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National Renewable Energy Laboratory

Wind Turbine Aeroacoustic Issues

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National Renewable Energy Laboratory

California Wind Energy Consortium Forum

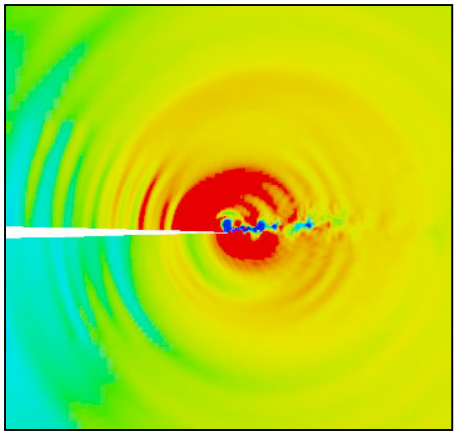
University of California, Davis

17-18 December 2002

Operated for the U.S. Department of Energy by Midwest Research Institute • Battelle • Bechtel

Presentation Overview

- *Importance of Wind Turbine Noise*
- *Sources of Wind Turbine Noise*
- *Current State of the Art*
- *NREL Research Program*
- *Future Plans*



Importance of Wind Turbine Noise

- *We are moving toward a sustainable energy future – EWEA estimates 12% of world's energy may come from wind turbines by the year 2020 (1,260,000 MW)*
- *This means wider deployment of wind turbines, at lower wind speed sites (close to people & transmission lines)*
- *We need efficient turbines to exploit these sites*
- *We need to minimize annoyance, which is a deterrent to deployment*
- *Trade off: improve performance with minimum impact on noise or reduce noise to promote deployment (dB(A) ~ kWh ~ $$$)*

The Earth Is Becoming Crowded!

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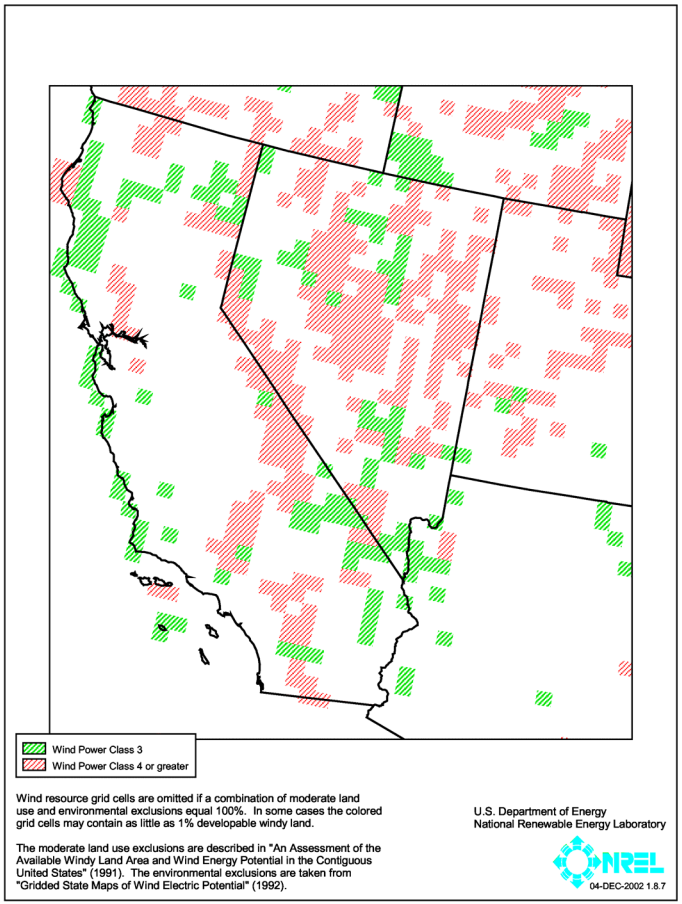
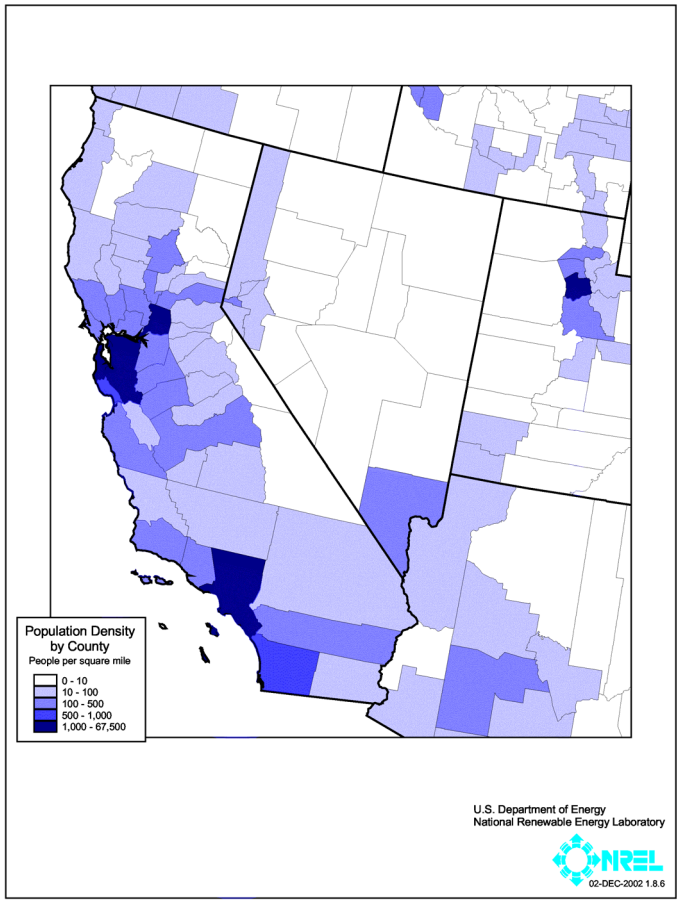
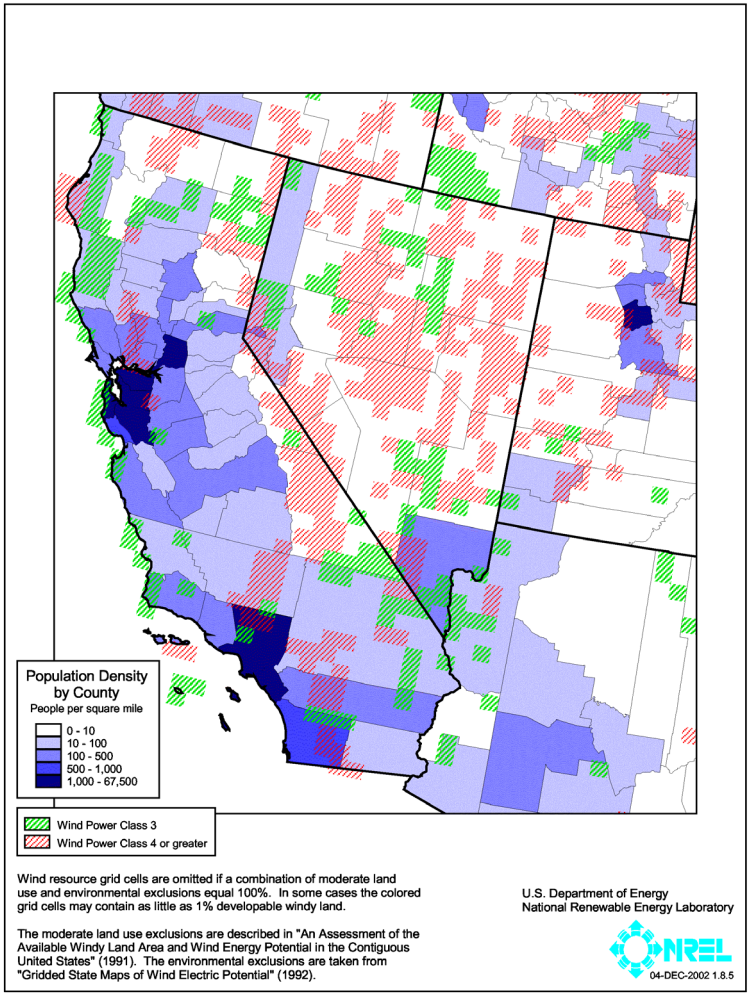
Class 3 and Class 4 Wind Sites



