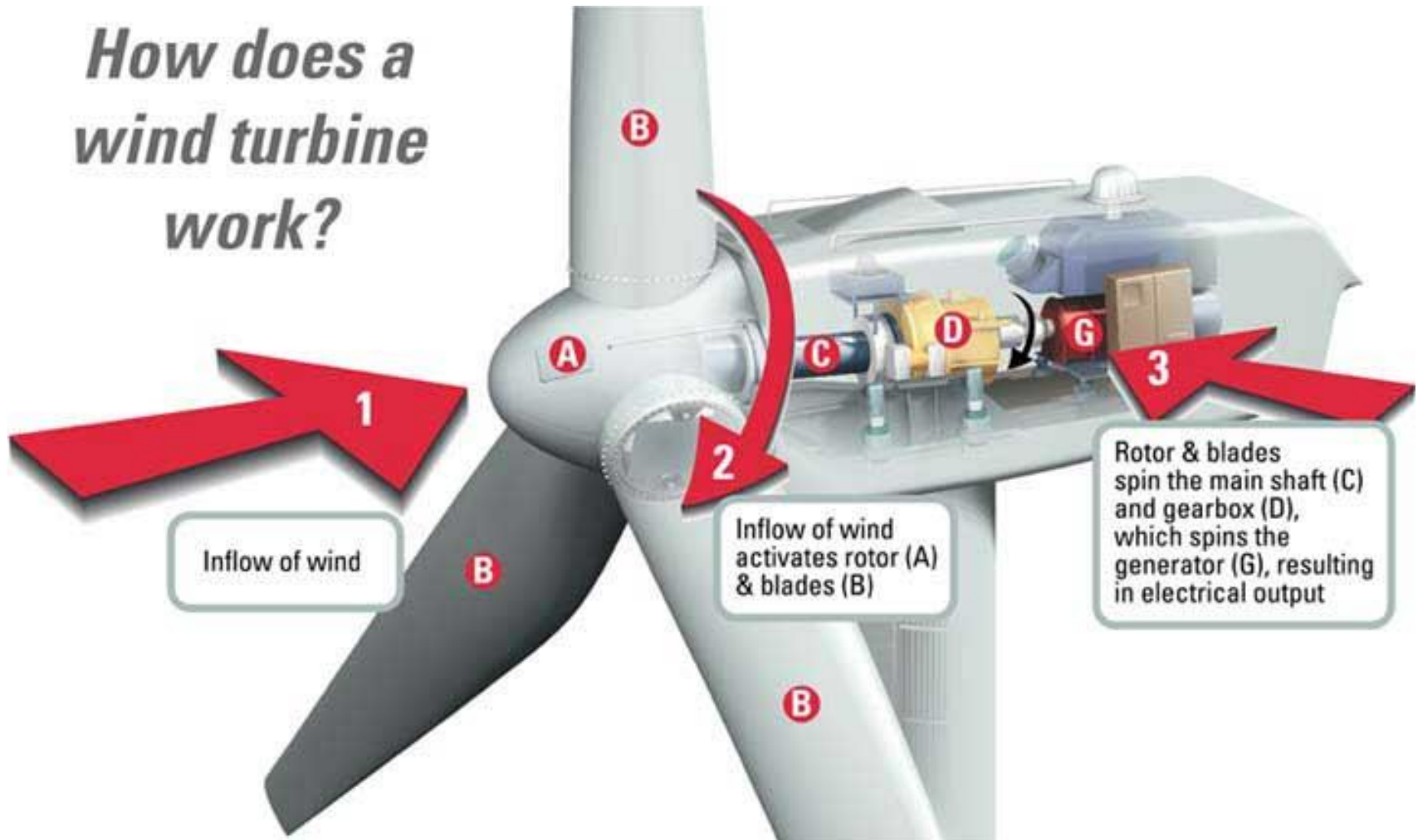


A photograph of an offshore wind farm. In the foreground, a large white wind turbine is shown from a low angle, looking up at its three blades. The blades are white and have a slight curve. The tower is also white. In the background, a long line of similar turbines stretches across the horizon over a calm blue sea. The sky is a clear, pale blue.

