Wake flow characteristics in low ambient turbulence conditions

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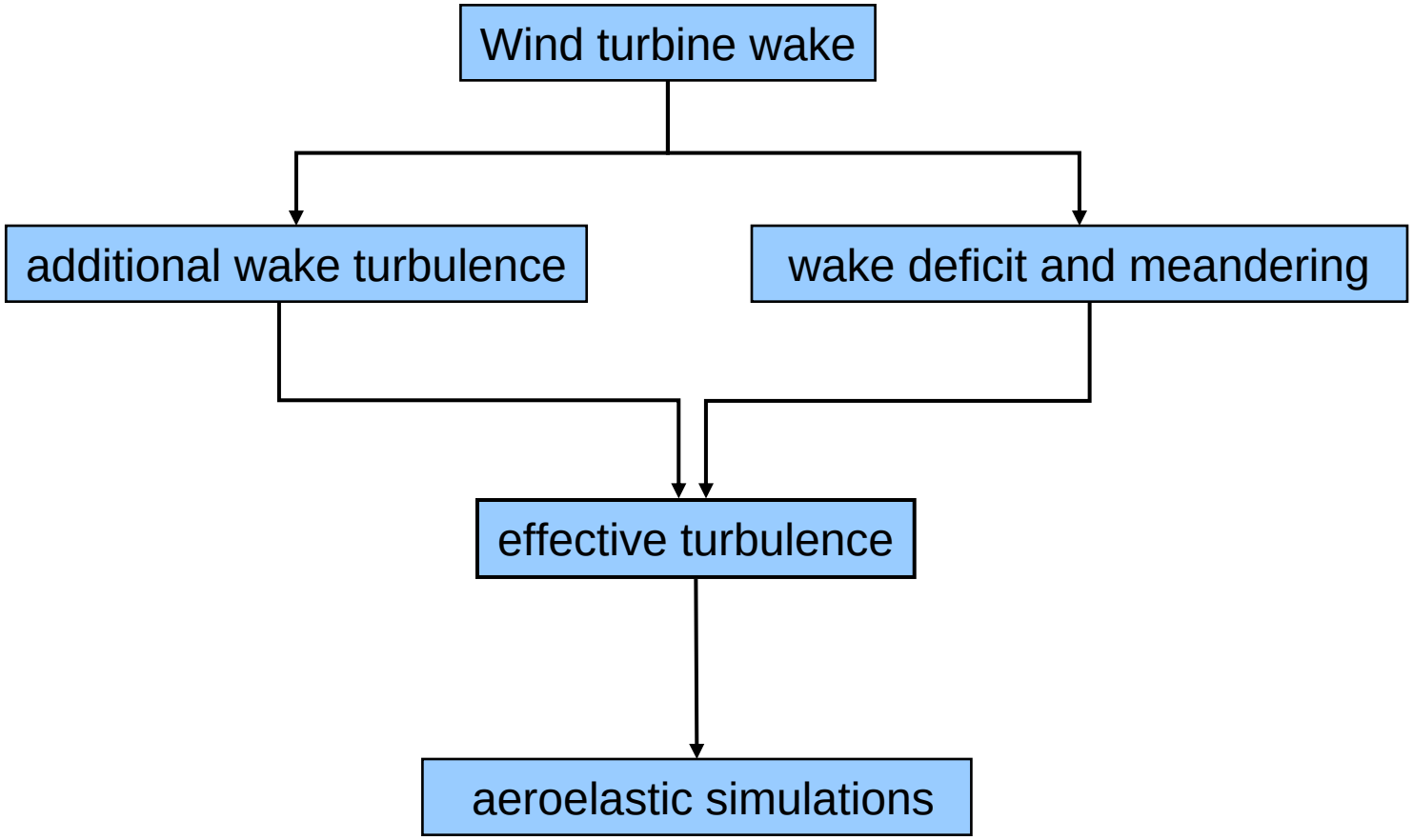
Outline