Population Density

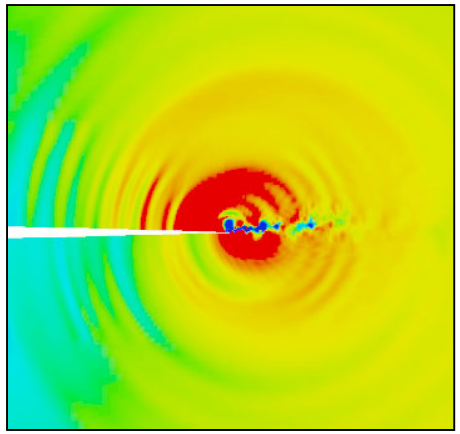


- *Design of wind turbines for low wind speed sites will have the effect of expanding the wind resource area*
- *More people will be impacted by turbine acoustic emissions*

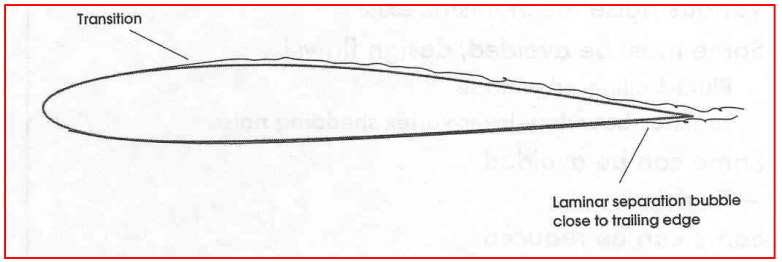


Presentation Overview

- *Importance of Wind Turbine Noise*
- ***Sources of Wind Turbine Noise***
  - ***gearbox, generator, brakes, electronics, tower …***
  - ***aeroacoustic (rotor blades)***
- *Current State of the Art*
- *NREL Research Program*
- *Future Plans*



- ***Sources of Wind Turbine Noise***
  - ***Laminar Boundary Layer Vortex- Shedding Noise***
  - ***Turbulent Boundary Layer Trailing Edge Noise***
  - ***Leading Edge Inflow Turbulence Noise***
  - ***Blunt Trailing Edge Noise***
  - ***Separation Noise***
  - ***Blade Tip Noise***



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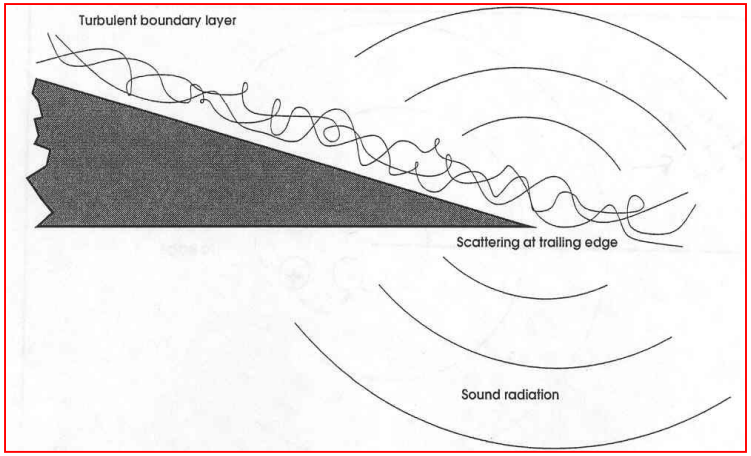

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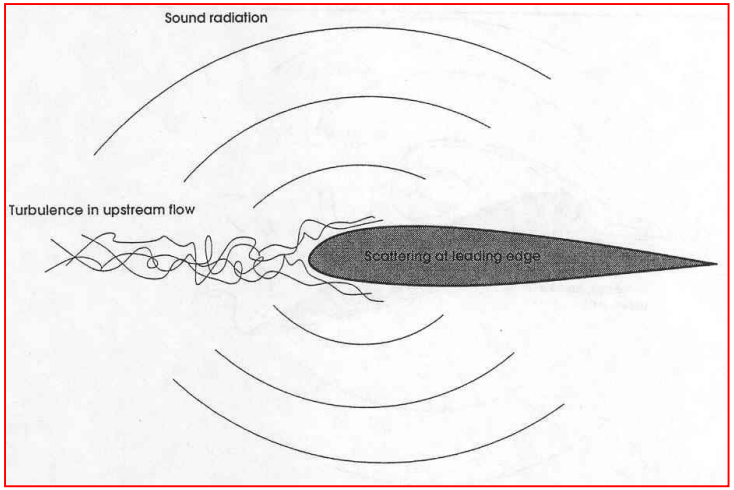

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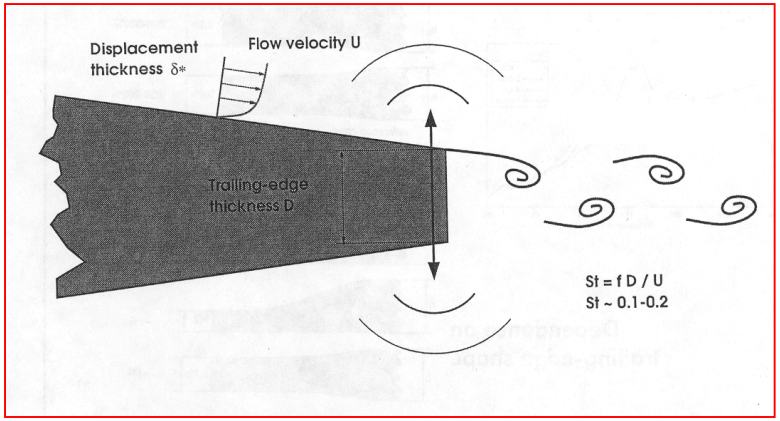

