



Transferring noise data from wind tunnels to rotors

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Agenda

- About Vestas – who we are
- The nature of Wind turbine noise emission.
- Measurement method
- Simulation requirements
- From wind tunnel to turbine



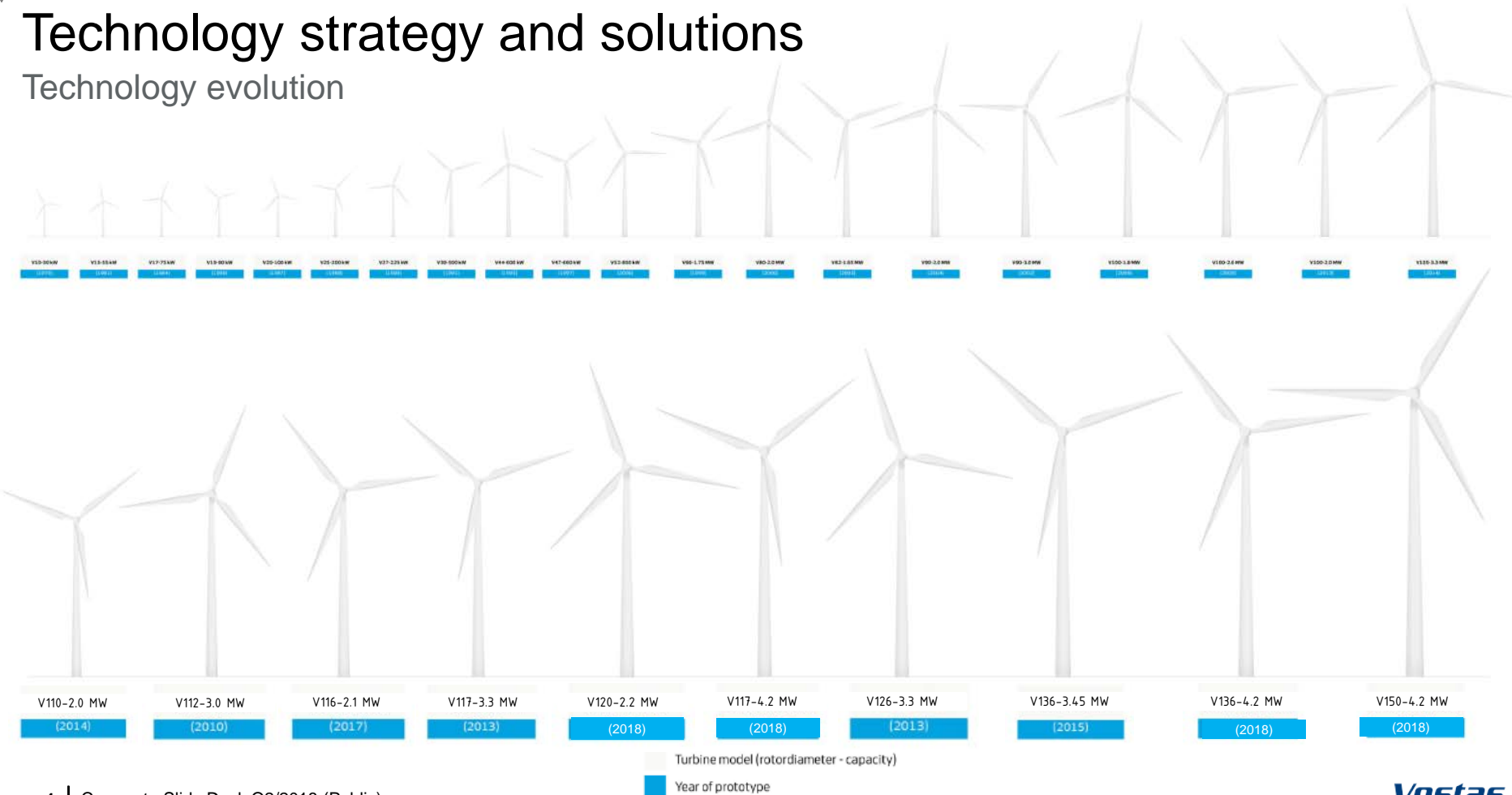
The global
leader in wind
technology





Technology strategy and solutions

Technology evolution



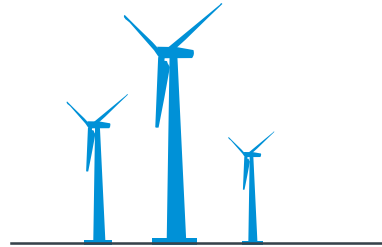
Vestas in brief

The only global wind energy company



+24,300

We employ more than 24,300 people worldwide and have more than 35 years of experience with wind energy



