Wind turbine Blind Test 3
Model experiments and predictions

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Background :

- Nowitech and Norcowe has about 35 PhD students together, many of these use or develop models for wind turbine performance predictions
- Full scale data bases not suited for prediction verifications
- Most multi-turbine model tests performed on very small models
- Interaction between turbines hard to predict
- How accurate are wind farm performance predictions?

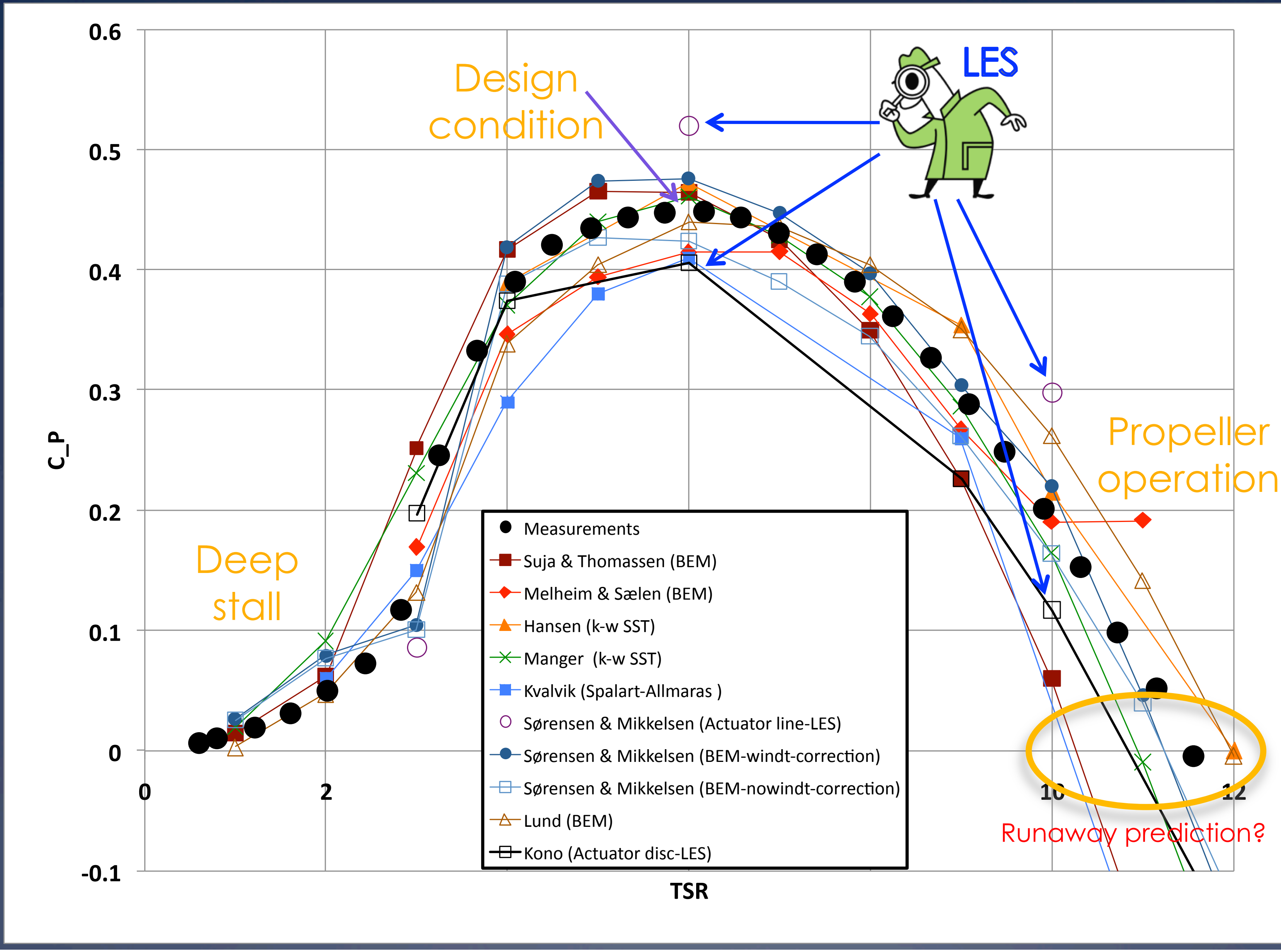
Need for high quality turbine data bases for model verifications

Blind test 1 (Bergen October 2011):

* Single turbine in wind tunnel, tested with uniform inlet velocity and low turbulence intensity
* Turbine geometry specified; predict turbine performance and wake development

