Low-noise wind turbine design

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Outline

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Sound characteristics

Noise sources

Rotor design considerations

Design tools

Sound characteristics

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Which sound characteristics need to be considered for low-noise wind turbine design?

Noise regulations usually based on sound <u>imission</u>

- Different regulations for different countries
- Noise limits may depend on wind speed, background noise, …
- Imission at neighbour depends on site details, meteo conditions, …

Acoustic wind turbine design based on sound <u>emission</u>

- Regulations often use overall sound level, tonality, low-frequency noise
- Other parameters: impulsiveness, directivity, infrasound, modulation
- Sound emission may depend on site and meteo conditions, such as wind speed, wind shear, atmospheric turbulence, blade soiling, …

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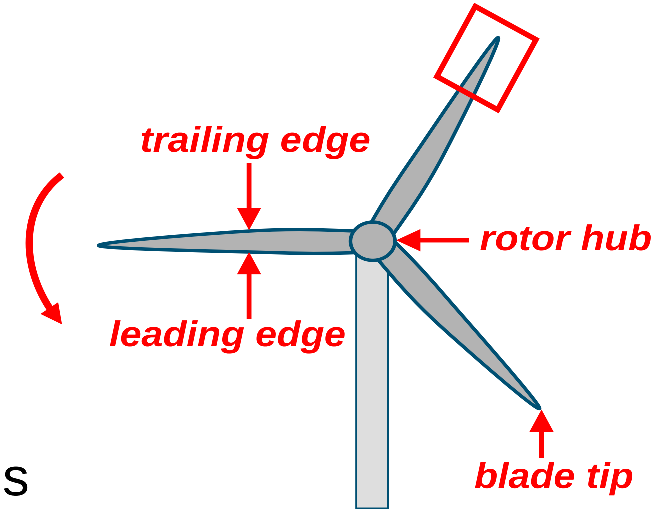
Sources of wind turbine noise

Modern large turbines

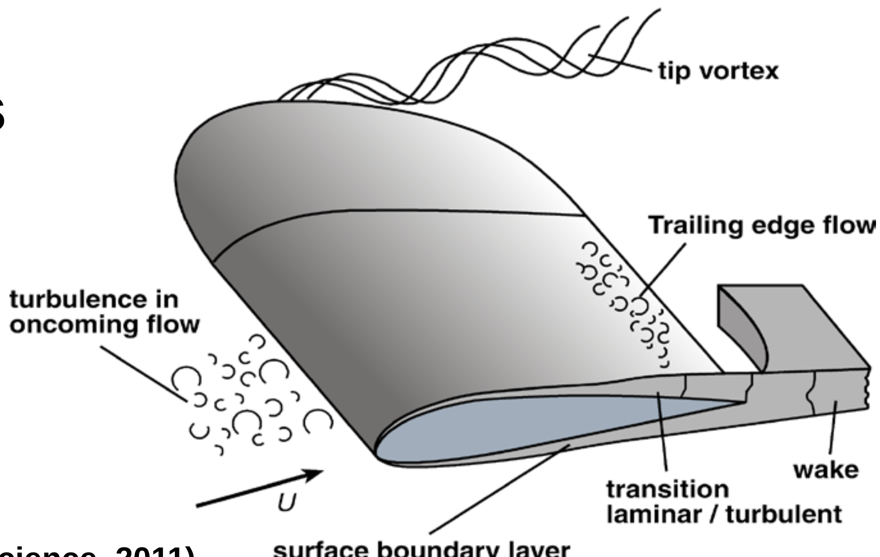
Mechanical noise from nacelle

- Mainly caused by gearbox and generator
- May generate tones and low-frequency noise
- Gearless turbines quieter than geared turbines



Aerodynamic noise from blades

- Usually dominant noise source
- Inflow turbulence noise
- Tip noise
- Airfoil self noise → trailing edge noise



Wind Turbine Noise (MultiScience, 2011)
Wind Turbine Noise (Springer, 1996)

Airfoil self-noise mechanisms

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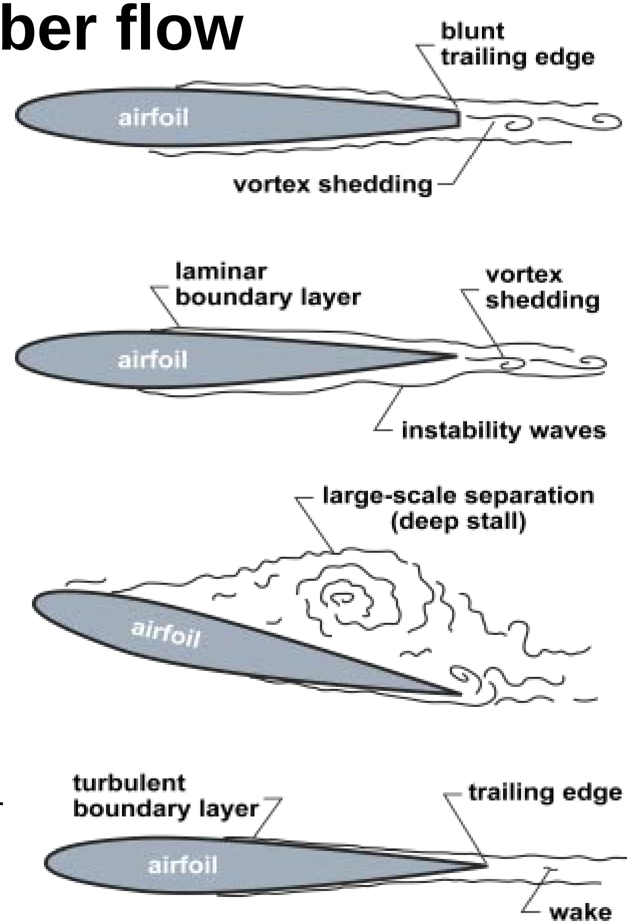
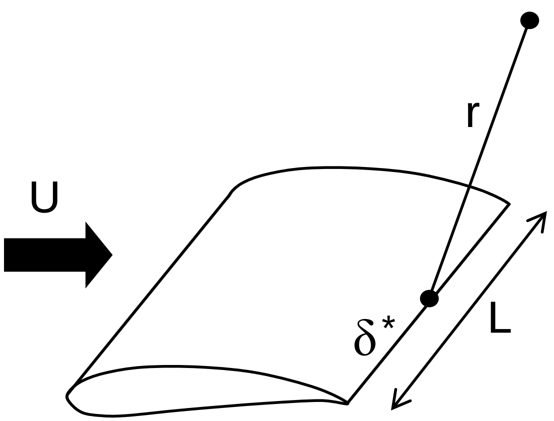
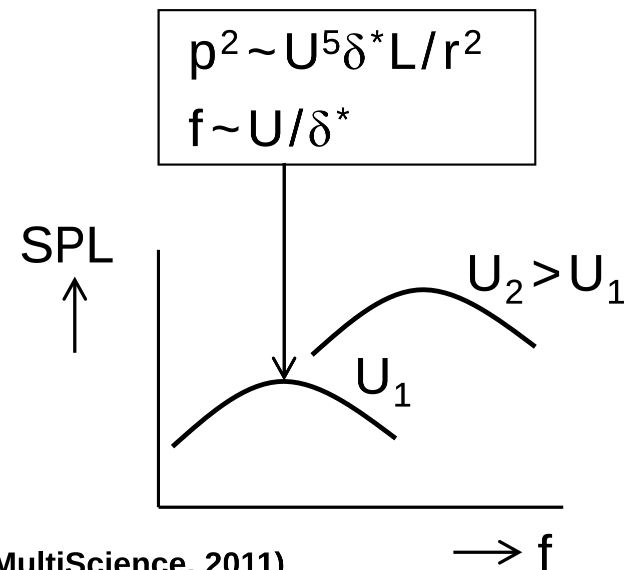
High Reynolds number, low Mach number flow



