Wind Turbines

Larry Caretto
Mechanical Engineering 496ALT

Alternative Energy

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Outline

- Wind profiles and their effects
- Turbine capacity factor
- Turbine power controls
- Effect of rated power per unit rotor area
- Tip speed ratio
- Turbine power calculator
- Environmental effects

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Wind Change with Elevation

- Wind speed is zero at ground level
- Simple equation for wind speed at height, z, relative to reference elevation, z_r, is $v(z) = v(z_r)(z/z_r)^a$
  - Value for a varies with area (urban *vs*. rural) and day *vs*. night
  - Can be determined in terms of atmospheric stability conditions
  - Default value is a = 1/7
    - Heinshon and Kabel, *Air Pollution*, 1999

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Wind Change with Elevation II

- Roughness length, r = z_0, accounts for rough terrain effects
  - z_0 is effective elevation where wind speed is zero (instead of ground at z = 0)
- Equation for wind speed at height, z, relative to reference elevation, z_r, is $v(z) = v(z_r) \ln(z/z_0) / \ln(z_r/z_0)$
  - Assumes neutral stability (ground neither heated or cooled)

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Roughness Parameters

- Open water (r = 0.0002 m)
- Completely open terrain with smooth surface (r = 0.0024 m)
- Agricultural area varying amounts of fences, hedgerows, buildings (r = 0.03 m, 0.055 m, 0.1 m, 0.2 m)
- Small villages (r = 0.4 m)
- Larger cities with tall buildings (r = 0.8 m)
- Very large cities/skyscrapers (r = 1.6 m)

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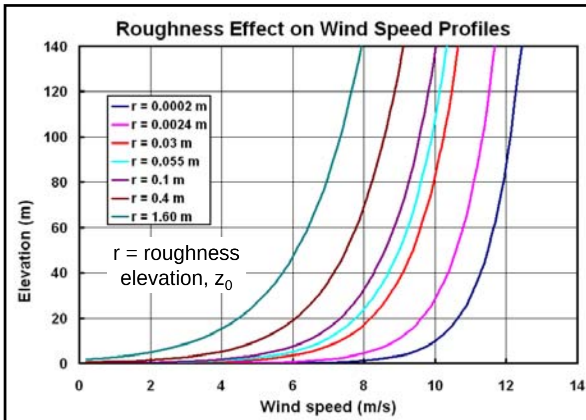

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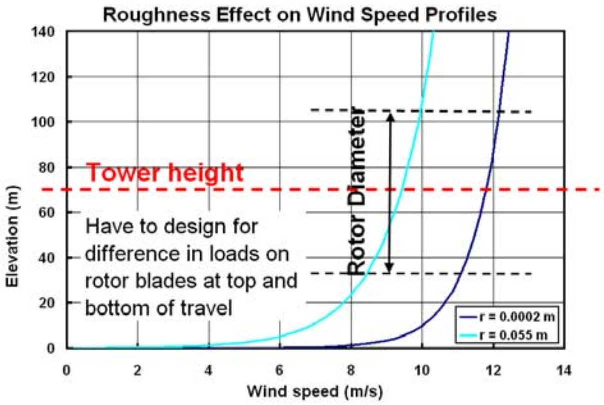

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More on Roughness

- Can get same power at lower tower heights with smoother surfaces
- Typical onshore tower heights are about the same as the rotor diameter
- Typical offshore tower heights are about 0.75 times the rotor diameter
- Offshore winds also have less impact from obstacles ("wind shade")

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Wind Capacity Factor

- Normally want a high capacity factor to make best use of capital investment
- For wind, fuel is free and speeds above rated power speed are useless
  - Can pick a small turbine that will run a large fraction of the time giving a high capacity factor but a low energy output
  - A larger turbine will have a smaller capacity factor but could have a larger energy output

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Wind Turbine Standards

- Developed by International Electro-technical Commission (IEC)
  - IEC 6400-nn standards for wind turbines
  - http://www.iec.ch/cgi-bin/procgi.pl/www/iecwww.p?wwwlang=e&wwwprog=dirdet.p&progdb=db1&committee=TC&number=88
- American Wind Energy Association (AWEA) is represents US on IEC
  - http://www.awea.org/standards/iec_stds.html

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Turbine Power Controls

- Pitch controls – adjusts the angle of the blades (pitch)
  - Reduces fraction of power extracted from wind, keeping generator power constant
- Stall controls adjust design the angle of the rotor blades to reduce lift force at higher wind speeds
  - Maintains constant force on rotor shaft as wind speed increases above maximum

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Turbine Power Controls II

- Passive stall control
  - uses basic rotor design to ensure proper control
  - no changes in rotor blades' position during operation
- Active stall control
  - Changes blade pitch to increase stall force in a manner similar to pitch control

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Power/Area Ratio

- Use larger rotor area to develop same power in lower winds
- Chart on next two slides taken from report prepared for California Energy Commission by California Wind Energy Collaborative at UC Davis
  - CEC-500-2005-181, December 2005
  - Shows data for several wind turbines ranked by ratio of rated power divided by rotor area (W/m²)

