

Energy Output

Andrew Kusiak
 Intelligent Systems Laboratory
 2139 Seamans Center
 The University of Iowa
 Iowa City, Iowa 52242 - 1527
andrew-kusiak@uiowa.edu
 Tel: 319-335-5934 Fax: 319-335-5669
<http://www.icaen.uiowa.edu/~ankusiak>



The University of Iowa

Intelligent Systems Laboratory

Outline

- The wind variation
- Distribution plotting
- The average bottle fallacy
- Mean power of the wind
- Betz' law
- Power density
- Power curves
- The power coefficient
- Calculator guide
- The power calculator
- Annual energy output



The University of Iowa

Intelligent Systems Laboratory

Characterizing Wind Variability

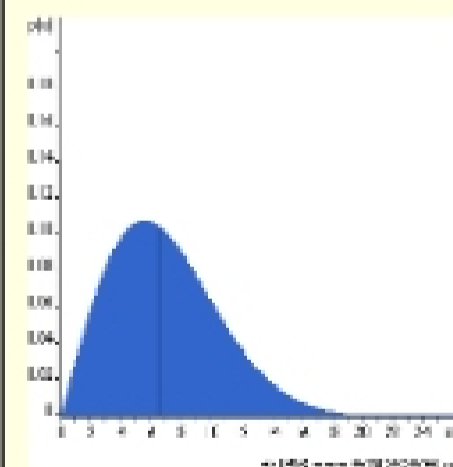
- ✓ Characterization of the **wind speed variability** is of importance to the wind industry
- ✓ Turbine **designers** use it to optimize the design of the turbines, e.g., by **minimizing the energy generation cost**
- ✓ Wind farm **designers** use it to locate wind farms and select turbines
- ✓ **Investors** use it to estimate the income from electricity generation



The University of Iowa

Intelligent Systems Laboratory

Wind Variations: Weibull Distribution



The General Pattern of Wind Speed Variation

- ✓ Weibull distribution describes the wind variation for a typical site
- ✓ The site has the mean wind speed of 7 m/s
- ✓ The shape parameter of the function is $k = 2$
- ✓ The data has been collected over a year period



The University of Iowa

Intelligent Systems Laboratory

Weibull Distribution

$$f(x; k, \lambda) = \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k}$$

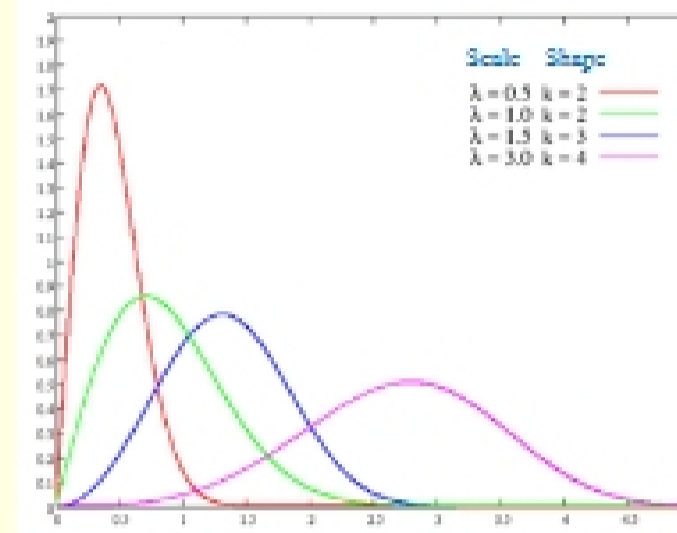
where:

$\lambda > 0$ is the **scale** parameter

$k > 0$ is the **shape** parameter of the distribution

For $k = 3.4$, the Weibull distribution appears similar to the normal distribution
 For $k = 1$, the Weibull distribution becomes the exponential distribution

