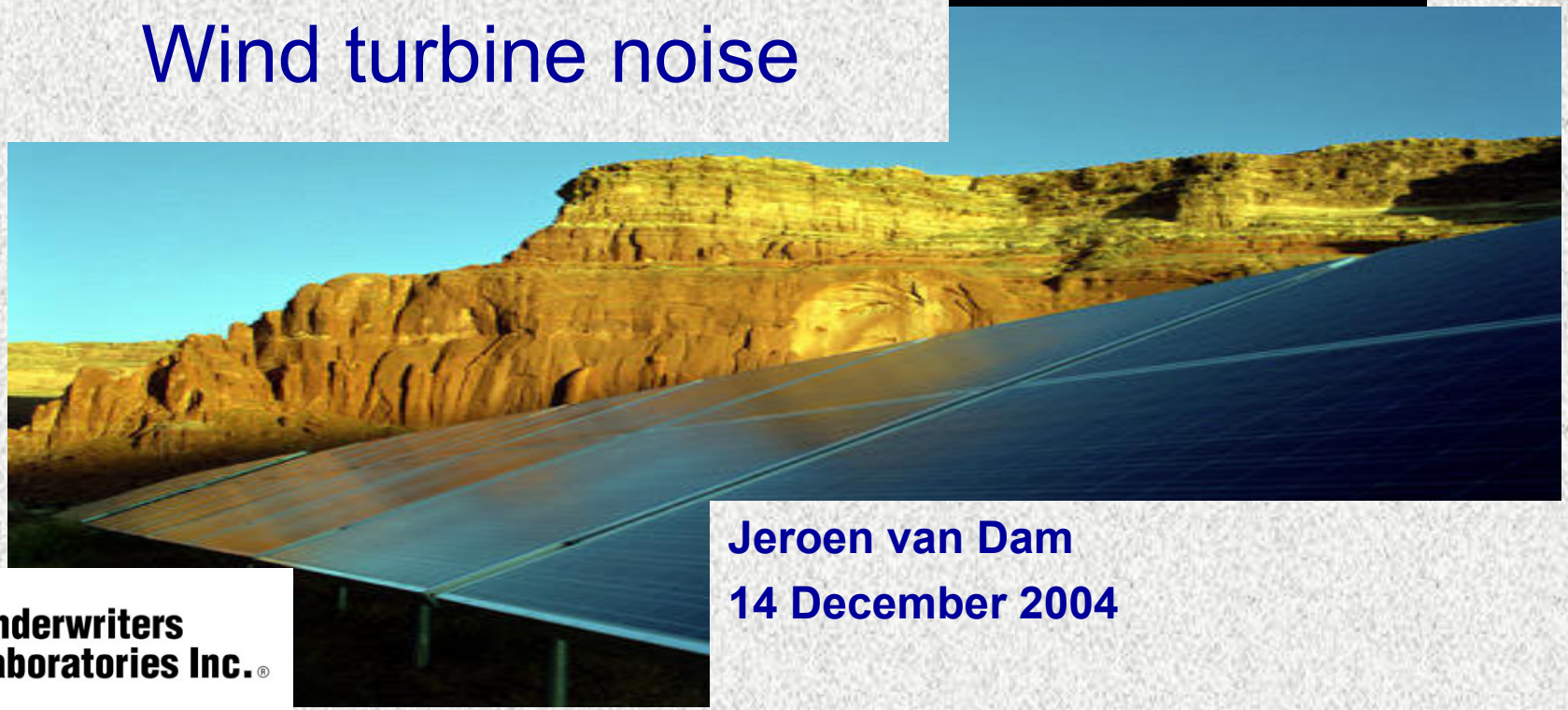
Wind turbine noise



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Underwriters Laboratories Inc.®

Contents

- Brief terminology
- Measurement techniques and results
- Examples of allowable levels