- Background for the work
- Measurement set-up
- Results
- Conclusions

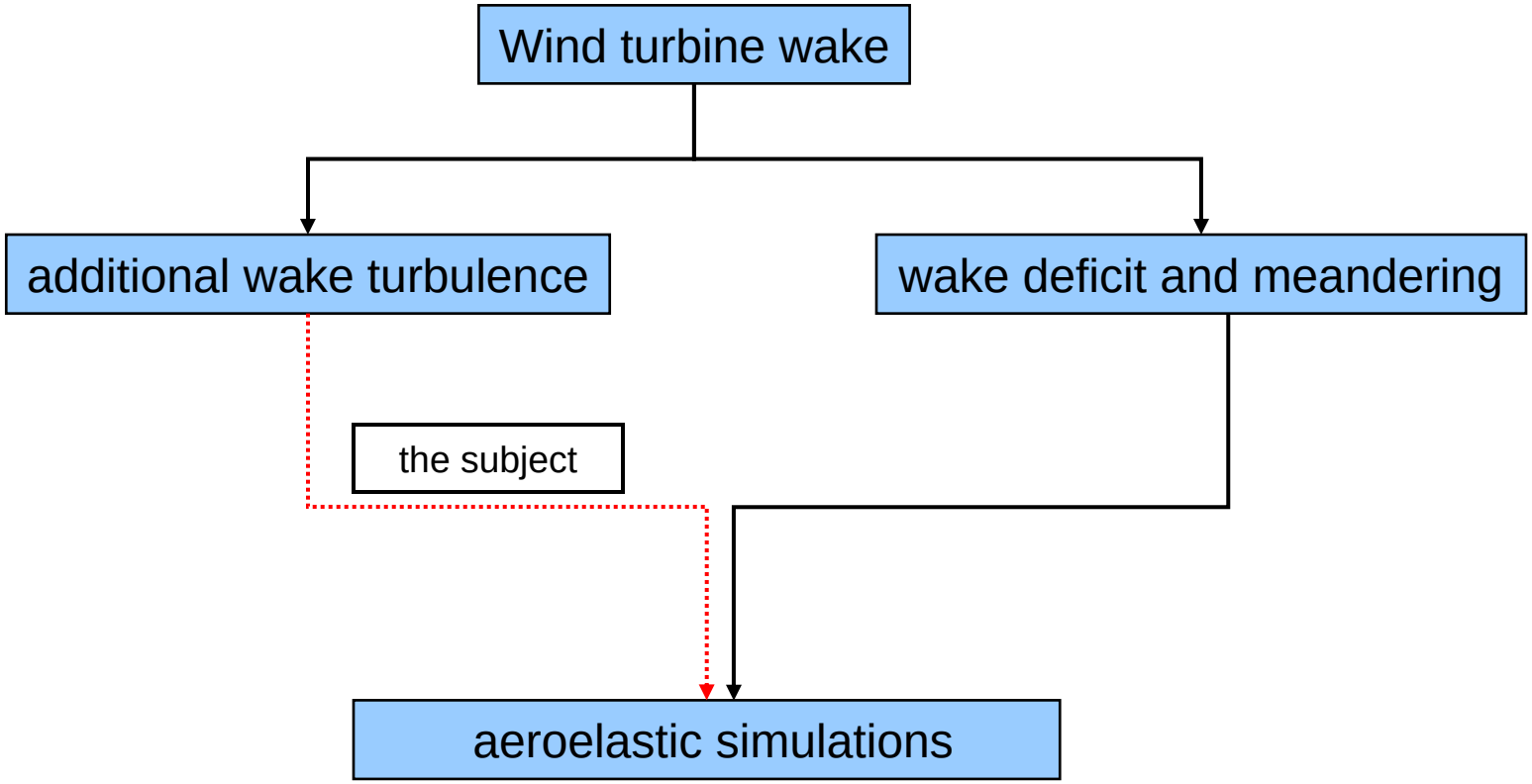
Background

- common way of modelling wake operation in aeroelastic simulations -



Background

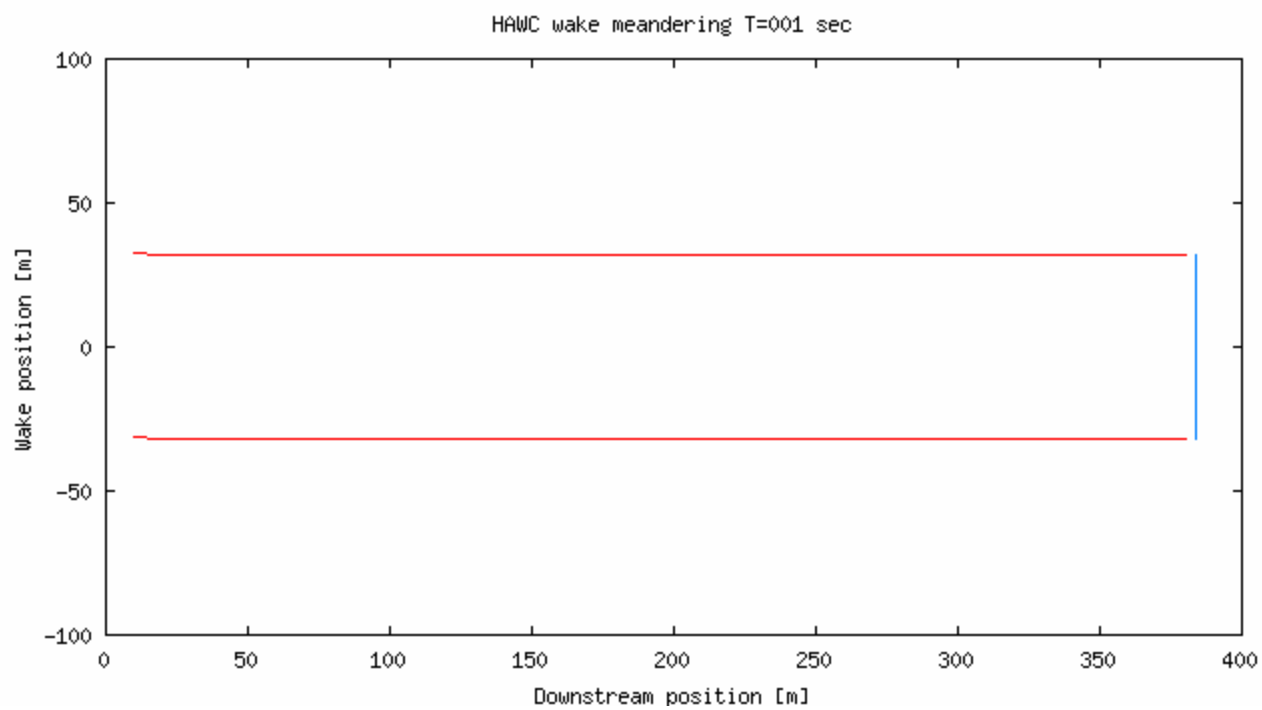
- new model for aeroelastic simulation of wake operation



Simulation of wake deficit meandering

- wake deficit meandering results in an apparent additional large scale turbulence for the downstream turbine

- wake deficit meandering is thought to be of major importance for the loads on the rotor



The subject

- investigate the turbulence generated within the wake

PROBLEM

- meandering of the wake deficit generates apparent turbulence which is superimposed the ambient turbulence along with turbulence generated within the wake

SOLUTION

- use measurements with low ambient turbulence where the contribution to the wake turbulence from wake deficit meandering is minimal