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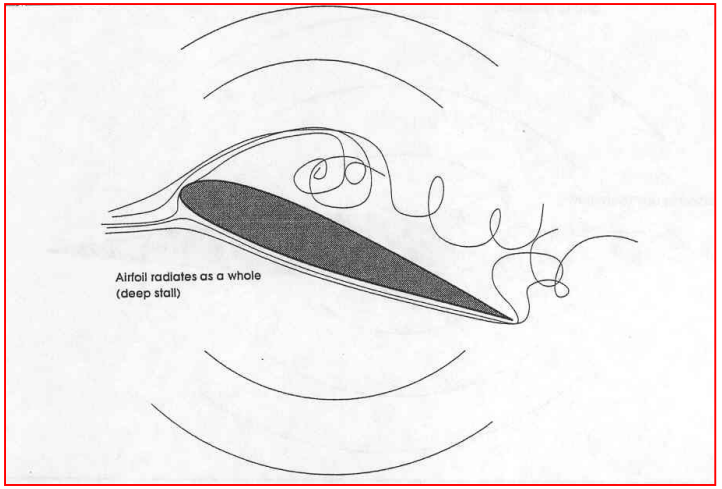

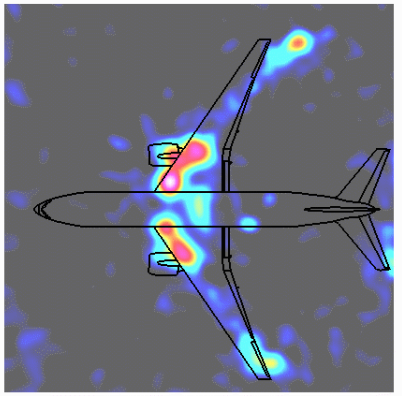

R. Stoker, The Boeing Company

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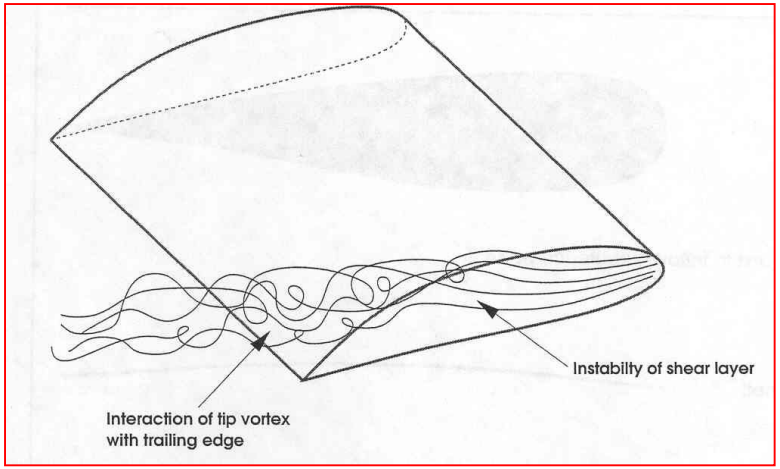

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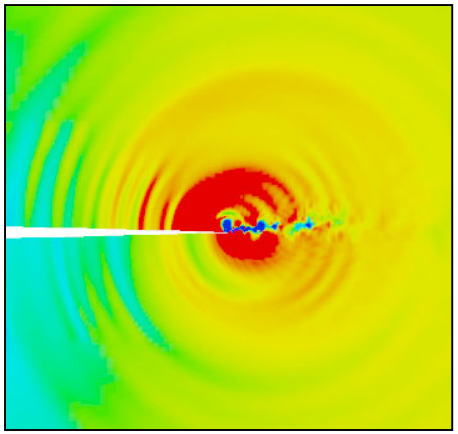
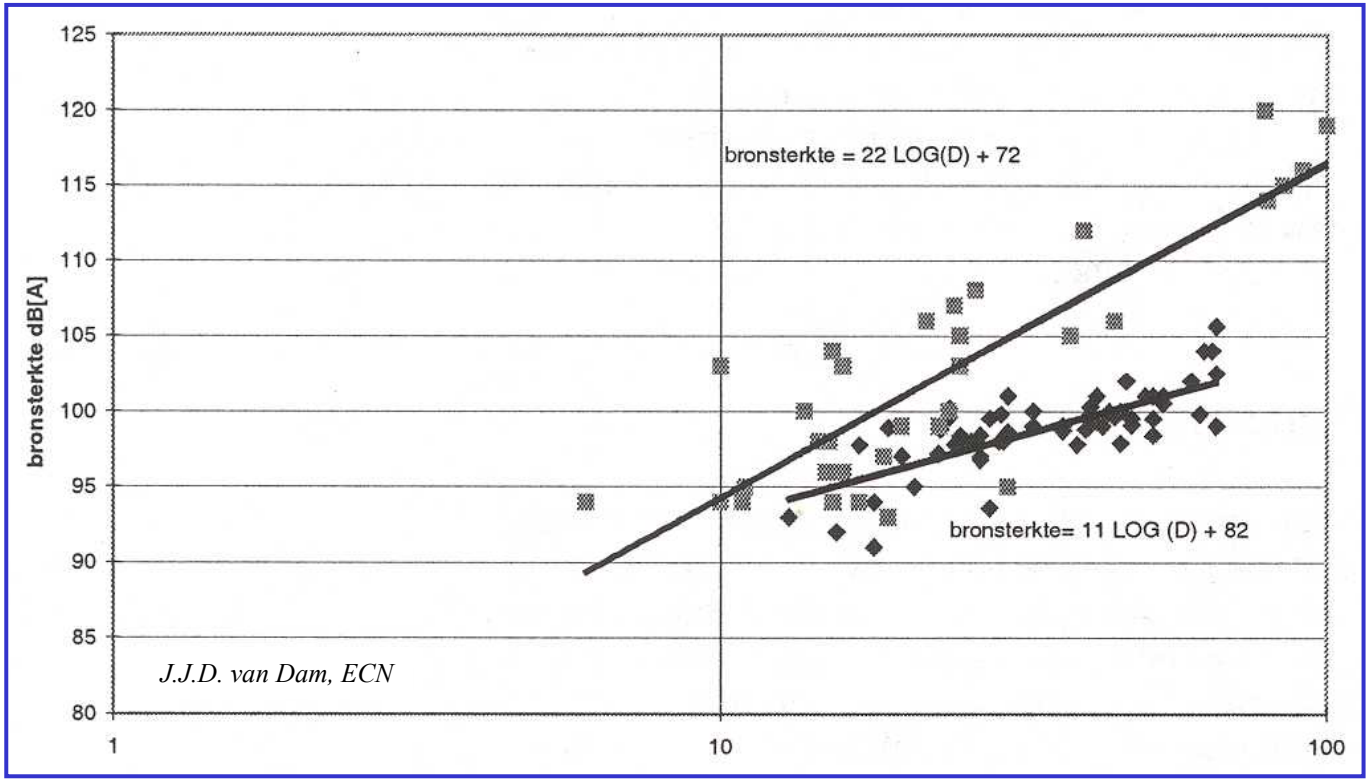


