How Noise is Generated by Wind Turbines

The mechanisms of noise generation

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Overview

Main sources of noise from wind turbines

- Causes
- Noise generating mechanisms
- Resulting noise characteristics

Strategies used in developing quieter turbines

Potential unwanted sound from wind turbines

Higher frequencies	Swishing, lapping, hissing, whistling.
Mid frequencies	Tones, whines.
Lower frequencies	Rumble, thumping.

Principal Sources of Noise

Aerodynamic sources

Motion of air around the blades

Various sources, complex mechanisms

Mechanical sources

Motion of mechanical & electrical components

Sources are more easily identified and controlled

All sources are strongly affected by rotor speed and loading

Aerodynamic Sources

Self Noise

Generally higher frequencies

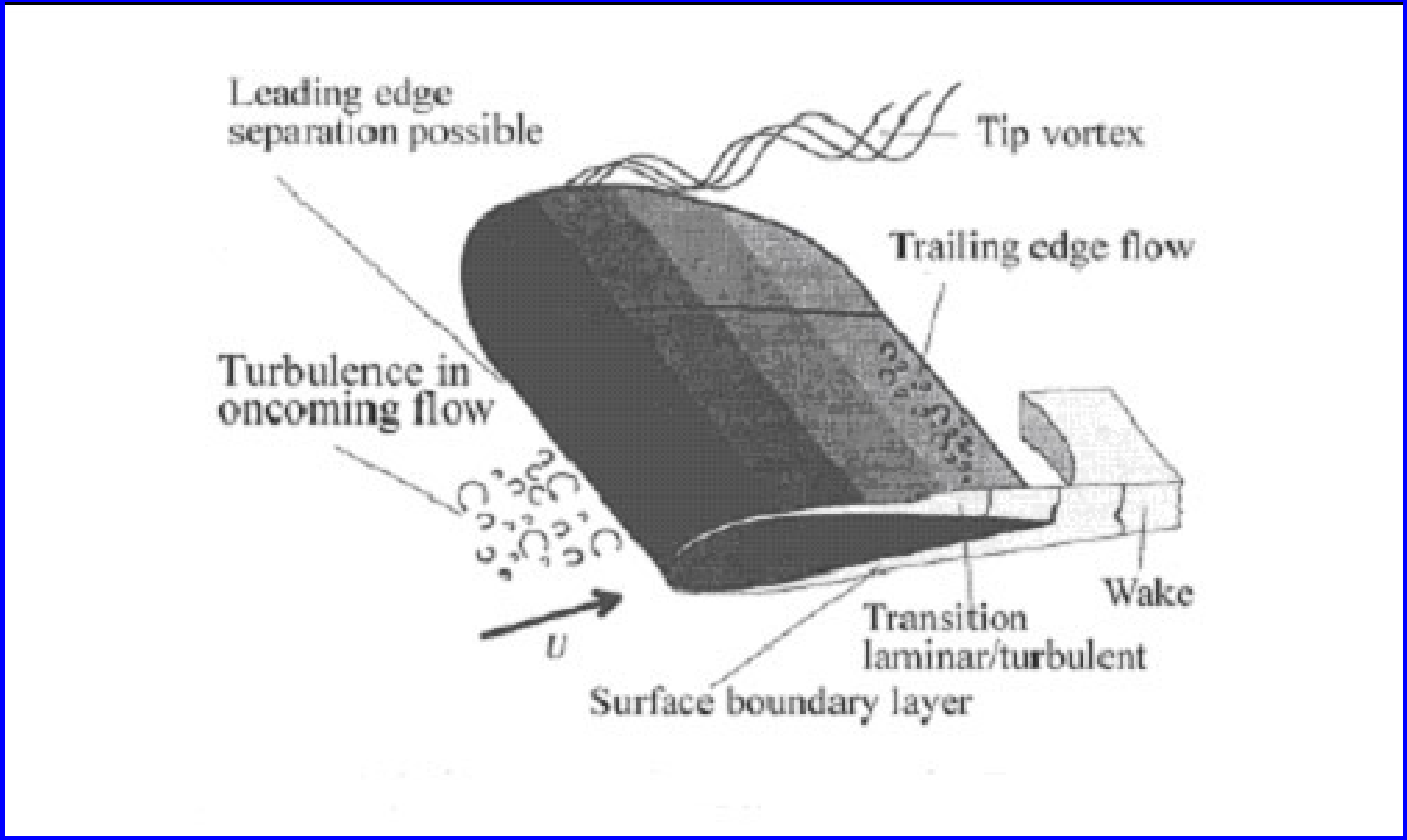
