Wind turbine noise measurements in controlled conditions

by Koen Boorsma (ECN)

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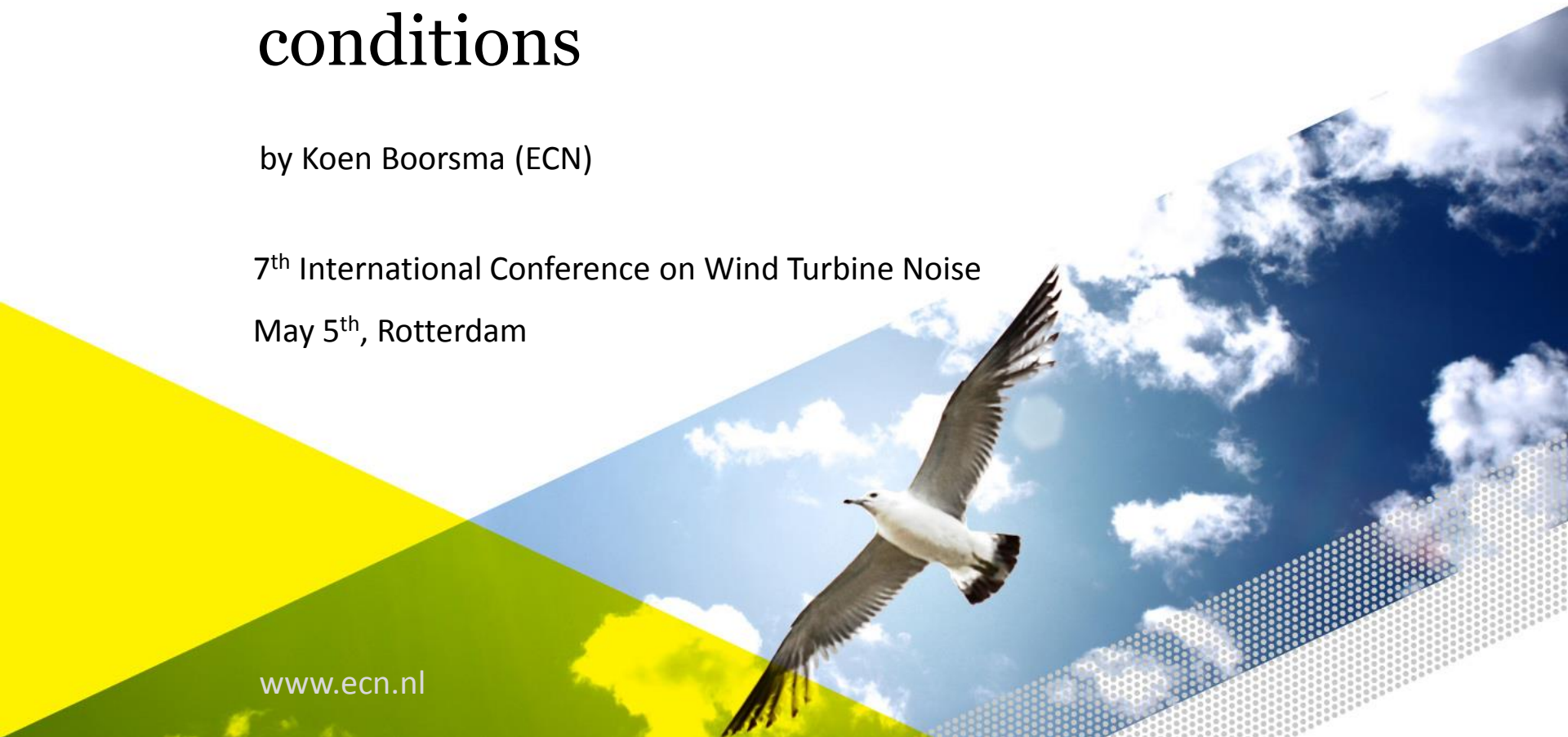


Motivation

- Noise is often not a primary consideration in detailed blade/turbine design

- Main priority is with yield and loads

- Large uncertainty in noise prediction complicates evaluating design changes

- There is a need for high quality validation measurements

- Field measurements suffer from uncertainty in inflow (spatial/temporal)

- Wind tunnel measurements suffer from scaling issues

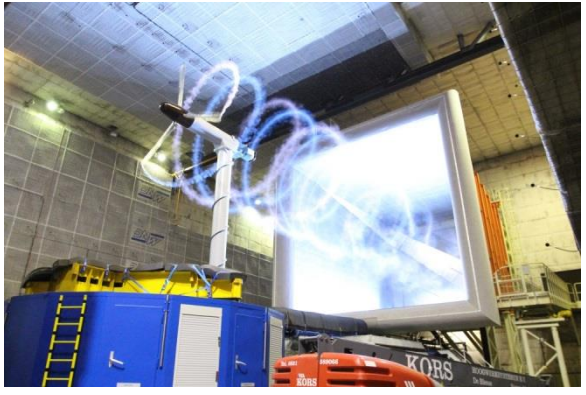
- Underlying aerodynamics dictating aero-acoustic noise needs to be known