Self-noise mechanisms

- Blunt trailing edge noise
- Laminar boundary layer vortex shedding
- Separated flow
- Trailing edge noise: lower limit





NASA-RP-1218 (1989)

Wind Turbine Noise (MultiScience, 2011)

Wind turbine noise sources

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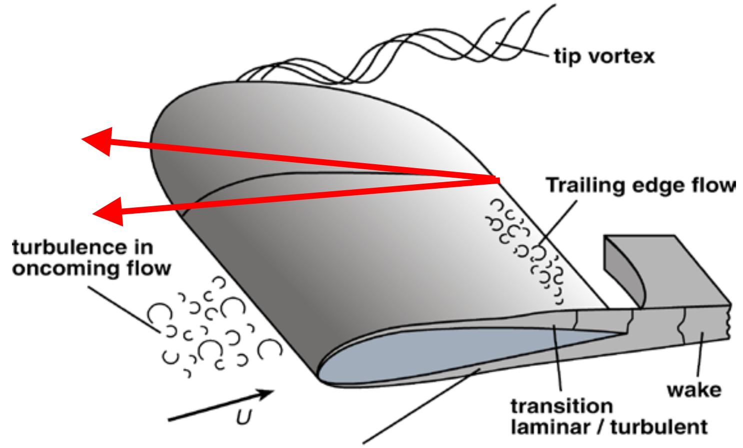
Noise sources in rotor plane

- Averaged over many revolutions
- Noise radiation towards the ground

Observations

- Turbine noise dominated by blades
- Noise radiated from outer part of blade
- Noise mainly produced during downstroke



Wind Turbine Noise (MultiScience, 2011)

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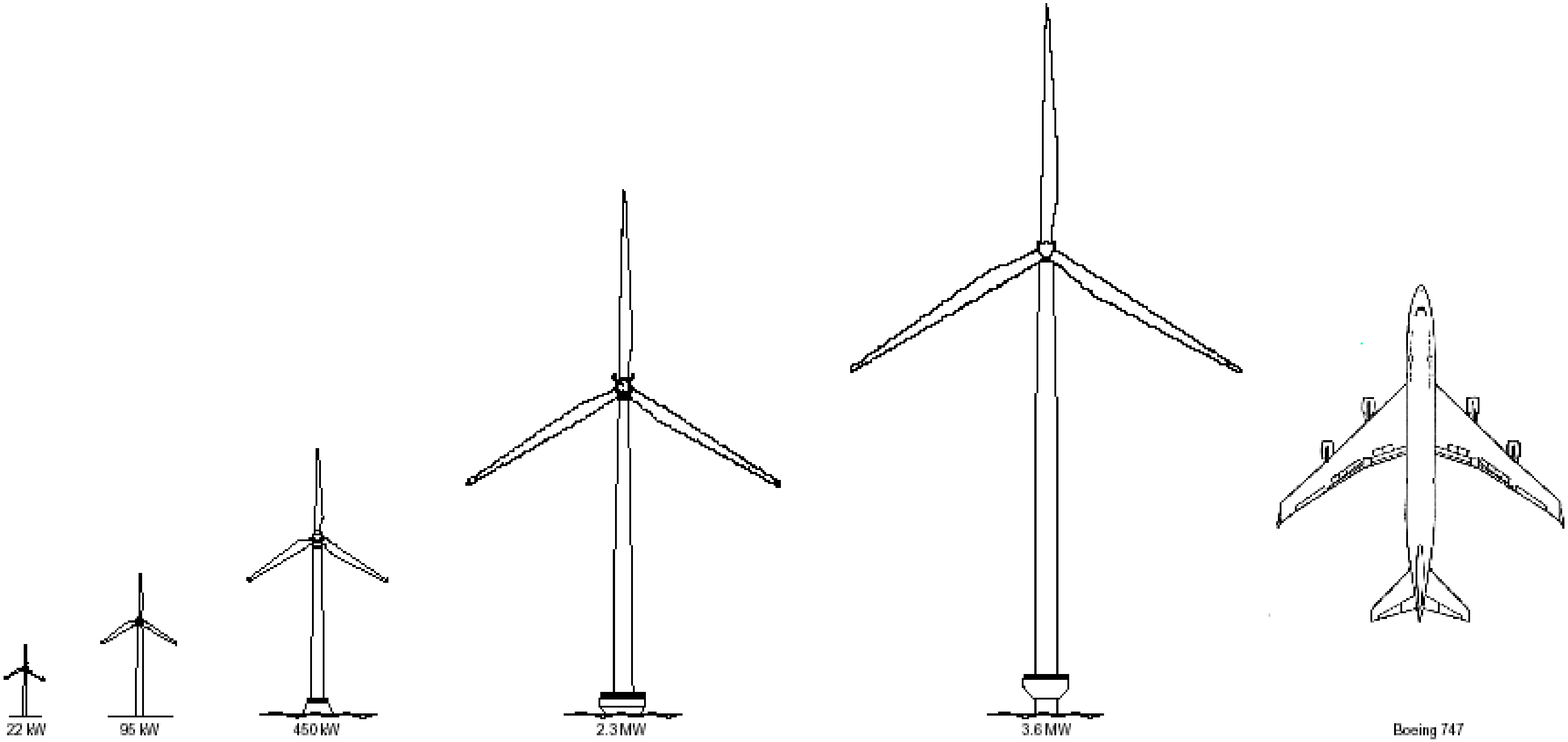
- Rotor size and tip speed
- Blade shape
- Blade add-ons
- Control strategies