Dominant at lower wind speeds

In-flow Turbulence

Lower frequencies

Dominant at higher wind speeds

Aerodynamic Sources

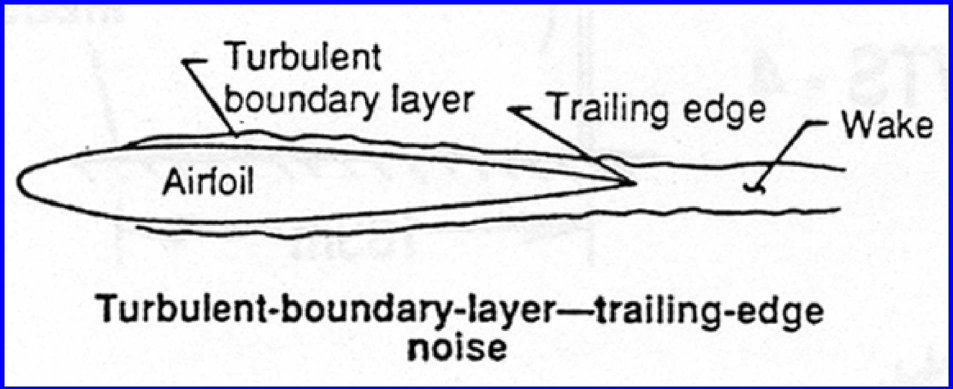


Source 'Wind Turbine Noise' Warner,Bareiß & Guidati

Aerodynamic Sources

Trailing Edge Noise

Turbulent boundary layer interacts with trailing edge



Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Broadband and the main source of high frequency noise

Component of blade swish noise

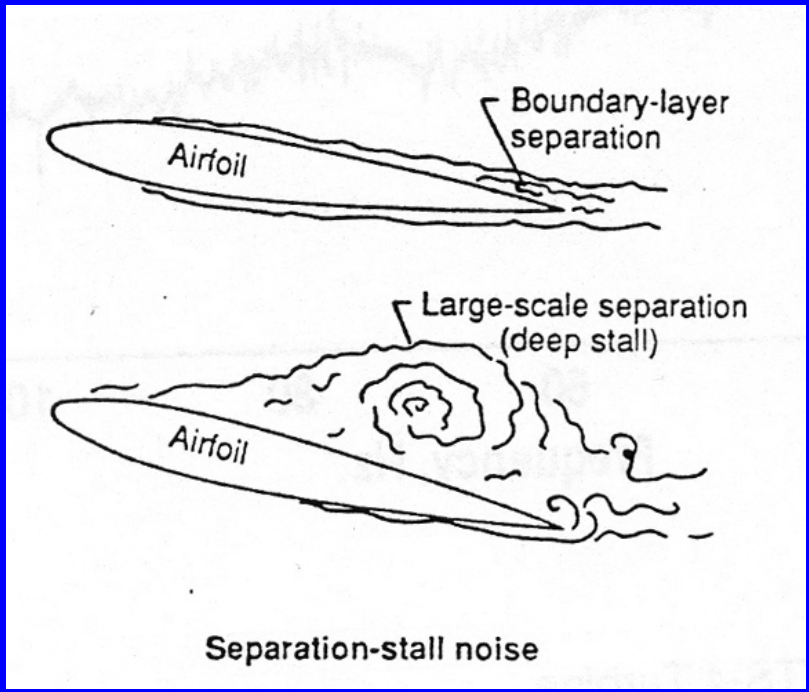
Minimised through design of the aerofoil section at trailing edge

Aerodynamic Sources

Separation-stall Noise

Separated boundary layer becomes turbulent and interacts with blade surface

Increases with angle of attack



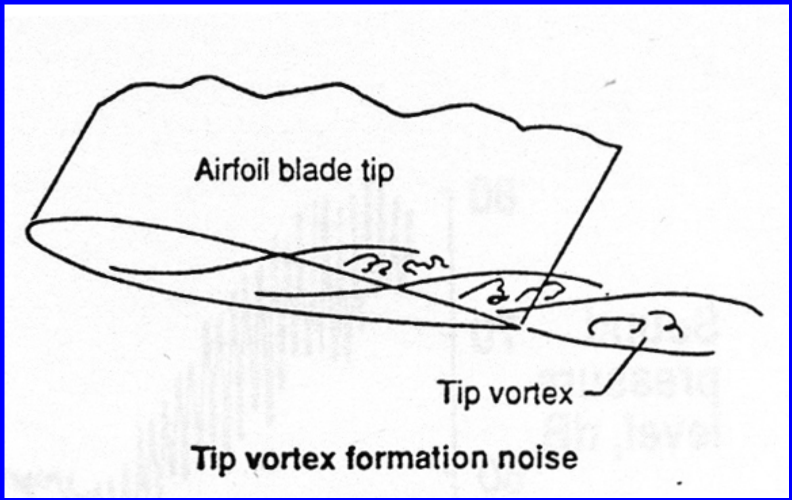
Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Minimised by blade pitch regulation