Compulsory results: C_P

10 sets of data from 8 groups

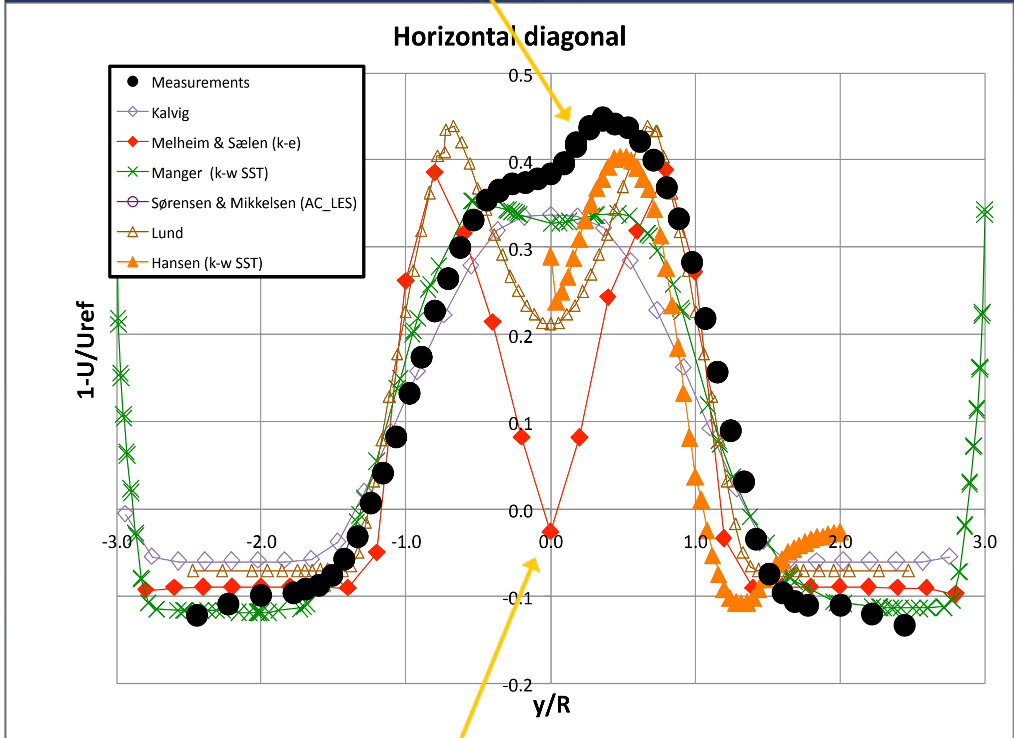


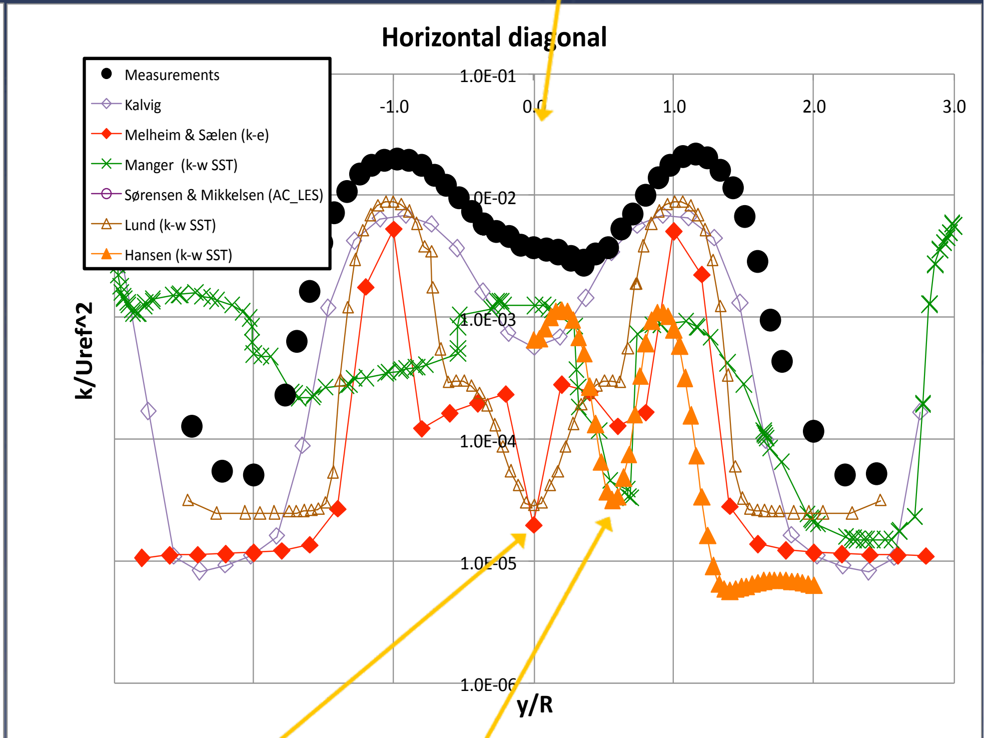
Wake data, X/D=5:
Design condition; TSR = 6

Horizontal diagonal

Note log scale for k/U_{ref}^2 !

Tower wake





No diffusion?

?

?

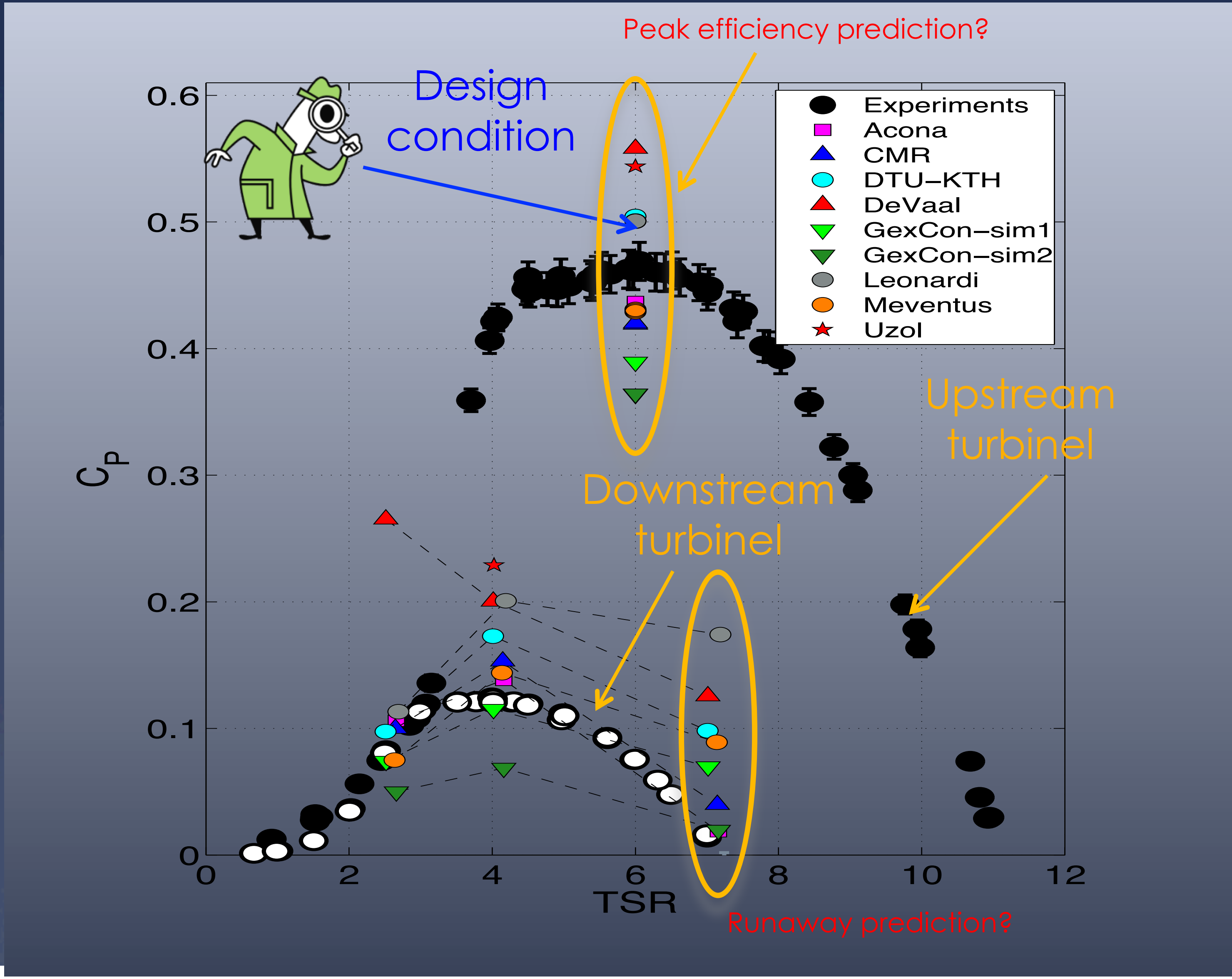
Instability in solutions?

