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Wind Turbine Basics and Preliminary Design Analysis

Presented to Moffett Productions as a part of NMSBA

300W C type vertical axis wind turbine generator, http://www.alibaba.com/

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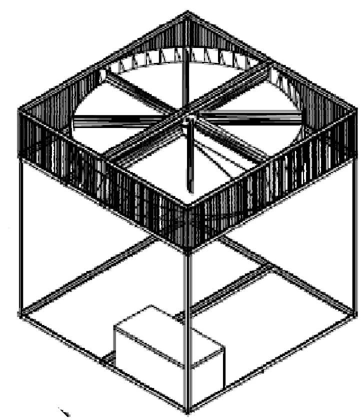

National Nuclear Security Administration

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Turbine Design Types Overview

http://www.pollutionissues.com/Ec-Fi/Electric-Power.html

http://www.eoearth.org/article/Darrieus,_Georges_Jeans_Mary

Horizontal Axis Wind Turbines (HAWT)

- Vast majority of grid connected commercial turbines
- Commercial wind turbines' power production is on the order of megawatts at ~$.05/kWh
- Requires yawing mechanism to point into wind
- Driven by a lift system
- Vibration concerns due to flexible structure
- Light weight design enables assess to high elevation greater wind speeds

Vertical Axis Wind Turbines (VAWT)

- Wind direction independent
- Less efficient design especially if drag type system
- Susceptible to damage from high wind conditions

Turbine Design Types Overview

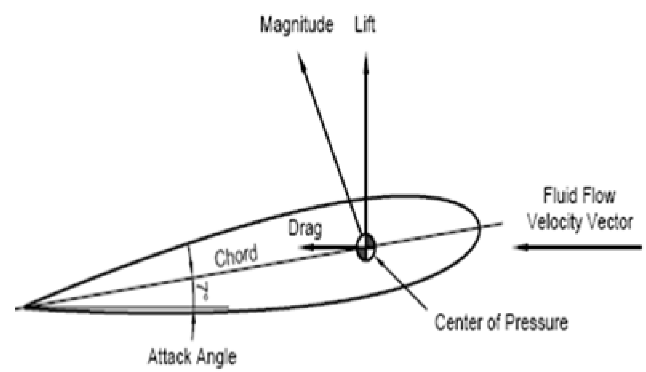
Drag machine

- Rotor surface cannot move faster than the wind speed resulting in reduced efficiency
- Relatively inexpensive and simple to design
- Useful for small power requirements
- Minimal current literature and research conducted due to limited number in operation

300W C type vertical axis wind turbine generator, http://www.alibaba.com/

Lift machine

- Efficiencies due to airfoil blades
- Rotor speed can be up to 10 times wind speed
- More complicated to analyze (typically need design software to analyze)
- Growing body of research and funding



http://www.oea.com/energy/home

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Wind Power

$$P_w = \frac{1}{2} C_p \rho A v^3$$

P_w = power output from wind turbine (W)

ρ = density of air, 1.225 kg/m3 (15^{o}C, sea level)

A = rotor swept area (m)

V = wind speed (m/s)

C_p = power coefficient

- <u>Betz limit law:</u> using the law of conservation of mass and energy no ideal wind-energy extraction machine can use more than 16/27 (59.3%) of the kinetic energy of the captured wind
- $C_{p\,max}$ = 0.59 (lift)
- $C_{p\,max}$ = 0.3 (drag)