Aerodynamic Sources

Tip Vortex Formation

Separated vortex flow interacts with blade surface



Source 'Assessment & Prediction of Wind Turbine Noise'
M.V. Lowson

Broadband ~ 2 to 3 kHz

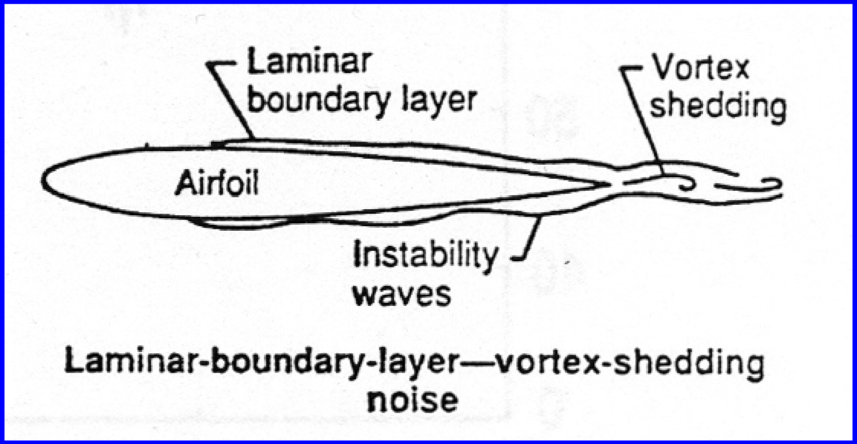
Component of blade swish

Minimised through design of the tip shape

Aerodynamic Sources

Laminar Boundary Layer Vortex Shedding

Instability in separated laminar flow from lower edge of blade



Source 'Assessment & Prediction of Wind Turbine Noise'
M.V. Lowson

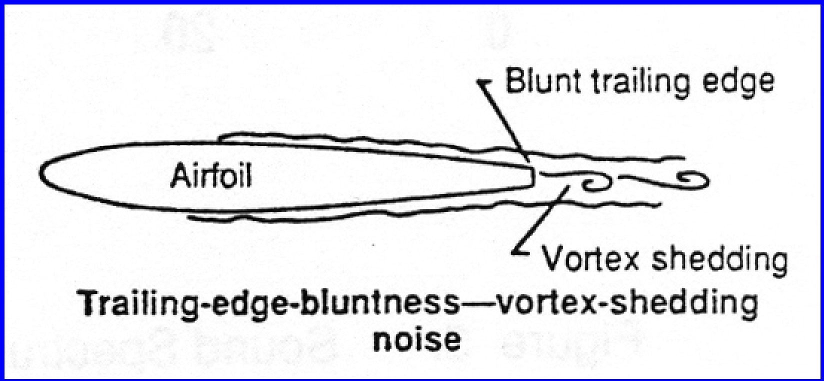
Tonal - typically around 3 kHz

Minimised by preventing separation through design of the blade

Serrated leading edge of aerofoil found to be effective

Aerodynamic Sources

Trailing Edge Bluntness Vortex Shedding



Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Instability in wake due to thickness of trailing edge

Tonal ~ 2 kHz

Component of blade swish

Minimised by using a sharper blade profile

Aerodynamic Noise

Blade Swish

Rhythmic modulation of aerodynamic noise

Audible close to the turbines

Amplitude and frequency varies with blade passage as aspect of sources change relative to observer

Variation in source characteristics may be augmented by in-flow turbulence, yaw error and high wind shear

Increasingly less distinct as distances from the turbine increases

Significant factor of reported annoyance

Aerodynamic Noise

Blade Swish

Source: Localisation and Quantification of Noise Sources on a Wind Turbine:Oerlemans & Lopez

Figure 1: Test set-up with G58 turbine and microphone array platform. The noise sources in the rotor plane (averaged over several rotations) are projected on the picture.