Blind test 2 (Trondheim October 2012):

- Two in-line wind turbines tested with uniform inlet velocity and low turbulence intensity
- Turbine geometry specified; predict turbine performances and wake development downstream of second turbine!

Power coefficient: C_P

9 sets of data from 8 groups



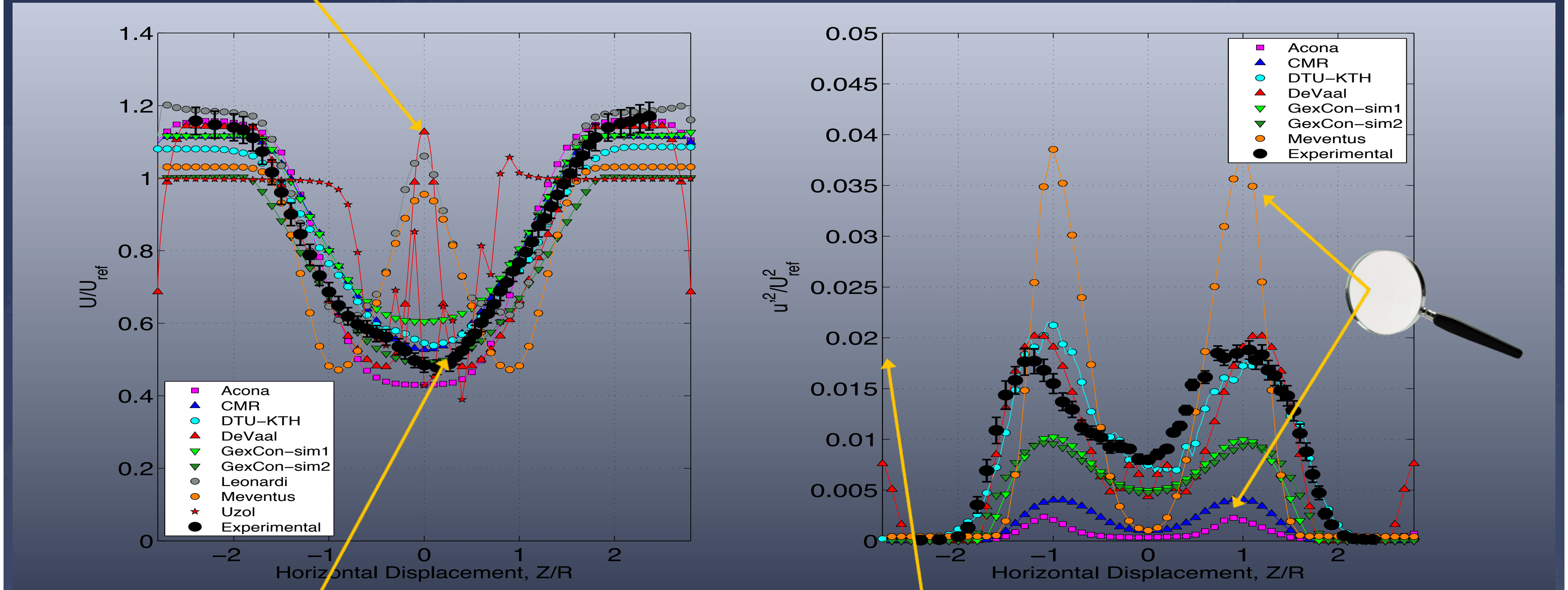
Wake data, X/D=4 downstream of T_2:

T1: design condition; TSR = 6,

T2: peak efficiency; TSR = 4

Horizontal diagonal

Hub not included!



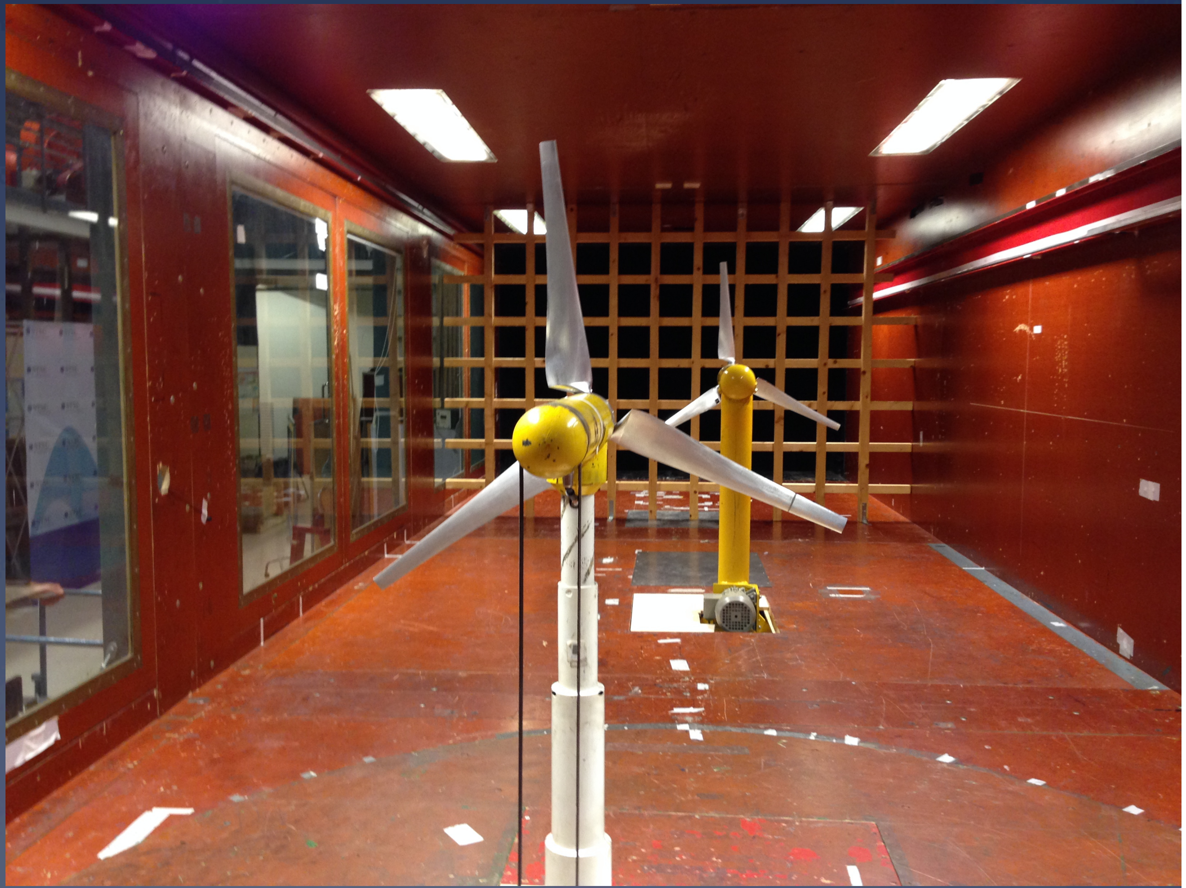
Tower wake

Log scale no longer needed!