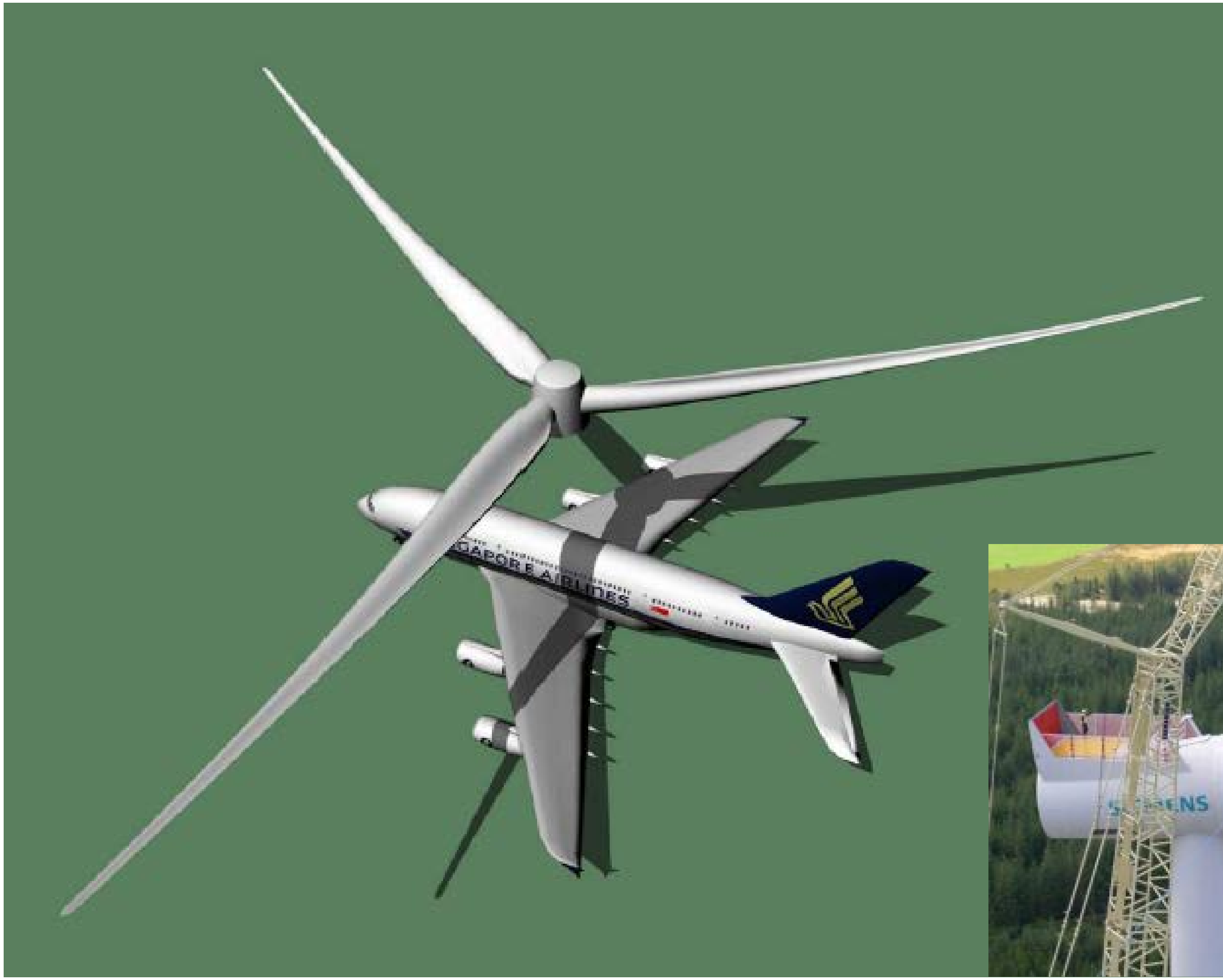
Design tools

Turbine size

The most dramatic historical design trend is SIZE



SWT-6.0-154 with an Airbus A380



Rotor diameter and tip speed

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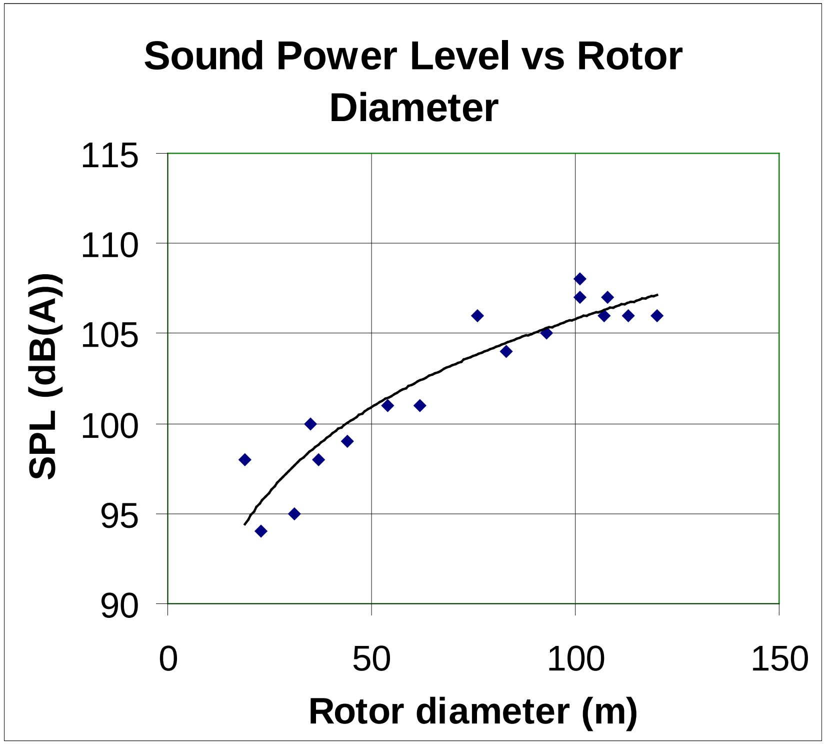
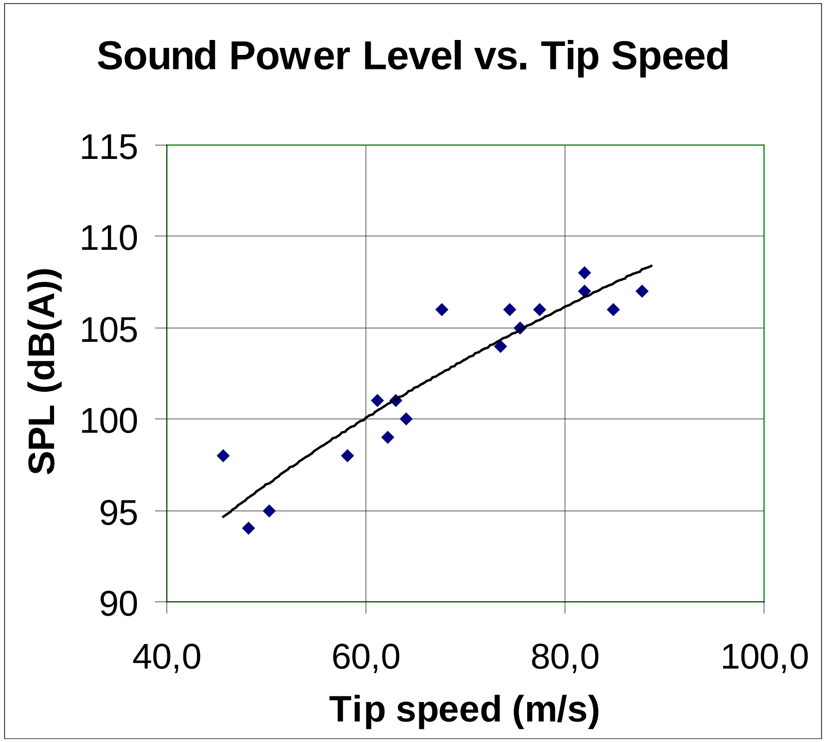
Development of sound power level over time