Aerodynamic Noise

Blade Swish

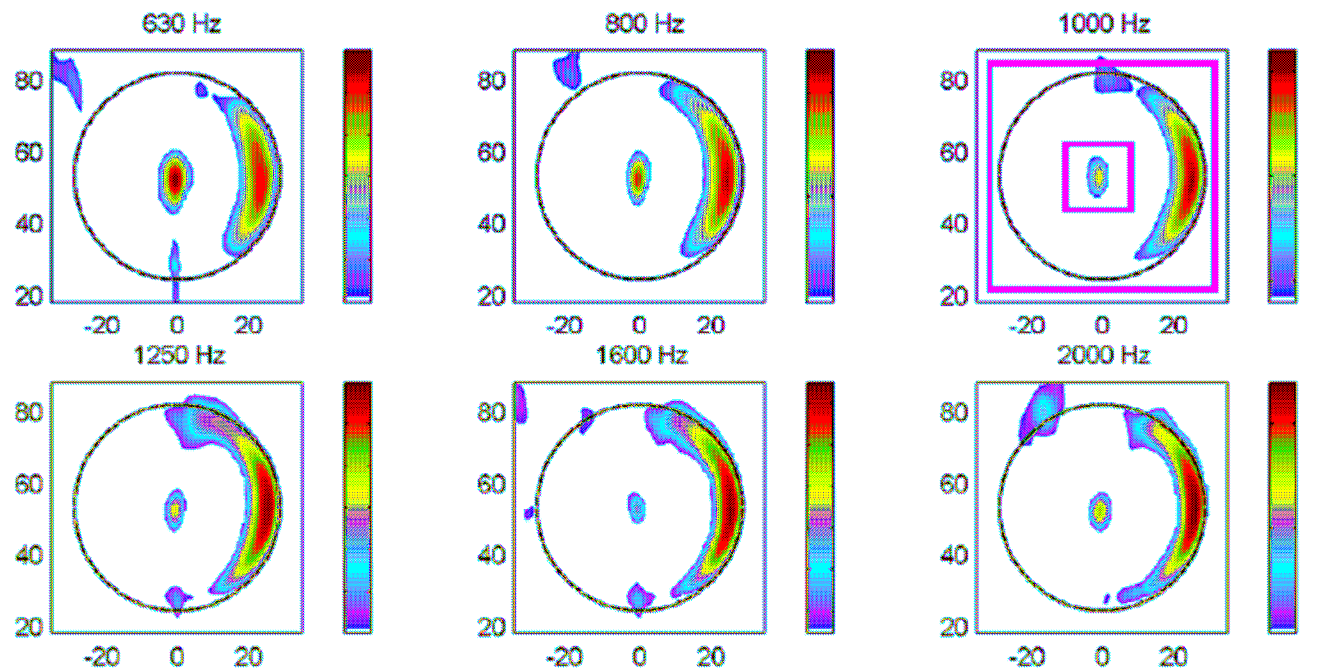


Figure 3: Typical example of noise source locations in the rotor plane, as a function of frequency. The trajectory of the blade tips is indicated by the black circle. The range of the color scale is 12 dB. The pink lines (1 kHz) indicate the integration contours for the quantification of blade and hub noise.

Source: Localisation and Quantification of Noise Sources on a Wind Turbine:Oerlemans & Lopez

