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Acoustic Array Measurements on a Full Scale Wind Turbine

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Content

Introduction

Wind turbine noise: obstacle for wind energy usage

- Dominant noise source: aerodynamic noise from blades
- Need of quiet wind turbine blades (European project SIROCCO)

Goals of the paper:

- 3-6 dB noise reduction from state of the art (2003) without jeopardizing performance
- Assess the turbine noise and identify whether the aerodynamic noise is the dominant source (particularly trailing edge)

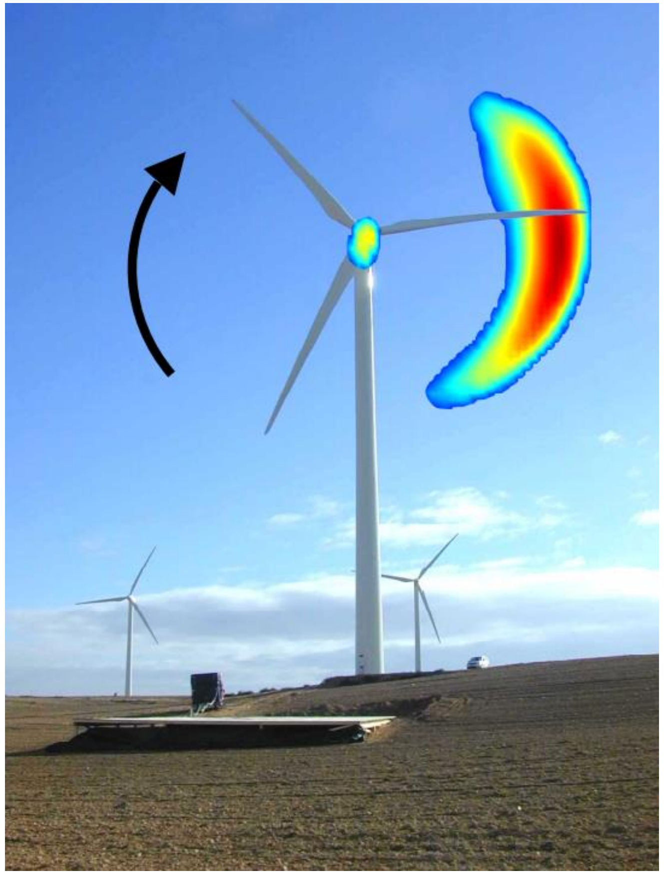

Figure 1: GAMESA G58 turbine with noise sources in the rotor plane projected on the picture.

Test setup

Three bladed GAMESA G58 turbine, different roughness treatment for each blade:

- Cleaned (a week before)
- Tripped (zigzag tape 0.4mm thick at 5%C)
- Untreated.

Acoustic array platform: 152 Panasonic WM-61 + 2 B&K (no wind screen and high density in the centre.)

Array shape: Elliptical – Pointed right side of rotor plane.

Windspeeds at 10 m of height : Hub windspeed * 0.760 [2]