- Compare population of wind turbines with different size
- Level clearly increases with diameter and tip speed





Sound and energy production

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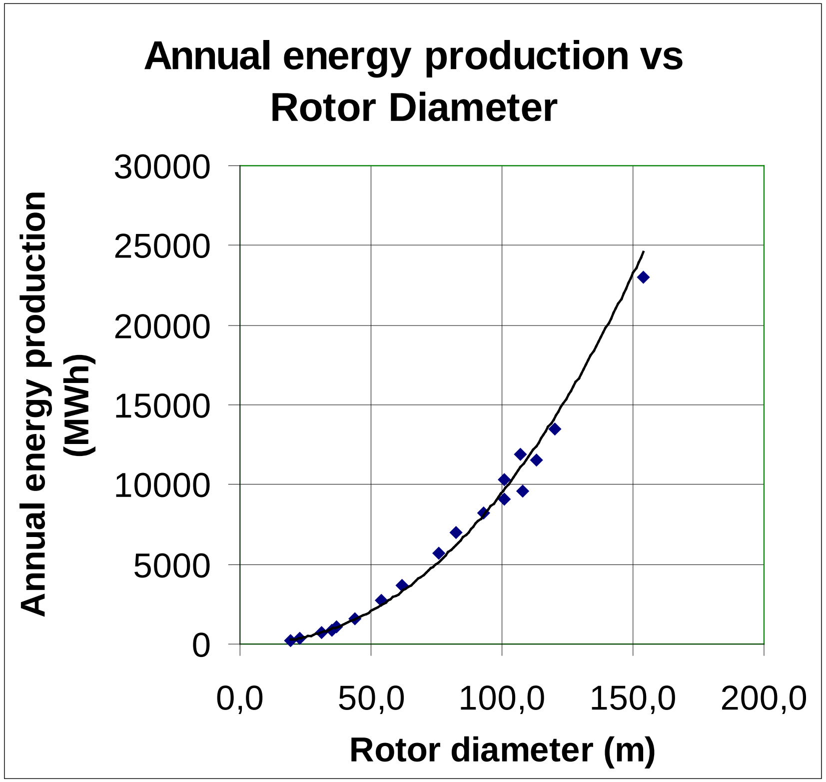
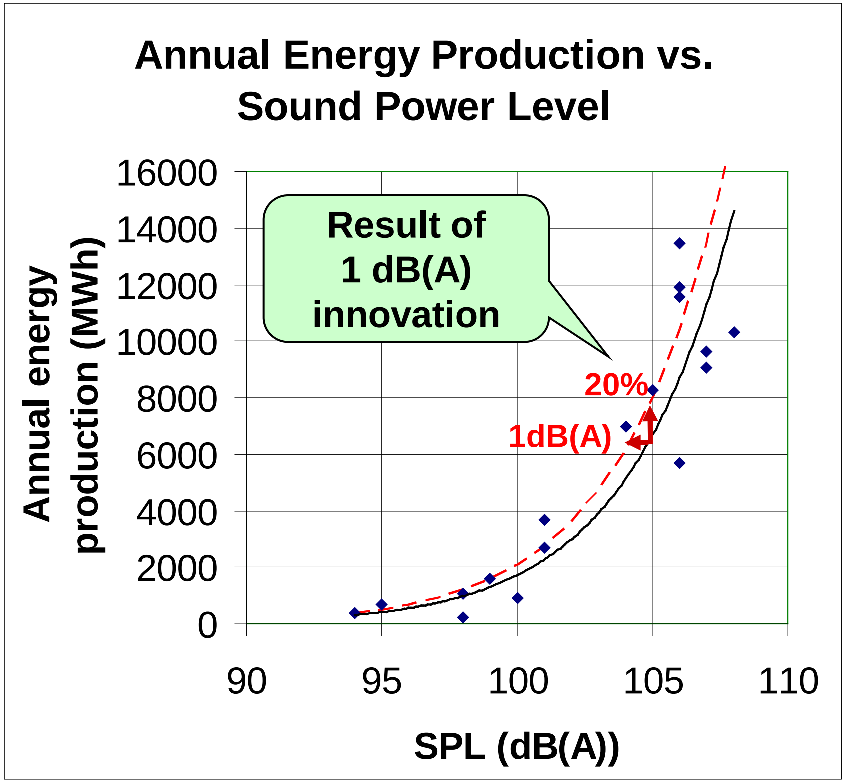
Clear relation between rotor size and energy production