Aerodynamic Noise

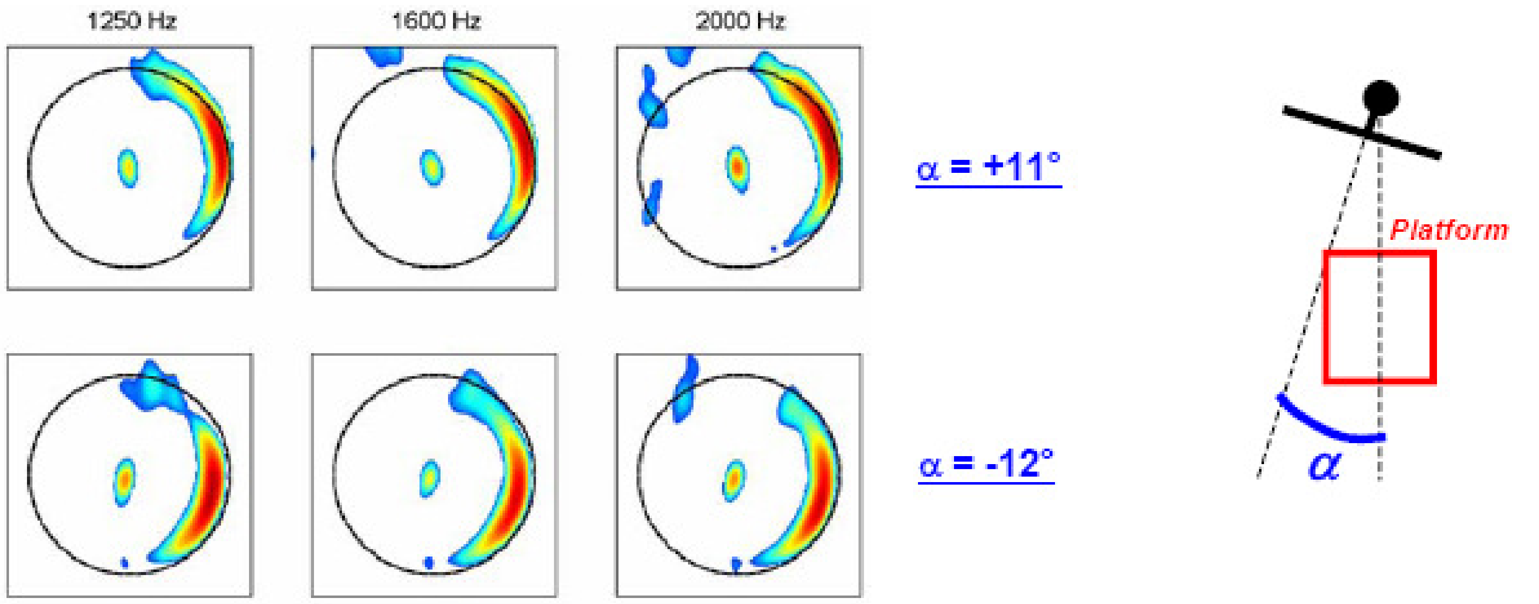


Figure 4: Shift of blade noise location due to difference in misalignment angle α.

Source: Localisation and Quantification of Noise Sources on a Wind Turbine:Oerlemans & Lopez

Aerodynamic Noise

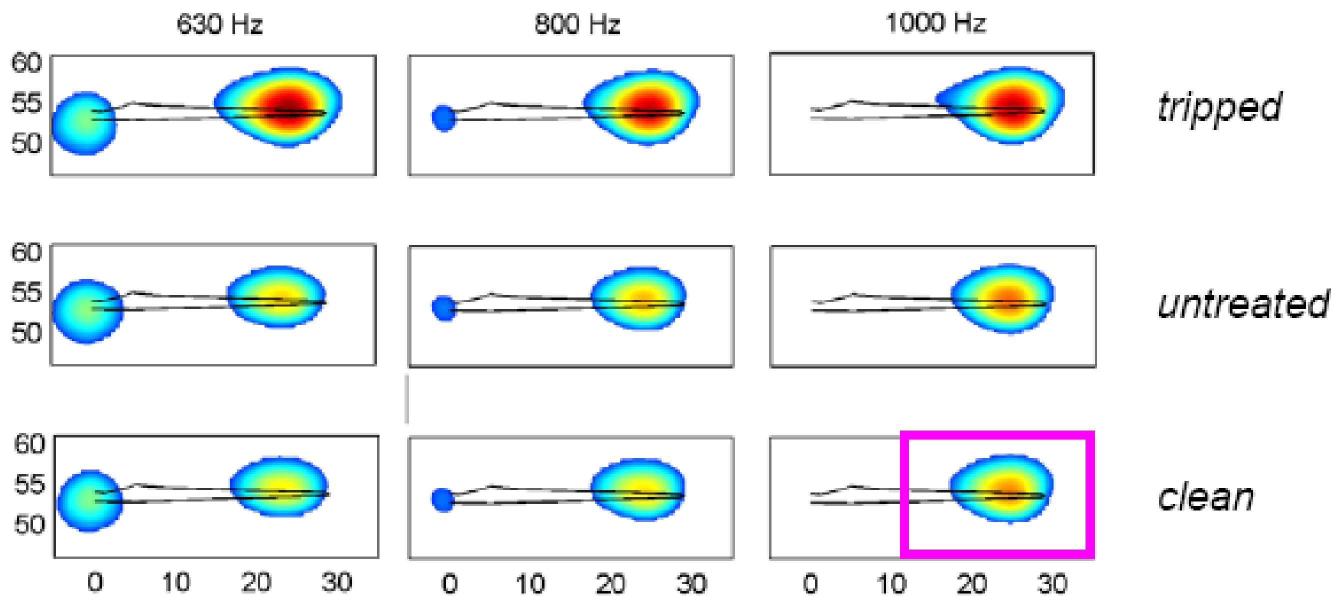


Figure 7: Averaged acoustic source plots showing the noise sources on the individual blades. The black line indicates the blade contour (leading edge on lower side). The range of the color scale is 12 dB and the color scale is the same for the three blades. The pink line (1 kHz) indicates the integration contour used for the quantification of the blade noise.