Commercial modern HAWT designs between 70% to 80% of $C_{p\,max}$

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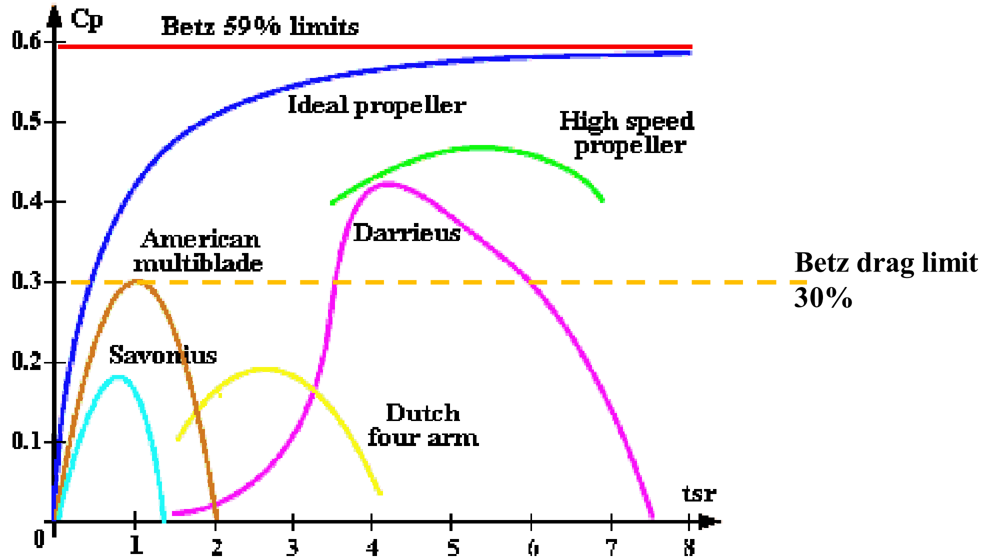
Power Coefficient (C_p)



http://www.windturbine-analysis.netfirms.com/index-intro.htm

- **Fraction of the power in the wind extracted by the rotor**

$$c_p = \frac{rotor\ power}{power\ in\ the\ wind}$$

- **Power coefficient varies with tip speed ratio (ratio of rotor tip speed to free wind speed)**
- ***Experimentally* and *analytically* obtained value (Ideal HAWT with parallelepiped blades)**

$$c_p = \frac{I_{shaft}\,\omega^3}{\rho A v^3} \qquad I_{shaft} = \frac{N_b \rho_b L_b W_b t_b L_b^2}{3}$$

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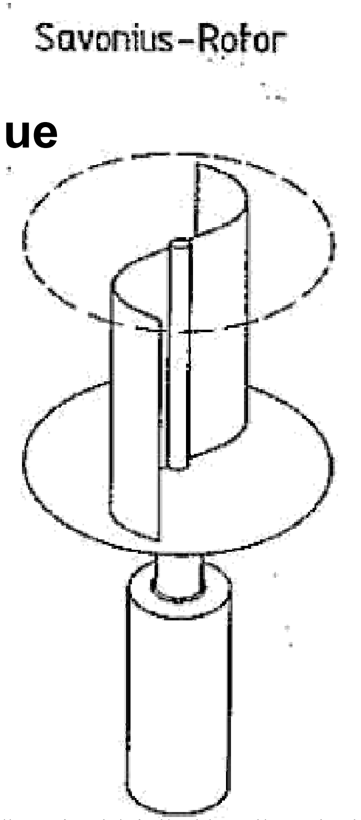
Savonius Rotor

- **Vertical axis drag turbine based on pressure difference between the retreating blade and the advancing blade due to differences in drag coefficients**
- **Wind tunnel performance study conducted by Sandia National Laboratories (May 1975) at Vought Systems Division Low Speed Wind Tunnel**