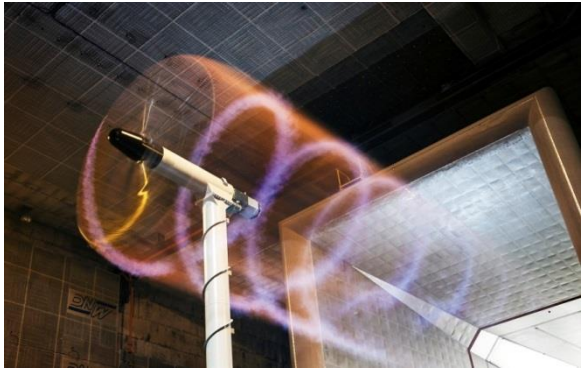
- An experiment in Europe largest wind tunnel has been executed

- New Mexico experiment at DNW-LLF in July 2014

Contents

- Test set-up
  - Model, tunnel, instrumentation and data acquisition
  - Test matrix
- Experimental results
  - Data reduction
  - Operational conditions
  - Special configurations
- Comparison to predictions
  - BPM modeling
- Conclusions and recommendations





New Mexico: Test set-up

- DNW-LLF open jet tunnel
  - 9.5 x 9.5 m^2 nozzle, closed loop
- Model
  - ø4.5m, 3 bladed, variable rpm and pitch angle
- Model instrumentation
  - Unsteady blade pressure sensors at 5 radial stations
  - Blade root strain gauges
  - Generator torque
- Flow field measurements
  - PIV @ 9 o'clock horizontal plane
- Six component balance at tower foot
- Acoustic measurements
  - Far field mics and microphone array

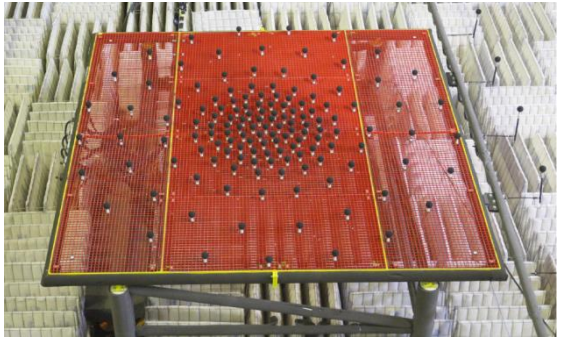
Acoustic set-up

- Acoustic lining / foam covering walls / hard objects
- Microphone phased array

-4x4m, 140 mics in circular arrangement, wind balls

-Sampled at 51.2 kHz between 15-60s per data point

-Out of jet flow but off-axis position due to external balance



- Far field microphones

-48 mics in 3 horizontal rows on side wall, wind balls

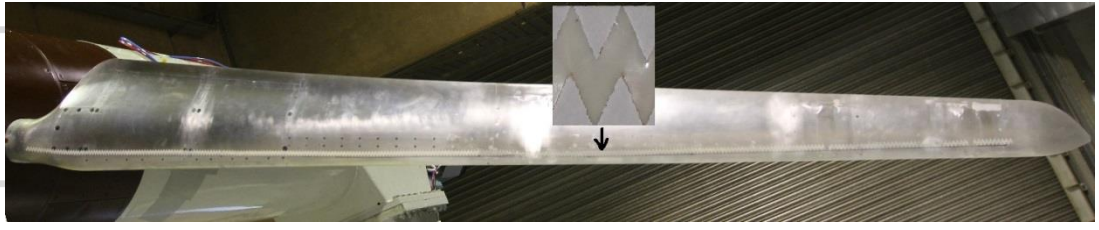
-Covering 40°-140° directivity (sideways is 90°)

-Same data acquisition parameters as array

- Synchronization with 5kHz pressure sensors

Configurations

Legend number	Configuration
0	Roughness on full blade
1	Guerney flaps long
2	Guerney flaps short
3	Outboard blade clean
4	Spoilers
5	Serrations
6	Pitch misalignment B2 (-20°)
7	Oil flow: sensors taped off
99	Blade off



Data reduction

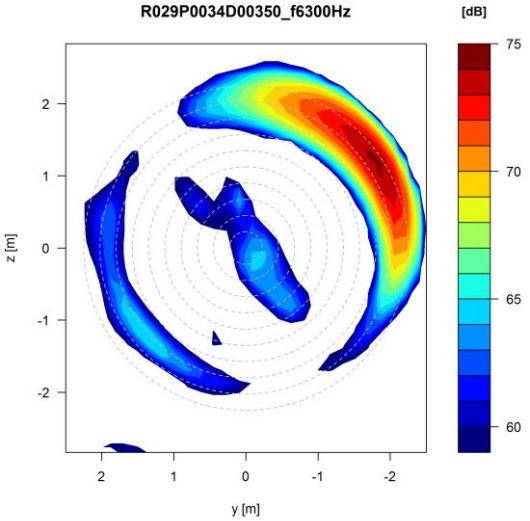
- Microphone phased array

-4096 block size -> df=12.5 Hz (500Hz high pass filter)

-CLEAN-SC beamforming algorithm with scanplanes to separate

a) rotor noise (x=0m, 2.8m>r>1.5m)

b) motor/gearbox noise (x=2.5m, r<1.4m)