Source: Localisation and Quantification of Noise Sources on a Wind Turbine:Oerlemans & Lopez

Aerodynamic Noise

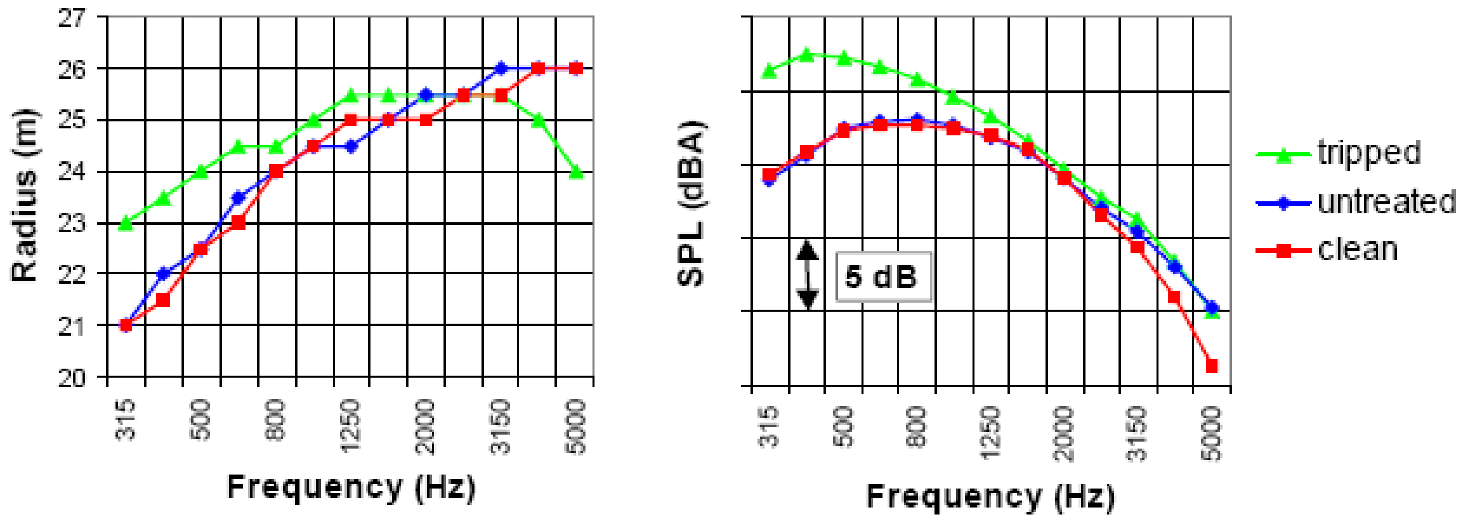


Figure 8: Average source location (left) and noise spectra (right) for the three blades.

Source: Localisation and Quantification of Noise Sources on a Wind Turbine:Oerlemans & Lopez

Aerodynamic Sources

In-Flow Turbulence

Blades respond to atmospheric turbulence caused by

- Nacelle yaw error
- Gradients of in-flow velocity due to high wind shear
- Wake effects from topographical features or turbines

Broadband but generally below 1 kHz

Minimised by optimal turbine positioning and separation

Aerodynamic Sources

Infrasonic noise

Below normal audible range

Characteristic of older passive yaw turbines in the USA with the rotor downwind of the supporting tower

Blades pass through wake from tower

Pressure pulsations related to blade passing frequency and harmonics

Levels produced by a modern wind farm significantly below perception threshold (order of –30 dB on site)