Blind test 3 (Bergen December 2013):

- Two in-line wind turbines offset sideways by approximately D/2
- Uniform flow, with 0.2 and 10% turbulence intensity
- Turbine geometry and turbulence field specified;

Predict turbine performances and wake development downstream of second turbine!



Contributors:

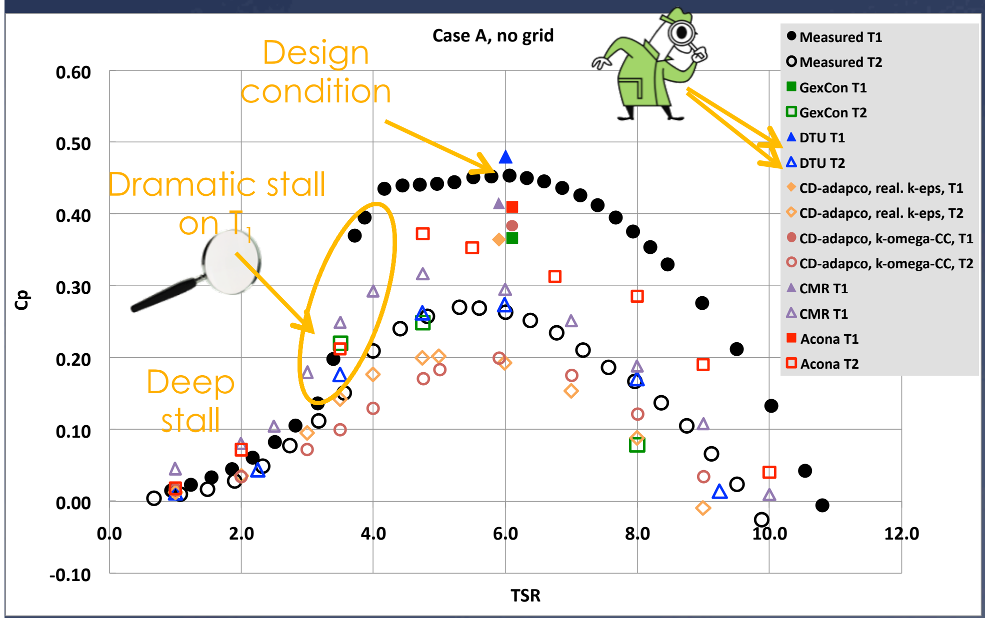
* Alcona Flow Technology; E. Manger (fully resolved 3D model/Fluent/k-ω SST, transient)
* CD-adapco; S. Evans & J. Ryan (Star-CCM+/k-ω SST and Realizable k-ε)
* CMR; A. Hallanger & I.Ø. Sand (Music by CMR, BEM model with hub but no tower, standard k-ε and subgrid model)
* DTU Mech. Eng. / KTH Mechanics; R. Mikkelsen, S. Sarmast, H.S. Chivaee & J.N. Sørensen (actuator line/LES)
* GexCon; M. Khalil (Flacs-wind by GexCon, actuator disk, standard k-ε, transient)

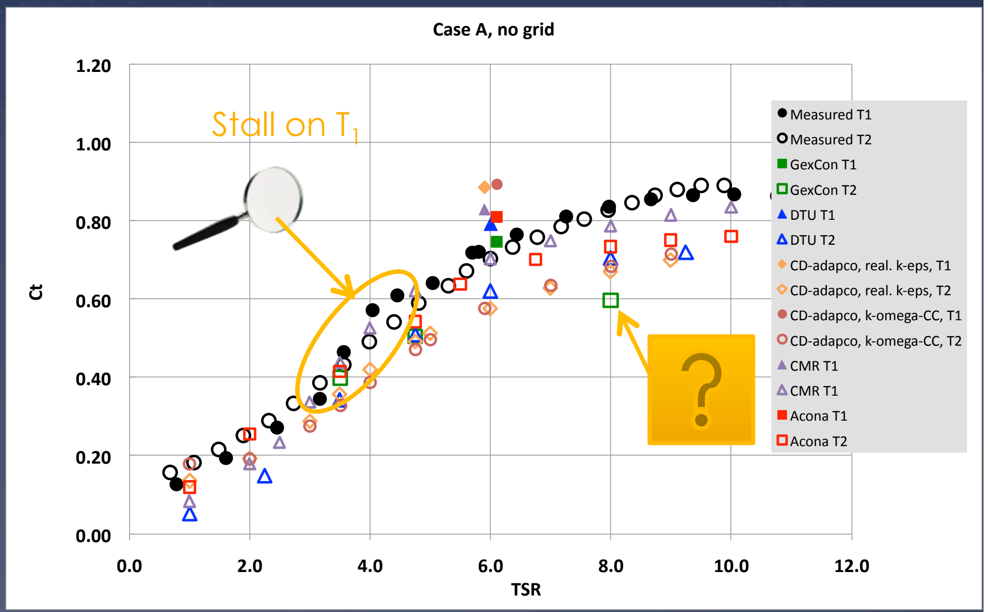
Case A, no grid: C_P & C_T

6 sets of predictions from 5 contributors

Filled symbols: Upstream turbine (T_1)
Open symbols: Downstream turbine (T_2)

Black symbols: Measurements





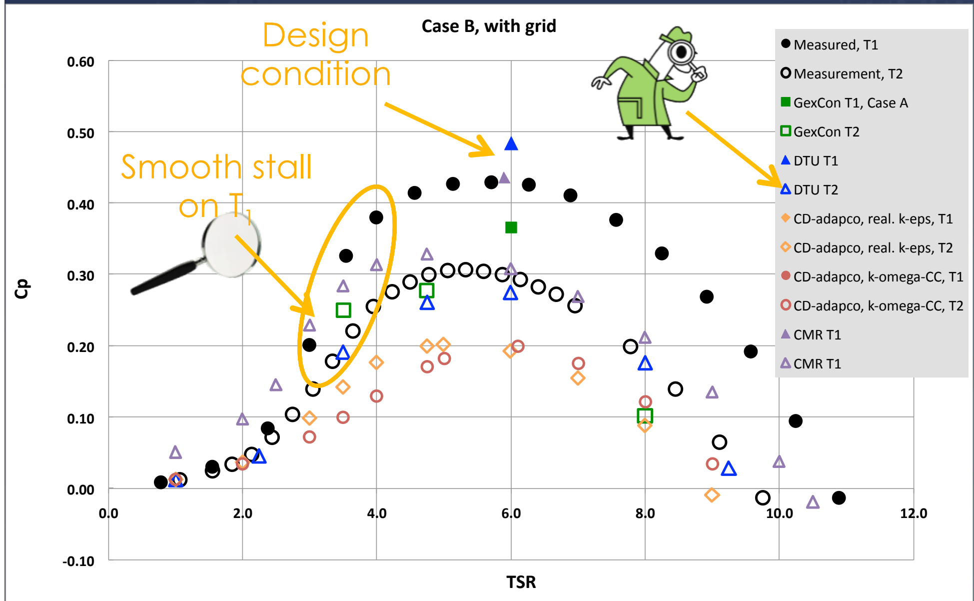
DTU has predicted C_p for both turbines extremely well.
C_T mostly underpredicted for T_2 !