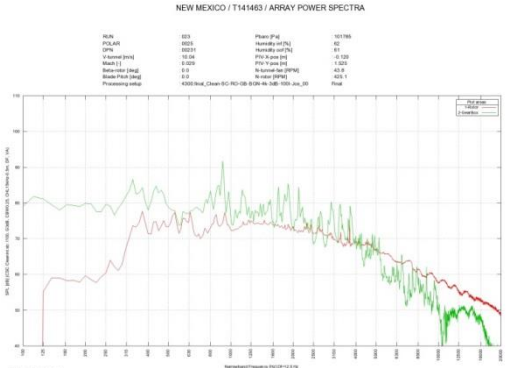


-Corrections for convective amplification, shear layer diffraction (open jet), distance correction -> PWL for each frequency

-Uncertainty in absolute level from integrated scanplanes quoted ±3 dB, <±1.5 dB for relative comparisons

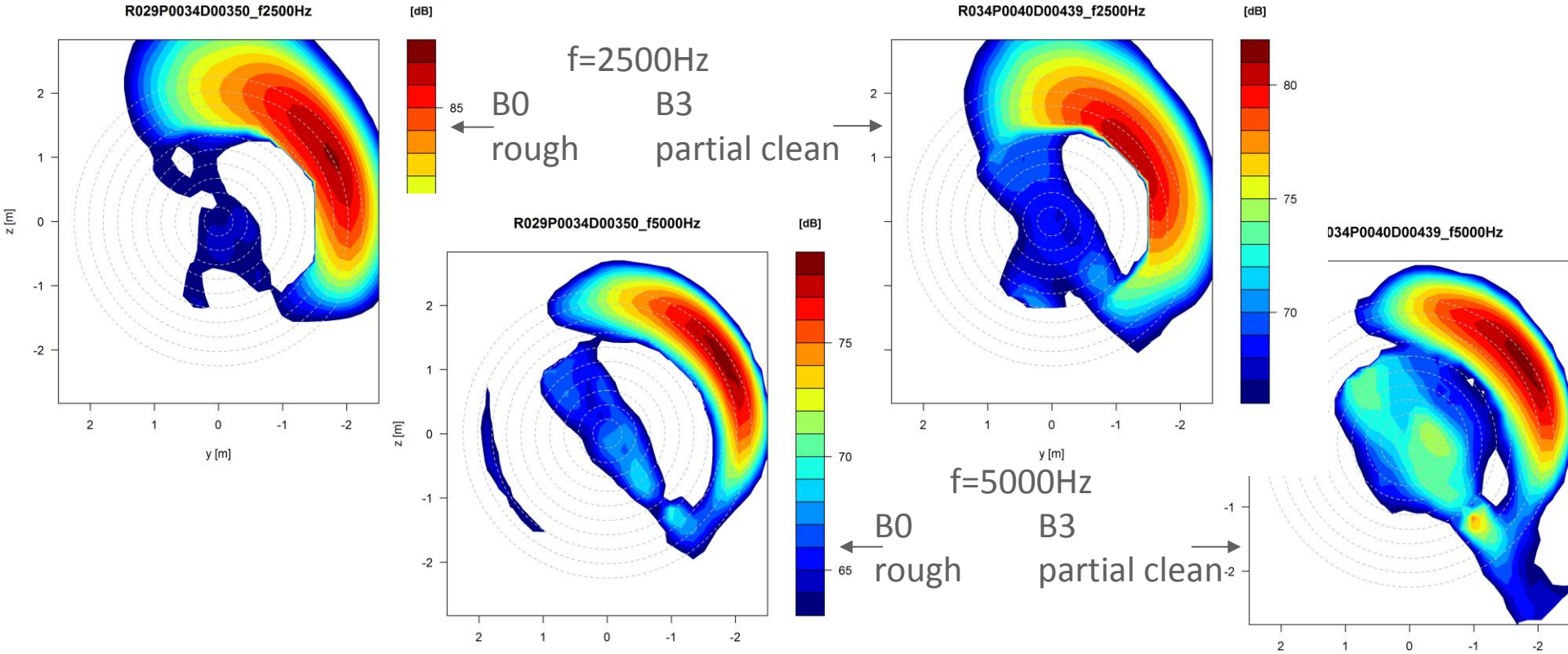
- Far field microphones