http://www.iwr.de/wind/tech/grund/typen.html

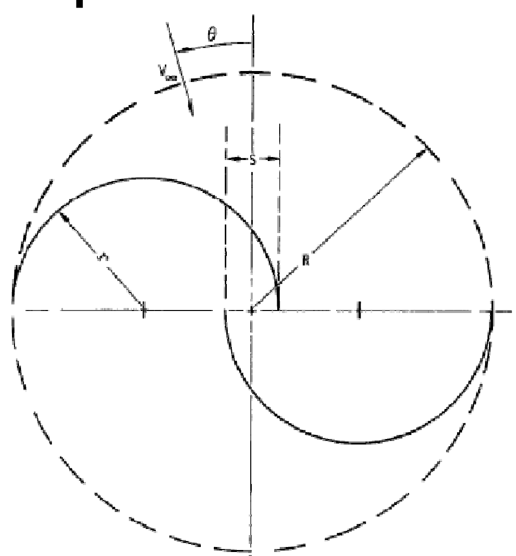


Figure 5. Schematic of the two-bucket Savonius rotor with 180° bucket

Sandia National Laboratories. SAND76-0131 Wind Tunnel Performance Data for Two- and Three-Bucket Savonius Rotors July, 1977.

SNL Savonius Rotor Experiment

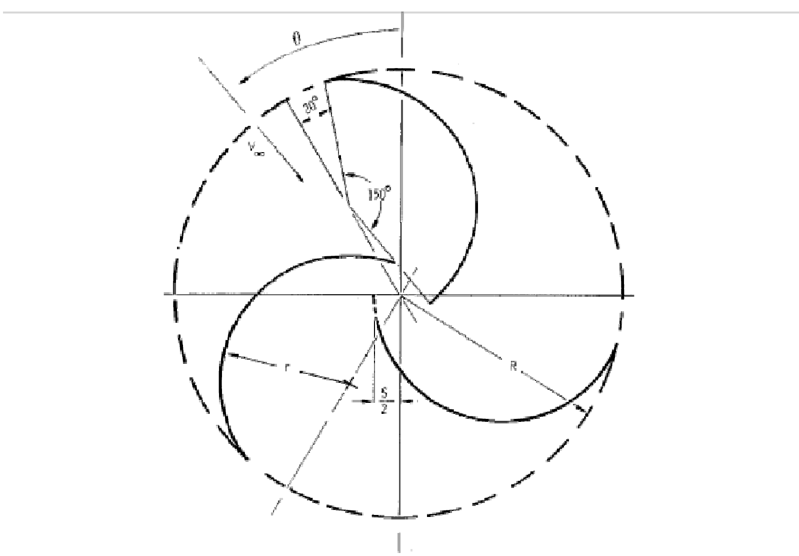


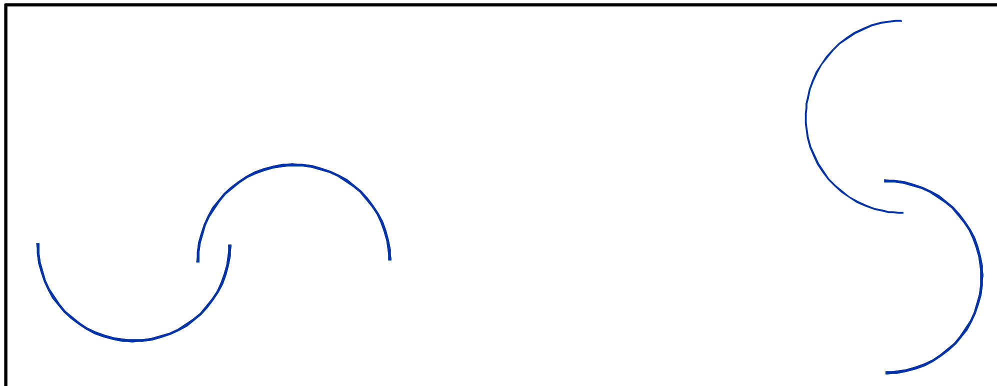
Figure 6. Schematic of the three-bucket Savonius rotor with 150° buckets.

- Variables
  - Number of buckets 2, 3
  - Gap spacing (s/d) 0, 0.1, 0.15, 0.2
  - Rotor height 1m, 1.5m
  - Free stream velocity 7m/s 14 m/s

Sandia National Laboratories. SAND76-0131 Wind Tunnel Performance Data for Two- and Three-Bucket Savonius Rotors July, 1977.