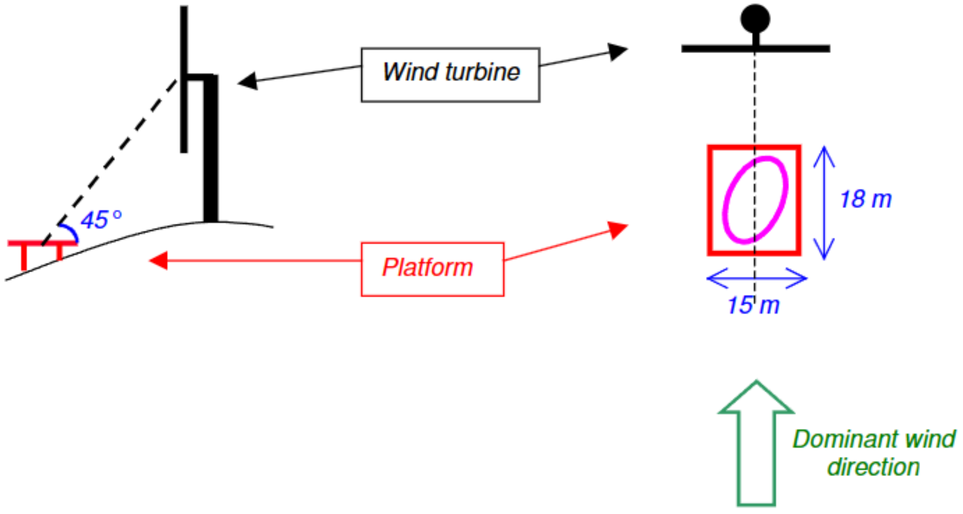

Figure 2: Side & top view of setup. Array platform and shape.

Data Acquisition

Before the measurements

- Sensitivity at 1 kHz determined for all array microphones
- Phase matching and frequency response of the microphones checked

Acoustic measurements

- Data from array microphones synchronously measured.
- Sample frequency of 51.2 kHz and 30 s of measured time.
- Hanning Window with a 2048 block size and overlap of 50%
- 500 Hz high-pass filter – dynamic range to low Pres. Amplitudes at high Freq.
- Sound level corrected for the filter response

Other turbine measurements: (Sample rate of 3 Hz)

- Wind speed, power production, turbine orientation, RPM, blade pitch angle, and temperature
- Turbine data were synchronized with the acoustic measurements

Test Program

110 measurements performed

- Regulation requirement: at least 30 valid measurements
- 35 measurements with the most stable conditions were chosen

Criteria for selection:

- Variation of wind speed within 15% (and within 1.5 m/s) of average
- Misalignment angle smaller than 12°, variation within 2° of average
- Variation in rotor RPM within 8% of average
- Variation in blade pitch angle within 3° of average
- Overloads in acoustic data (e.g., due to wind gusts) less than 1%

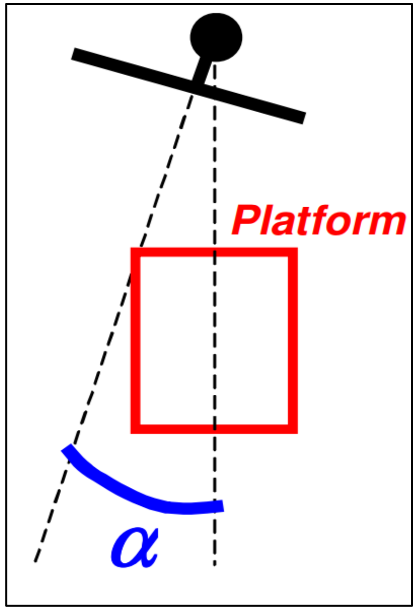

Figure 3: Misalignment angle.

WIND SPEED AT 10 (m/s)	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.5	9.5-10.5
# Measurements	6	6	12	5	6

Array Processing: Noise Source in the Rotor plane

- Hub noise and blade noise can be separated
- Possible to locate where the blade noise is produced
- Integrated effect of all the 3 blades

Steps used:

- Compute averaged cross-power matrix (all microphones in the array)
- Discard the main diagonal of the matrix (improve resolution and suppress background noise)
- Application of a frequency-dependent spatial window to microphone signals

Additional considerations:

- Scan plane placed in the wind turbine rotor plane: 1 m resolution
- Angle between rotor axis and horizontal plane
- Sound convection in the atmospheric boundary layer
- The narrowband acoustic source plots were summed to 1/3-octave bands, and the scan levels were normalized to a distance of 0.282 m (1/√(4π)).