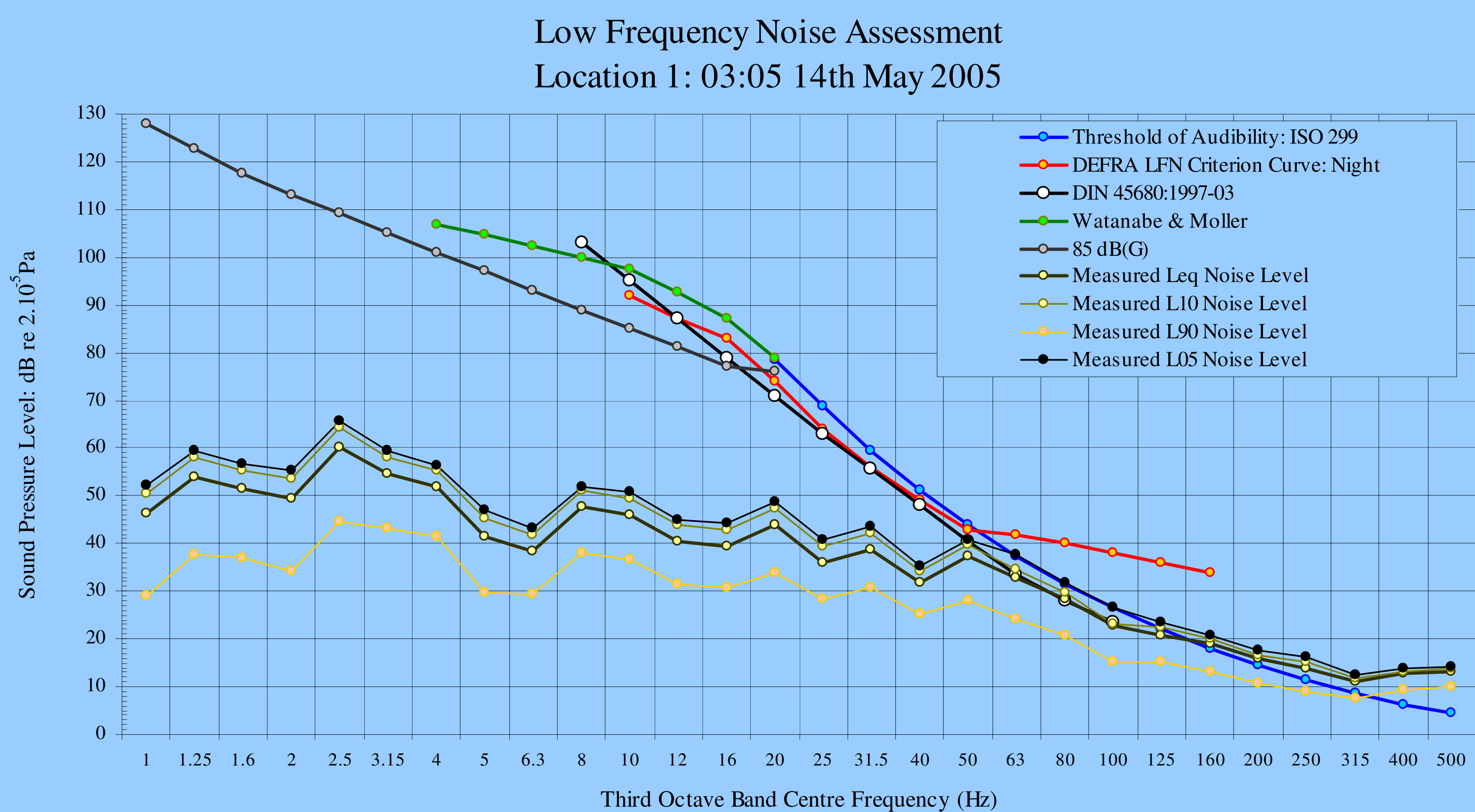
Turbulent wind conditions generate high background levels of infrasound

Aerodynamic Sources

Low frequency noise

- Overall turbine noise is broadband
- Noise level decreases as distance from the turbines increases due to geometric spreading of sound energy
- Atmospheric absorption attenuates high frequencies at a higher rate with distance than lower frequencies
- Noise spectrum becomes biased towards spectral regions dominated by in-flow turbulence
- Overall received level becomes increasingly insignificant compared to residual noise

Infrasound and Low Frequency Noise



Aerodynamic Sources

Mitigation in general

Reduce tip speed

- Aerodynamic sources typically proportional to $(\text{tip speed})^5$
- Increased rotor torque » increased turbine weight and cost