SNL Savonius Rotor Experiment Results

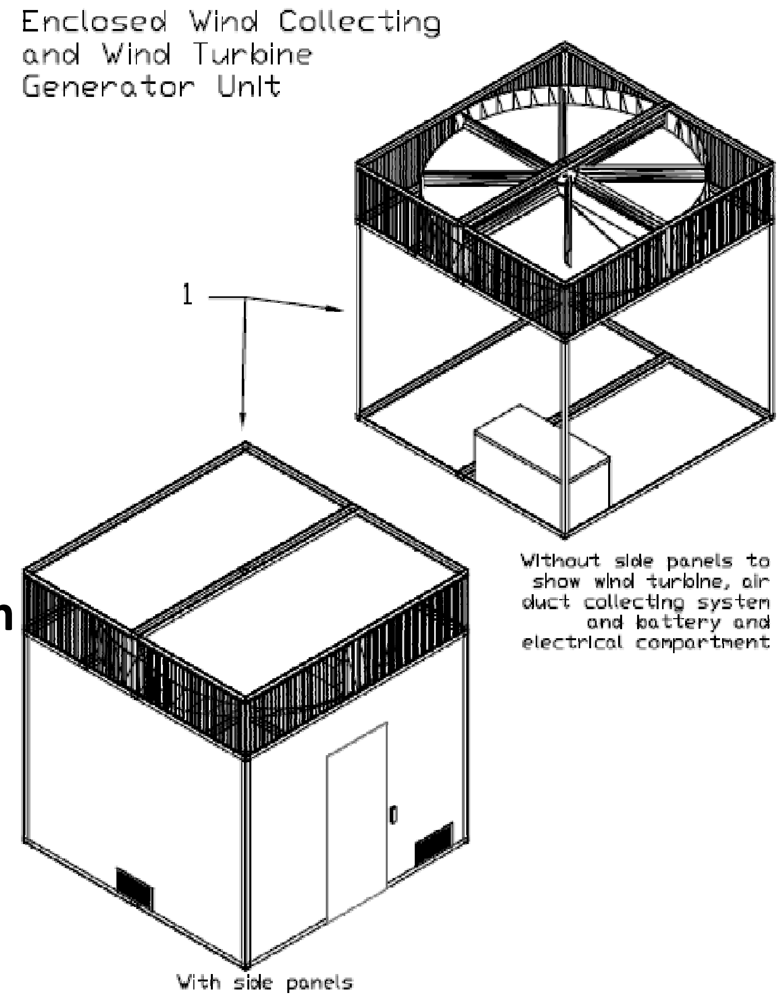
- **Static torque coefficient** for the 2 bucket system had ***higher variability*** **and** ***greater minimum torque*** **values than the 3 bucket system. Double 2 bucket systems with 90 degree offset was optimal.**
- **Bucket overlap ration** **between** ***0.1-0.15*** **was optimal**
- **Peak** **power coefficient (Cp)** **values ranged between** ***0.22-0.26*** **for the** ***two-bucket*** **configuration and were** ***0.15-0.17*** **for the** ***three bucket*** **configuration**



