Wind Turbine Noise Prediction

An overview of Exa’s PowerFLOW capabilities

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How do people think about wind turbine noise?
Impact for the wind turbine blade industry

- People living near turbines are protected by noise regulation limits
  - Noise generates limitations for onshore turbines
    - Many turbines have to run at reduced power due to the regulations
    - Some large wind farm project canceled due to noise

- 1 dB(A) of noise reduction could increase the annual energy production by 2-4%
  - Wind turbine noise becomes a key design parameter for manufactures!

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Oerlemans, 2012 & 2016
Wind turbine noise

Why simulations?

- Noise reduction add-ons designs
- Wind tunnel tests
- Field tests and certification

Performing measurements is too expensive for every new design

Exa PowerFLOW can help performing digital wind tunnel and field noise tests

Oerlemans, 2012 & 2016
Computational methodology

► Exa’s PowerFLOW: Based on the Lattice-Boltzmann Method
  ▶ Efficient, explicit, fundamentally transient compressible flow and acoustic solver
  ▶ Run detailed truly rotating geometries (LRF) geometries without any simplification
  ▶ Direct simulation or using VLES turbulence closure model

► Exa’s PowerACOUSTICS: Post-processing capabilities for further analysis
  ▶ Calculate far-field noise with time domain FW-H solver based on Formulation 1A
  ▶ Noise metrics and digital certification using wind tunnel or flyover configurations (SPL, OASPL, PWL, EPNL, ICE, ..)

Boltzmann description
PowerFLOW transient source terms
XP
PF-FFN
Aeroelastic analysis coupled with ABAQUS
Far-field noise levels
Aerospace applications

When accuracy hits the fan...
CAA simulations with Exa's PowerFLOW.
Full wind turbine simulation

AIAA 2012-2290 paper considering NREL turbine calculation

- Simulation effort: a full day for 3 revolutions

![Computational Domain Diagram]

**Perot et al, 2012**
Full wind turbine simulation
Full wind turbine simulation

Force and torque prediction

- Good agreement with experiments
- Different flow regimes captured w/o changing solver physics
  - A: Attached
  - B: Transitional
  - C: Fully stalled

Torque vs. inflow speed

Normal force coefficient

Perot et al, 2012
Full wind turbine simulation

Aeroacoustics

- Near field noise result (50-500 Hz)
- Overall SPL directivity for certification

Perot et al, 2012
Oerlemans, 2007
Wind turbine blade section noise

Model scale wind tunnel studies of trailing edge noise

- With PowerFLOW, using smaller (wind tunnel) models we can
  - Deepening our understanding of the actual noise source mechanisms
  - Design studies with noise suppression add-ons (serrated trailing edges, VG’s, porous materials,..)
- Simulation effort: two days for 15 flow passes (@ Re=1.5 million)

Perot et al, 2012
van der Velden et al, 2015 & 2016 & 2017
Wind turbine blade section noise
Wind turbine blade section noise

Optimization of trailing edge noise reduction add-ons

*Using FIND in PowerACOUSTICS we can identificate noise sources and act adequately to reduce the dominant sources*

Conventional serrations

Iron-shaped serrations

Hybrid-combed serrations

Avallone et al, 2017
van der Velden & Oerlemans, 2017
Wind turbine blade section noise

Validation and verification with Viriginia Tech wind tunnel data

- Successful validation with various customers. Trends like:
  - Serration geometry changes (thickness, aspect ratio, length)
  - Serration flap angle changes
  - New designs

- AIAA 2017-4172 paper

van der Velden & Oerlemans, 2017
Wind turbine blade section noise

Fully automated process on Exa Cloud; from pre- till post-processing

- Direct input; only geometry information and characteristic quantities needed
- Direct output; over +50 different images/tables
  - Pressure and friction distribution
  - Boundary layer development, profiles, coherence and edge phase speed
  - Near-field noise information using dilatation fields, surface dB maps and wavelet decomposition
  - Far-field noise information using beamforming array comparison and full 360 degrees directivity

On the Exa Cloud in one 1-2 days from input to fully generated output
References (incomplete list)