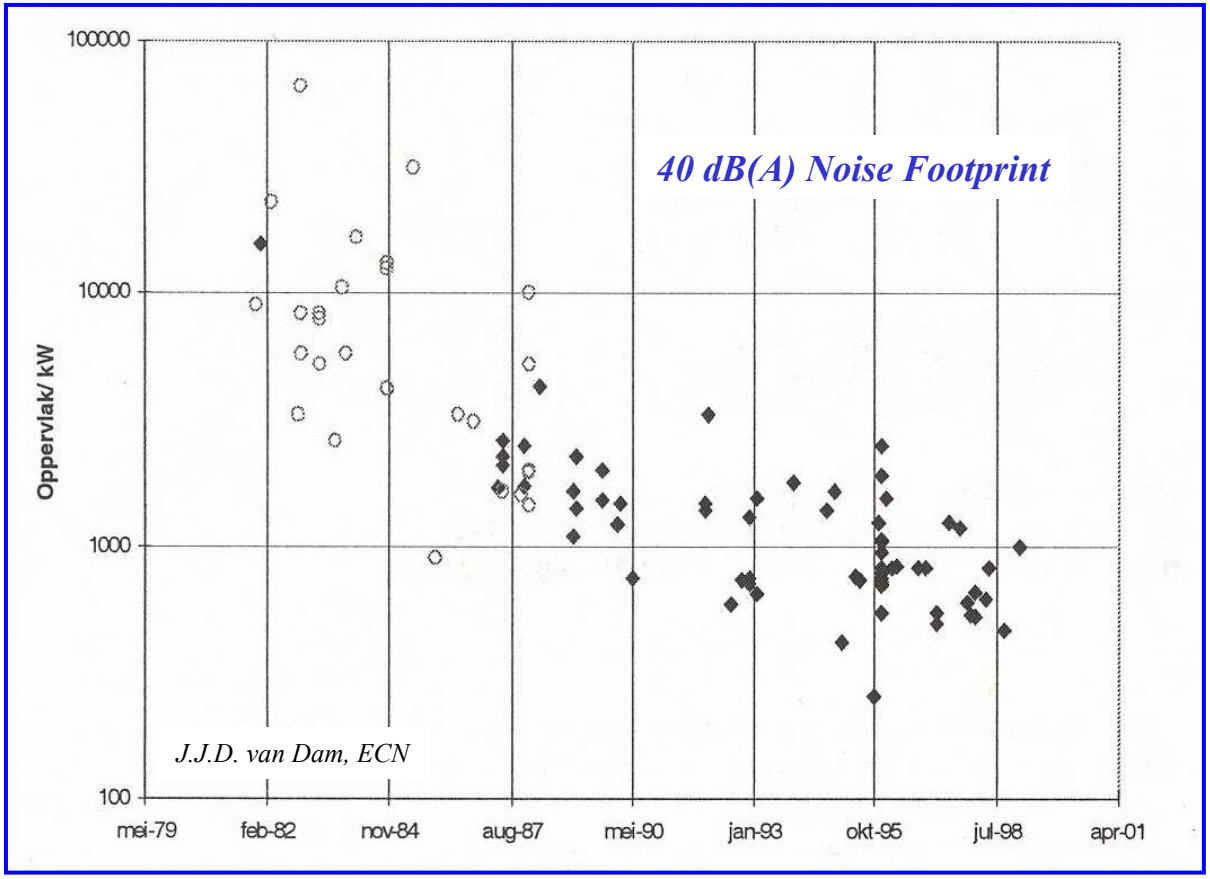
Acoustic Emission Trends with Turbine Size



Sound Power Level – dB(A)

Rotor Diameter (m)

Trends in Noise Footprint with Time



Circular Area (m^2)/kW

Calendar Year Time Scale

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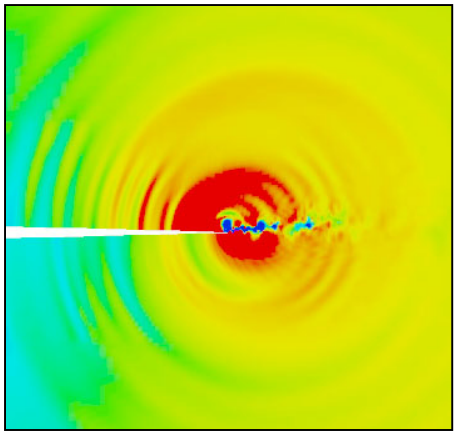
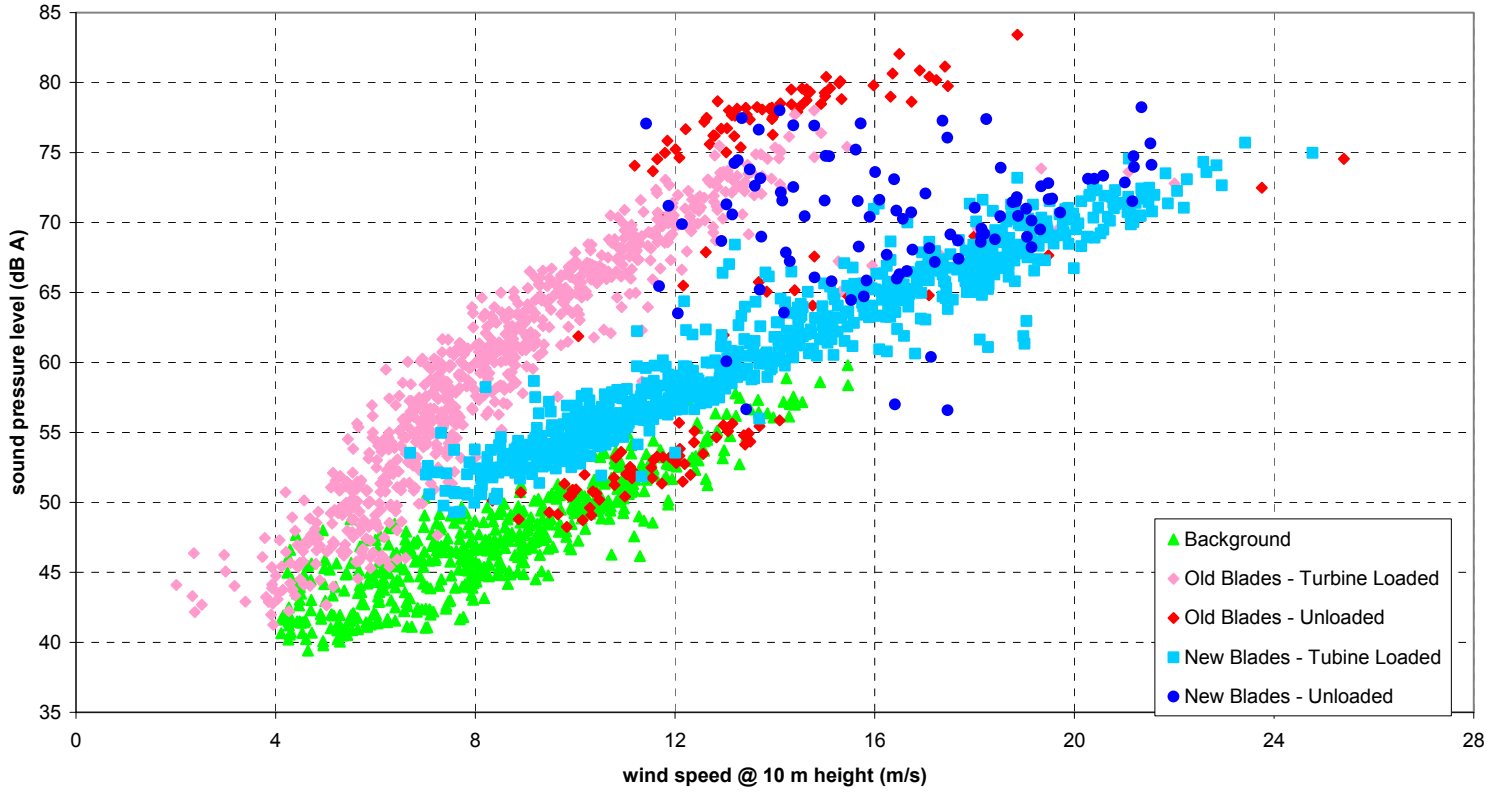