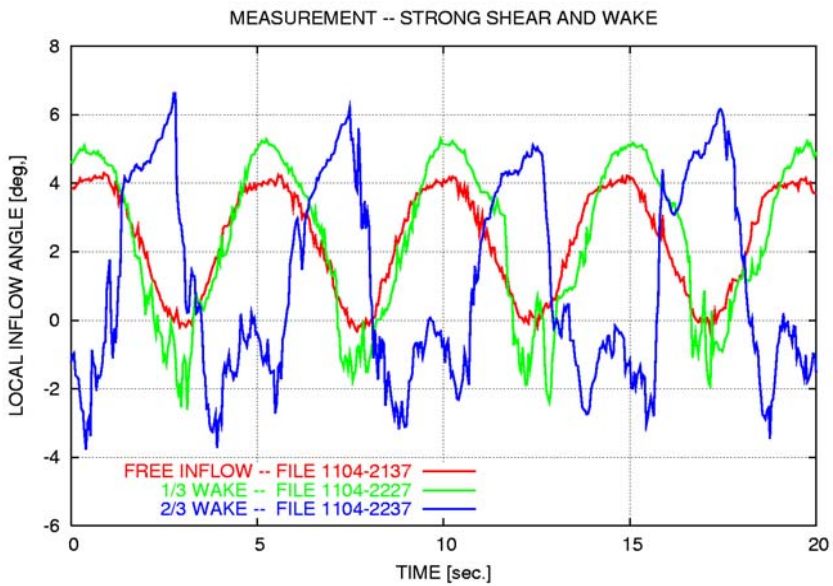
Measurements

APPROACH

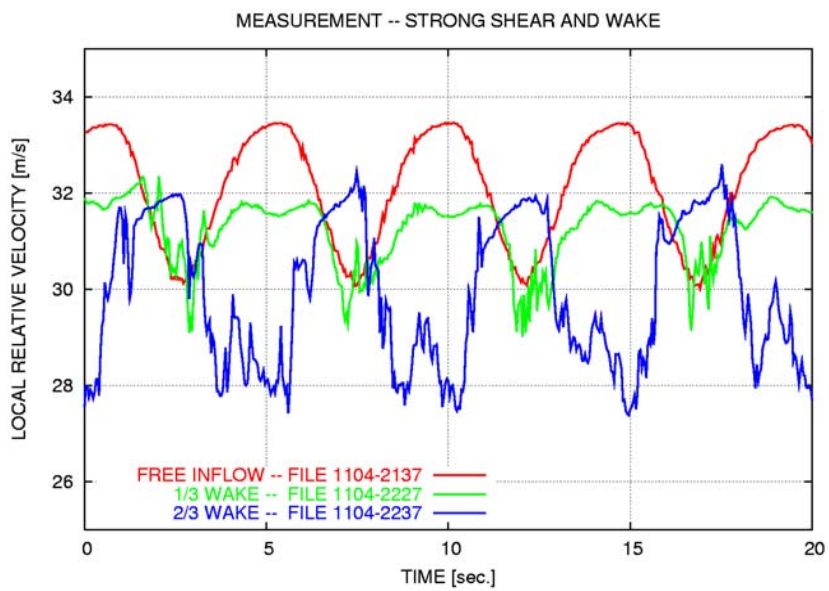
- **inflow measurements on one of the blades of an 80 m diameter turbine operating in wake conditions (3.3 D), situated on land but close to the North sea**

Measured quantities

local inflow angle



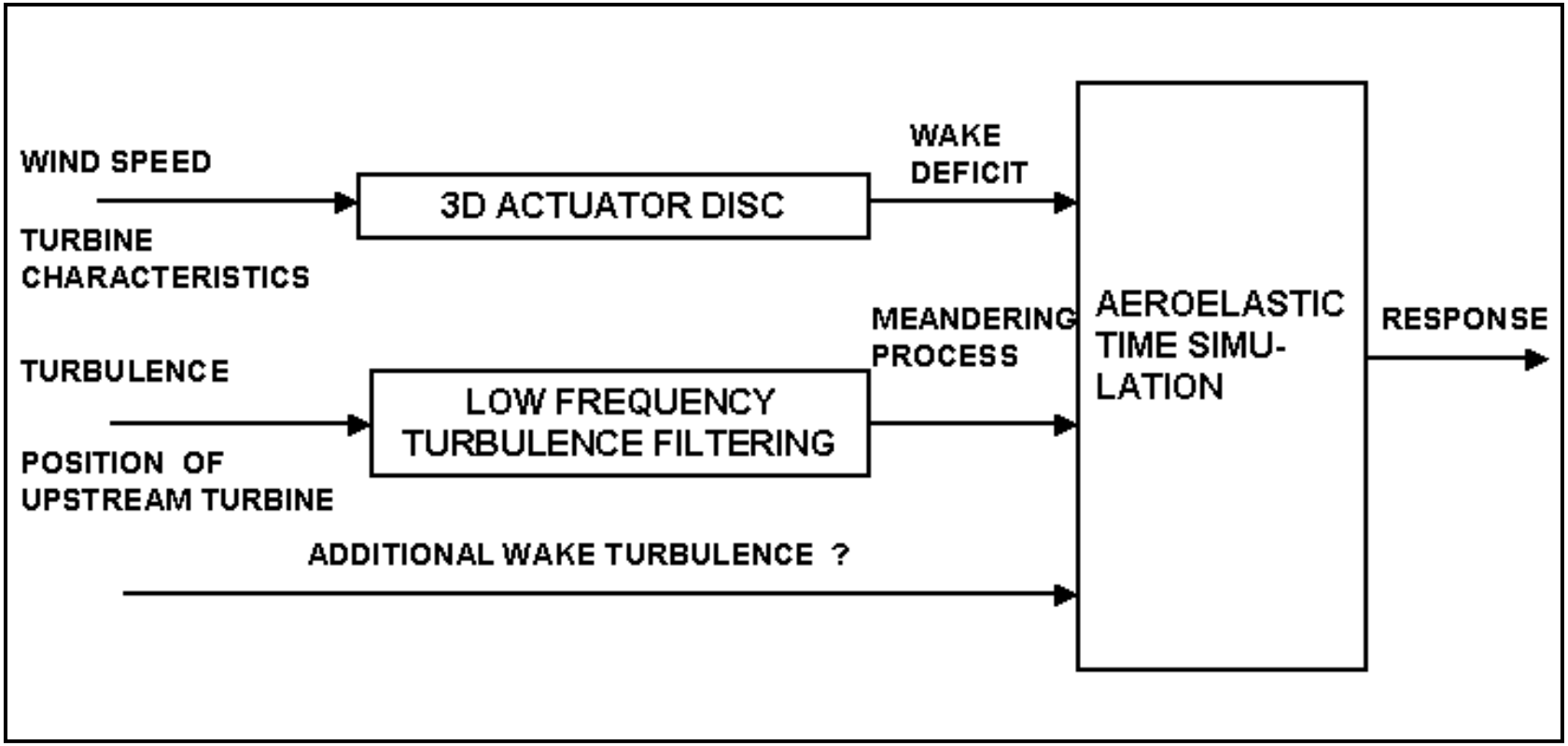
local relative velocity



for the present analysis, three 10 min. series measured within 1 hour with low ambient turbulence has been analyzed, 1 series in free inflow, 1 in 1/3 wake operation and 1 in 2/3 wake operation