Relation between sound level and AEP illustrates the value of 1 dB noise reduction





Blade shape

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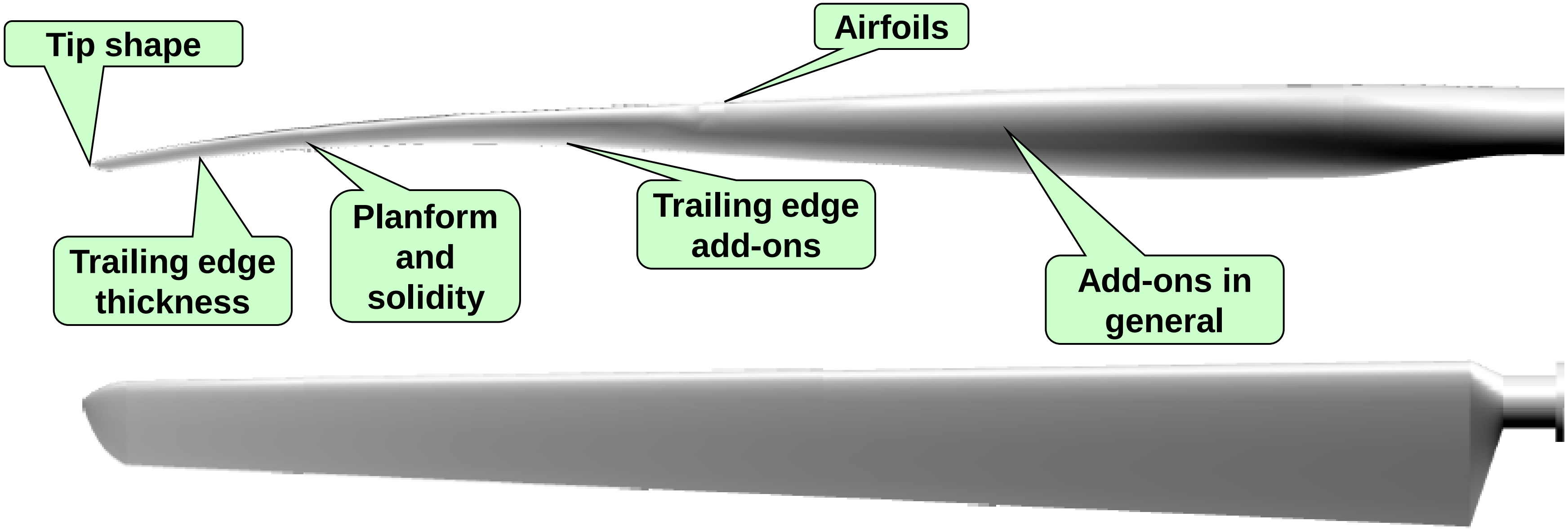
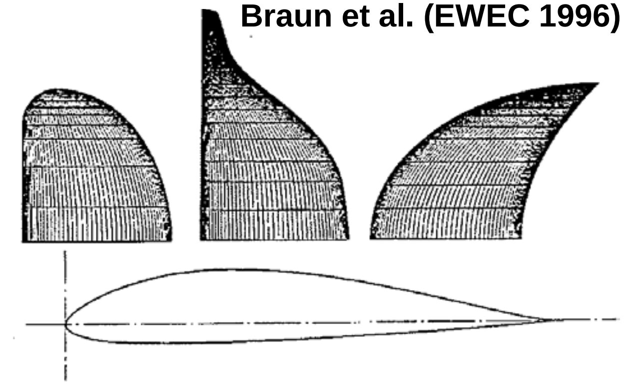
Development of blade shape – scaled to same size

- Solidity changed from ~10% to much less than 5%
- Airfoils changed from 1930s aircraft types to modern custom-made types
- Blade add-ons yield noise reduction of several dB’s
- Blade tip shape designs eliminate tip noise



Low-noise blade design

Braun et al. (EWEC 1996)

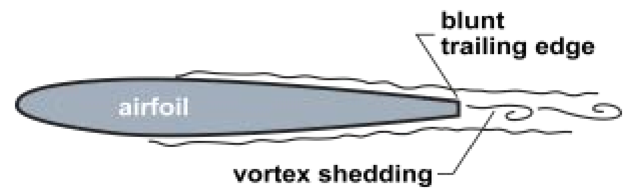


Tip shape

- Current design practice developed early 1990's
- No excess noise with right planform and inflow

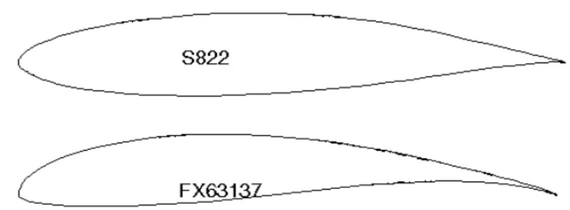
Trailing edge thickness

- Prevent bluntness tones by thin trailing edge



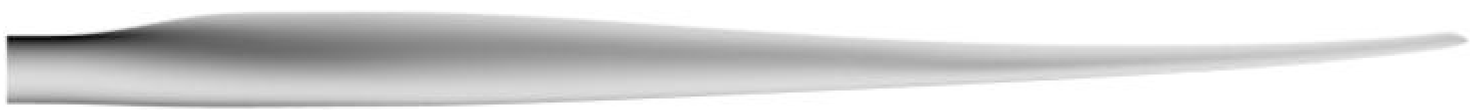
Airfoils

- Optimized wind turbine airfoils (loads, power, noise)