Aeroacoustic Field Tests at NREL

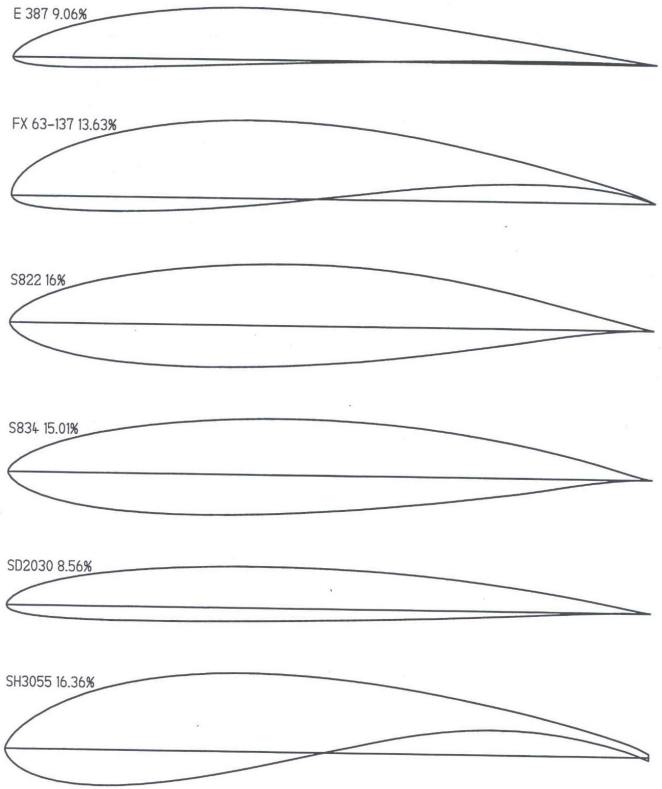
- SWWP Whisper H40
- AOC 15/50
- Bergey Excel
- Bergey Excel (SH3052)
- Bergey XL.1
- NPS 100
- SWWP AIR-X
- SWWP Whisper H80

Bergey Excel 10 kW Turbine Improvements



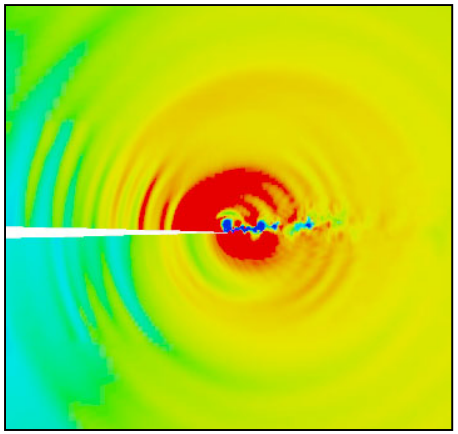
Wind Tunnel Tests

- ***Conduct wind tunnel <u>aeroacoustic</u> tests to measure noise emissions of various airfoils and the sensitivity to inflow turbulence***
- ***Conduct wind tunnel <u>aerodynamic</u> tests to obtain complementary performance data***

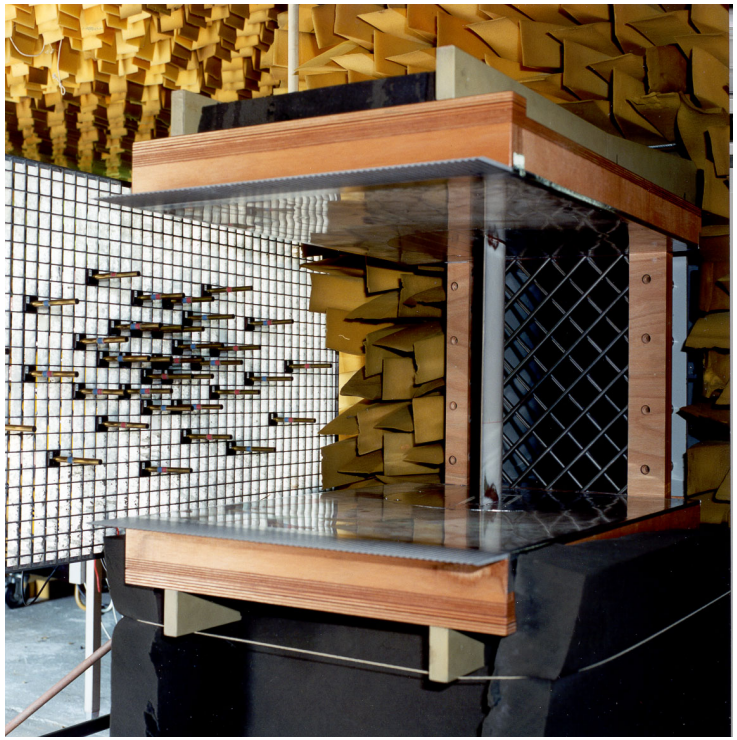


Airfoils Tested

- *SD 2030*
  - *Southwest Windpower AIR-403 and AIR-X*
- *FX 63-137*
  - *Southwest Windpower Whisper H40/H80*
- *S822*
  - *Tangler/Somers (Re = 1,000,000)*
- *S834*
  - *Tangler/Somers (Re = 400,000)*
- *SH 3055*
  - *Bergey XL.10 (mod)*
- *SG 6043*
  - *Selig/Giguere (Low Re and High L/D)*