Double 2 bucket system with 90° offset

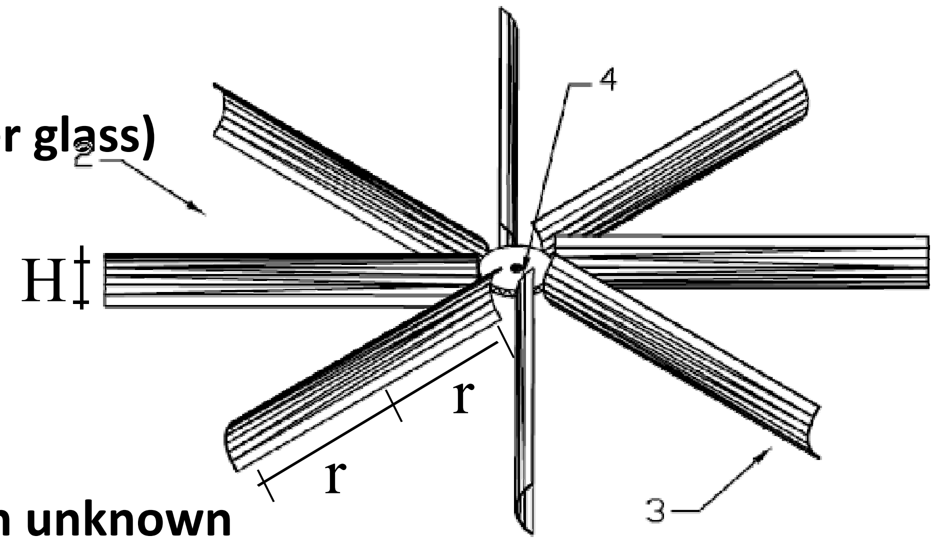
Design Assumptions

- Inconspicuous design to avoid radar detection
- Portable – not grid-tied , battery charging
- Nominal dimension 9m x 9m x 9m
- Power 1.5kW – 3.0 kW
- Air Duct System
  - Removed for initial calculations
  - Potentially useful to protect turbine from high wind conditions
- Turret
  - Rotor shape makes design independent of wind direction



Design Assumptions

- Rotor shape and dimension
  - No deflection due to gravity loads – blade supported on bottom
  - Material unspecified (assume fiber glass)
  - Diameter = 9 meters
  - Assume 3 blades
  - Cupped shape
- Wind Speed
  - Portable design therefore location unknown
  - Height of turbine approx 9 m
  - Solve for minimal wind speed for feasibility study
- Similar performance to a Savonius



Wind Turbine, Gear Box, Generator and Shaft Drawing

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Solving for wind speed, v

$$v = \left(\frac{P_w}{{}^{1}/_{2}\, C_p \rho A} \right)^{1/3}$$

P_w = 1.5 kW

ρ = density of air, 1.225 kg/m3 (15^{o}C, sea level)