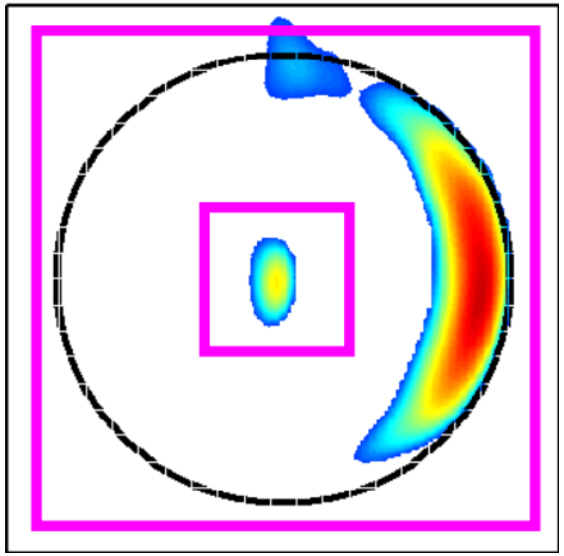

Figure 4: Rotor plane.

Array Processing: Noise Source on the Rotating Blades

- Three rotating scan planes: one per each of the three individual blades
- Allows comparison between noise generated with different blade surface roughness

Steps used:

- Determine the start position of the scan planes (0.5 m of resolution in both directions)
- Narrowband acoustic source dealt as in the previous method
- Measurements scanned only during the downward movement of the blades (0° to 180°)
- Only the first two rotations after the start of each acoustic measurement were processed (one at a time)
- Noise from the blades quantified using an integration method for moving sound sources

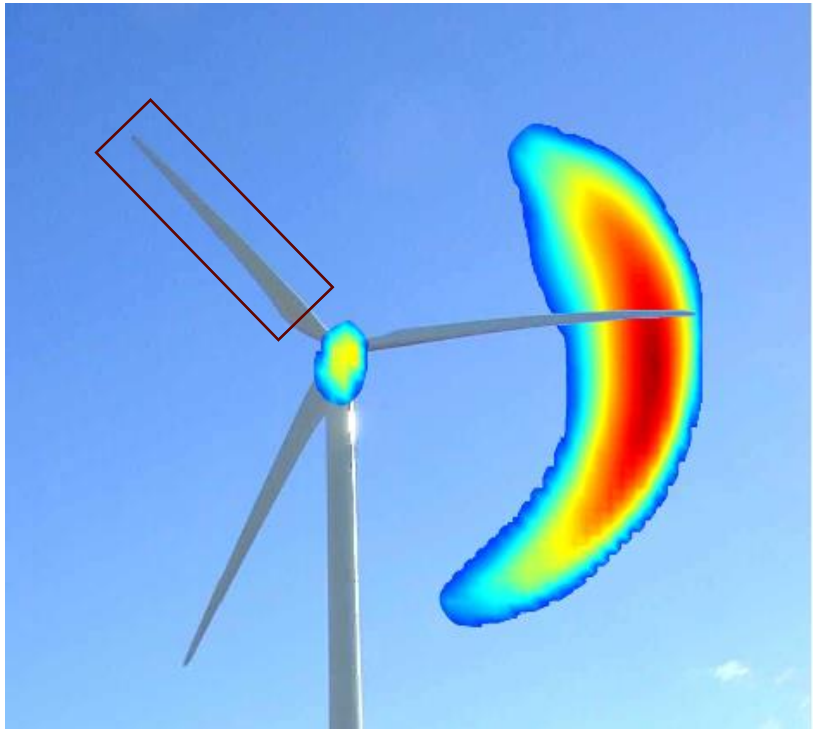

Figure 4: rotating blade plan.

Results - Noise Source in the Rotor plane

1. All downward radiated noise is produced during the downward movement of the blade.
2. Blade noise > Rotor hub noise
3. Blade noise is produced by the outer part of the blades.
4. The source moves outwards for increasing frequency.
5. Combination of convective amplification and directivity of TE noise?