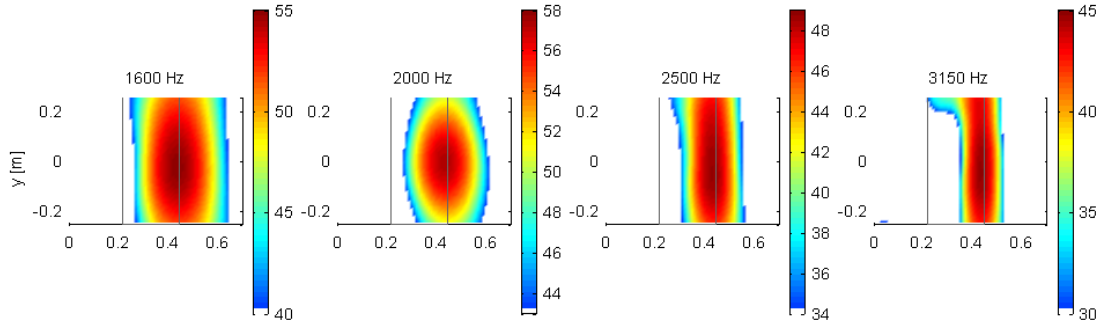
NLR Small Aeroacoustic Wind Tunnel



Netherlands National Aerospace Laboratory (NLR) Small Anechoic Wind Tunnel

- *Anechoic chamber absorbs noise below 250 Hz*
- *16”x20” open jet (260 ft/sec)*
- *Acoustically lined end plates*
- *Inflow turbulence generators*
- *48-microphone phased array acoustic antenna*

Source Plot Showing Strong Trailing Edge Imissions



Source Plot Showing Strong Leading Edge Imissions

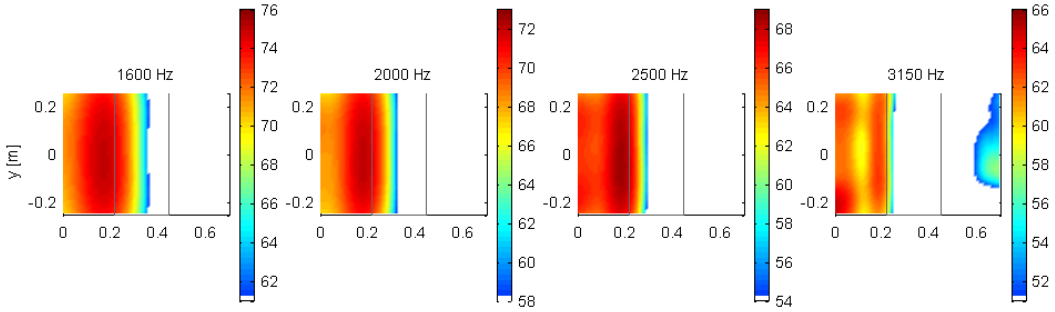
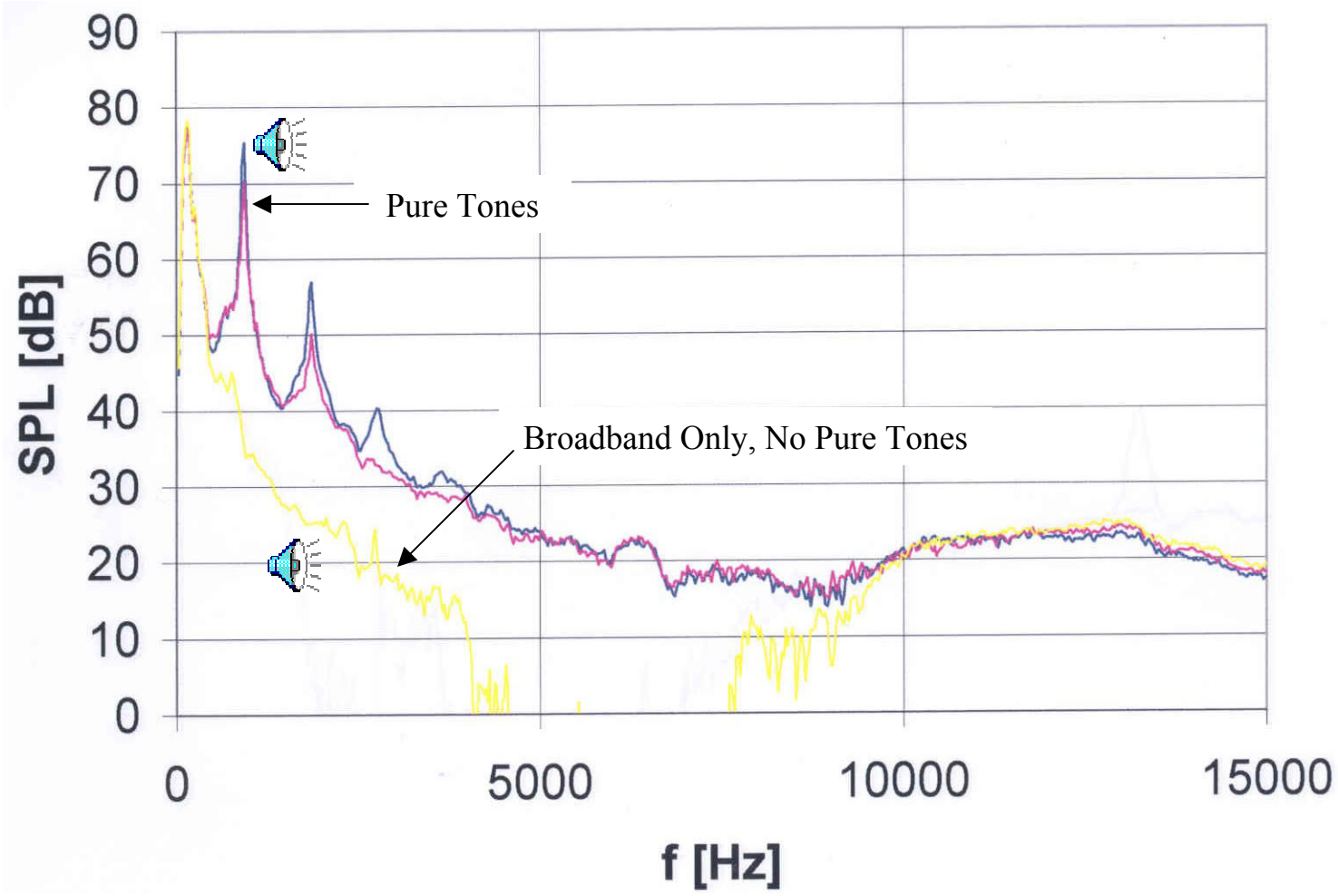