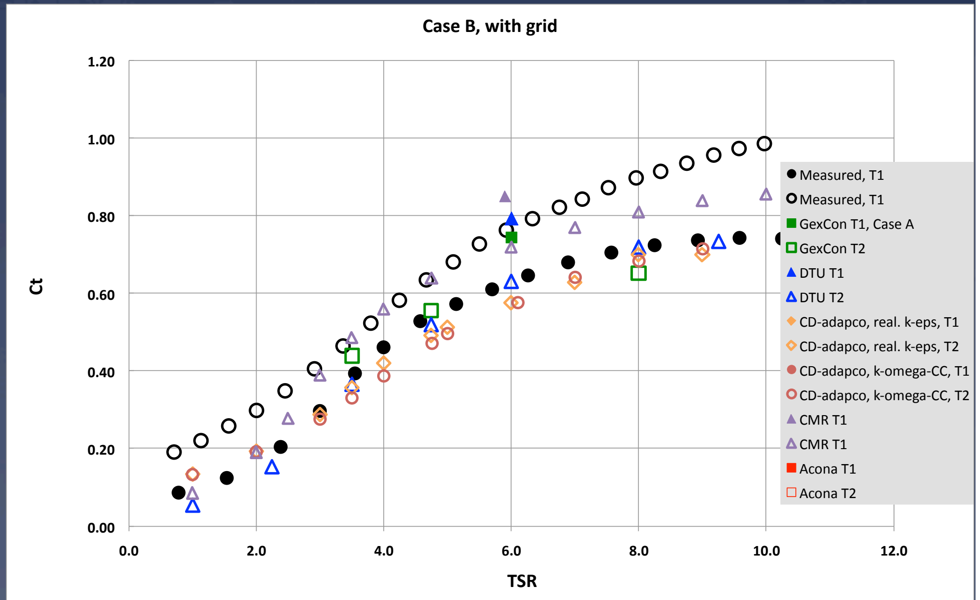
Case B, with grid: C_P & C_T

5 sets of predictions from 4 contributors

Filled symbols: Upstream turbine (T_1)
Open symbols: Downstream turbine (T_2)