A = 4rH (m) = 4*2.25m*1.25m = 11.25 m^2

C_p = power coefficient = .17

V= 10.86 m/s

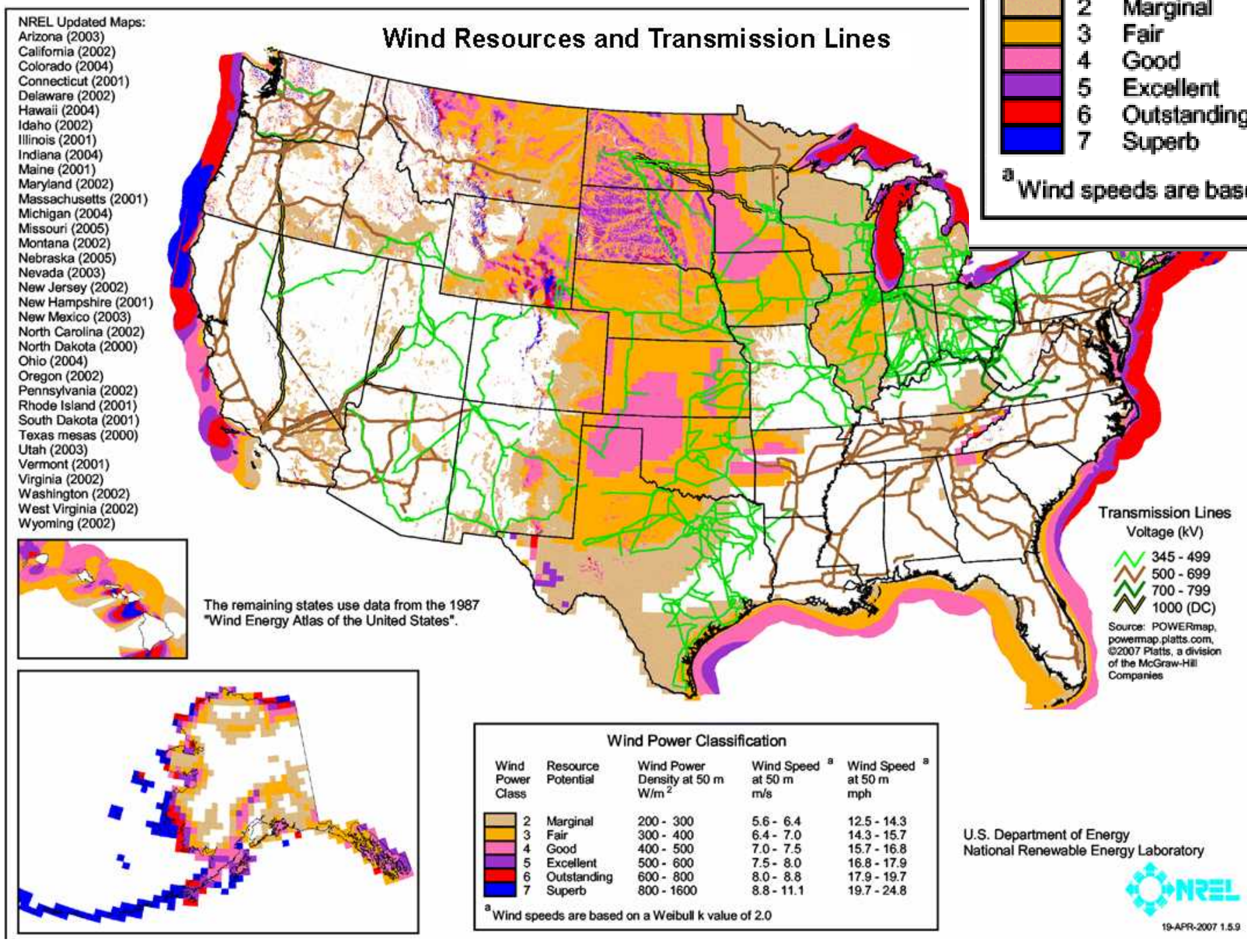
United States Wind Speed Data

- What does 10.9 m/s mean?

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed [a] at 50 m m/s	Wind Speed [a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0



Effect of elevation on wind:

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^n$$

Solving for v2…

h_1=9m v_1=10.9 m/s

h_2=50m n = ground surface friction coefficient choose 0.2

N=0.1, water or smooth ground

N=0.2, tall crops

N=0.3 city downtown

v_2= 15.3 m/s

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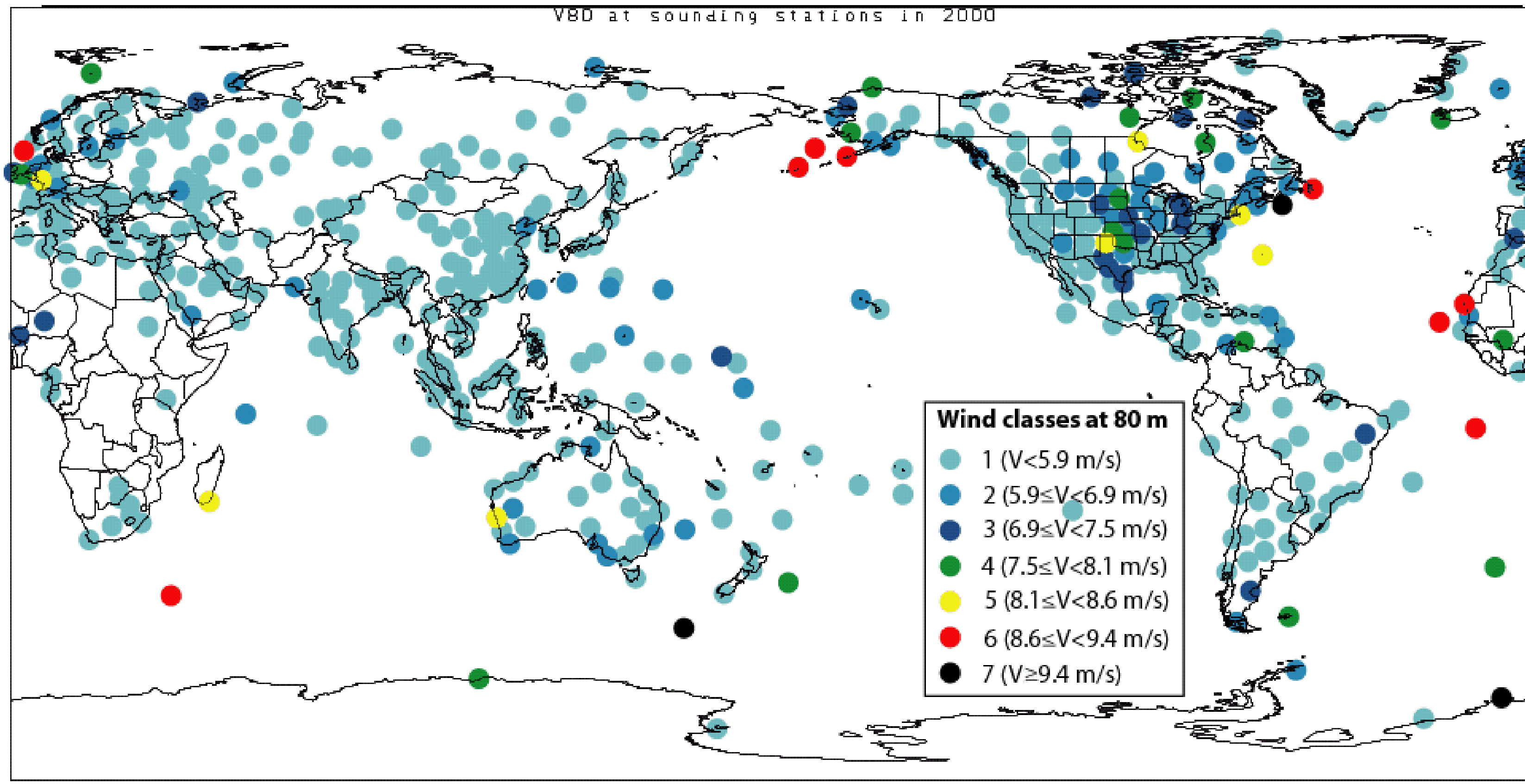
Global Wind Speed Data



Map of wind speed extrapolated to 80 m an averaged over all days of the year 2000 at sounding locations with 20 or more valid readings for the year 2000 (Archer, 2005) .