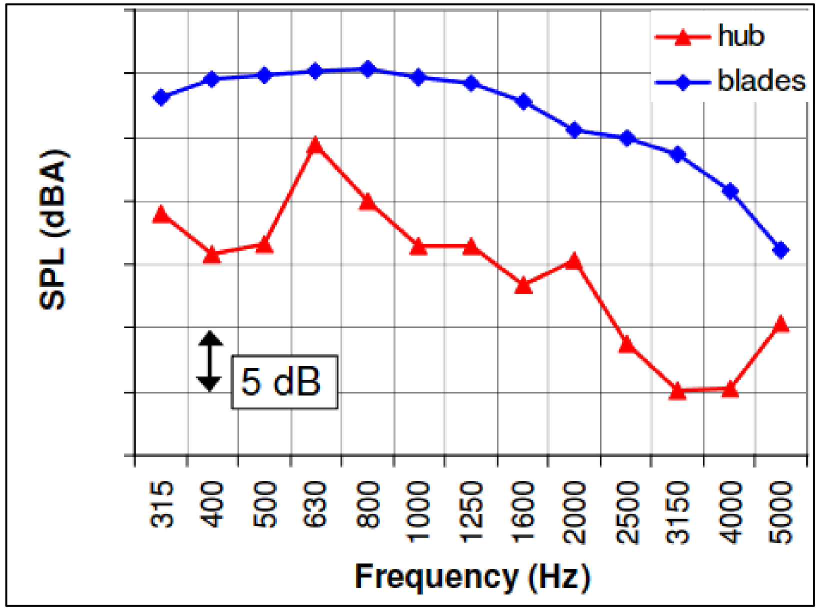

Figure 6: Average spectra of hub and blade noise.