Simulation model

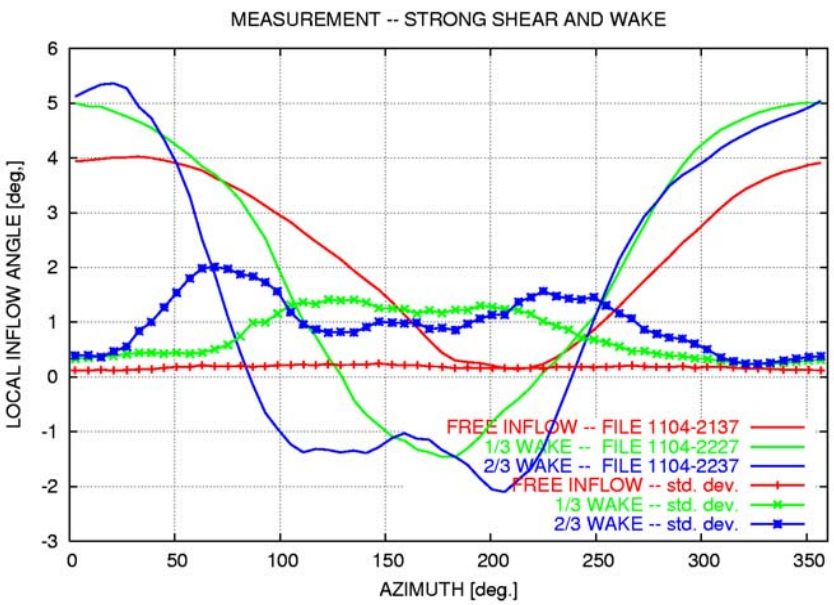
The HAWC aeroelastic code + sub models for wake deficit and meandering



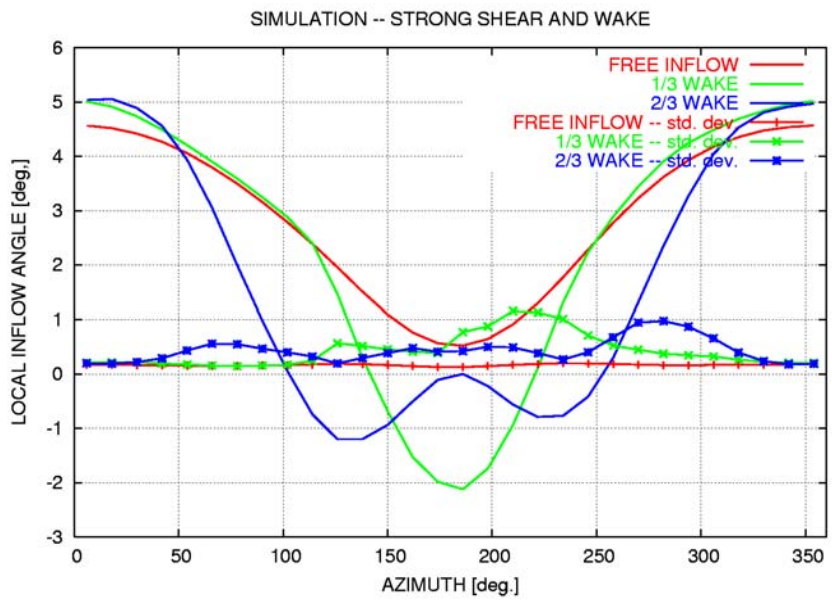
Results - local inflow angle

- local inflow angle binned on rotor azimuth position in free inflow and 1/3 and 2/3 wake operation, respectively
- 3% turbulence used in the simulations

measurements



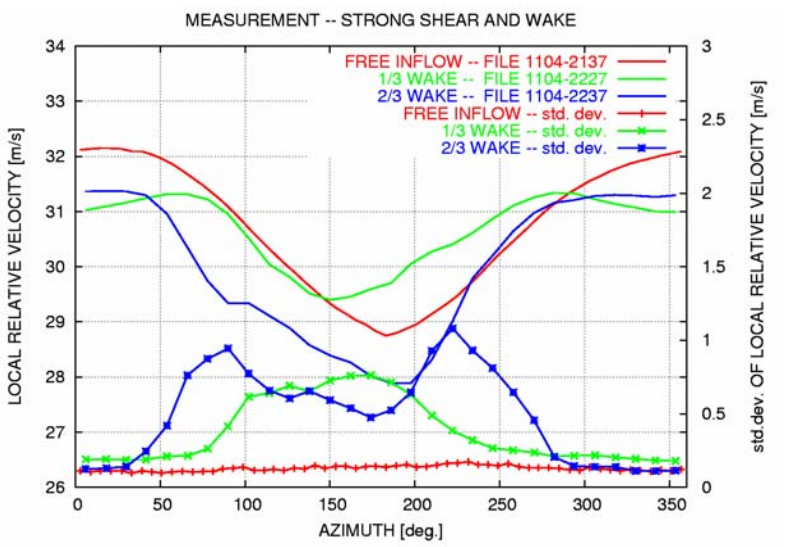
simulation



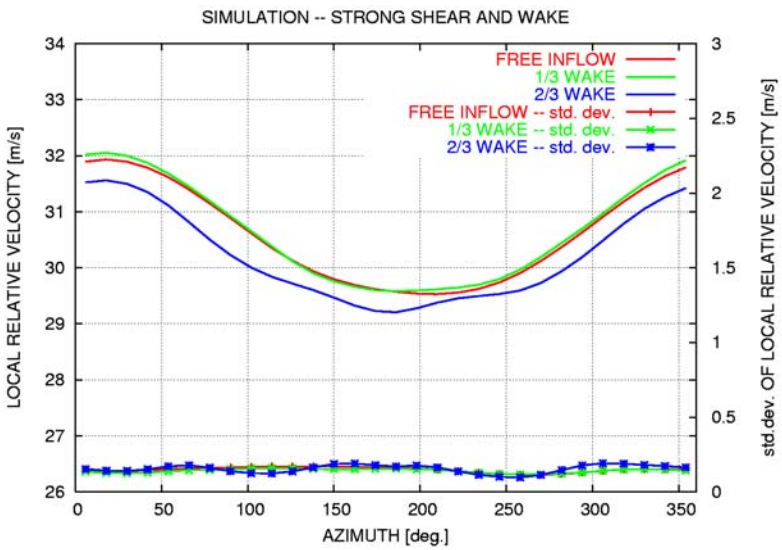
Results - relative velocity

- relative velocity binned on rotor azimuth position in free inflow and 1/3 and 2/3 wake operation, respectively
- 3% turbulence used for the simulations