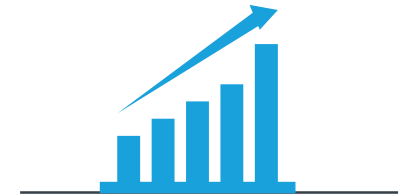
+40,200

We have a total of 40,228 combined turbines under service, or around 79 GW



+ 64,900

We have more than 64,900 turbines or 94 GW of installed wind power capacity in 79 countries worldwide spanning six continents



€ 2,260m

Vestas' revenue for Q2 2018 was EUR 2,260m

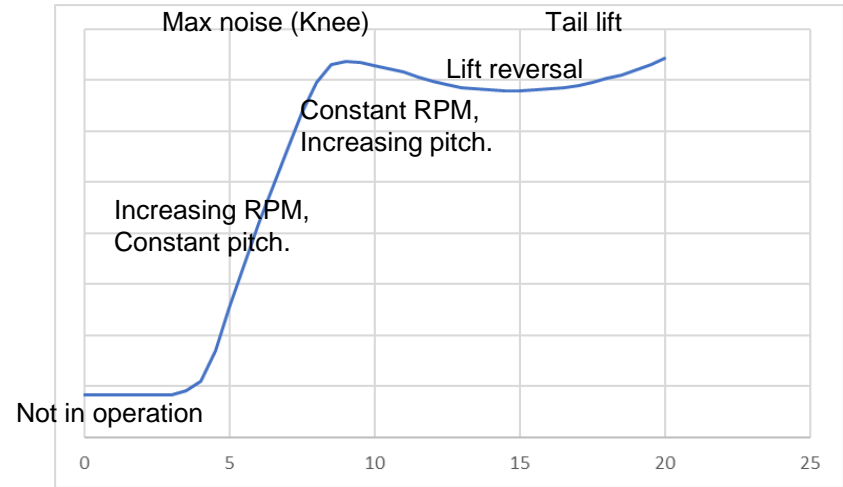


Low Cost of Energy, low Noise turbines



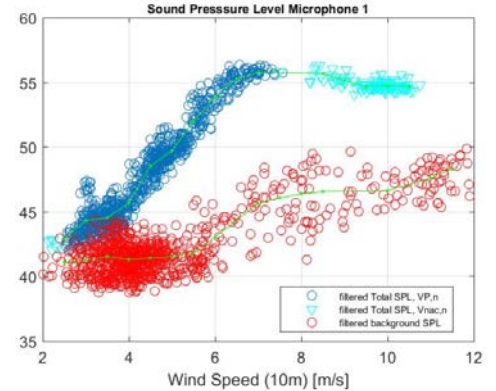
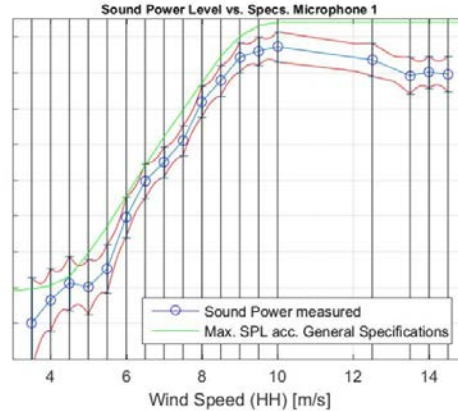
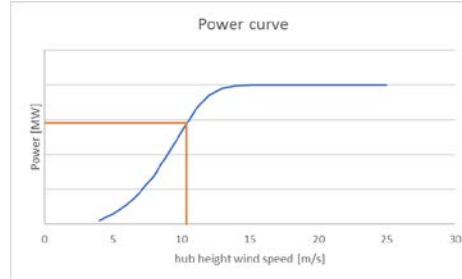
Wind turbine noise emission

