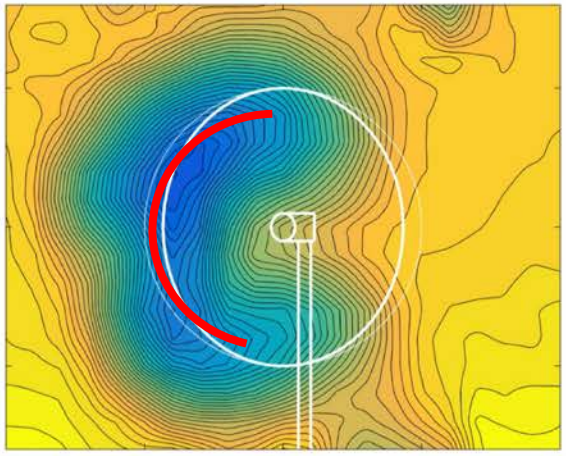
ForWind

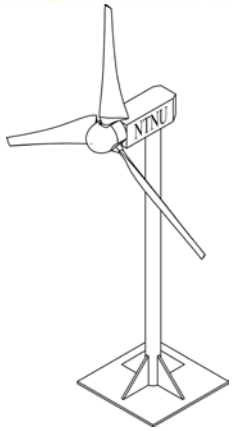
D=0.58m
SD 7003
Low blockage
CW rotation

Model wind turbines

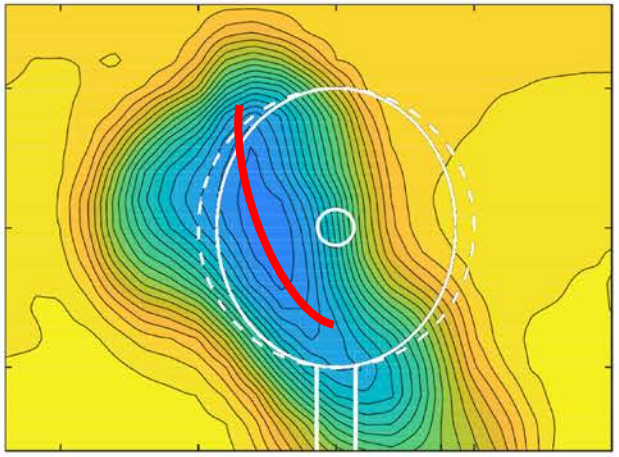
Streamwise velocity 6D behind +30° yawed turbine