Planform and solidity

- Trend to slender thick blades affects trailing edge noise



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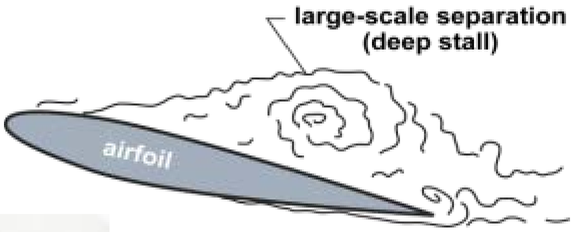
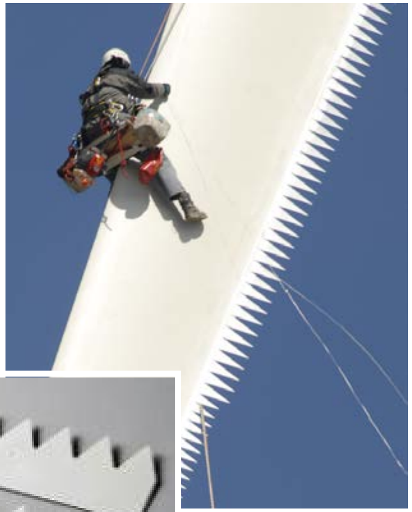
Blade add-ons

Add-ons used to improve blade performance



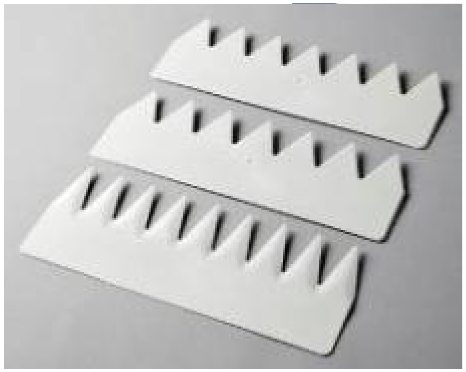
- Increase power output
- Reduce noise
- Lay-out may depend on site conditions



Vortex generators

- Delay separation: no excess stall noise
- May generate self-noise if placed wrongly

Trailing edge serrations / DinoTails®



- Reduce trailing edge noise if properly applied
- May increase power by flap effect

Low-noise controls

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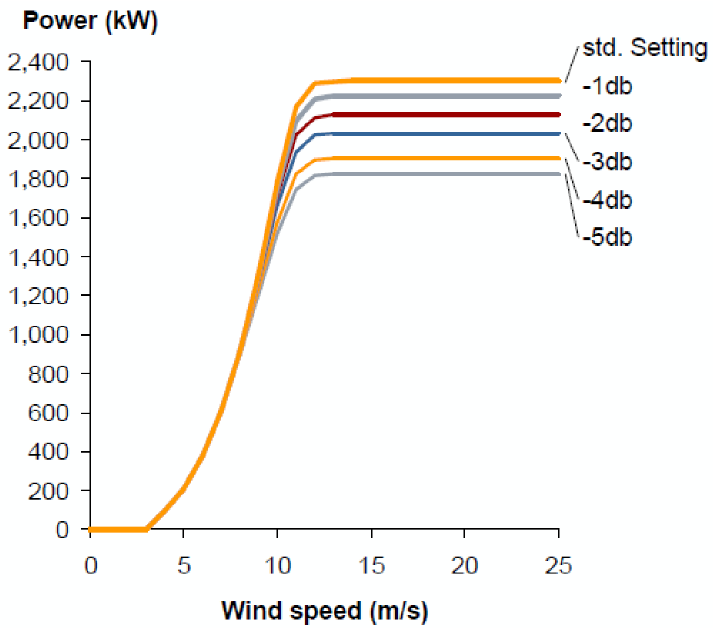
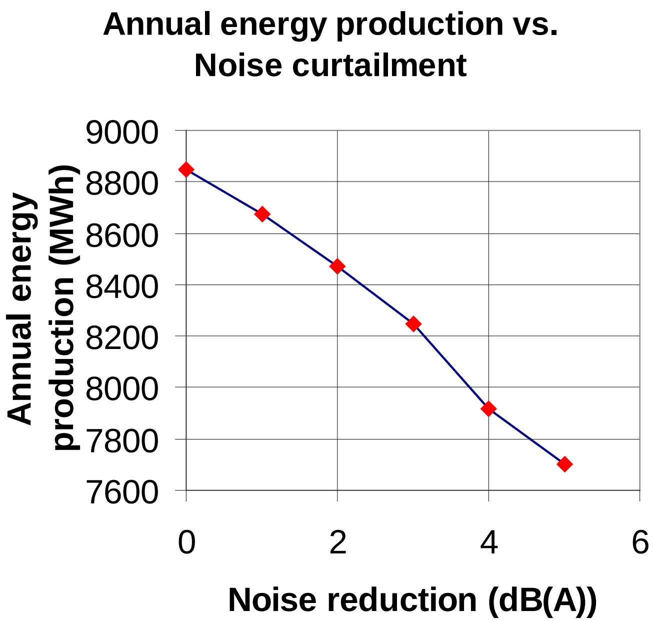
Smart controls reduce noise at minimum energy loss

- Stall regulation now replaced by pitch regulation and variable speed
- Control settings can be tailored to specific site conditions
- Cyclic pitch can alleviate azimuthal variations in inflow angle, which can reduce noise by preventing partial separation
- 1 dB noise reduction costs 2-4% annual energy production





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Design tools

- Advanced experiments
- Noise prediction tools

Acoustic wind tunnel testing

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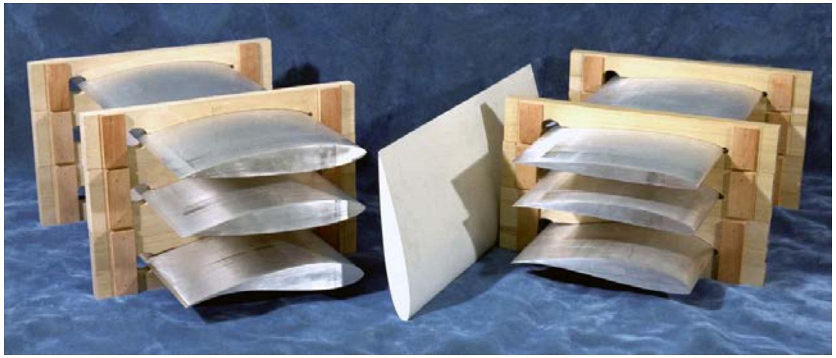
Assess acoustic performance for controlled conditions