measurements



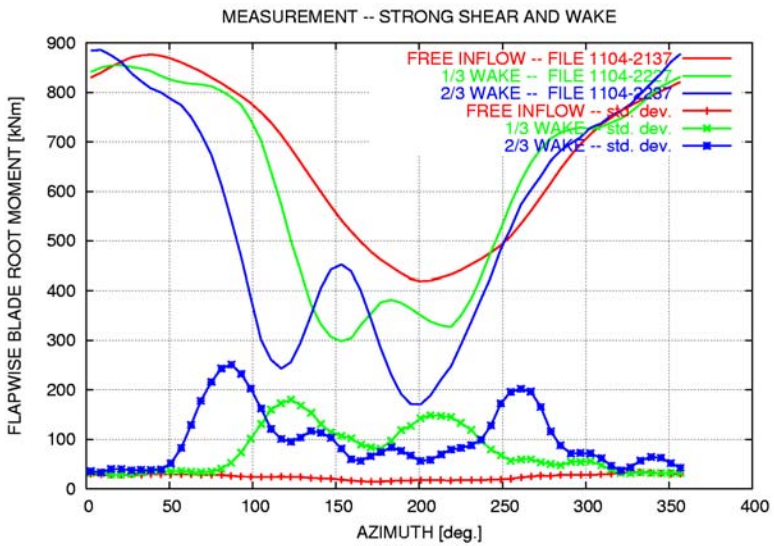
simulation



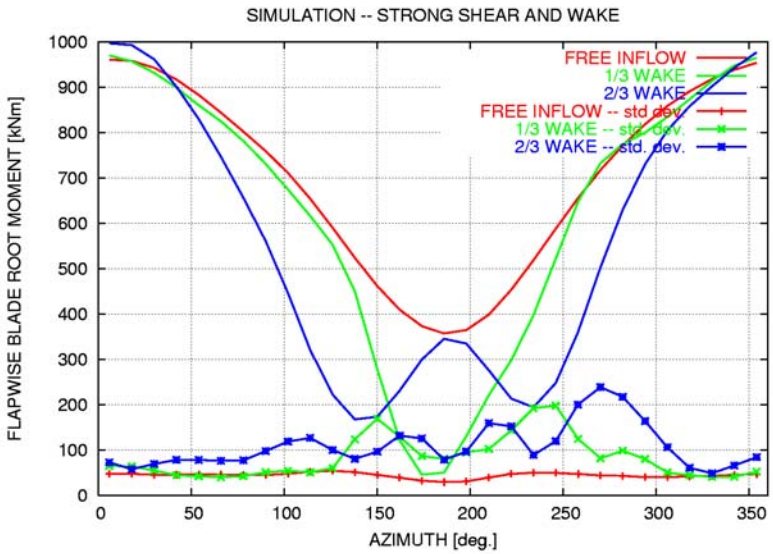
Results - flapwise blade root moment

- flapwise blade root moment velocity binned on rotor azimuth position in free inflow and 1/3 and 2/3 wake operation, respectively
- 3% turbulence used for the simulations

measurements



simulation



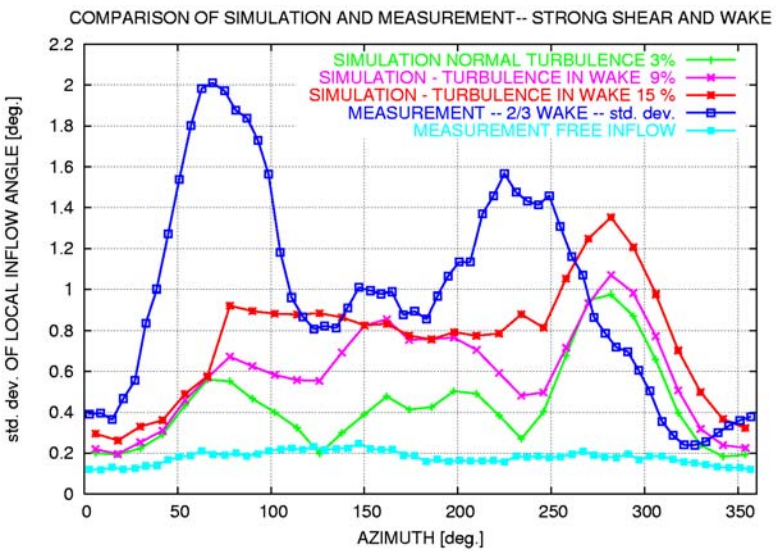
Overall result of comparison

- in particular the comparison of measured and simulated standard deviation of the relative velocity shows that additional turbulence should be added, when the blade is inside the wake region
- as a first attempt, wake turbulence was simply modelled by up-scaling of the ambient turbulence for the blade being inside the wake region

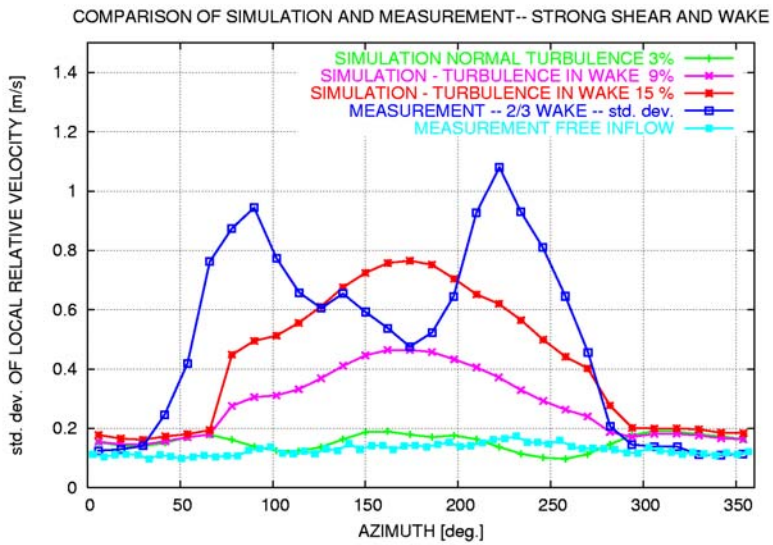
Results of adding turbulence within the wake

- turbulence for the blade inside the wake has been increased to 9% and 15% respectively

measured and simulated inflow angle - std.dev.