-Motor/generator noise dominant by far



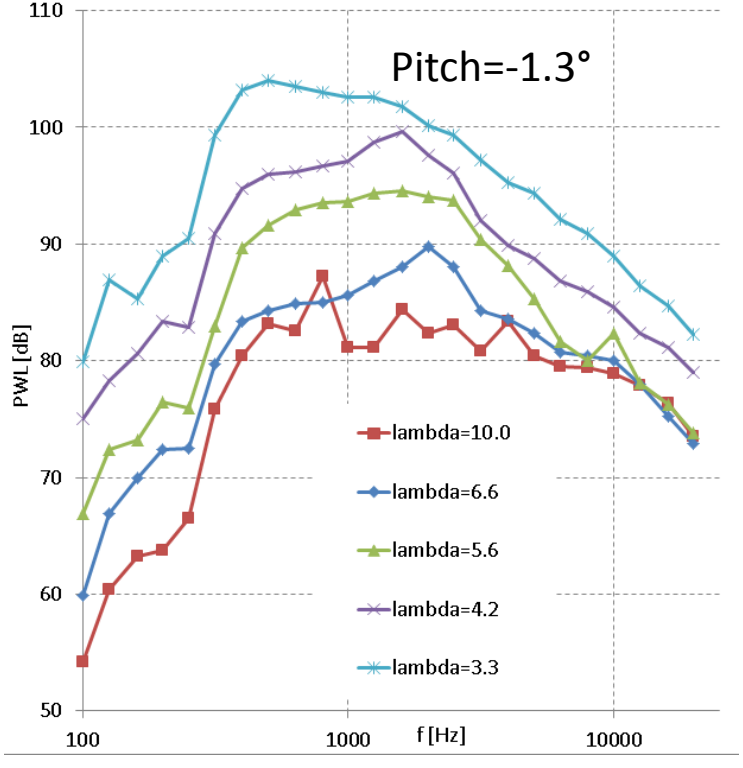
Beamforming plots

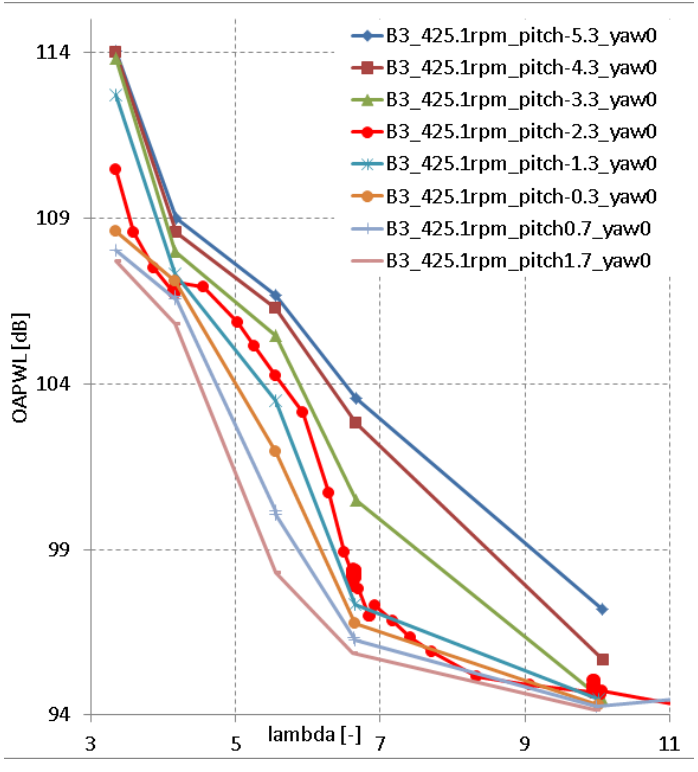
- λ=6.7, pitch=-2.3°, 425 rpm



Spectra and OAPWL

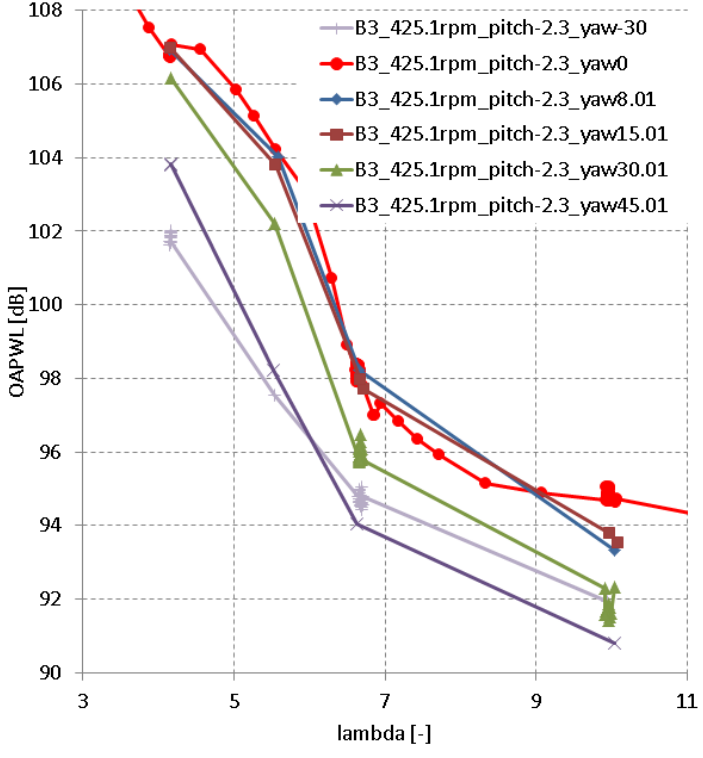
- Partially clean, 425 rpm

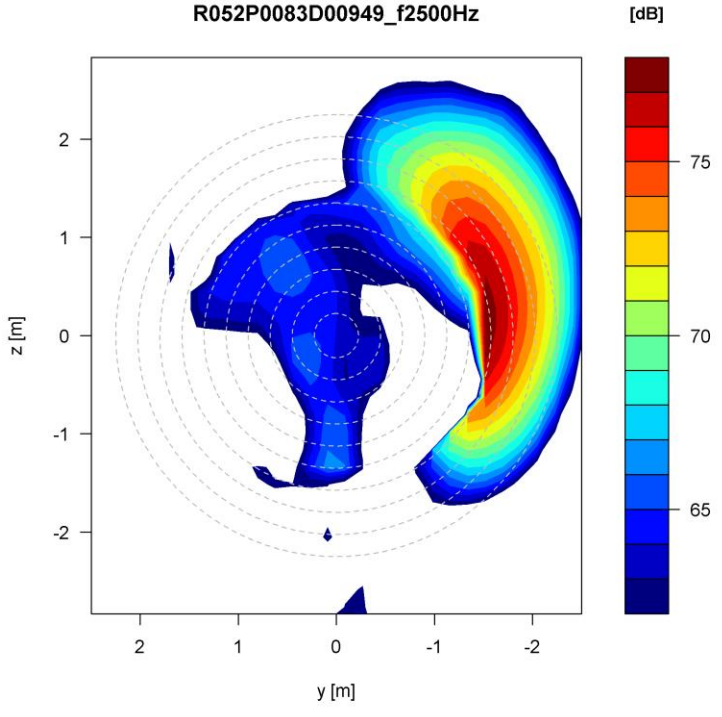




Influence of yaw

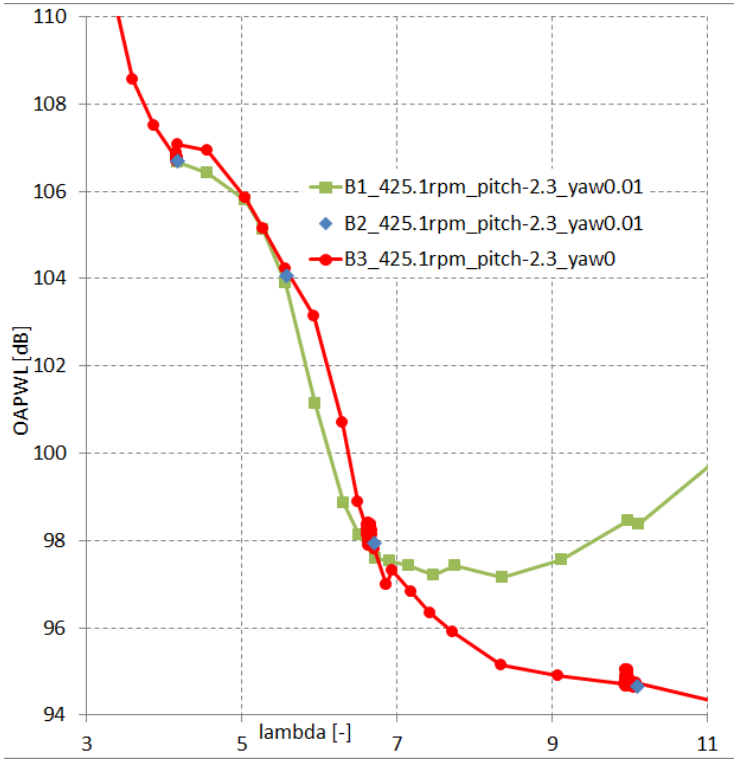