Sound power vs. sound pressure

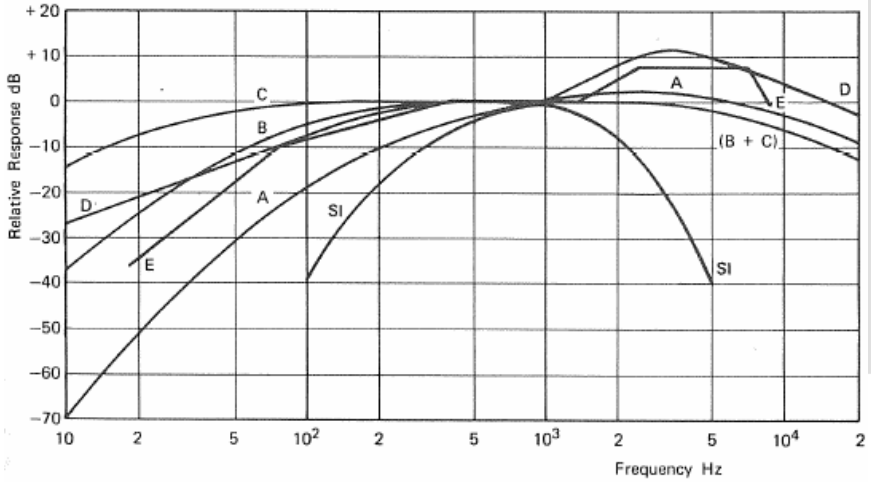
- Sound power level is a measure of the *source* strength; typical values 90-105 dB(A)
- Sound pressure level is a measure of the level at a receptor (neighbor, microphone); typically <45 dB(A)

Source/Activity	Indicative noise level dB (A)
Threshold of hearing	0
Rural night-time background	20-40
Quiet bedroom	35
Wind farm at 350m	35-45
Car at 40mph at 100m	55
Busy general office	60
Truck at 30mph at 100m	65
Pneumatic drill at 7m	95
Jet aircraft at 250m	105
Threshold of pain	140

Information taken from The Scottish Office, Environment Department, Planning Advice Note, PAN 45, Annex A: Wind Power, A.27. Renewable Energy Technologies, August 1994

dB scale

- dB scale is a logarithmic scale:
  - Doubling distance to turbine reduces sound pressure level 6dB
  - Two turbines produce 3dB more then one turbine.
  - Examples:
    - 40dB(A) + 40dB(A) = 43dB(A)
    - 40dB(A) + 45dB(A) = 46dB(A)
- A-weighting compensates for sensitivity of human ear



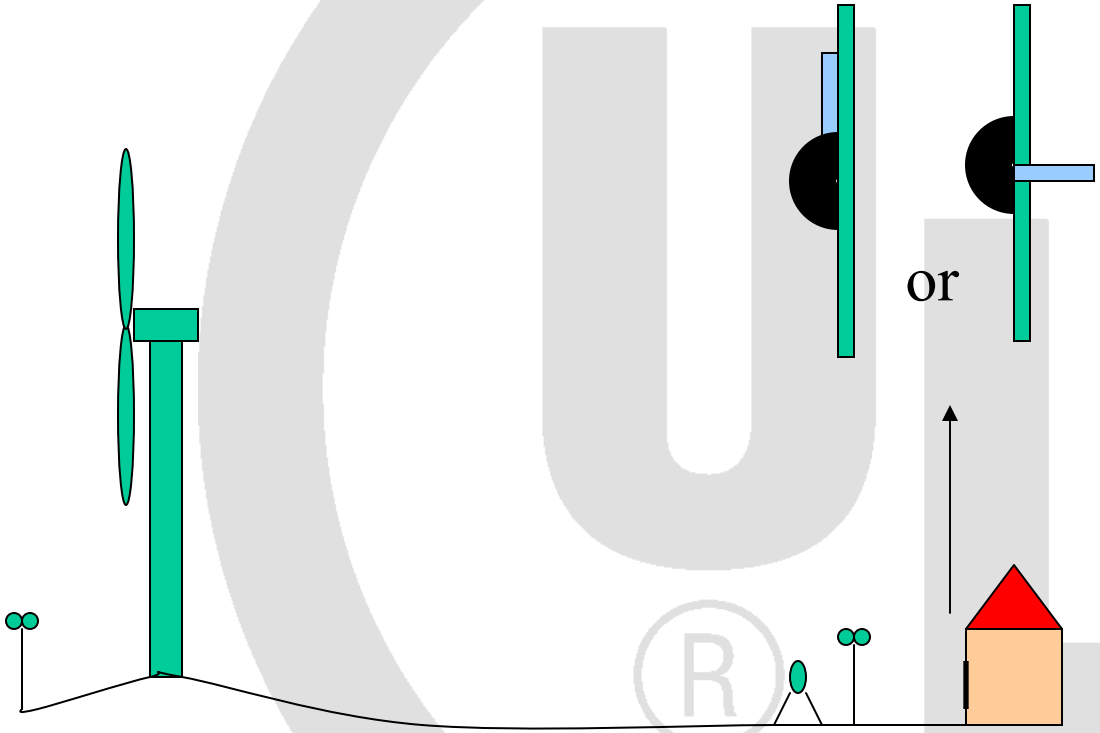
Source: Acoustic noise measurements, Bruel & Kjaer