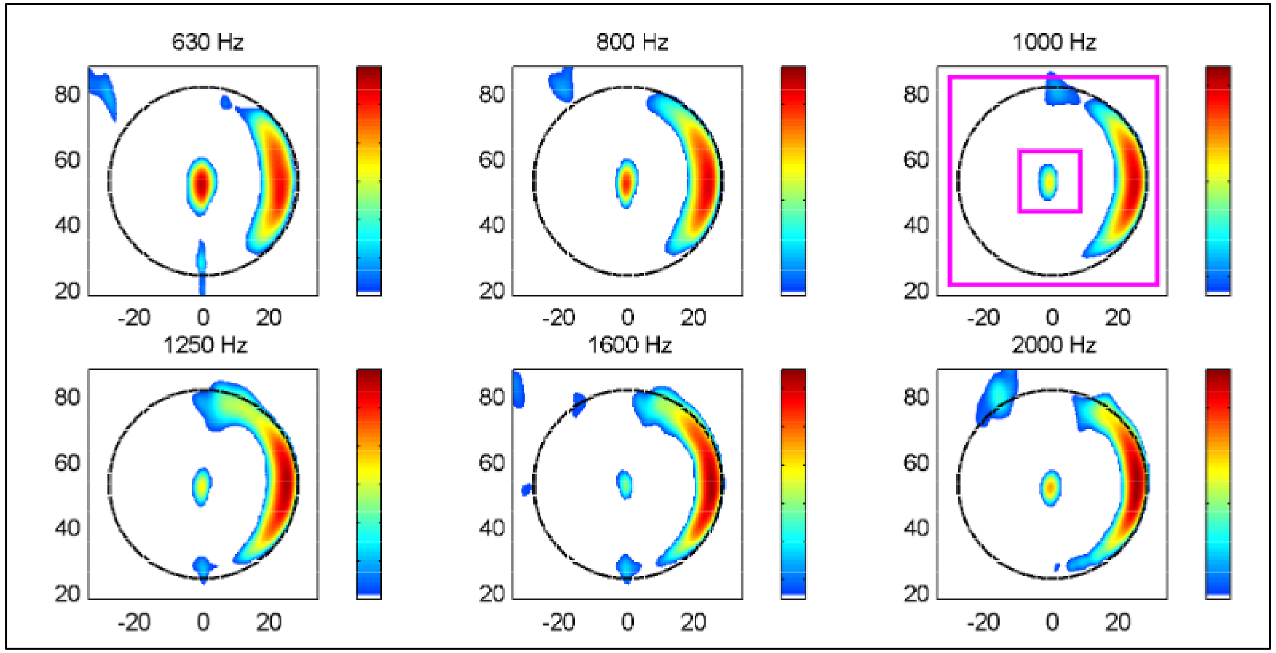

Figure 7: Noise source location in rotor plane. The range of colour scale is 12 dB. Trajectory of blade tips in black.

Results - Noise Source in the Rotor plane

Misalignment angle effects:

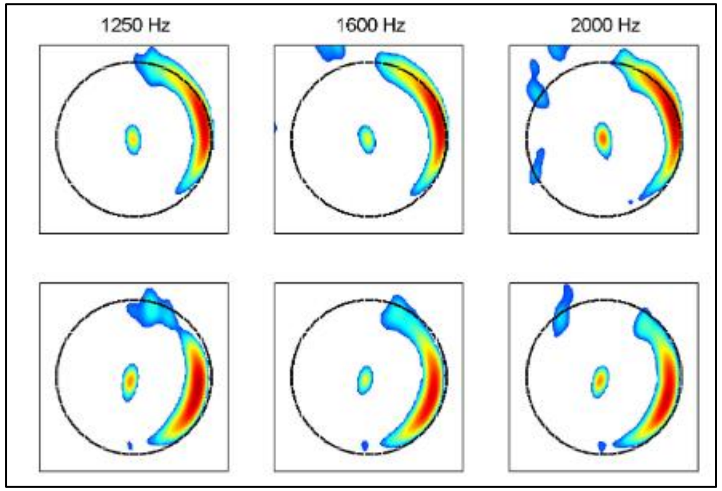

Figure 8: Average spectra of hub and blade noise. α = $+11^{\circ}$ (top) and -12° (bottom)

1. The source region shifts upwards or downwards depending on the rotor plane alignment with the array platform.
2. Due to change of the blade velocity in direction of the array.

Correction for the speed effects:

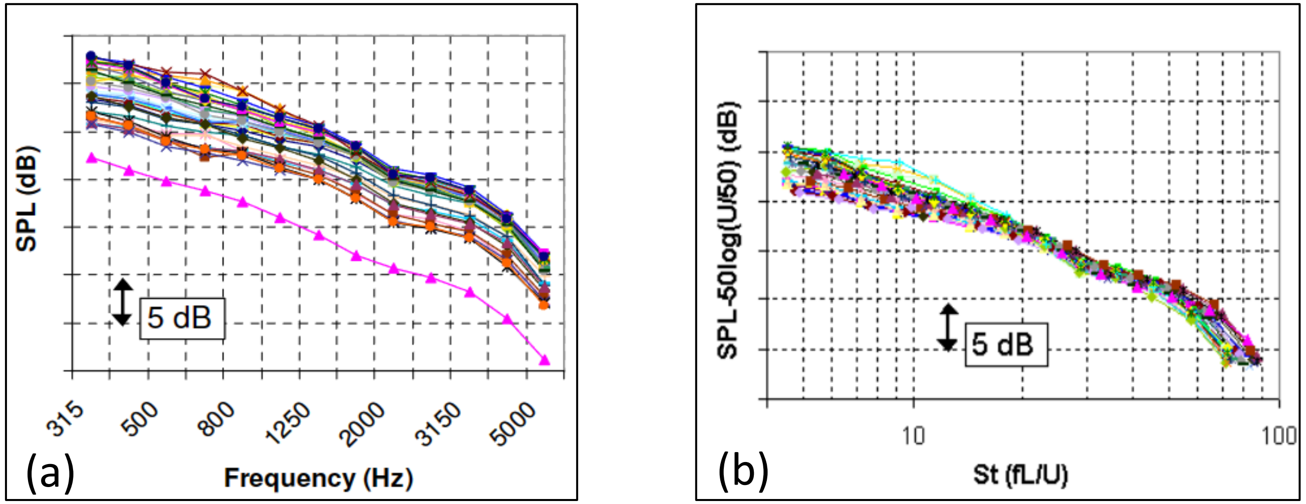

Figure 9: (a) Measured and (b) normalised blade noise spectra as function of St number.