Black symbols: Measurements

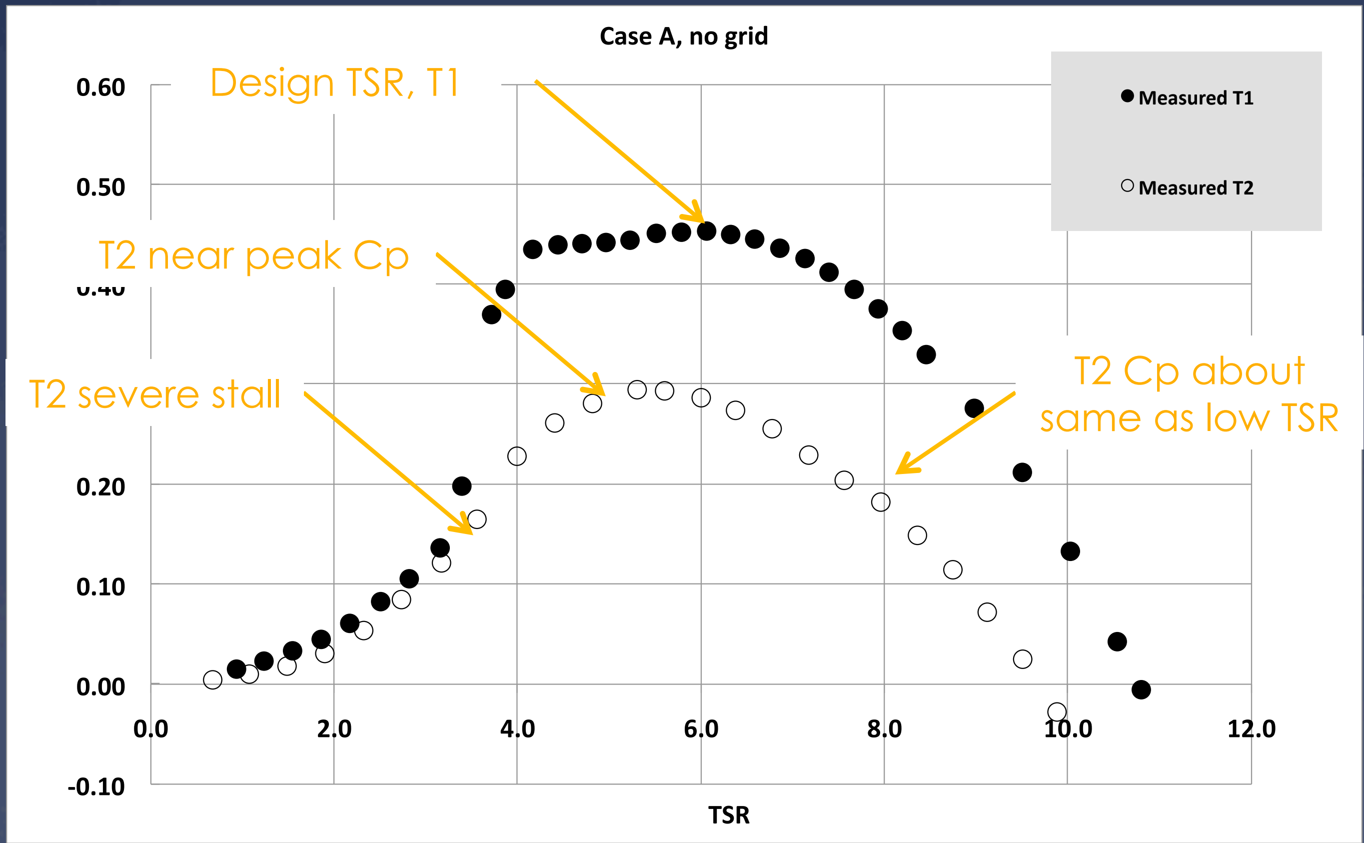




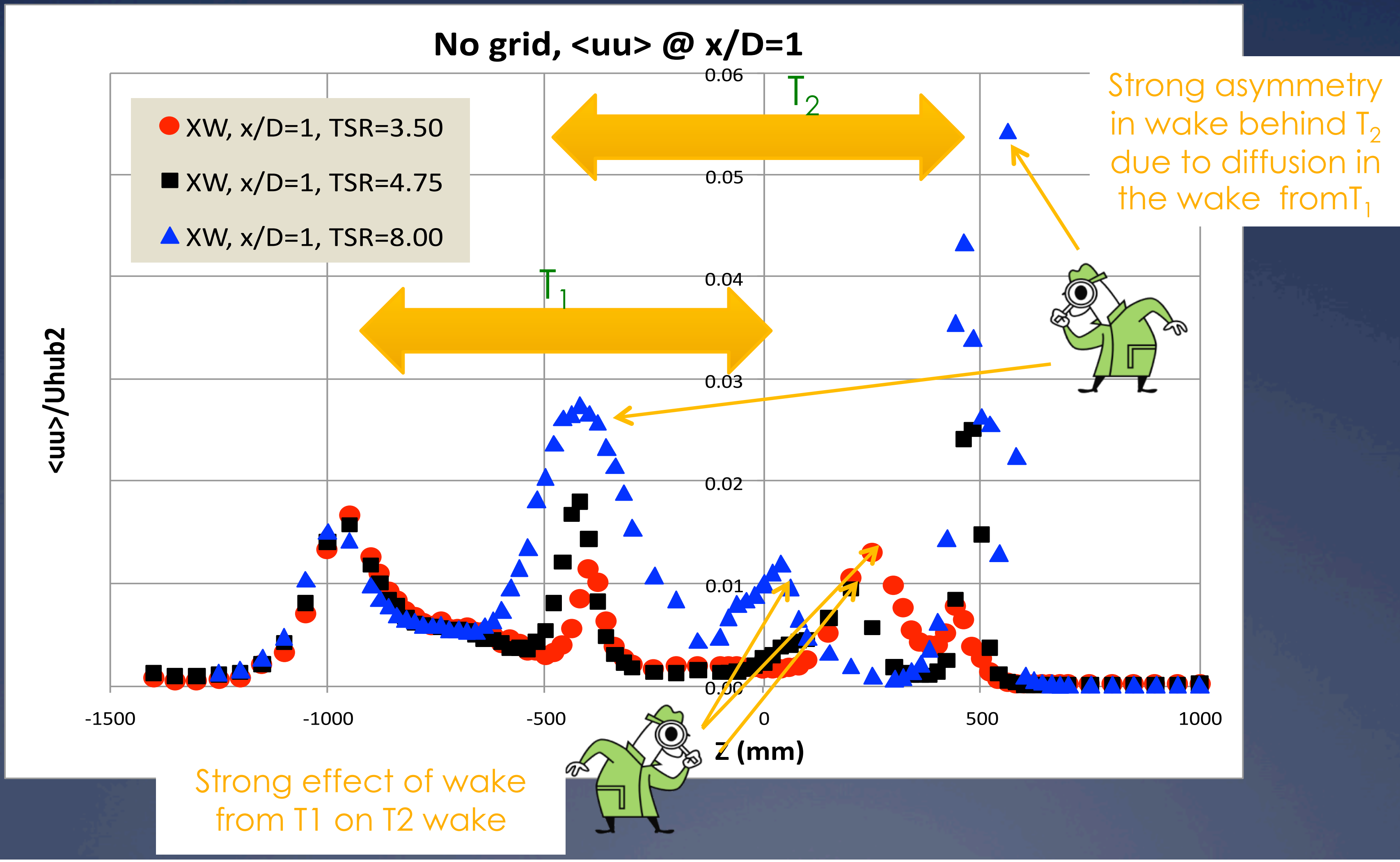
Smooth stall for T_1 and max C_p slightly reduced with turbulence
Max C_p for T_2 somewhat increased
C_T reduced for T_1 but hardly affected for T_2

Wake data requested downstream of T_2 when TSR = 6 for T_1 (peak performance)

- TSR = 3.5 for T_2 (stall region)
- TSR = 4.75 for T_2 (peak performance)
- TSR = 8.0 for T_2 (partly propeller operation)



The turbulent energy distribution in the wake depends on the turbine operating conditions (Measurements along horizontal diagonal 1D behind T_2) T_1 operates at max C_P, T_2 at variable TSR