Weibull Distribution



Median

$$\lambda \ln(2)^{1/k}$$

Mode

$$\lambda \left(\frac{k-1}{k}\right)^{1/k}$$

Mean

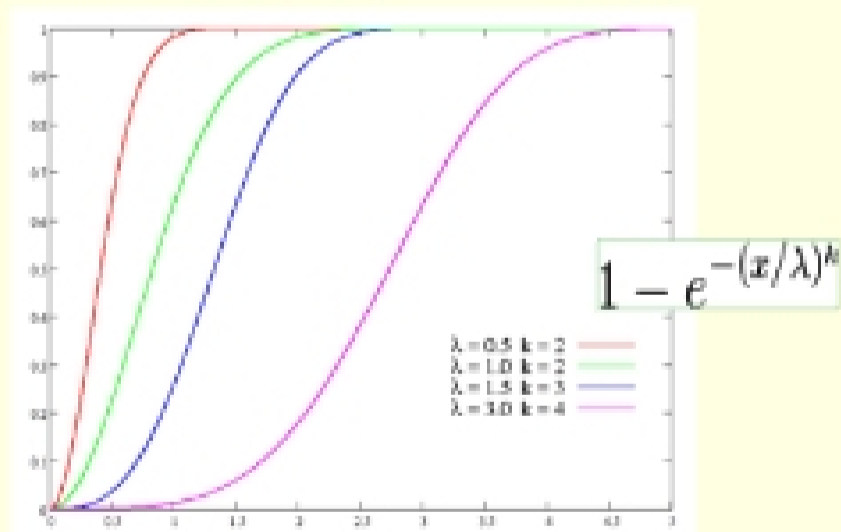
$$\lambda \Gamma\left(1 + \frac{1}{k}\right)$$

where the gamma function is

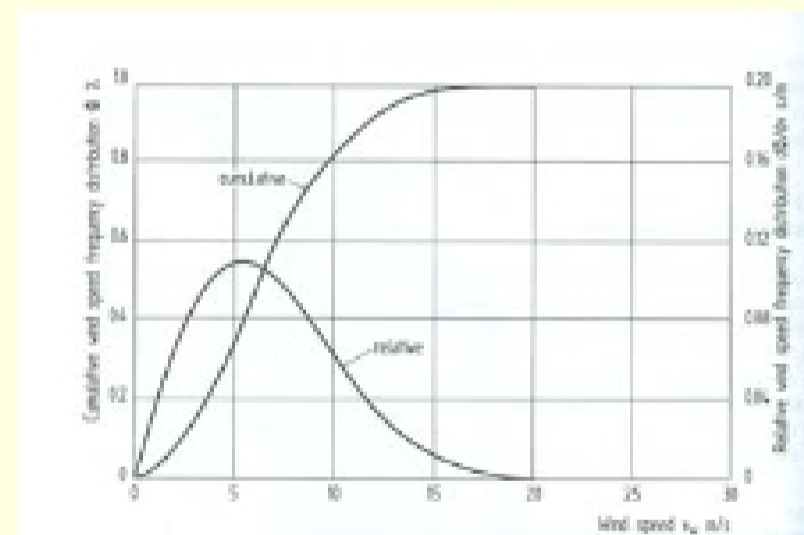
$$\Gamma(z) = \int_0^{\infty} t^{z-1} e^{-t} dt$$