Illustration of Undesirable Pure Tones



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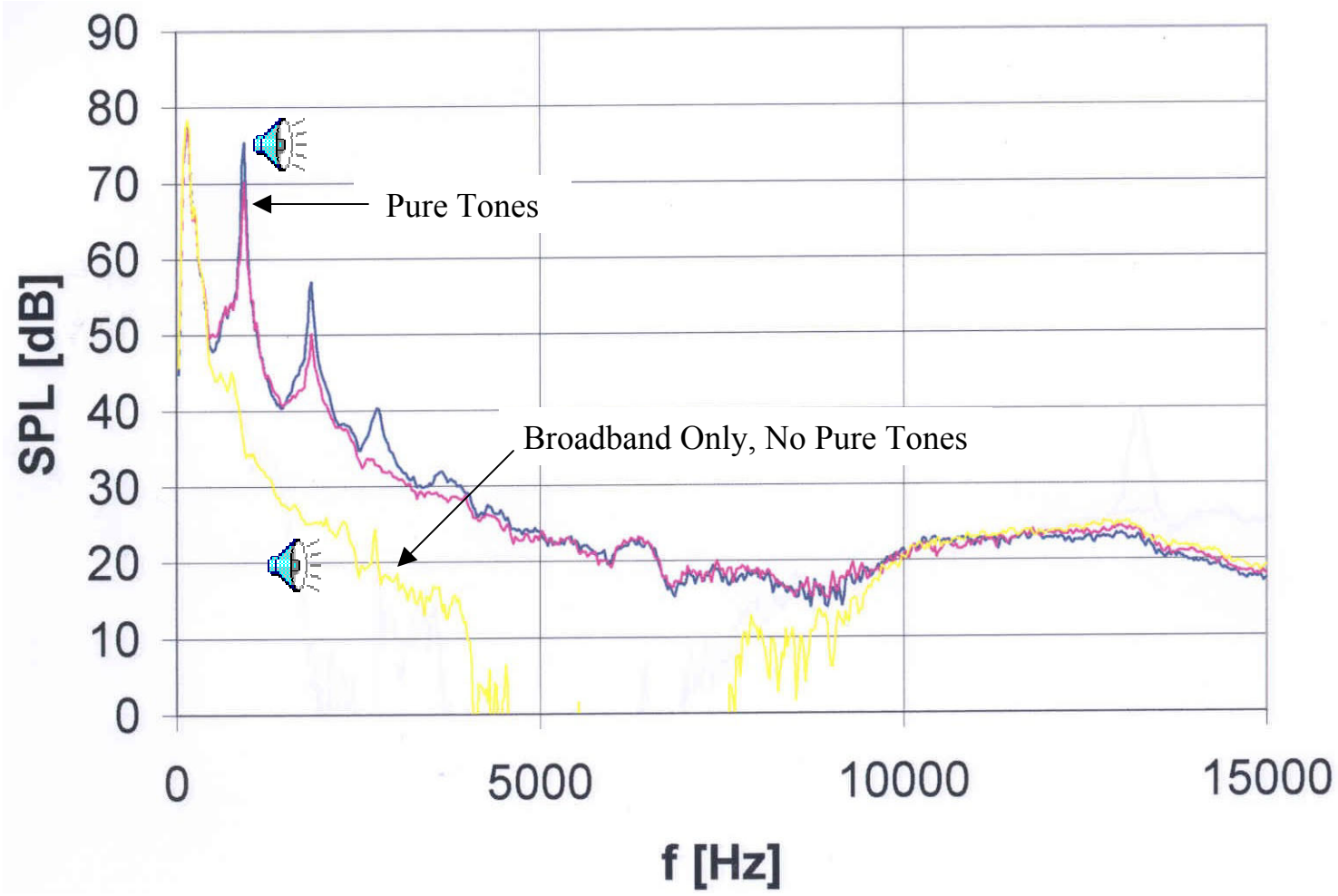

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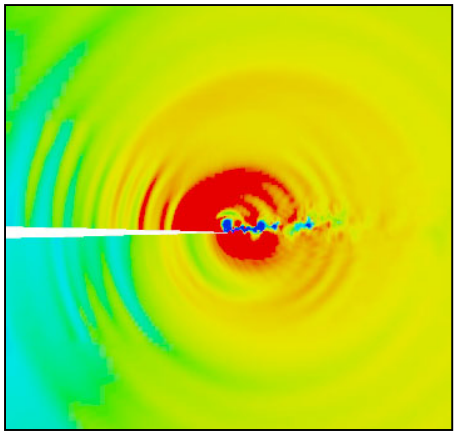
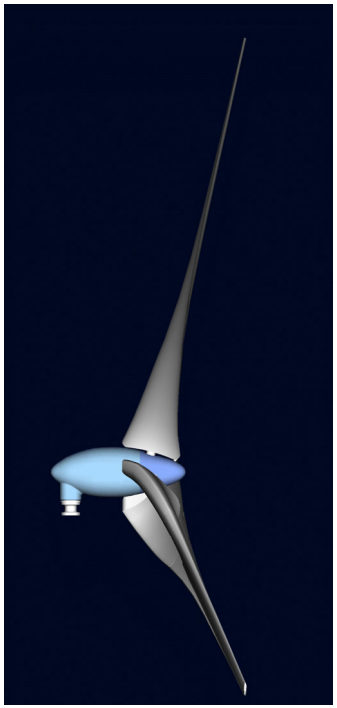
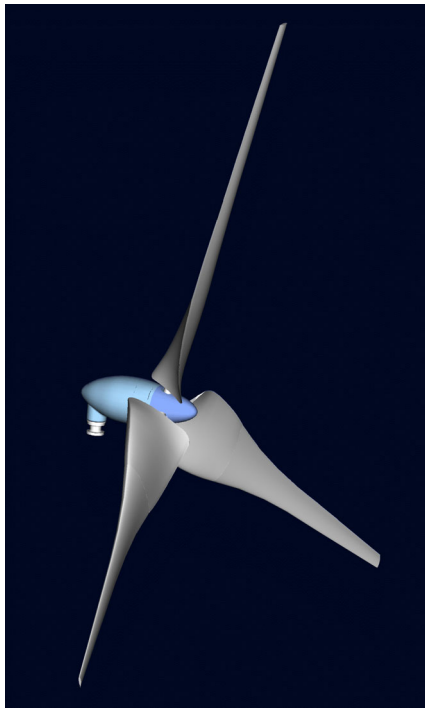


Putting It All Together in a New Design

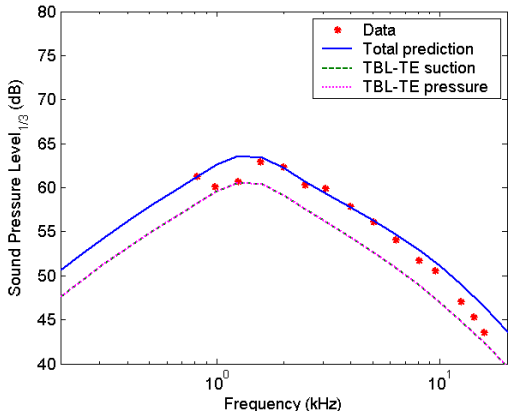
- *Choose airfoil(s)*
  - *Aerodynamic performance*
  - *Aeroacoustic emissions*
- *Optimize planform*
  - *Energy capture codes*
  - *Aeroacoustic design code*
- *Avoid tower shadow problem (low-frequency impulsive noise)*
  - *CAA codes???*