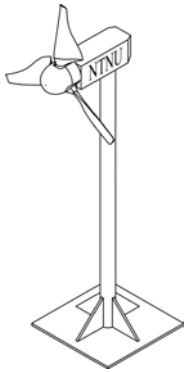
NTNU



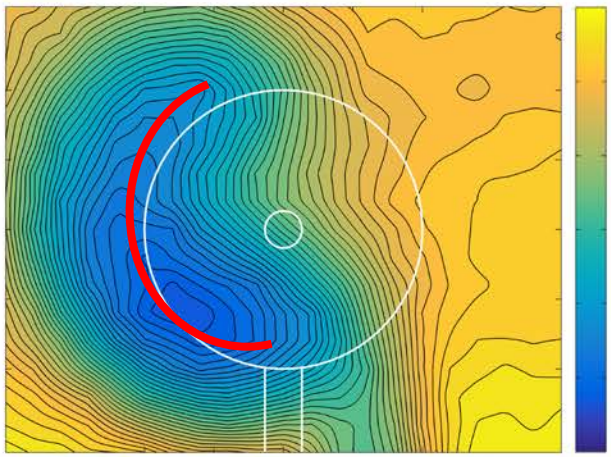


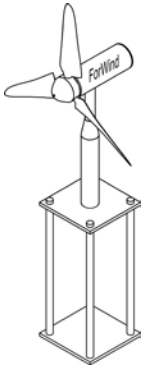
Small NTNU





ForWind

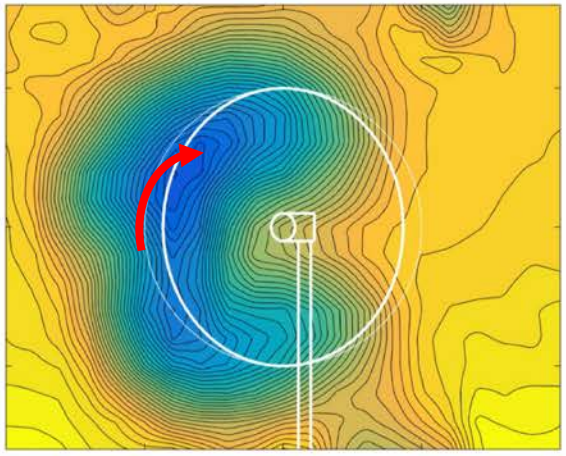


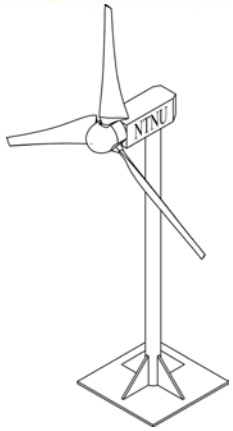


Model wind turbines

Streamwise velocity 6D behind +30° yawed turbine

NTNU





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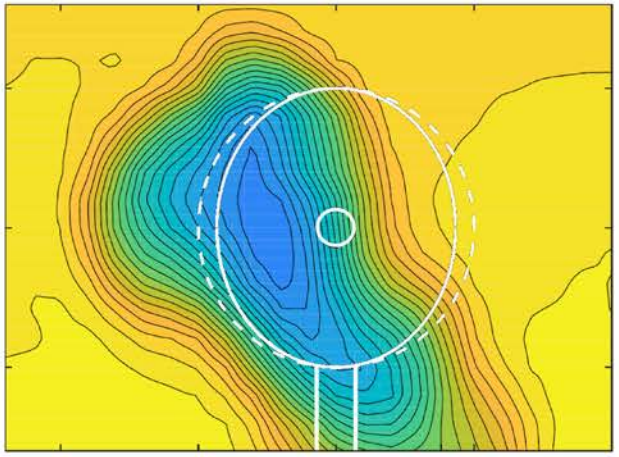
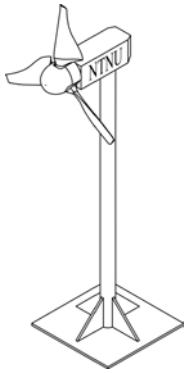
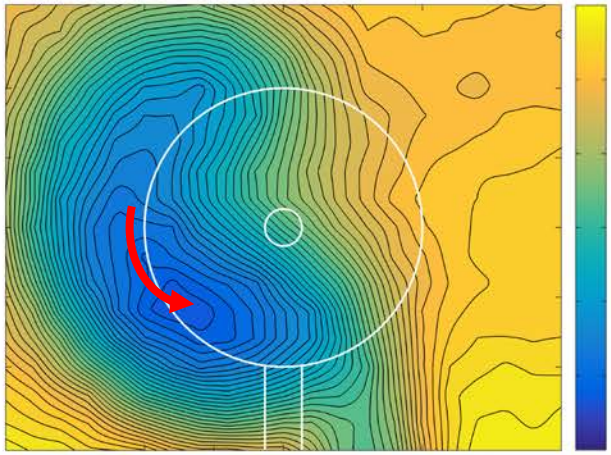
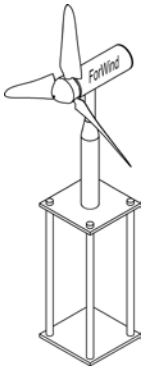




ForWind





Publications

"Comparative study on the wake deflection behind yawed wind turbine models"

Published in Journal of Physics: Conf. Series

"Wind tunnel experiments on wind turbine wakes in yaw: Effects of inflow turbulence and shear"

Posted as discussion paper on Wind Energy Science

"Wind tunnel experiments on wind turbine wakes in yaw: Redefining the wake width"

Posted as discussion paper on Wind Energy Science

"Blind test 5 - The wake behind a yawed model wind turbine"