Manufacturer	Rated Power (MW)	Rotor Diameter (m)	Power/ Area (W/m²)
NEG Micon	1.5	82	284
GE Wind	1.5	77	322
Vestas	1.8	80	358
NEG Micon	1.5	72	368
Vestas	0.66	47	380
GE Eind	1.5	70.5	384
Mitsubishi	0.6	44	395
Nordex	0.6	43	413
NEG Micon	0.75	48	414
Bonus	1.3	63	417

Manufacturer	Rated Power (MW)	Rotor Diameter (m)	Power/ Area (W/m²)
GE Wind	0.9	52	424
NEG Micon	0.9	52	424
Bonus	0.6	42	433
Bonus	1	54.2	433
Nordex	1	54	437
Mitsubishi	1	54	437
Bonus	2	76	441
Nordex	1.3	60	460
NEG Micon	2.5	80	497

Tip Speed Ratio

- Measure of this factor is called the tip speed ratio, $\lambda = r\omega/V$
  - r is rotor radius
  - ω is rotational speed of rotor
  - V is wind speed
- Measure of resistance to air flow due to rotor rotation to the air
  - No blade rotation, little resistance
  - High speed blade rotation would make the rotor look like more like a solid

Effect of tip-speed ratio on c_p

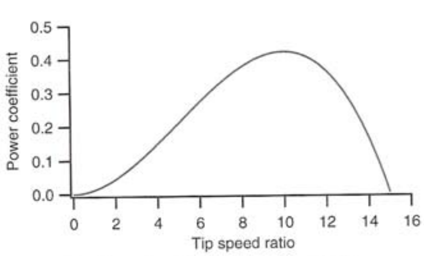

Figure 3.28 Sample $C_p - \lambda$ curve for a high tip speed ratio wind turbine

Maxwell, *et al. Wind Energy Explained, Theory Design and Application*, Wiley, 2002

Equation for Maximum C_p

$$C_{p,\max} = \frac{16\lambda}{27}\left[\lambda + \frac{1.32 + \left(\frac{\lambda - 8}{20}\right)^2}{B^{\frac{2}{3}}}\right]^{-1} - \frac{0.57\lambda^2}{\frac{C_L}{C_D}\left(\lambda + \frac{1}{2B}\right)}$$

- λ = tip speed ratio ($4 \le \lambda \le 20$)
- B = number of rotor blades ($1 \le B \le 3$)
- C_L/C_D = lift-to-drag ratio ($C_L/C_D > 25$)
- Actual c_p values may be less if blades do not have optimum design because of manufacturing requirements (also hub friction losses)

Maximizing C_p

- Generators need to operate at a constant speed to maintain a fixed voltage for the grid
- Want rotor speed variation for rotor-tip speed that maximizes C_p
- Current solution is use of variable speed drives and inverter or rectifier to provide constant voltage for grid

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Turbine Power Calculator

- Provides calculations of annual energy output for various turbine models
- Allows specification of user-input power curve (kW output *vs* wind speed)
- Uses Weibull parameters for wind distribution
  - Some location wind data or user input
- http://www.windpower.org/en/tour/wres/pow/index.htm

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Environmental Impacts

- Visual impact
- Noise
- Effect on birds (avian impacts)
- Electromagnetic interference
- Not discussed
  - Environmental benefits in reduction of fossil-fuel generated pollutants, including greenhouse gas CO_2

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Mitigating Visual Impacts

- Use local land forms to minimize visibility of roads and avoid erosion
- Use buildings that minimize urban or industrial appearance of rural projects
- Use non-obtrusive colors and designs
  - May conflict with flight regulations and with methods to reduce avian impact
- Design electrical lines to reduce their visual impact

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Mitigating Visual Impacts II

- Minimize signs
- Use minimal lighting required for safety and aircraft warnings
  - May help to reduce effects on birds who feed on insects attracted to lights
- Control layout of turbines, especially different types, to minimize visual impact

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Turbine Noise

- Mechanical noise from gears, cooling fans, generator, yaw drives, etc
  - Can be minimized by low noise designs and is not significant in new turbines
- Aerodynamic noise
  - From flow of air around turbine blades
  - Generally increases with tip speed
  - Broadband character
  - Main noise component

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Sound Basics

- Sound power level, L_W, in decibels (dB) = 10 $\log_{10}(W/W_R)$
  - W = source sound power
  - W_R = reference sound power (10^{-12} W)
- Sound pressure level, L_p, in decibels = 10 $\log_{10}(p/p_R)$
  - p = instantaneous sound pressure
  - p_R = reference sound pressure = 200 μPa

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Sound Basics II

- A change of 1dB cannot be perceived
- A 3 dB change is barely perceptible
- A 5 dB change will generate some community response
- A 10 dB increase in sound is perceived as a doubling of sound
  - This will almost always result in an adverse community response
- Frequency weighting on A, B, C scales

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Sound Basics III

- dB(A) scale weighted towards frequencies to represent human hearing
  - Threshold 0 dB(A)
  - Wisper 30 db(A)
  - Talking 60 dB(A)
  - City traffic 90 dB(A)
  - Rock concert 120 dB(A)
  - Pain threshold 140 dB(A)
  - Jet engine 10 m away 150 dB(A)