Measurement techniques

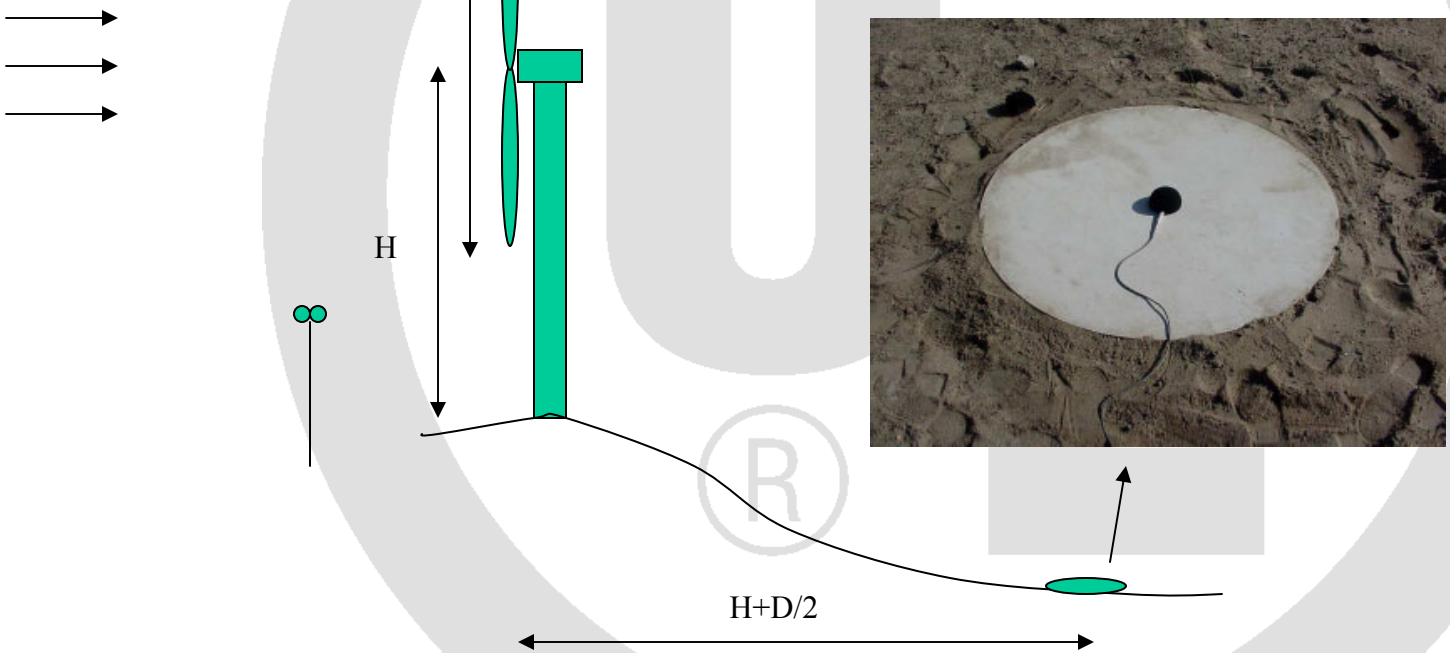
- IEC 61400-11, 2nd edition. Wind turbine noise measurement techniques
- IEA recommended practices for wind turbine testing, part 10 “Measurement of noise immission from wind turbines at noise receptor locations”

- Measuring the source and calculating immission is typically preferred.
- IEC method used for certification of a turbine type