- Attempted operated at constant tip speed ratio to maximize energy capture
- Causes continuous changing pitch and rpm as function of wind condition
- LwA is function of wind speed
- Measured according to IEC 61400-11



How to measure wind turbine noise

- IEC 61400-11
- Large number of 10 sec averages – L_{pA} , P
- In situ calibration for P_{max}
- Correct for background noise
- Binning & interpolation to L_{WA} & Std at each WSP
- 1/3 octave band resolution



What we typically see

- Simulation attempts during constant 10 min average operation at each wind speed
 - Obviously wrong – turbines are never operating steady state.
- Simulations in predefined flow field – lookup table for rpm/pitch
 - Obviously wrong – deflections and controller reactions disregarded.
- CFD simulation of turbines in terrain
 - Include terrain influence
 - Still assuming constant or lookup operation of the turbine
 - Still wrong – deflections and controller reactions disregarded.

All far from simulated test campaigns.

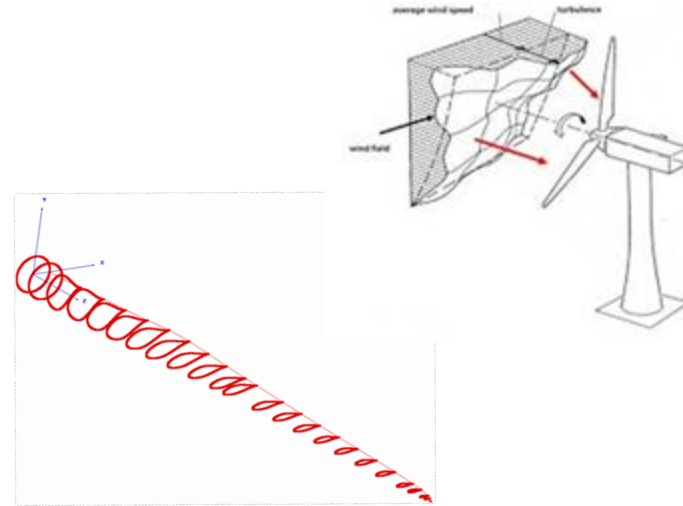
Simulation requirements

What is needed

- Simulated performance testing – i.e. simulated 10 sec values

Influencing parameters:

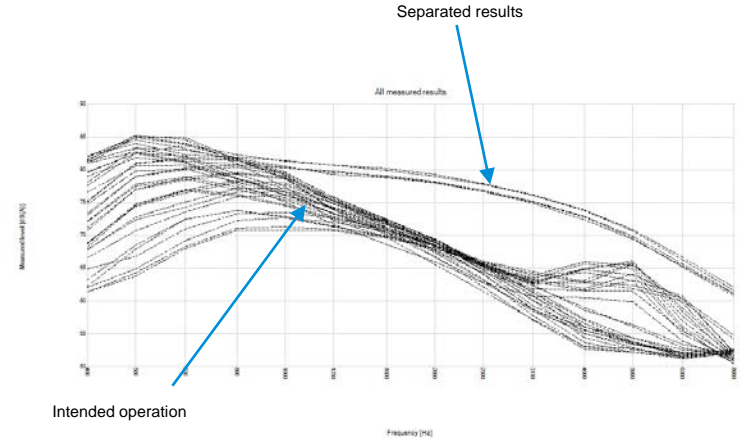
- Turbine model – Flex – including controller.
- Inflow field – turbulence and shear
- Turbine geometry – cone and tilt
- Blade planform – n cross sections.
- Contribution from each blade, each cross section, each time step – condensed to 10 sec averages.



Profile performance

Results from wind tunnel testing

- Approach
 - Aero acoustic wind tunnel campaigns
 - Acoustic array for L_{pA} – minimum 1/3 octave band resolution
 - AoA from negative separation to positive separation
 - Minimum one inflow speed – preferably in the Re range for the actual profile.
 - Sometimes supplemented by measured BL thickness.