- 2D airfoil sections and model rotors
- Acoustic and aerodynamic measurements
- Clean and turbulent inflow conditions
- Smooth and rough blade surface
- Vary flow speed and angle attack
- Design and test different add-on concepts

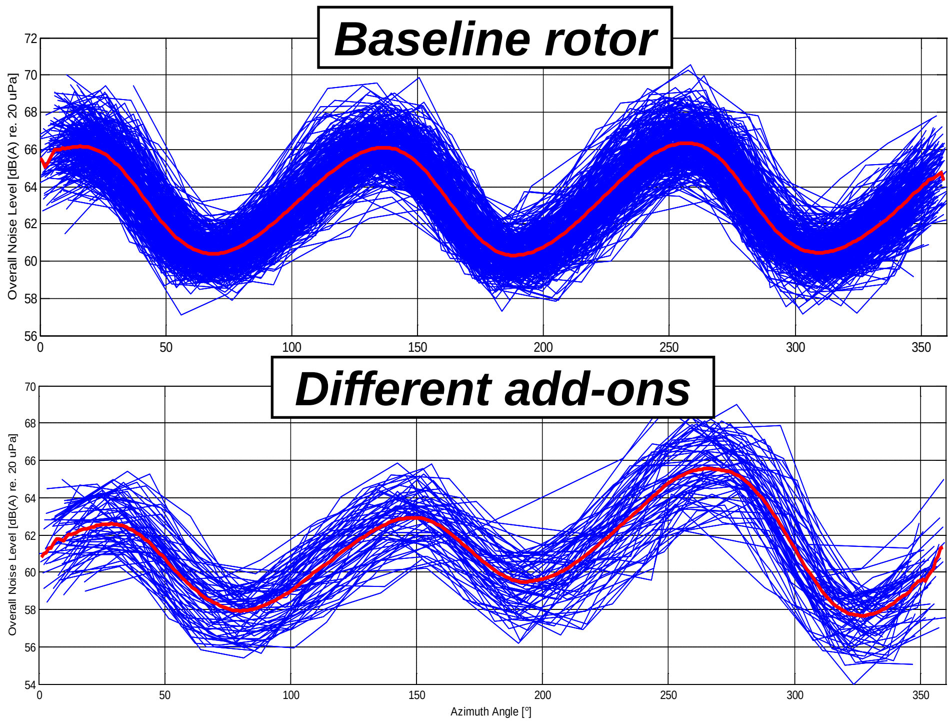


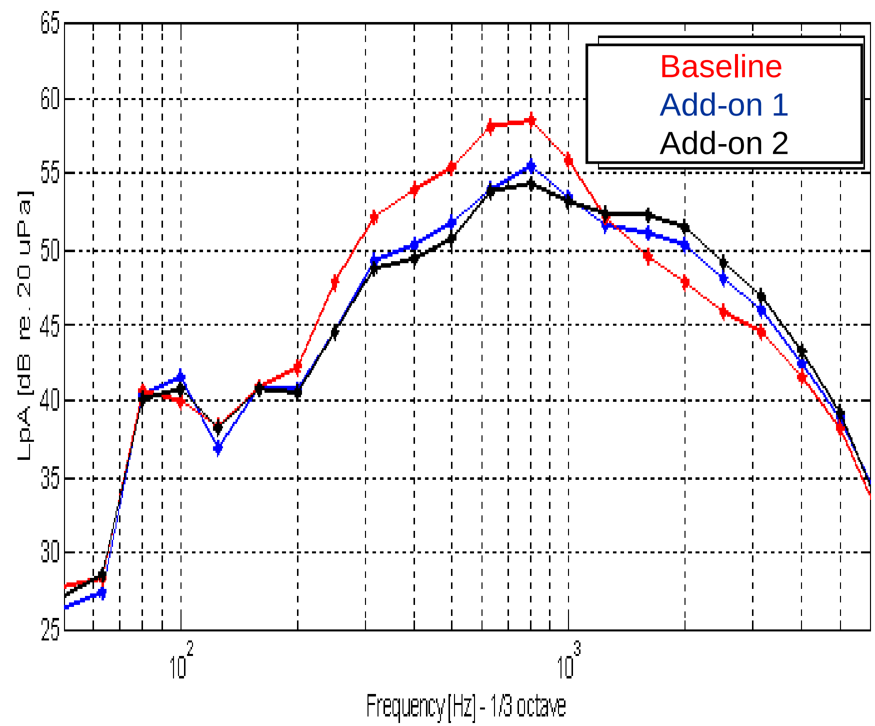
AIAA-2004-3042

Field testing: downstroke

Fast acoustic assessment of different configurations

- Relative comparison of different add-ons for identical conditions
- Measurements can be done at different positions - directivity
- Focus on noise during downstroke

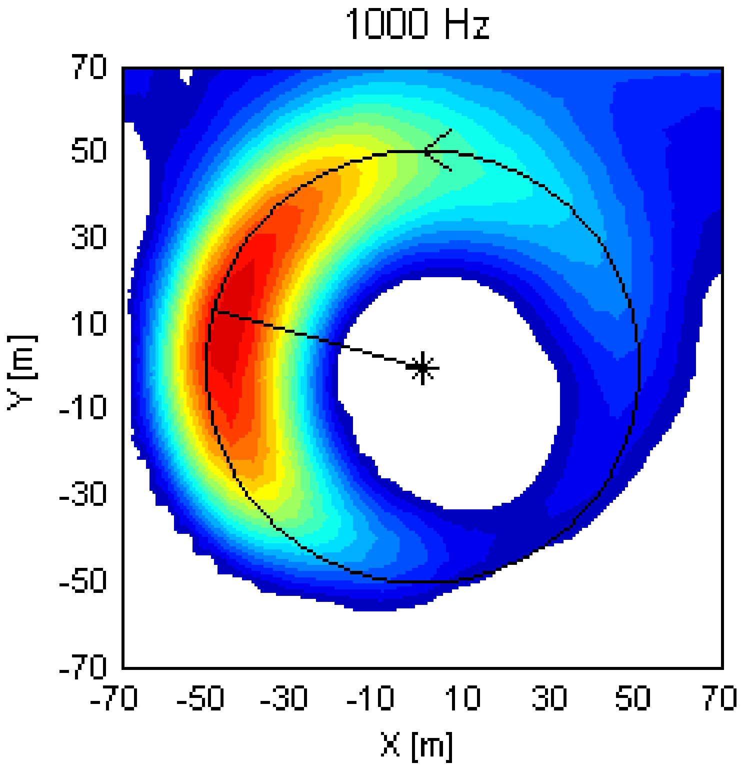




Field testing: microphone array

Acoustic assessment of complete rotor plane

- Azimuthal and radial distribution of noise sources
- Measurements can be done at different positions
- Frequency dependence of noise sources