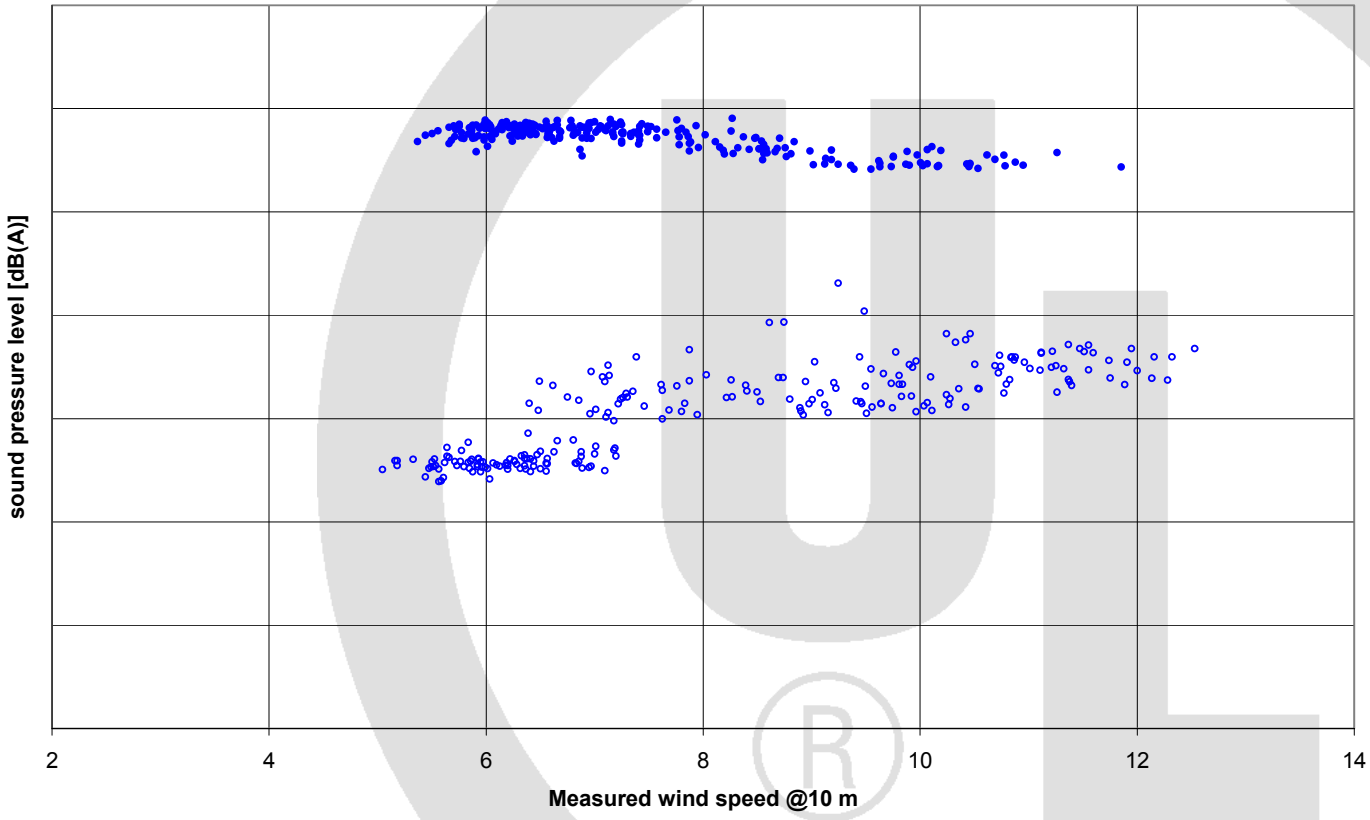
IEA method



IEC 61400-11 method



Results


sound pressure level [dB(A)]
2
4
6
8
10
12
14
Measured wind speed @10 m

Sound power level

- Background correction

$$Ls = 10\log\left[10^{0.1L_{s+n}} - 10^{0.1L_n}\right]$$

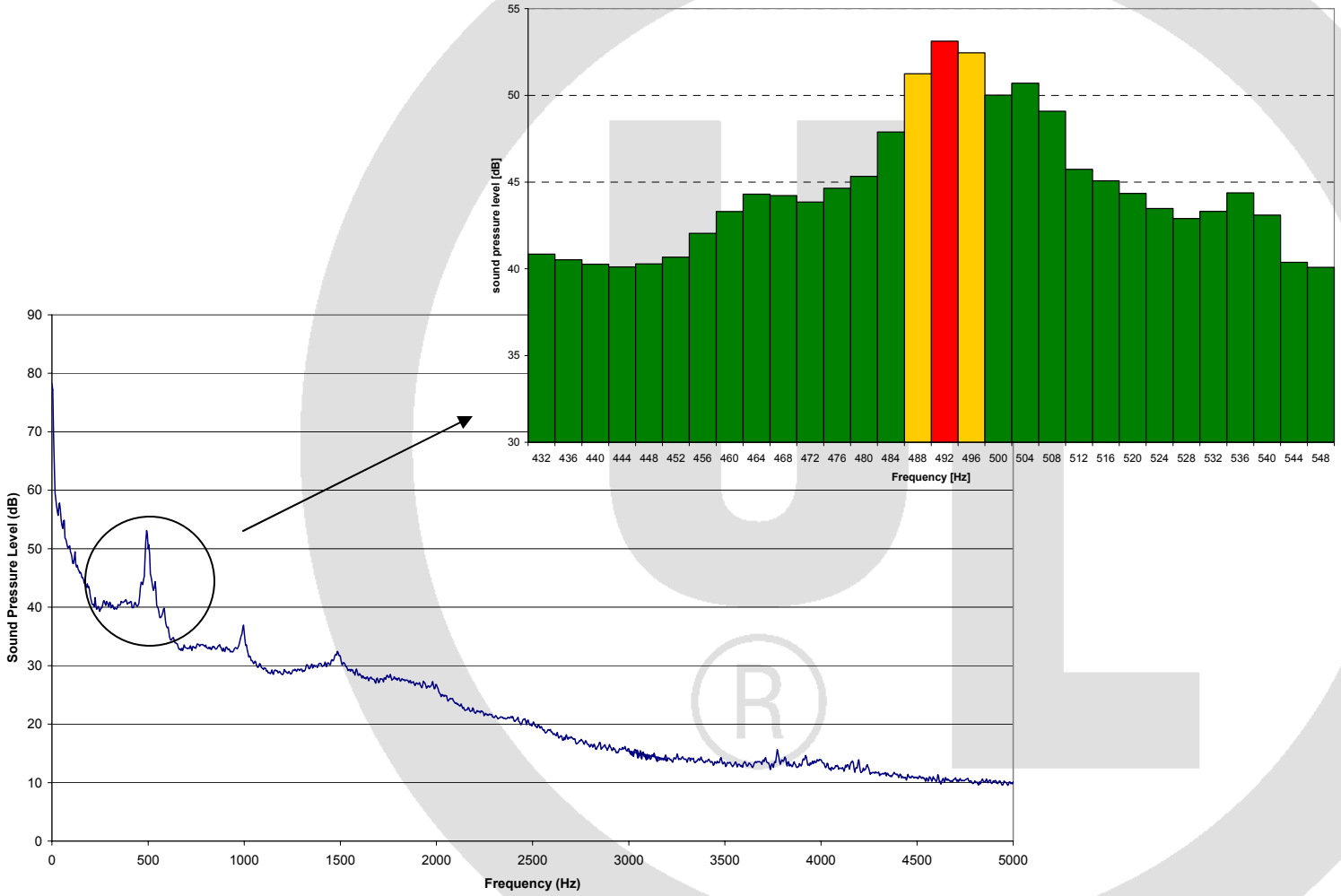
- Obtain apparent sound power level from background corrected sound pressure level

$$L_{WA} = L_{Aeq,c} - 6 + 10\log\left[\frac{4\pi R_1^2}{S_0}\right]$$

Results

- For wind speed range 6-10 m/s:
  - Apparent sound power level
  - 1/3rd octave spectra
  - Directivity (optional)
  - Tonality