$$SPL_{norm} = SPL - 10 * x * \log\left(U_{blade}/U_{ref}\right)\ ;\ U_{ref} = 50\ m/s$$

Variable "x" : Dependence of blade noise on flow speed. Acoustic energy (p^2) is proportional to $\sim U^x$.

x = 5 gives best data collapse, indicative of trailing edge noise and around 6 for inflow turbulence noise. [ref:3,4]

Results - Noise Source on the Rotating Blades

1. The outer part of blade produce most of the noise.
2. The source moves outwards with increasing in frequency.
3. At f = 630 Hz, the hub is relatively noisier.
4. In comparison, the tripped blade produces higher noise both at low and higher frequencies. – Trailing edge noise.
5. The untreated blade is slightly noisier than clean blade at higher frequencies.

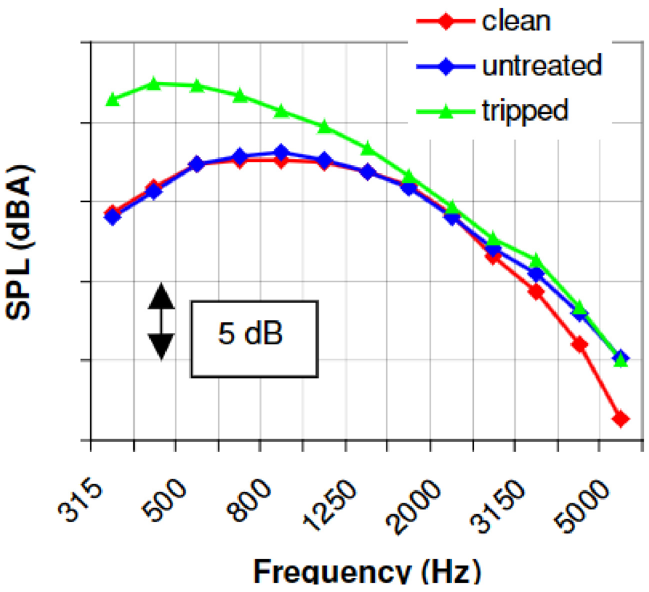

Figure 11: Average noise spectra for three blades.

- The tripped spectrum peaks at 400 Hz and other two peaks at 800 Hz.
- The lower peak frequency for the tripped blade may be due to an increased BL thickness.