- Partially clean, 425 rpm

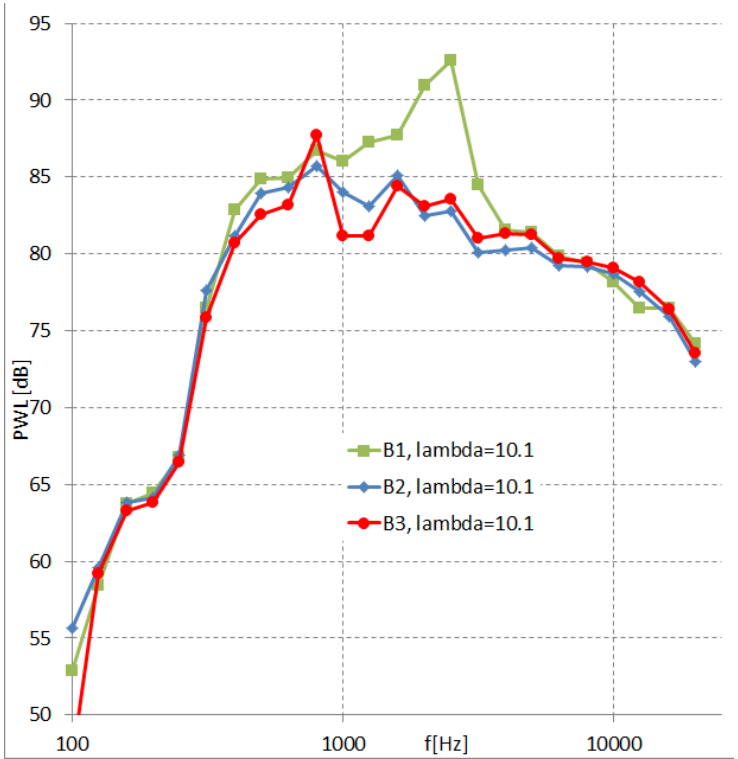




Effect of Guerney flaps

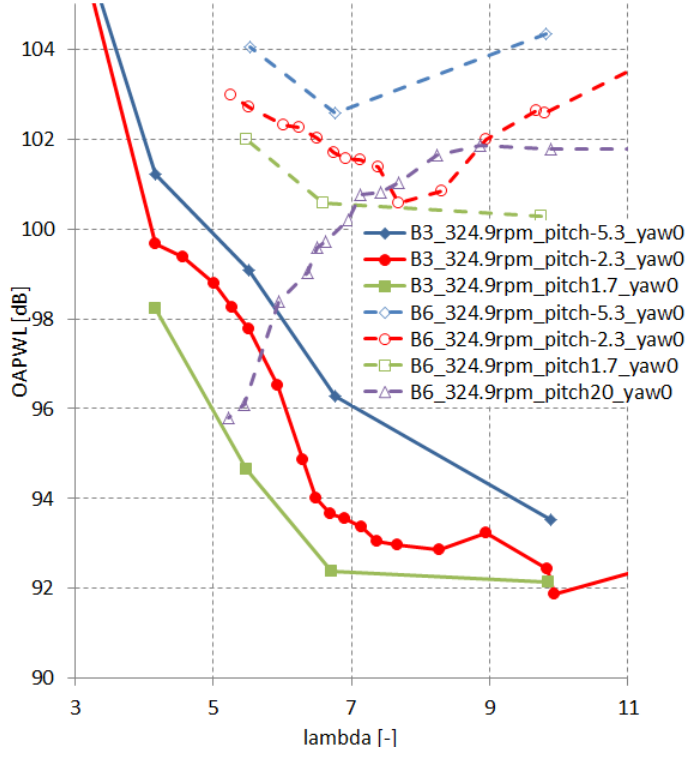
- G-flaps r<0.6R (B1), G-flaps r<0.46R (B2), Partially clean (B3), pitch=-2.3°, 425 rpm

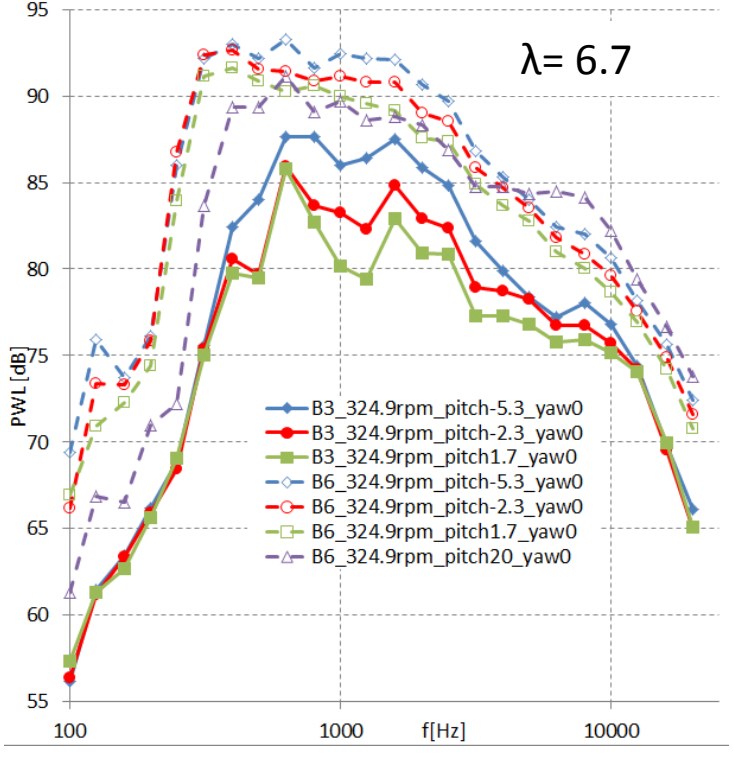




Effect of pitch offset blade 2 (-20°)