$$f(x; k, \lambda) = \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k}$$

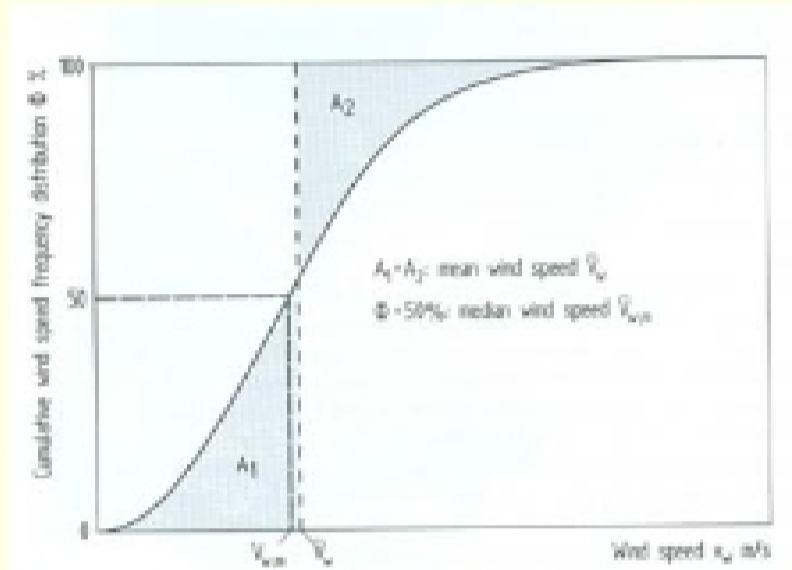
Cumulative Distribution Function



PDF and CDF

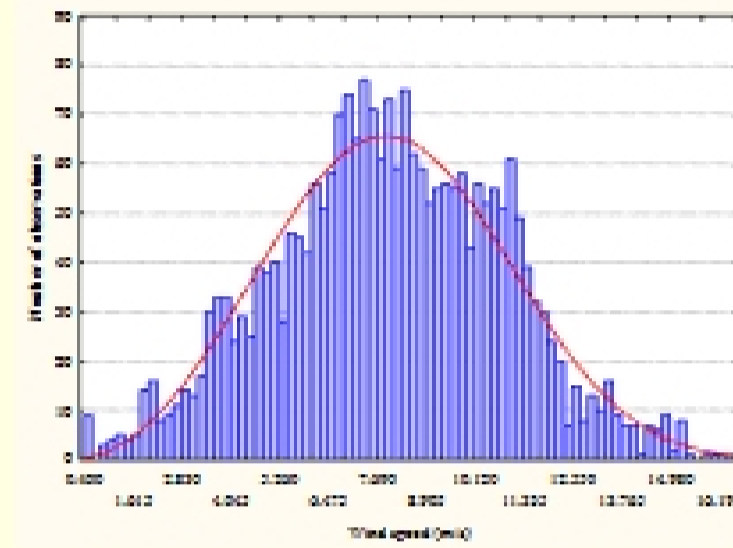


CDF: Mean vs Median Wind Speed



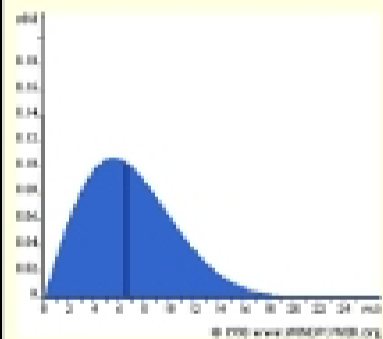
The University of Iowa E. Hau (2006) Intelligent Systems Laboratory

Wind Speed Histogram



The University of Iowa Intelligent Systems Laboratory

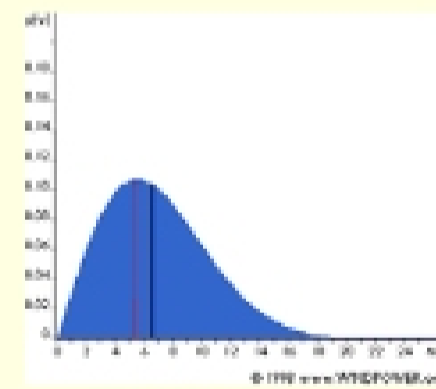
Description of Wind Speed



- ✓ The area under the pdf curve is always exactly 1 (the probability that the wind is blowing at some wind speed including 0 is 100 %)
- ✓ Median = 6.6 m/s (Half of the blue area is to the left)
- ✓ This means that 50% of the time the wind speed is less than 6.6 m/s, the other 50% of the time it is greater than 6.6 m/s
- ✓ Note: The median 6.6 m/s is not equal the mean 7m/s due to asymmetry of the pdf

The University of Iowa Intelligent Systems Laboratory

Description of Wind Speed



- ✓ Mode = 5.5 m/s (The most common wind speed)
- ✓ The statistical distribution of wind speeds depends on location, climate conditions, the landscape, and its surface
- ✓ The Weibull distribution may thus vary in its shape, determined by the pdf parameters

The University of Iowa Intelligent Systems Laboratory