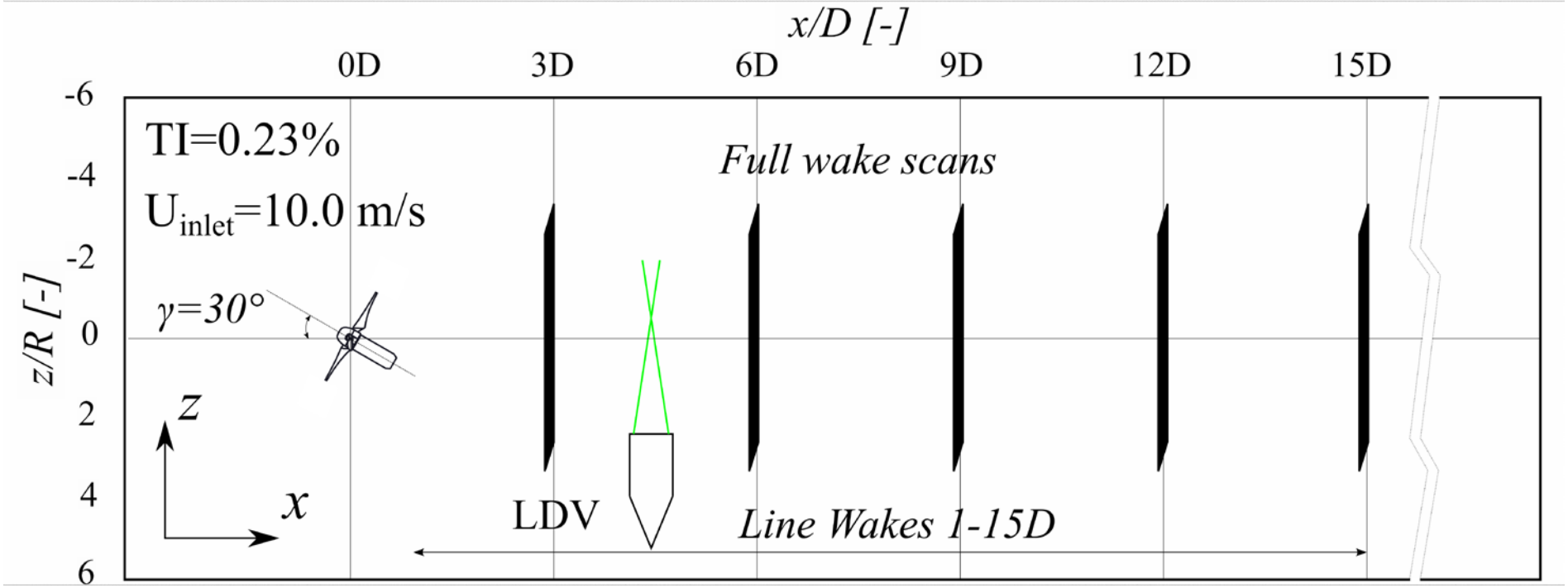
In process

"Performance and loads of two interacting wind turbines operated at different yaw"