Wind tunnel Scaling

Model examples

- Multiple mechanisms simultaneously active.
- TBLTE the far most important mechanism
- Transfer from tunnel to rotor is made by result scaling.
- Most models assume flow speed dependency in v^5 . Experience from field testing is a slightly higher exponent.
- Scaling is based upon a combination of BL thickness and flow speeds.
- Work on 1/3 octave band level.
- Move level and peak freq. to appropriate position



Turbulent-boundary-layer—trailing-edge noise



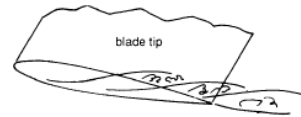
Laminar-boundary-layer—vortex-shedding noise



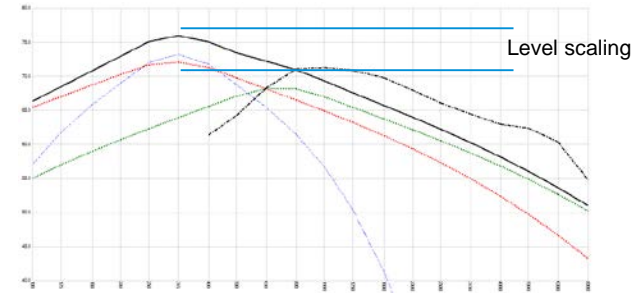
Separation-stall noise



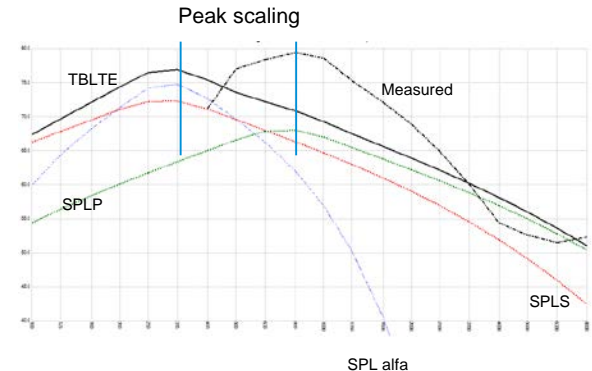
Trailing-edge-bluntness—vortex-shedding noise



Tip vortex formation noise



Comparison NACA0012 versus Wind turbine profile, identical operational conditions

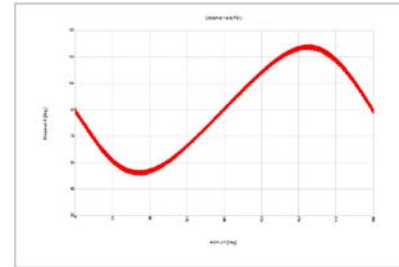
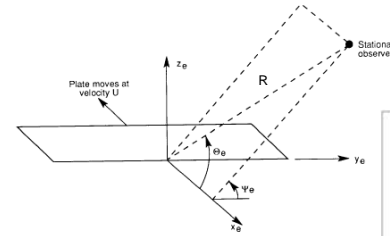


Popular models

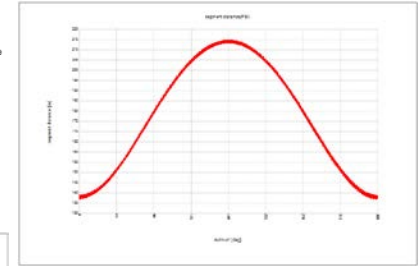
Multiple models

- BANC-II (Simple approach 2012) for TE noise
 - Scale 1/3 octave band values by: chord length, observer distance, Mach number, boundary layer thickness, temperature and density.
 - Valid for operational conditions not too far from test.
- BPM (State of the art Engineering approach from NASA, 1989) all mechanics symmetric profiles
 - Require testing at multiple flow speeds.
 - Extract mathematical equations to fit test results.
 - Equations applied on actual rotor performance.

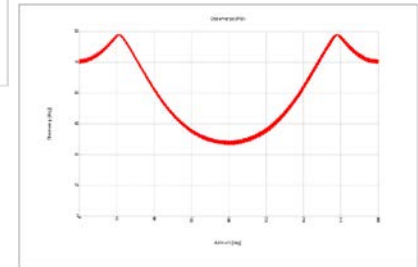
Directivity of noise emission from each cross section.



Blade segment observer θ



Blade segment observer distance



Blade segment observer ψ

Take away

- Target is to simulate measurement campaigns
- Follow IEC 61400-11– a large number of 10 sec values, averaged following standard.
- Simulations must be based on load case simulations for the investigated situation.
- Profile database from wind tunnel campaigns must cover all relevant cross sections.
- Do not disregard root end.
- Not rocket science – simple scaling



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