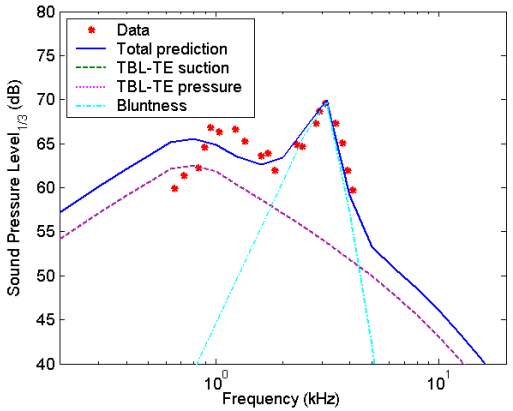


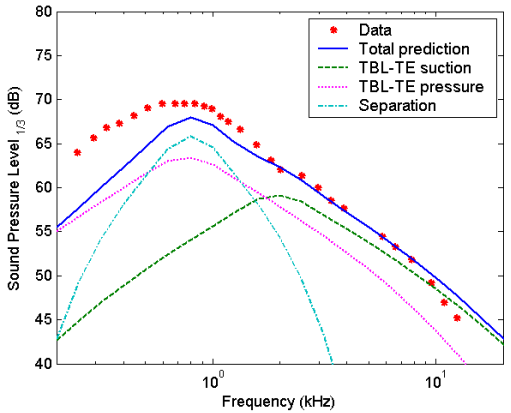


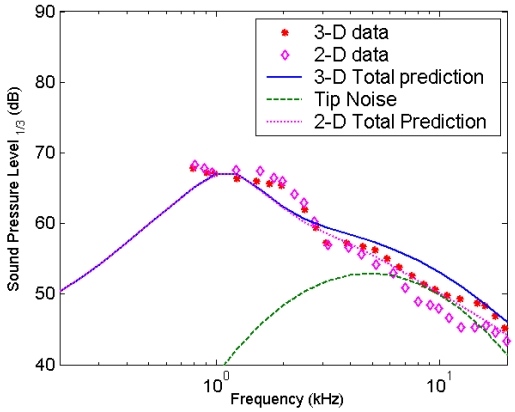
Southwest Windpower "Storm" 1.5 kW

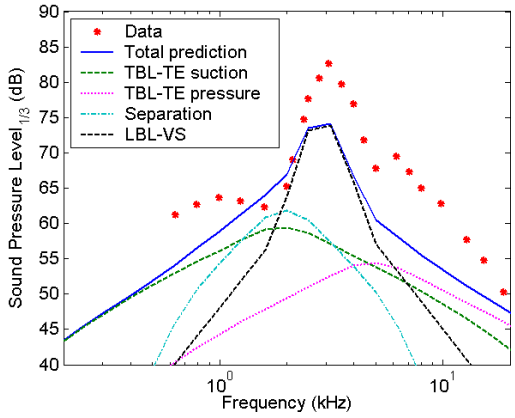
Quasi-Empirical Noise Prediction Codes



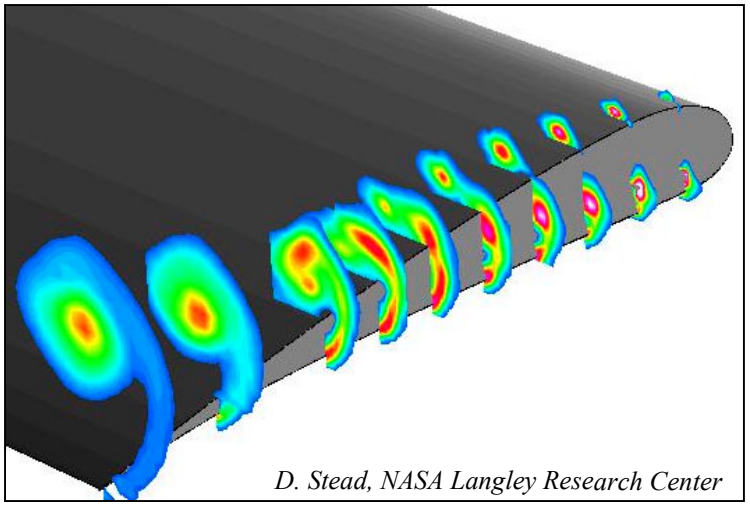


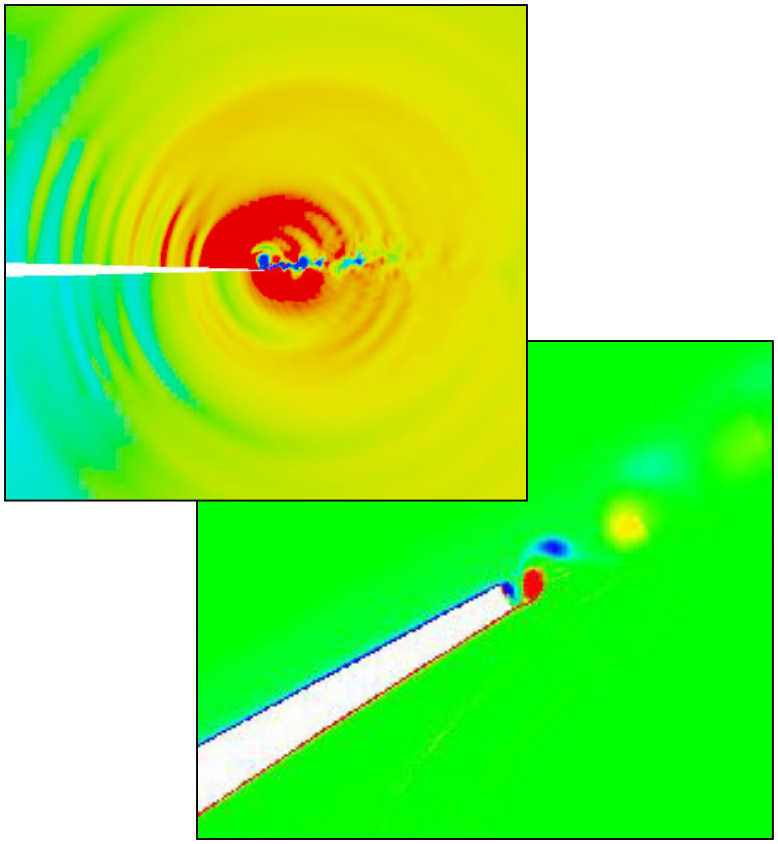






Computational Aeroacoustics





- *Builds on fundamental equations of motion with CFD input to CAA*
- *Attempts to capture flow physics*
- *Used extensively in airframe noise studies with considerable success*

Summary

- ***In the future, wind turbines are likely to be deployed closer to people.***
- ***Wind turbine noise is an issue if it becomes a deterrent to deployment – there is a trade off between cost effectiveness ($$$) and noise.***
- ***Many complex noise sources need to be considered.***
- ***Lowest noise emission level for large turbines is ≅ 99 dB(A) [600 m^2/kW for 40 dB(A) at receptor location].***
- ***NREL field tests, wind tunnel tests and computer code development to understand and mitigate noise emissions .***
- ***Improvements expected for small and large wind turbines.***