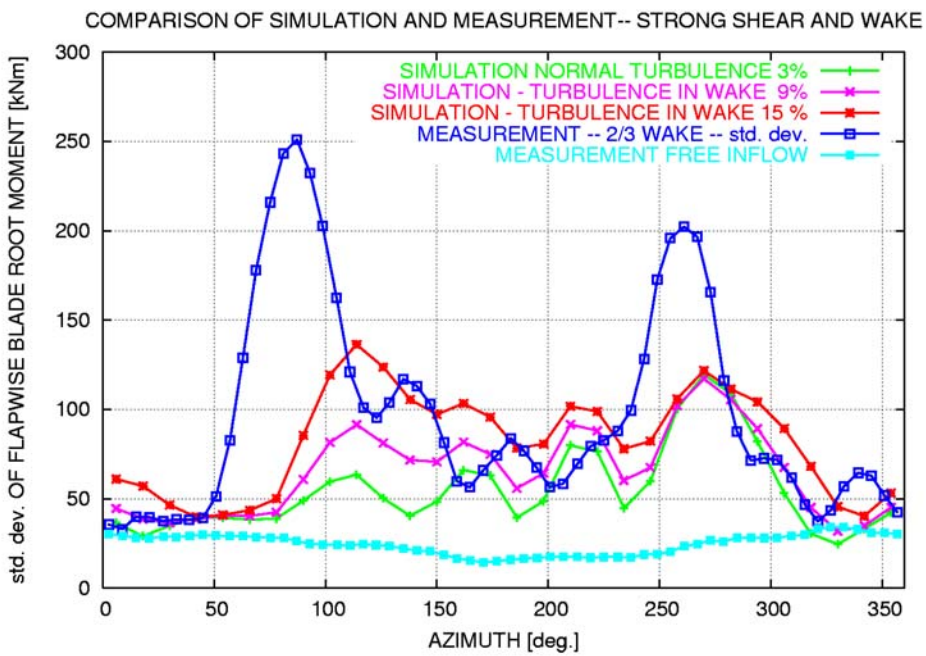
measured and simulated relative velocity - std.dev.



Results of adding turbulence within the wake

- turbulence for the blade inside the wake has been increased to 9% and 15% respectively

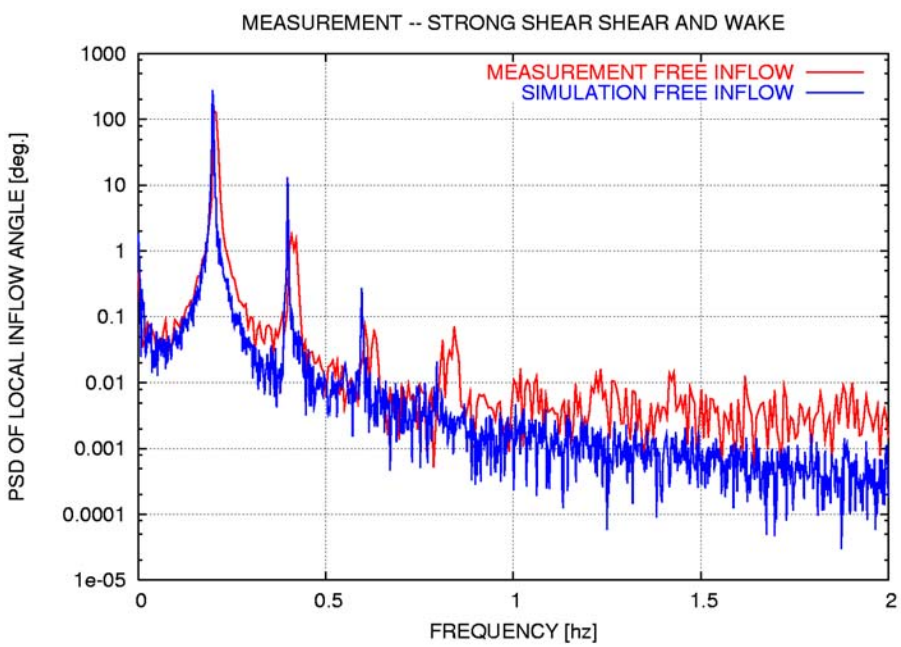
measured and simulated flapwise blade root moment - std.dev.