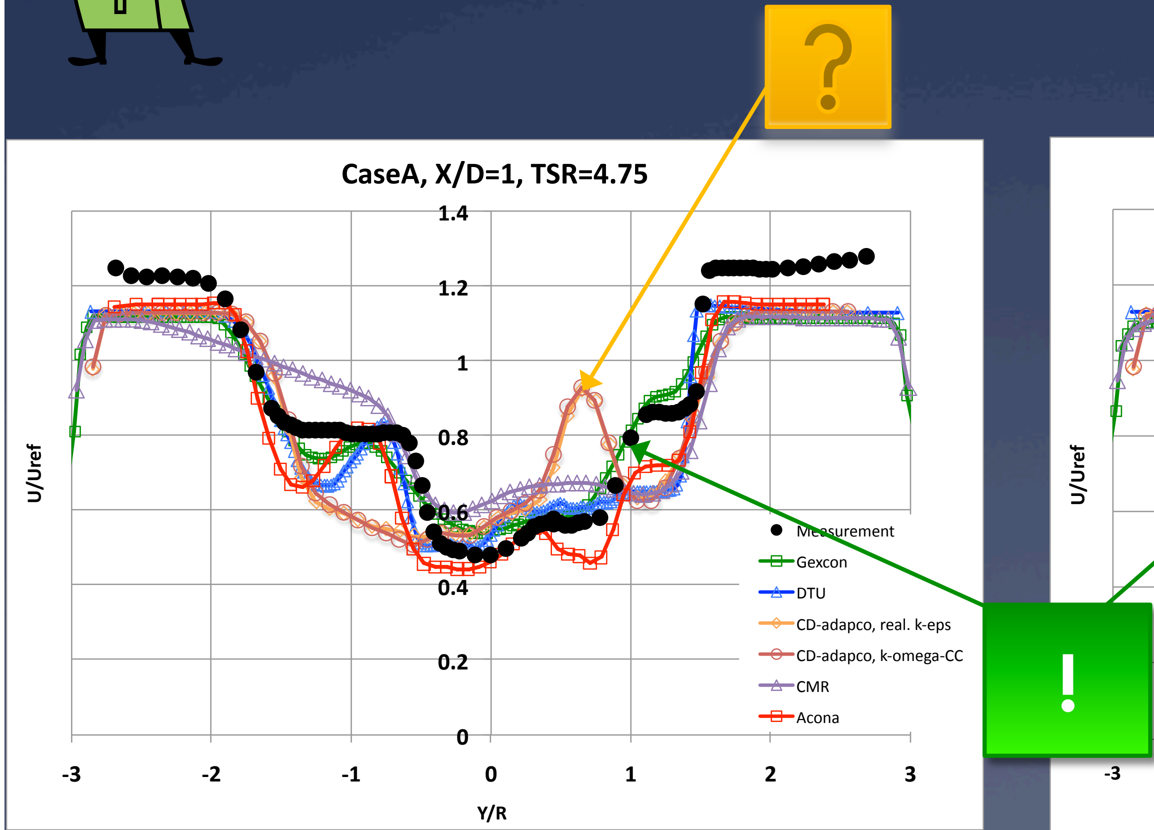


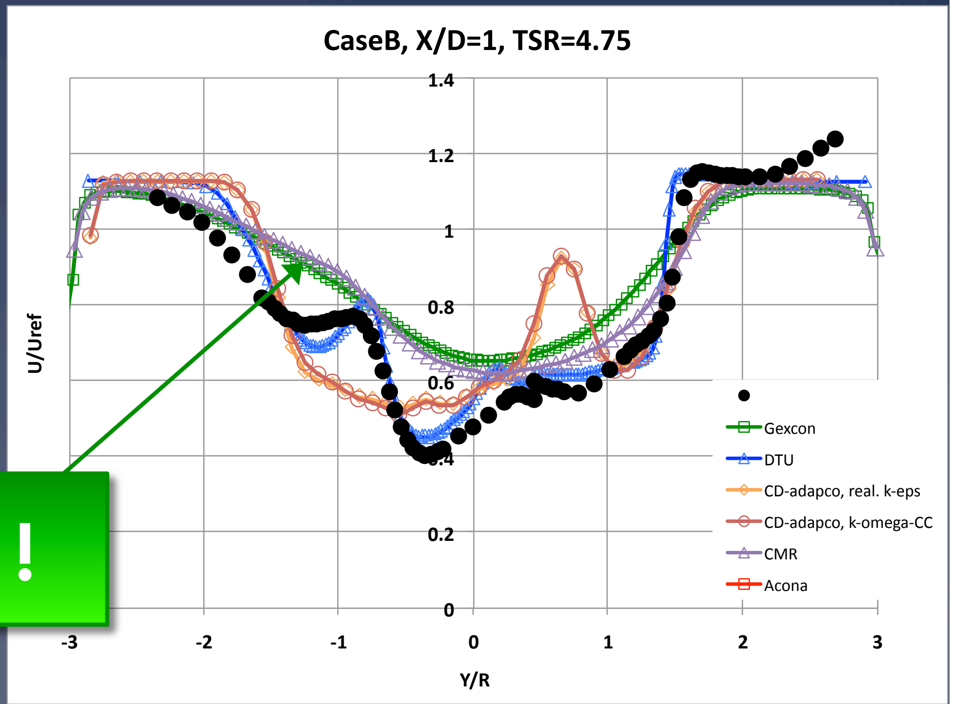
Comparing cases A & B at X/D=1

TSR_1=6.0 and TSR_2=4.75

(Both turbines at best performance)

Mean velocity





Case A, low turbulence

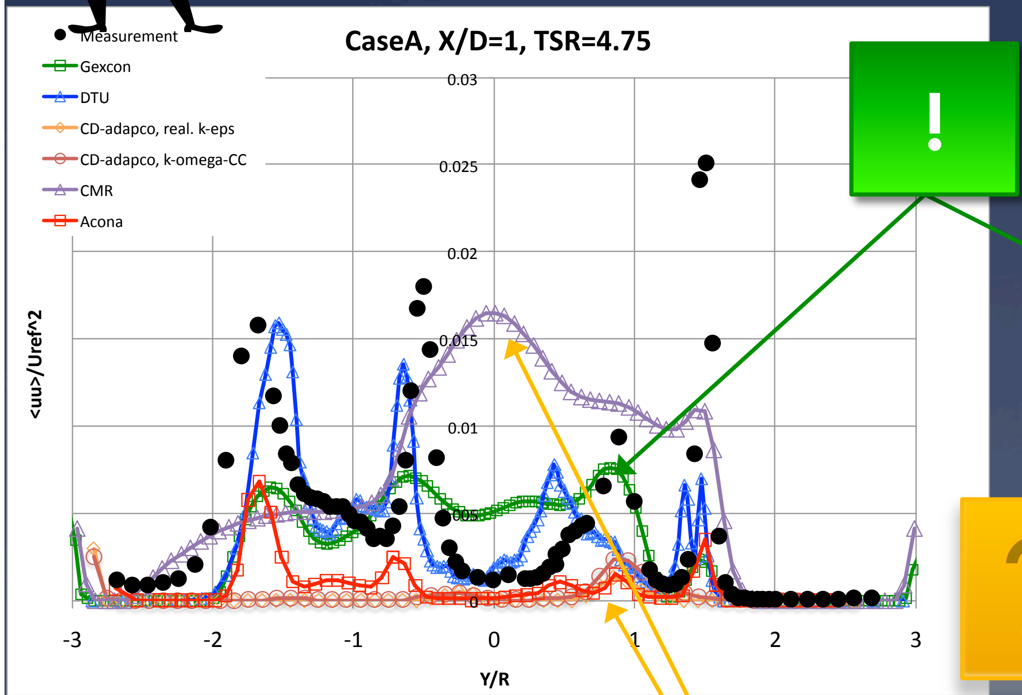
Case B, grid turbulence

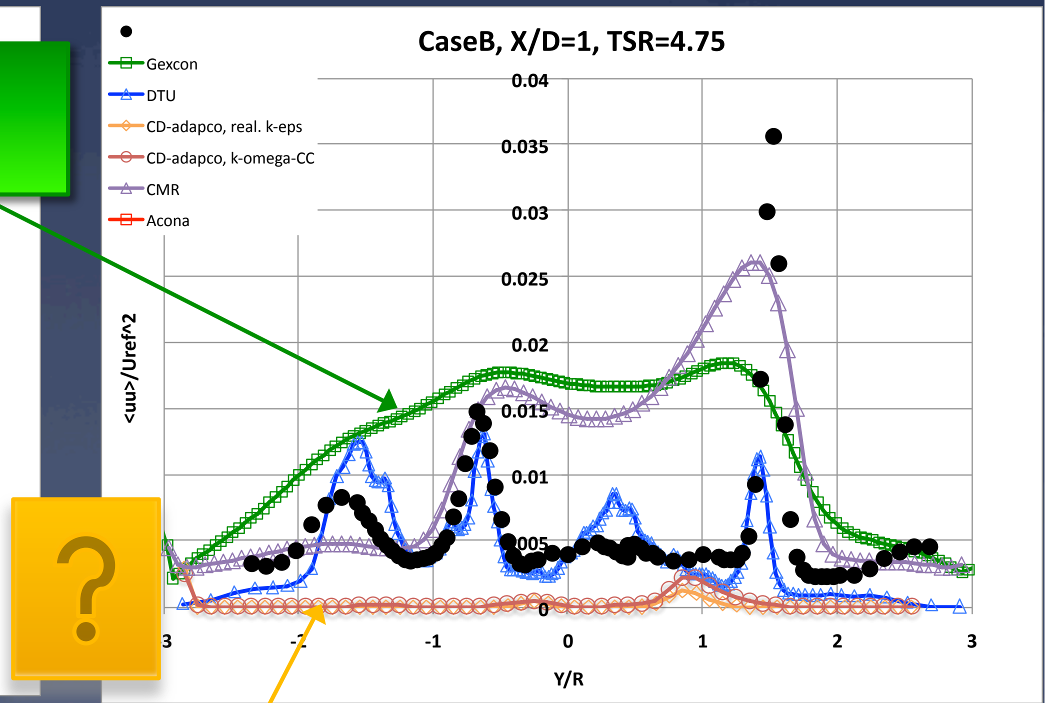
Comparing cases A & B at X/D=1

TSR_1=6.0 and TSR_2=4.75

(Both turbines at best performance)