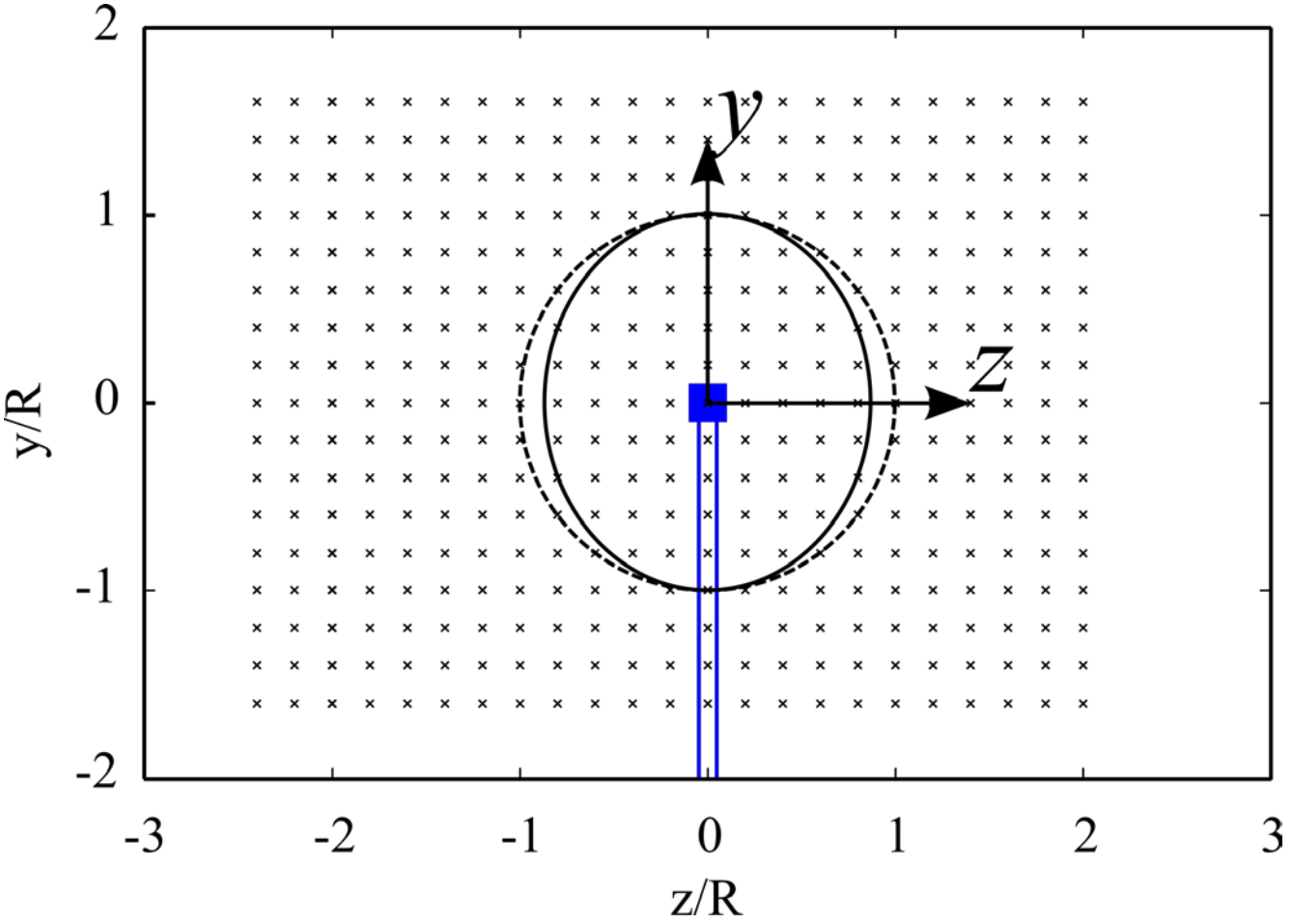
In process

"An Experimental Study on the Far Wake Development behind a Yawed Wind Turbine"