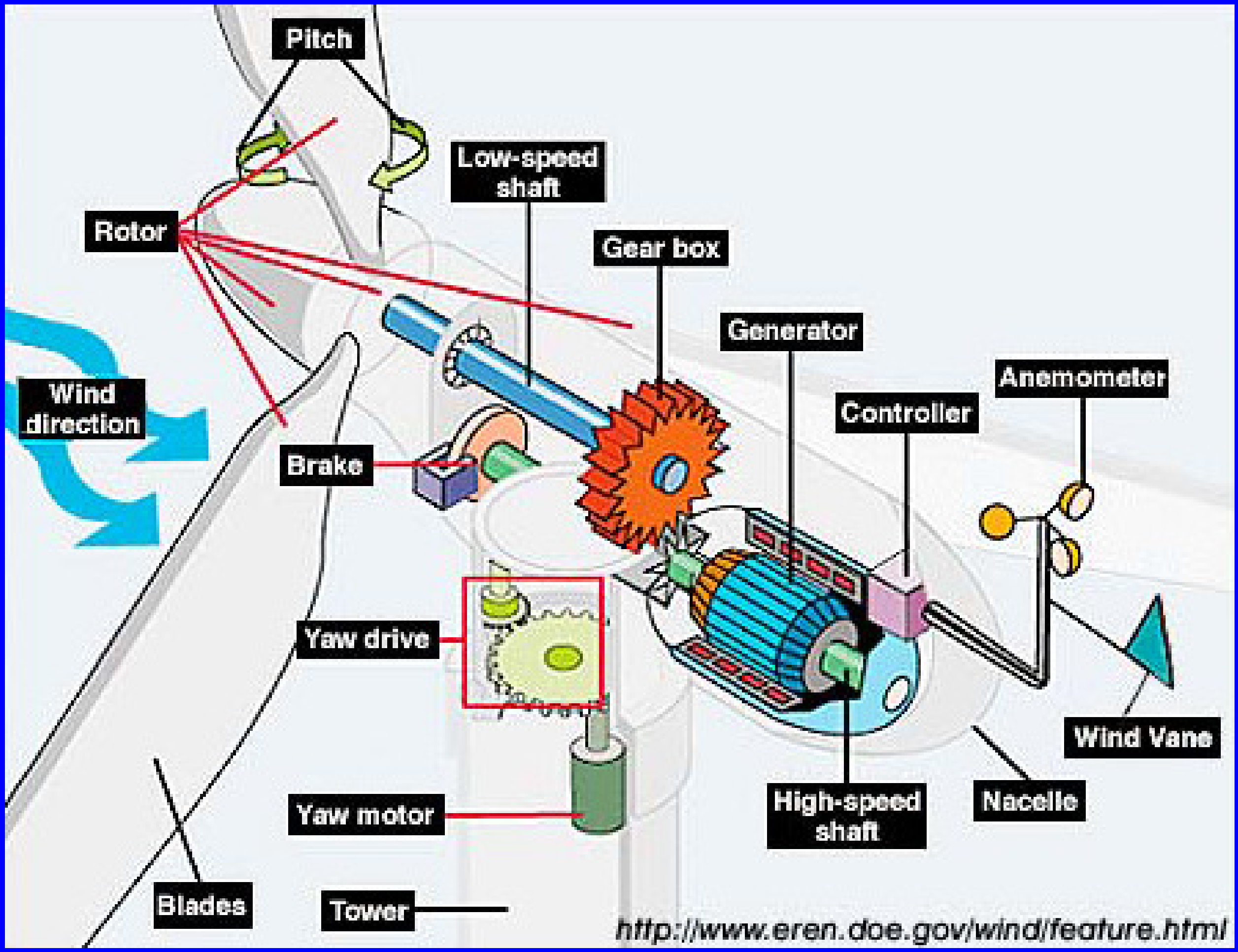
Blade pitch regulation

- Optimise angle of attack to prevent mechanisms developing

Improved blade design and condition

- Boundary layer trips prevent instabilities
- Clean surfaces, patch holes
- Noise modelling in development of blade design

Mechanical Sources



Mechanical Sources

Gearbox

Generator

Yaw drive

Cooling system

May have significant tonal elements

Mechanical Sources

Gearbox noise sources

Originating from gear train at tooth mesh frequencies

Low speed shaft mesh	High speed shaft mesh
< 100 Hz	~ 400 to 800 Hz

Misalignment of high speed shaft between gearbox & generator

~ 25 to 30 Hz

Mechanical Sources

Gearbox noise sources

Vibration of the drive train in gearbox and shafts transmitted into supporting structure

Noise radiated by nacelle housing, tower or blades

Mitigation

Treat sources: Quieter gearbox design, maintenance

Treat transmission paths: resilient couplings, mountings

Treat radiating surfaces: blade damping treatments etc

Direct drive: no gearbox - hub coupled directly to generator

Mechanical Sources

Generator noise source

Vibration due to coil flexure of the generator windings

Yaw and pitch drive

Noise from hydraulic compressors

Cooling system

Noise from fans

Oil cooling may be quieter than electric fans

Summary

Aerodynamic Noise
- In-Flow Turbulence
- Self Noise

Turbine Positioning & Control, Blade Design

Mechanical Noise
- Gearbox
- Generator
- Yaw & Pitch Drives
- Cooling System

Gearbox Quality

Vibration Isolation

Damping

Maintenance