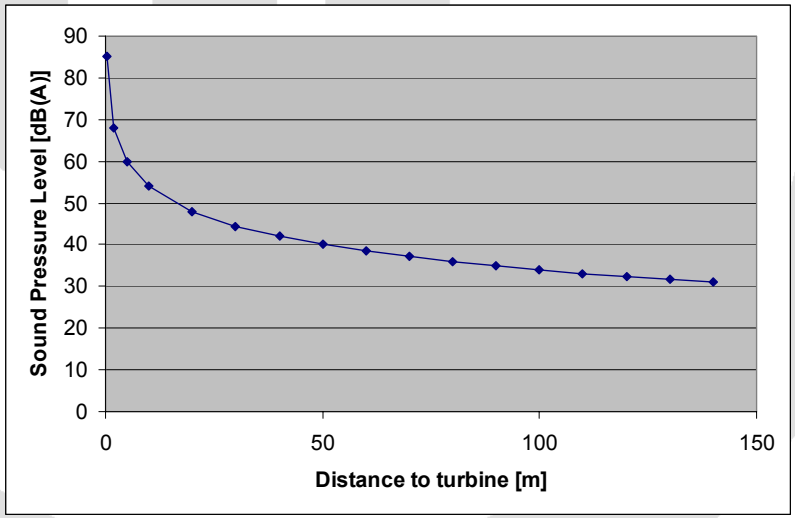
Tonality


sound pressure level [dB]
55
50
45
40
35
30
432 436 440 444 448 452 456 460 464 468 472 476 480 484 488 492 496 500 504 508 512 516 520 524 528 532 536 540 544 548
Frequency [Hz]
Sound Pressure Level (dB)
90
80
70
60
50
40
30
20
10
0
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
Frequency (Hz)

Noise propagation

- Simple models, spherical or semispherical spreading, input: sound power level
- Semi complex, frequency dependence, input: octave or 3rd octave spectrum
- Complex, includes wind shear, input: 3rd octave spectrum