- Pitch offset (B6), Partially clean (B3), 325 rpm





Comparison against predictions

- How well can we simulate noise levels and the variation thereof?
- The BPM[1] model is a relatively simple sectional approach that can be used to calculate wind turbine noise

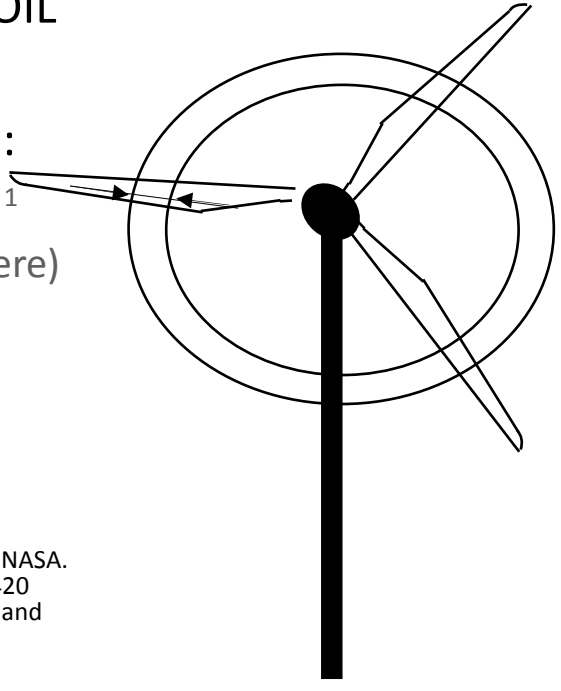
-Previous comparisons to field data have been satisfactory