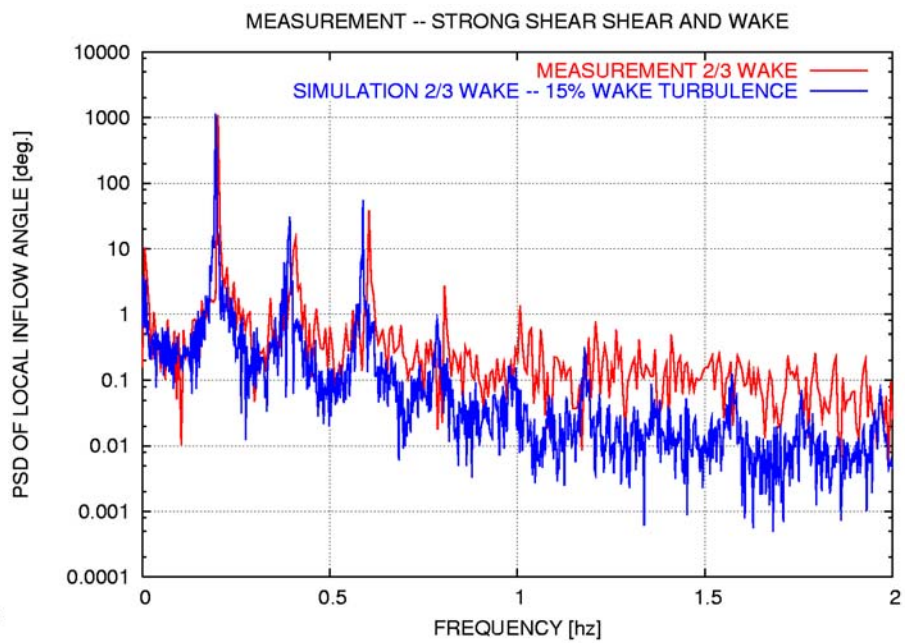
Results - comparison of power spectra

local inflow angle

free inflow



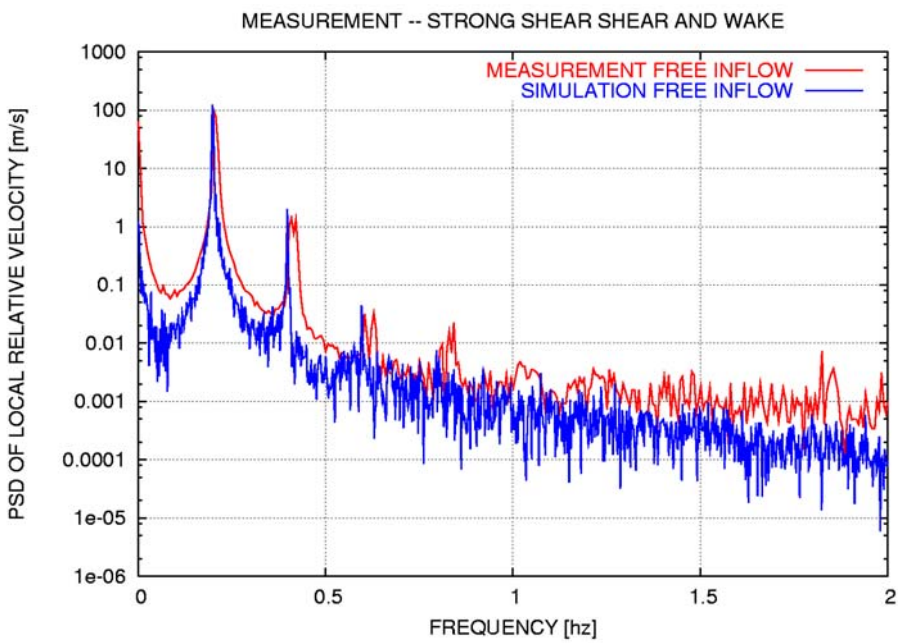
2/3 wake operation



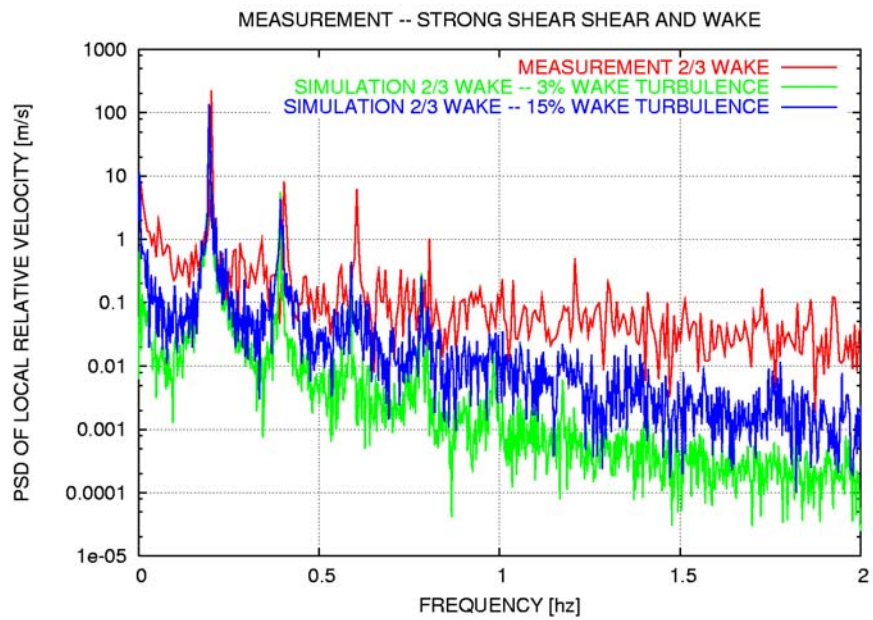
Results - comparison of power spectra

local relative velocity

free inflow



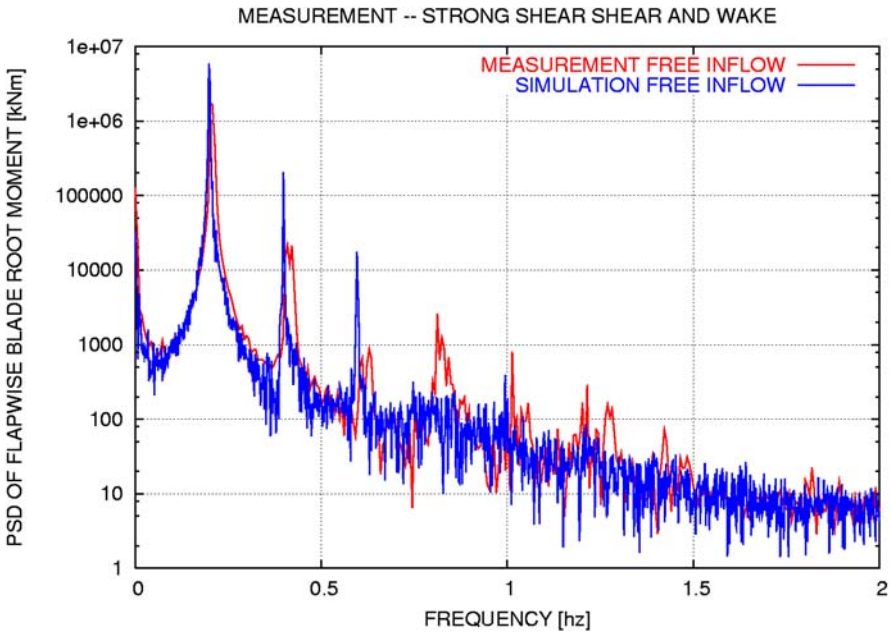
2/3 wake operation



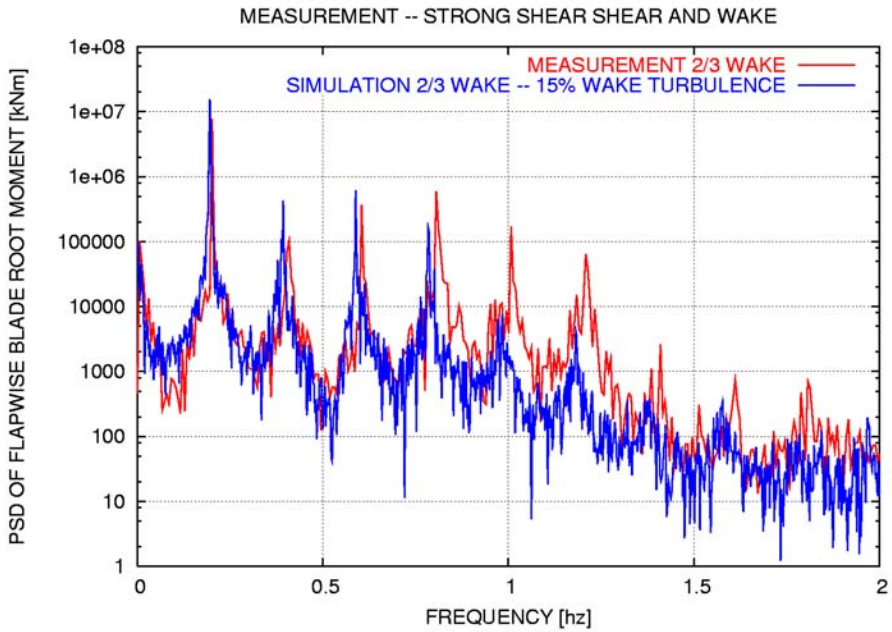
Results - comparison of power spectra

flapwise blade root moment

free inflow



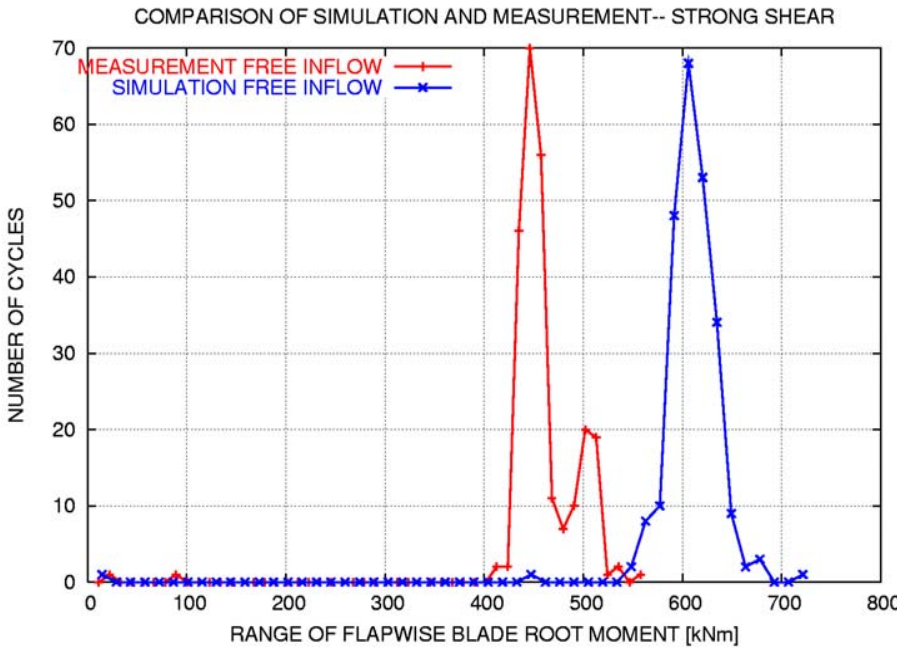
2/3 wake operation



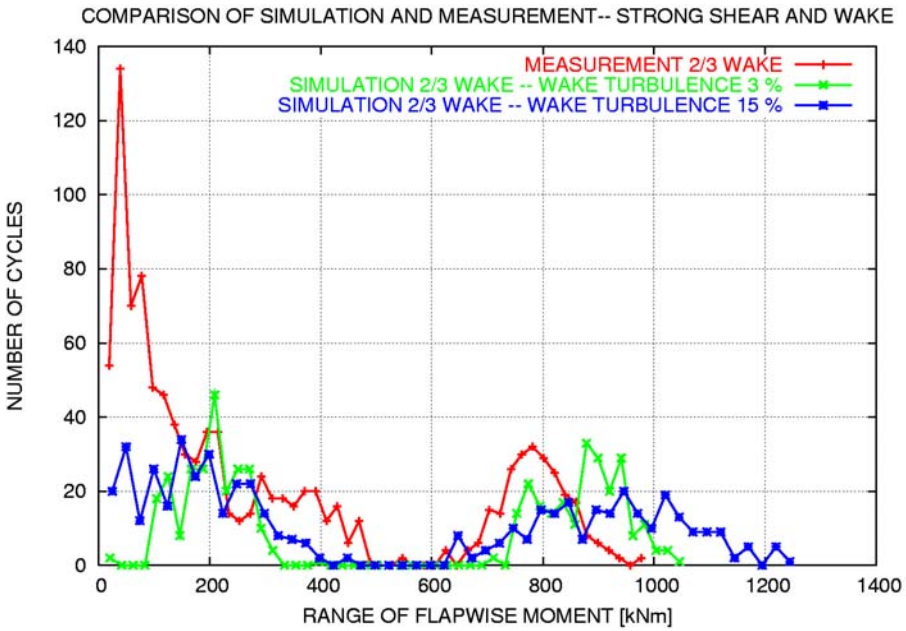
Results - comparison of fatigue ranges

flapwise blade root moment

free inflow



2/3 wake operation



Conclusions

- **inflow measurements with a five hole pitot tube have given detailed data of wake flow characteristics (deficit and turbulence)**
- **the experimental data provide an excellent basis for implementation of a procedure for adding wake turbulence in a new wake simulation model**
- **wake turbulence intensity as function of depth of the deficit and function of the gradient of the deficit will be added**
- **comparison of measured and simulated fatigue ranges of the flapwise blade root moment indicates that the turbulence within the wake has length scales less than the ambient turbulence**
- **the new wake simulation model will be further developed with simple engineering models for all the model components (velocity deficit, meandering and wake turbulence)**