Wind Turbine Blade Design

Joseph Rand
The Kidwind Project
joe@kidwind.org
877-917-0079

How does a wind turbine work?

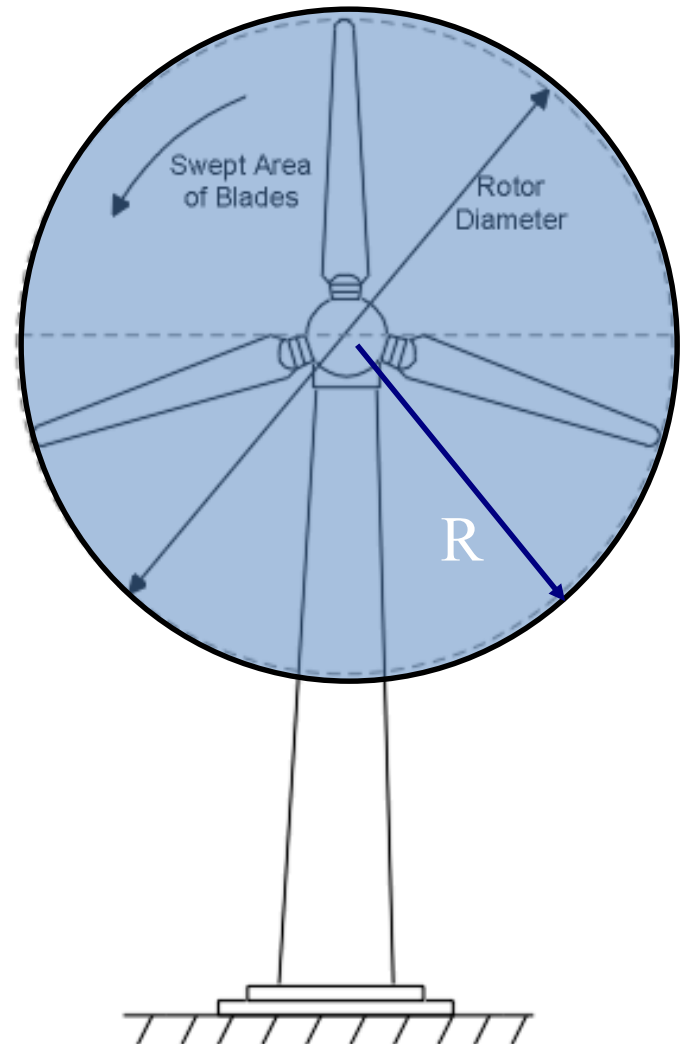


Calculation of Wind Power

$$\text{Power in the Wind} = \frac{1}{2}\rho AV^3$$

- Effect of swept area, A
- Effect of wind speed, V
- Effect of air density, ρ

Swept Area: $A = \pi R^2$ Area of the circle swept by the rotor (m^2).



Many Different Rotors...



Blade Composition

Wood

Wood

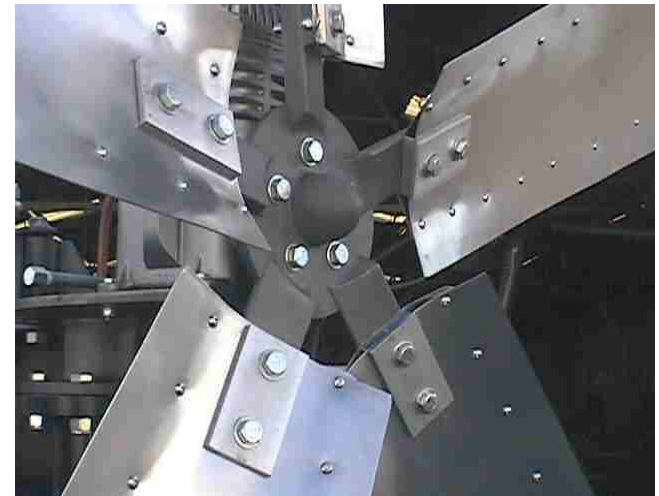
- Strong, light weight, cheap, abundant, flexible
- Popular on do-it yourself turbines
- Solid plank
- Laminates
- Veneers
- Composites