- It requires input of boundary layer displacement thicknesses δ^*
- As such it is dependent on the local airfoil aerodynamics

[1] T.F. Brooks, D.S. Pope and M.A. Marcolini (1989): "Airfoil self noise and prediction". Reference publication 1218, NASA

Modeling approach

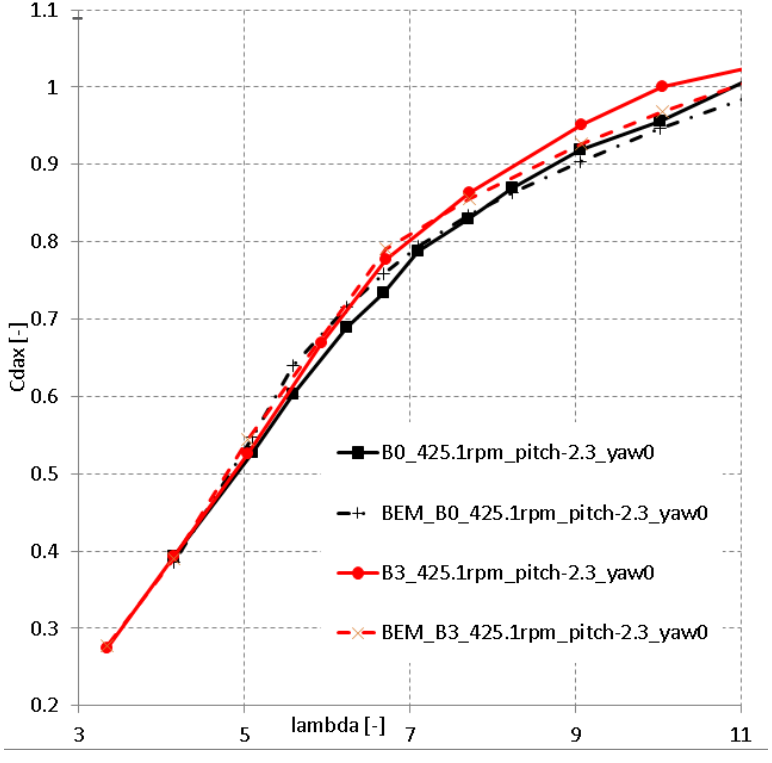
- For all airfoils: Generate database of $\delta^* = f(Re,\alpha)$ using RFOIL
- Calculate quasi-steady aerodynamic state using BEM
- For every blade element two noise sources are calculated:
  1. Trailing edge noise using the model of Brooks, Pope and Marcolini[1]
  2. Inflow noise using the model of Amiet[2] and Lowson[3] (neglected here)
- Separately calculate tip noise for each blade[1]
- Sum noise sources ('acoustically') over elements yielding total blade and turbine sound power level.

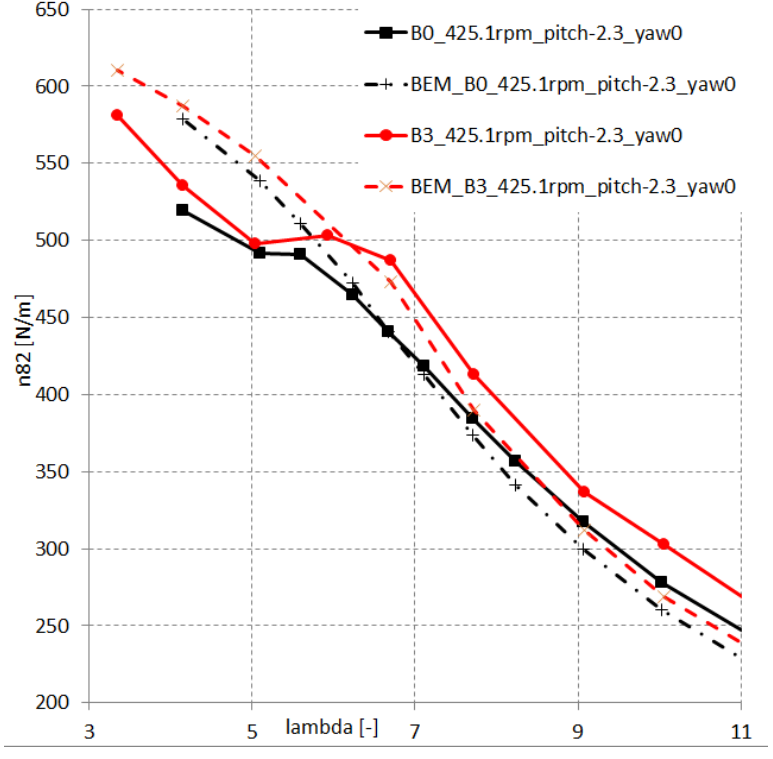


[1] T.F. Brooks, D.S. Pope and M.A. Marcolini (1989): "Airfoil self noise and prediction". Reference publication 1218, NASA.
[2] R.K Amiet (1975): "Acoustic radiation from an airfoil in a turbulent stream". Journal Sound Vib., 41(4):page 407-420
[3] M.V. Lowson (1993): "Assessment and prediction of wind turbine noise ". ETSU W/13/00248/REP, Dept of Trade and Industry.