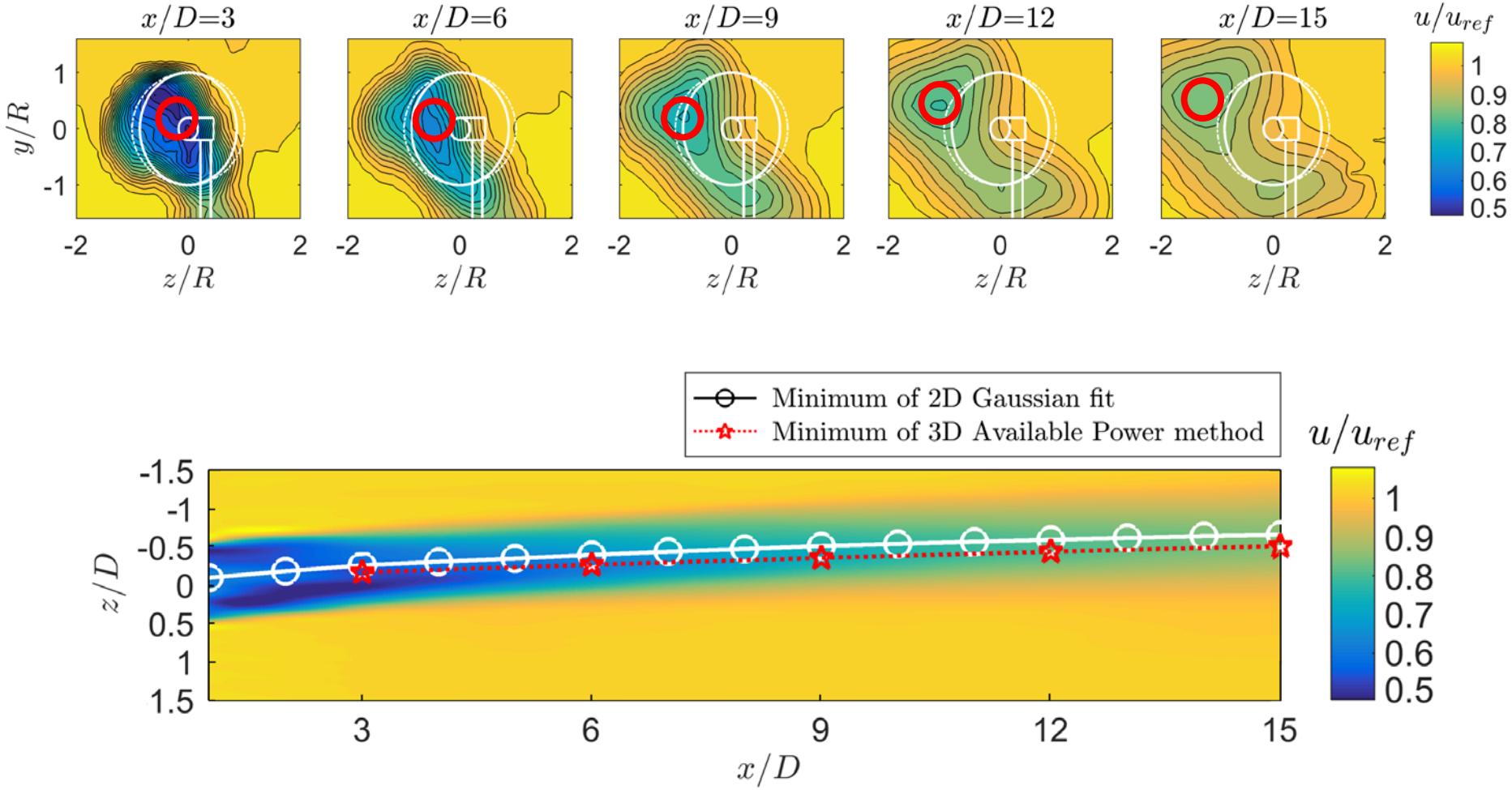
Experimental setup



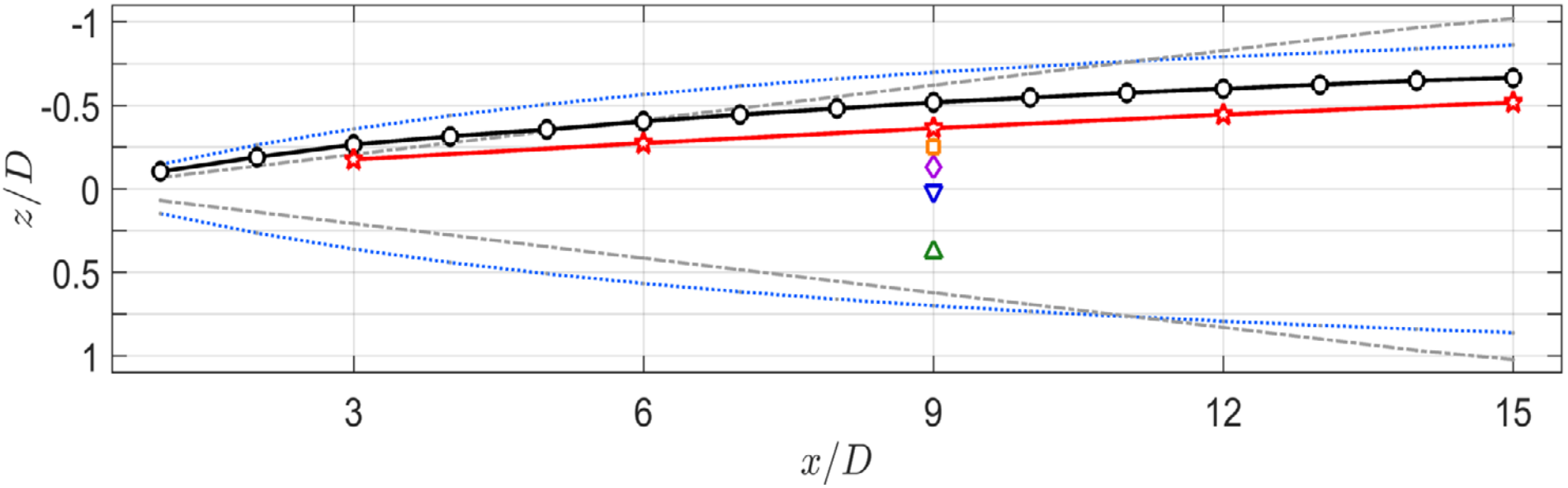
Experimental setup



Results


x/D=3
x/D=6
x/D=9
x/D=12
x/D=15
u/u_{ref}
1
0.9
0.8
0.7
0.6
0.5
y/R
z/R
Minimum of 2D Gaussian fit
Minimum of 3D Available Power method
z/D
x/D

Results



$\gamma = 30°$, 2D Gaussian fit	$\gamma = 20°$, 3D Av. power method
$\gamma = 30°$, 3D Av. power method	$\gamma = 10°$, 3D Av. power method
$\gamma = \pm 30°$, JCM model predictions	$\gamma = 0°$, 3D Av. power method
$\gamma = \pm 30°$, BPA model predictions	$\gamma = -30°$, 3D Av. power method

Conclusions

Rotor size and turbine dimension have large influence on wake shape

Wake behind yawed turbine is complex and asymetric

Larger wake deflection from line wake analysis

Analytical wake models over predict wake deflection

Thank you for the attention!

I’m looking forward to your Questions

Norwegian University of Life Sciences