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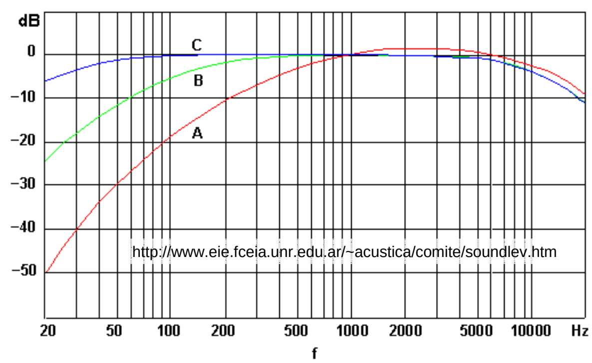
Decibel Weighting Scales



Wind Turbine Noise

- Energy in sound waves (and sound intensity decreases with square of distance from source
- The sound level emitted by a wind turbine is about 100 dB(A)
- One rotor diameter (43 m) away the sound is about 55 – 60 dB(A)
  - Applies to white noise; humans perceive pure tones more easily

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Wind Turbine Noise II

- Since noise level is on a log scale, doubling the sound pressure level increases the total sound by 3 dB(A)
  - $SPL_1 = 10 \log_{10}(p/p_R)$
  - $SPL_2 = 10 \log_{10}(2p/p_R) = 10 \log_{10}(p/p_R) + 10 \log_{10}2 = SPL_1 + 3$
- Sound map calculator available at http://www.windpower.org/en/tour/env/db/dbcalc.htm

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Reducing Noise

- New blade designs reduce noise
- Avoid slits, holes, blunt regions, and other obstructions that generate noise
- Three main contributions
  - Trailing edge noise
  - Tip noise
  - Inflow turbulence noise
- Various regulations limit noise from turbines in US and Europe

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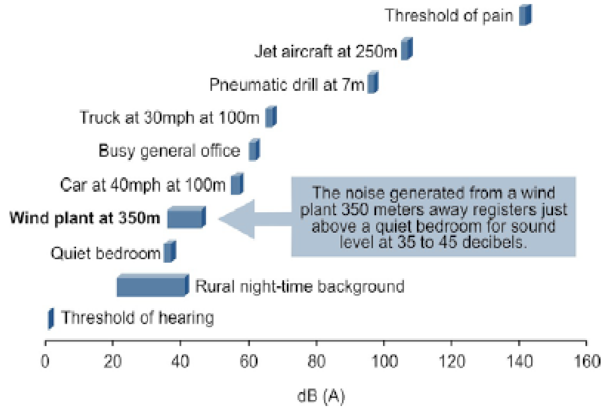

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DOE report, 20% Wind by 2030, July, 2008.
http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf

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Avian Impacts

- Wind energy advocates usually say that problems are only associated with migration routes as in Altamont Pass
- Look at impact relative to other sources
- Audubon society supports wind energy
  - "When you look at a wind turbine, you can find the bird carcasses and count them. With a coal-fired power plant, you can't count the carcasses, but it's going to kill a lot more birds." -- John Flicker, National Audubon Society, president

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http://www.renewableenergyaccess.com/rea/news/story?id=46840

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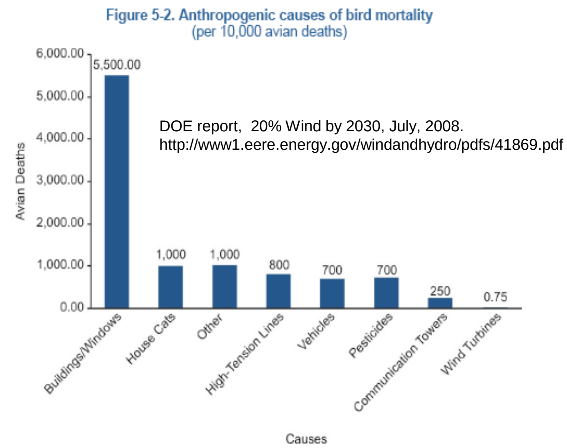

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Reducing Avian Impacts

- Avoid migration corridors
- Fewer, larger turbines
- Avoid micro habitats or fly zones
- Tower designs with few or no perch sites
- Remove nests and birds from site
- Bury electrical lines
- Site specific studies

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Bat Deaths

- Unexpectedly high bat fatalities at wind energy sites, especially those on ridge tops in the eastern United States
- The Bats and Wind Energy Cooperative (BWEC) formed in 2003
  - Bat Conservation International (BCI), US Fish and Wildlife Service, American Wind Energy Association (AWEA), and NREL
  - http://www.batsandwind.org/

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Electromagnetic Interference

- Based on scattering off rotating blades
  - Same signal may be received (with distortion) simultaneously by two receivers
  - Effect lessened by modern turbines that do not use metal in rotor blades
  - Not a problem if electromagnetic signals are not present
  - Not well understood in a quantitative sense for improved designs

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