- Shortcomings: Turbulence
- Country dependent



Examples of allowable noise regulations

- Denmark:
  - 45 dB(A) for single residence,
  - 40 dB(A) for groups of residences,
  - 5 dB(A) penalty for prominent tones
- Germany:
  - Commercial: 65 dB(A), 50 dB(A) (day, night)
  - Mixed: 60 dB(A), 45 dB(A)
  - Residential: 55 dB(A), 40 dB(A)
  - Rural: 50 dB(A), 35 dB(A)
  - penalty for tones
- Sweden:
  - industrial\commercial 60, 55, 50 (day, evening, night).
  - Residential: 50, 45, 40
  - recreational: 40, 35, 35
  - 5dB(A) penalty for tones

Examples of allowable noise regulations cont'd

- Netherlands, guideline:
  - Background noise dependent, base line 40dB(A) at 1m/s, 50dB(A) at 12m/s
- France:
  - 5dB increase of background noise (3dB(A) at night)
- UK, guideline:
  - Maximum of (background noise + 5dB(A)) or 35-40 dB(A) day
  - Maximum of (background noise + 5 dB(A)) or 43dB(A) at night
  - 2-5dB(A) penalty for tones
- Greece, law nr 2280:
  - industrial: 70 dB(A),
  - mainly industrial 65dB(A)
  - mixed industrial and residential: 55dB(A)
  - mainly residential: 50dB(A)
  - inside dwelling with open windows: 45 dB(A),
  - Penalties for tonality up to 6 dB(A)

Examples of allowable noise regulations cont'd

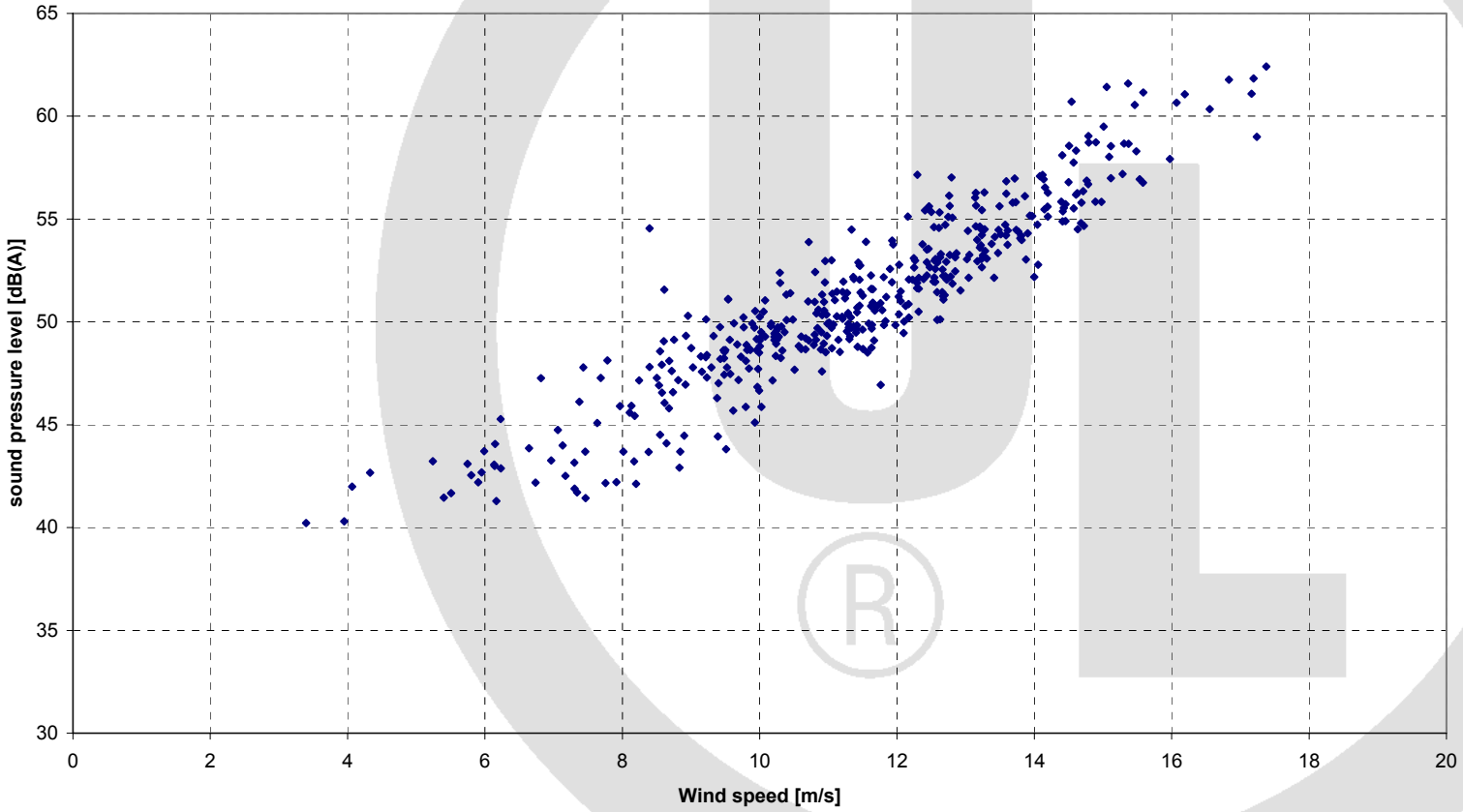
- USA:
  - Varies state by state, county by county,
  - California Assembly Bill 1207: SWT shall not exceed 60dB(A) at nearest dwelling except for short term events