Loads validation

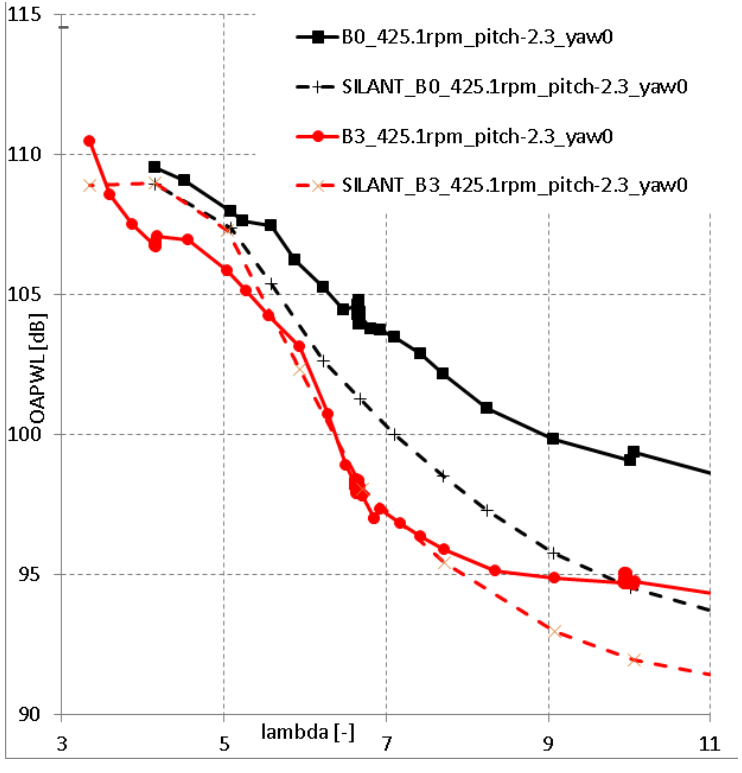
- Partially clean (B3) and rough (B0), 425 rpm

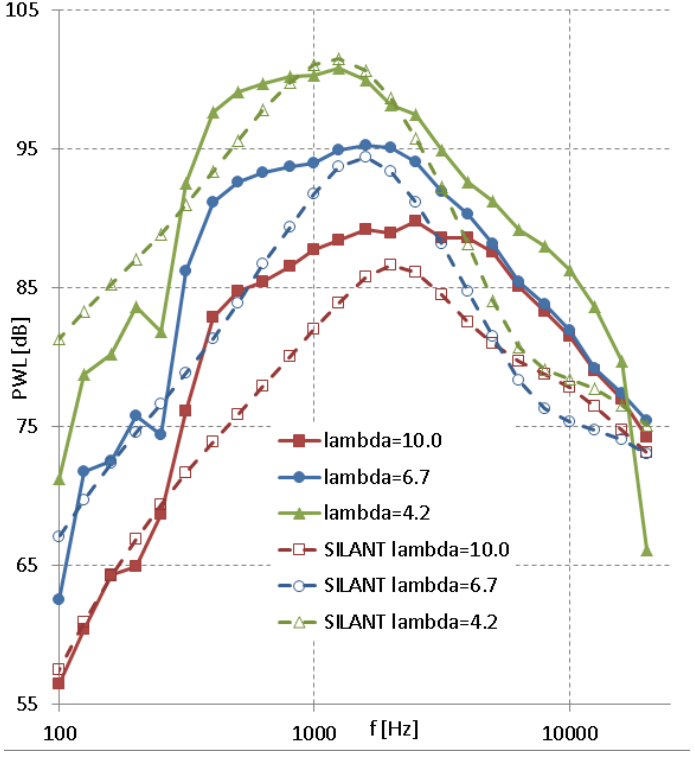




SILANT – validation

- Partially clean (B3) and rough (B0), 425 rpm





Concluding

- Large database featuring variety of operational conditions and configs

-Mic array data reduction successfully separated rotor noise

-Integration of beamforming plots yields spectra and overall levels

-Far field mics overshadowed by motor/generator noise (standstill tests?)

- Comparison to predictions

-First comparison to BPM model is very encouraging!

-Database is open within IEA Wind Task 29 for more comparison actions (CFD/CAA) and analysis

- Acknowledgement

-Hermann Holthusen (DNW) for raw data reduction

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-Steering committee (TU-Delft, Technion, DTU), IEA Wind (Task 29)

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