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^n$$

h_1=9m
h_2=80m

v_1=10.86m/s
n = 0.2
v_2= 16.8 m/s

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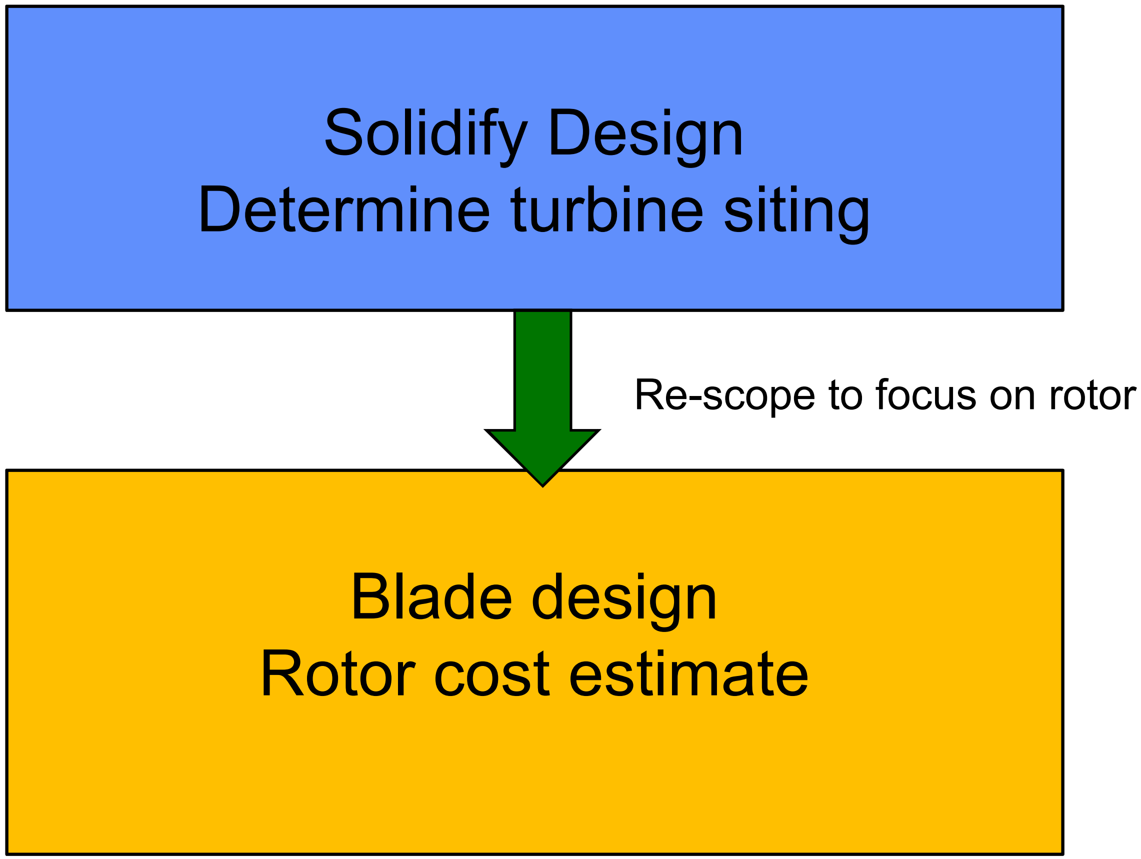
Next Steps


Solidify Design
Determine turbine siting
Re-scope to focus on rotor
Blade design
Rotor cost estimate

References

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Burton, Tony et al. Wind Energy Handbook Chichester: John Wiley & Sons Inc, 2001.

Manwell, J.F., J.G McGowan and A.L. Rogers. Wind Energy Explained Theory, Design and Application Chichester: John Wiley & Sons Inc, 2009.

Paraschivoiu, Ion. Wind turbine design: with emphasis on Darrieus concept Montreal: Polytechnic International Press, 2002.

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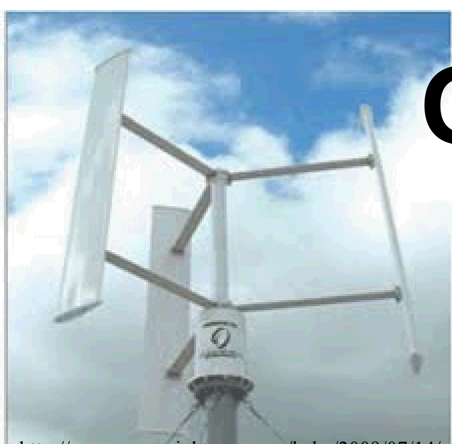
QUESTIONS/COMMENTS



http://www.greenrightnow.com/kabc/2009/07/14/new-texas-water-tower-will-combine-wind-power/

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Design Worksheet

Pw	1.5	kW
rho	1.225	kg/m3
diameter	9	m
blade height	1.25	m
Area	11.25	m^2
Power Coefficient	0.17	
H of turbine	9	m
n=	0.2	
V required @ turbine	10.85912	
V required at 50m	15.30171	

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