Field testing: microphone array

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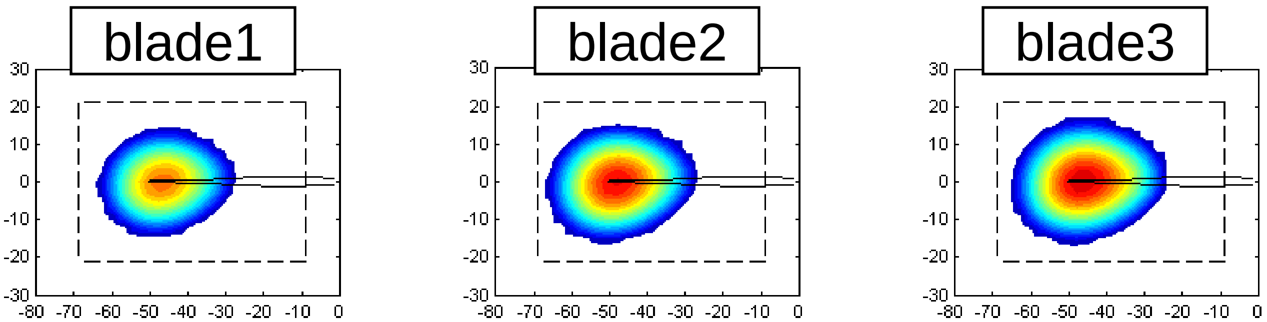
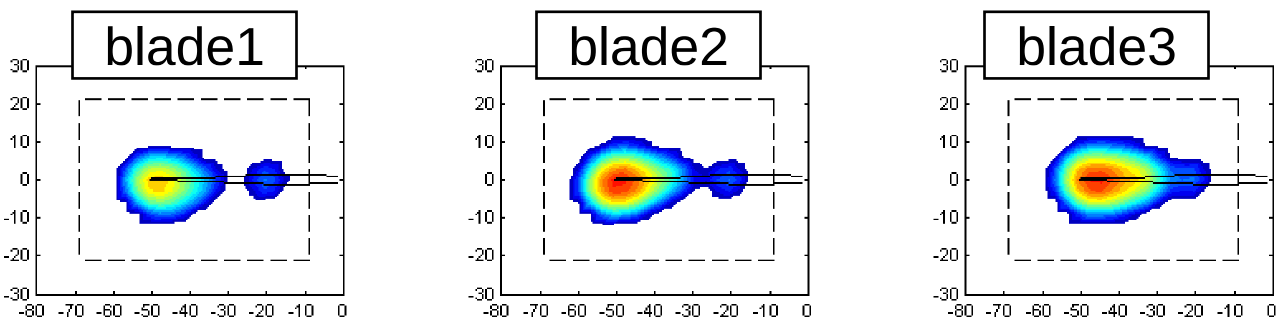
Comparison of noise from different blades

- Azimuthal and radial distribution of noise sources for each blade
- Compare blades/ add-ons for identical conditions

1250 Hz, complete revolution



2 kHz, 1 o'clock



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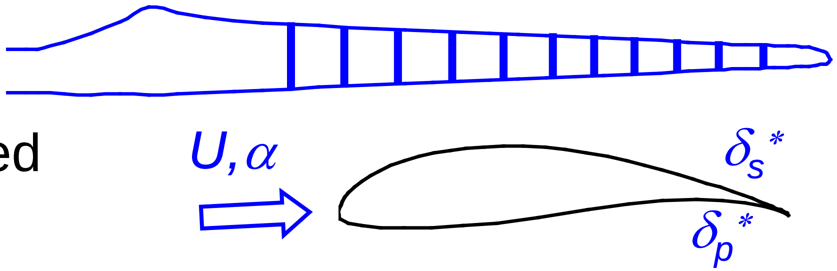
Noise prediction tools



Wind Turbine Noise (MultiScience, 2011)

Global rules of thumb

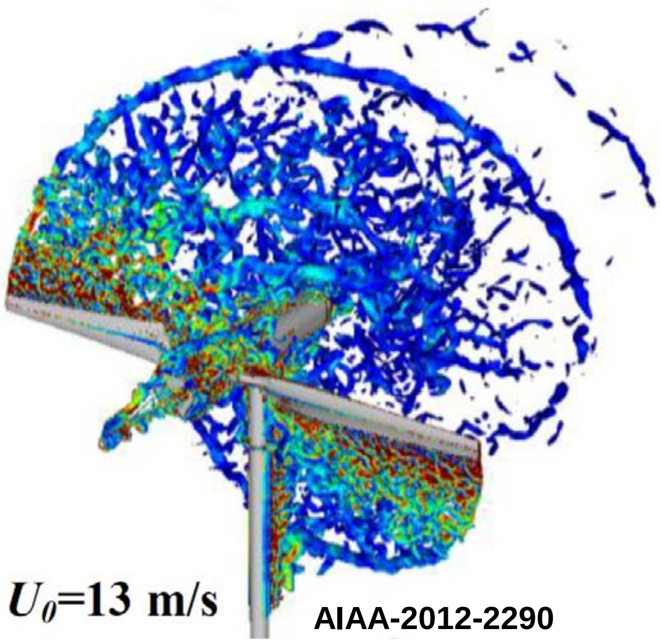
- Rough estimate based on size and speed
- Cannot be used for rotor design

Semi-analytical, semi-empirical prediction methods

- Fast and reliable estimate of rotor noise
- Useful for blade design studies
- Not all flow details are included

Numerical prediction methods

- All flow details can be included
- Long computational turn-around times
- Accuracy to be verified



AIAA-2012-2290

Conclusion

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Wind turbines have many potential noise sources

- Mechanical noise, tip noise, inflow noise, airfoil self-noise

Many noise sources can be suppressed by good design

For modern turbines the dominant noise source is trailing edge noise from the outer part of the blades

Several design options for further noise reduction

- Blade add-ons
- Smart control strategies
- Blade shape (planform, airfoils, tip design)