Normal stress, $\langle u^2 \rangle$





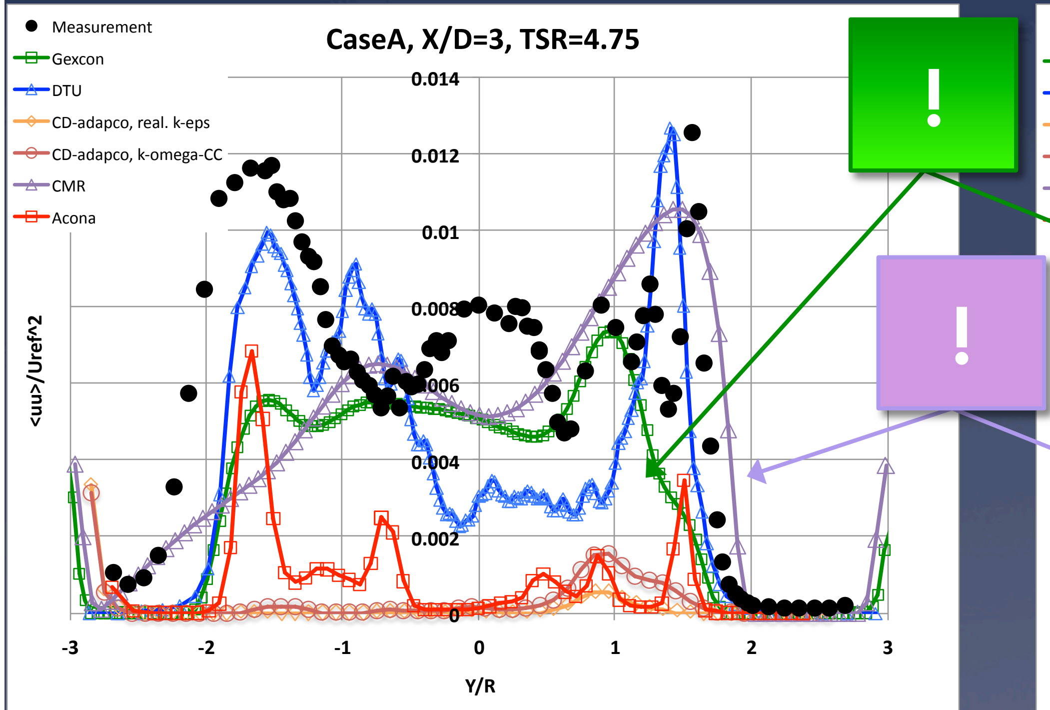
$\langle u^2 \rangle$ less than $\langle u_e^2 \rangle$

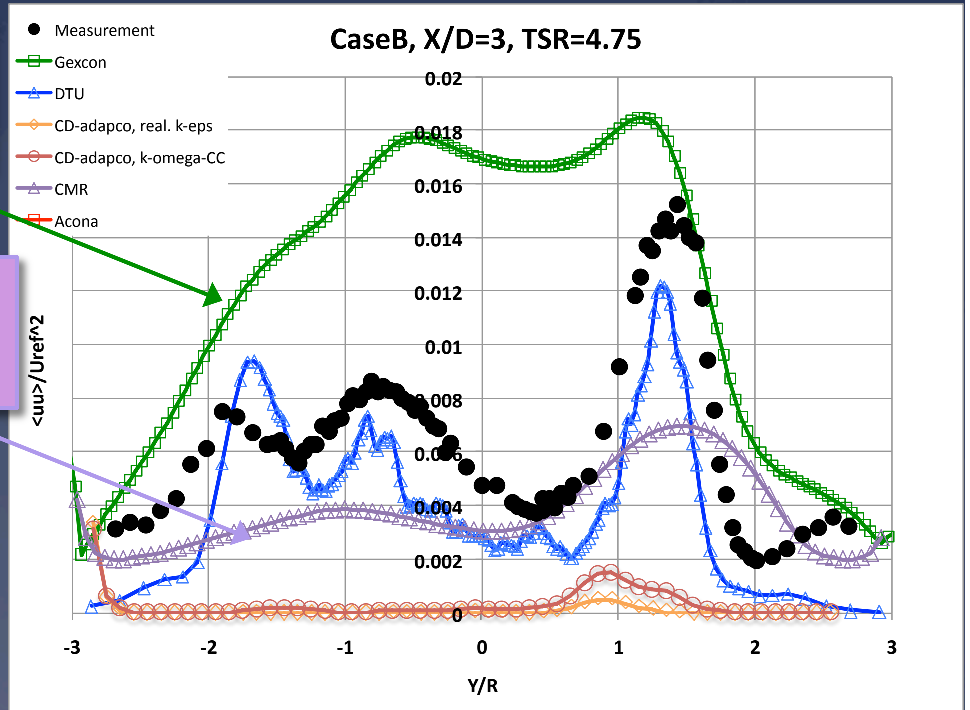
Case A, low turbulence

Case B, grid turbulence

Cases A & B at X/D=3
TSR_1=6.0 and TSR_2=4.75
(Both turbines at best performance)

Normal stress, <u^2>





Case A, low turbulence

Case B, grid turbulence

Tentative conclusions....

- The test case proved to be as challenging as we hoped for, with strong non-homogeneities in the mean velocity and multiple sharp peaks in the stress distributions.
- It is a bit surprising that there is still a significant scatter in predicting Cp and Ct of T1 at its design condition for the low turbulence case when the data has been out for 2 years.
- Some of the methods reproduced very few of the details that characterized the interactions between the two wakes.
- Some predictions showed strong sensitivities to the background turbulence while others were completely insensitive to this.
- The only Large Eddy Simulation this year proved to be very capable of reproducing all changes in the flow. Is this because LES is superior or because DTU did a good job? Another LES would have been welcome!

Thank you for your attention.

Questions?