Perception

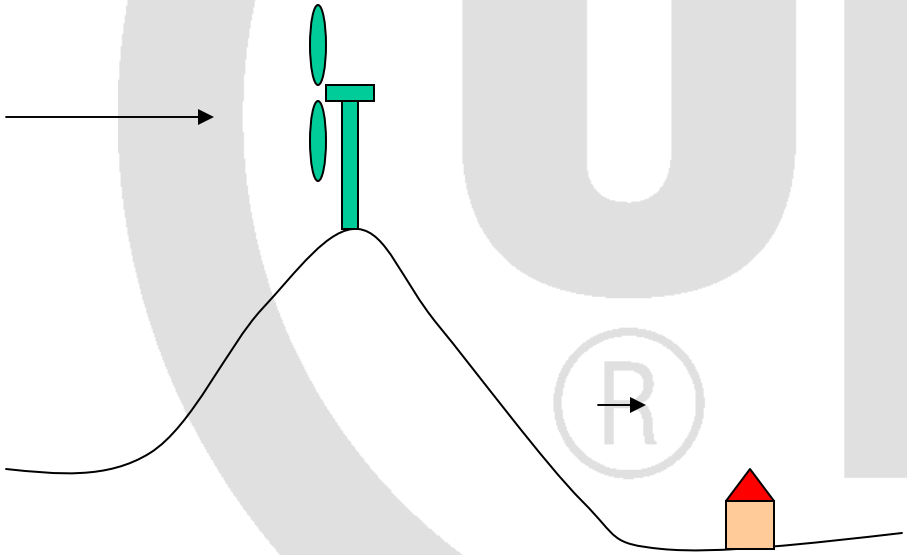
- Sound quality:
  - Amplitude variations
  - Intermittent noises (yaw actions, stops, starts)
  - Tonality
- Psycho-acoustics
  - Ownership
  - Control
  - Human ear smarter then microphone
  - “Psycho-acoustics, facts and models” E. Zwicker, H. Fastl

Background noise

- Back ground noise increases with wind speed
- Typical levels 30-45dB(A)