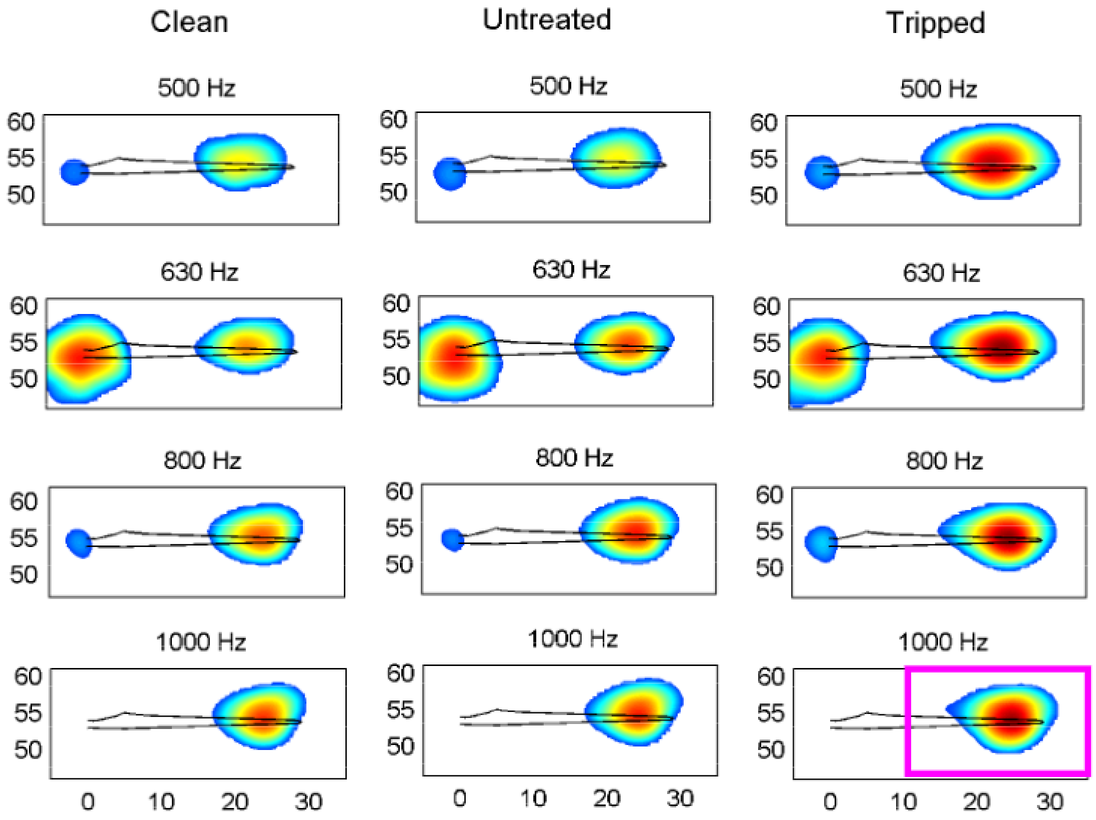

Figure 10: Noise sources on individual blades. The range of colour scale is 12 dB. The Pink line (1 kHz) indicates the integration contour.

The spectra in Fig 9: acoustic data for downward part of one rotation.
Difference in average blade noise levels b/w 2 rotations < 0.3 dB for all freqs.

Results - Noise Source on the Rotating Blades

Correction for the speed effects:

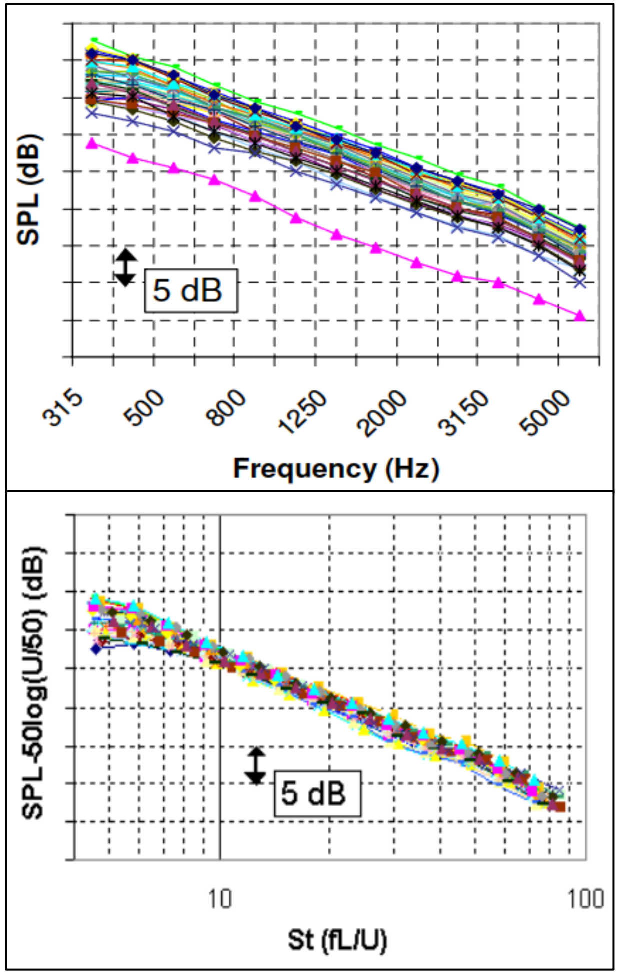

Figure 12: (a) Measured and (b) normalised noise spectra for tripped blade.

Flow state on untreated blade compared to cleaned blade:

- ➢ Aerodynamically clean? – no transition close to LE.
- ➢ Or both blades dirty? – Transition close to LE.

Flow state on tripped blade:

- ➢ Higher levels at low frequency – over tripping?
- ➢ No. Compared with experiments with several types of tripping for trailing edge noise levels.
- ➢ Produced by the thick suction side BL.

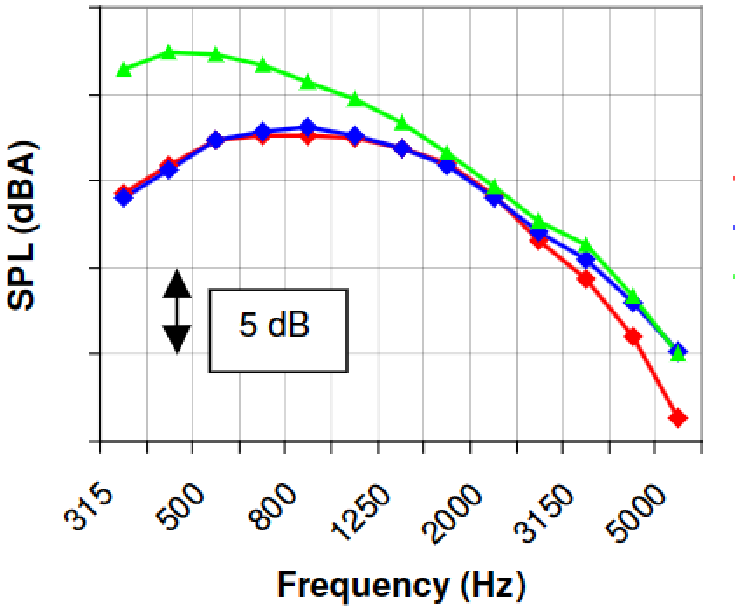

Figure 13: Average noise spectra for three blades.

- ➢ Small difference at high frequencies could be because of contamination on the pressure side.

Conclusions

- Three blades with different roughness were compared: untreated, cleaned, and tripped
- Two array processing methods were used: rotor plane and individual blades

  - The Aerodynamic noise from the blades was proven to be the dominant source
  - Practically all the noise is produced during the downward movement of the blades
  - Blade noise produced by the outer part of the blade, but not the tip itself
  - Tripped blade is significantly noisier than the clean and untreated blades
  - Acoustic results shown that the untreated blade was aerodynamically clean
  - Two mechanisms could be responsible for the aerodynamic noise: inflow-turbulence noise and trailing edge noise. Results strongly indicate that the trailing edge noise is the responsible mechanism for this turbine.

References

[1] Oerlemans, Stefan & Méndez, Beatriz. (2005). Acoustic Array Measurements on a Full Scale Wind Turbine. 10.2514/6.2005-2963.

[2] IEC norm 61400-11, "Wind turbine generator systems – Acoustic noise measurement techniques" (2002).

[3] Oerlemans, S., and Migliore, P., "Aeroacoustic wind tunnel tests of wind turbine airfoils", AIAA paper 2004-3042 (2004).

[4] Brooks, T.F., Pope, D.S., and Marcolini, M.A., "Airfoil Self-Noise and Prediction", NASA Reference Publication 1218 (1989)

Thank You! Question?