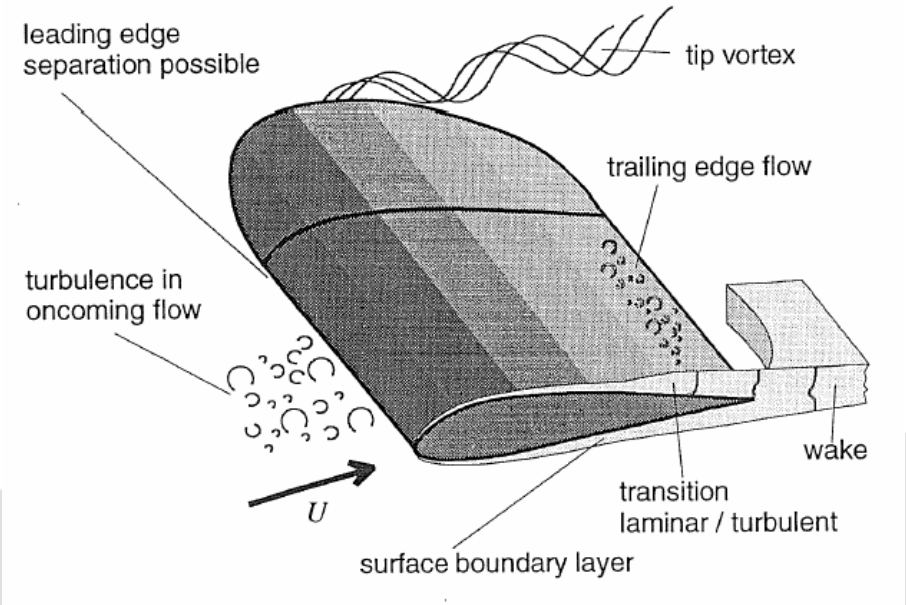


Background noise



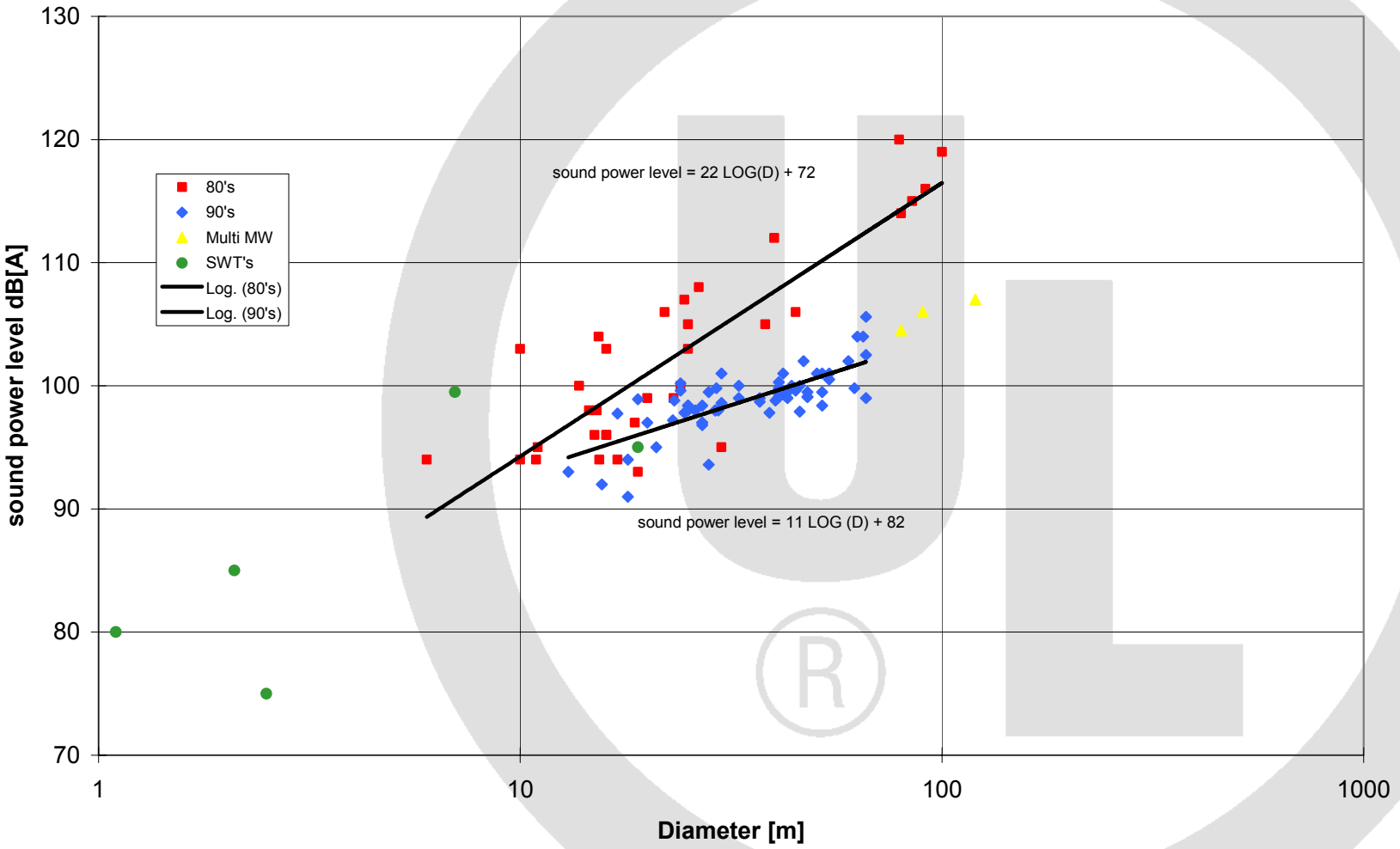
Noise sources

- Gearbox
- Cooling fans
- Generator
- Power converter
- Hydraulic pumps
- Yaw motors
- Bearings
- Blades



Source: “Wind turbine noise” Wagner, Bareiß, Guidati

Development



SWT's

- High rpm with more variation
- Less sophisticated controls
- Flutter
- Closer to dwellings, sometimes on houses
- No cut out wind speed
- References:
  - P. Migliore, J. van Dam, A. Huskey "Acoustic tests of small wind turbines", January 2004, NREL CP-500-34662
  - Paul Gipe, www.wind-works.org

Conclusions

- Turbines make noise
  - Typically both turbine noise and background noise increase with wind speed
- Noise level is not the only important measure
  - Sound quality
  - Psychological effects
- Planning is key