Blade Composition

Metal

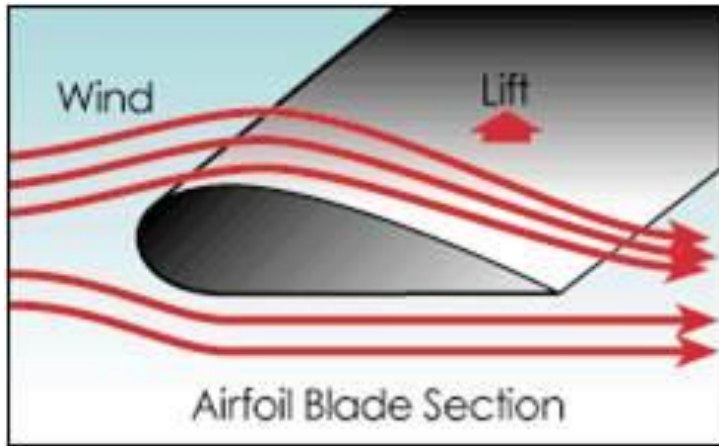
- Steel
 - Heavy & expensive
- Aluminum
 - Lighter-weight and easy to work with
 - Expensive
 - Subject to metal fatigue



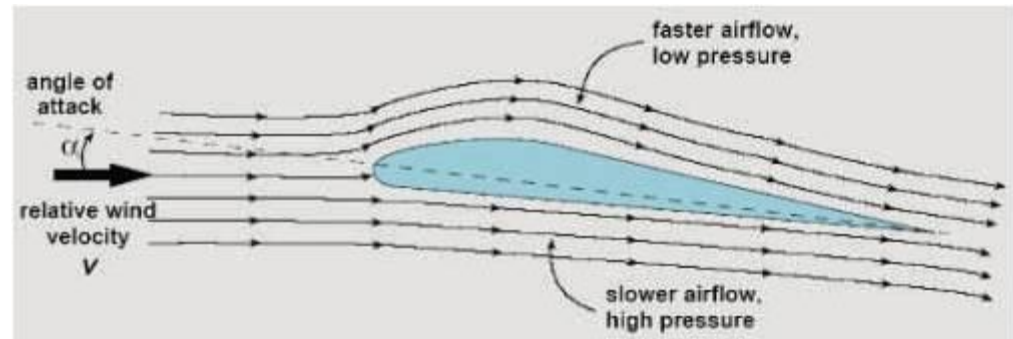




Airfoil Shape



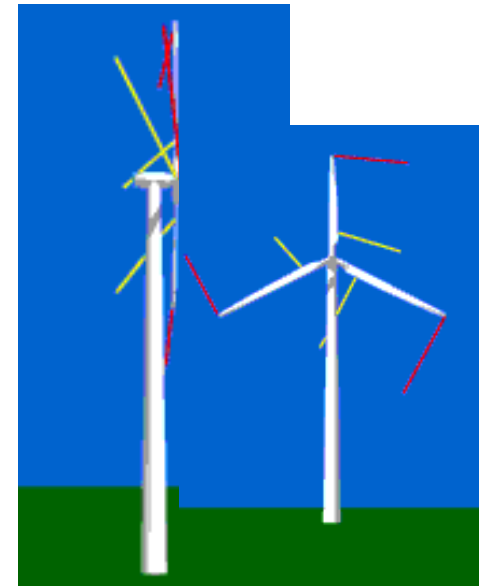
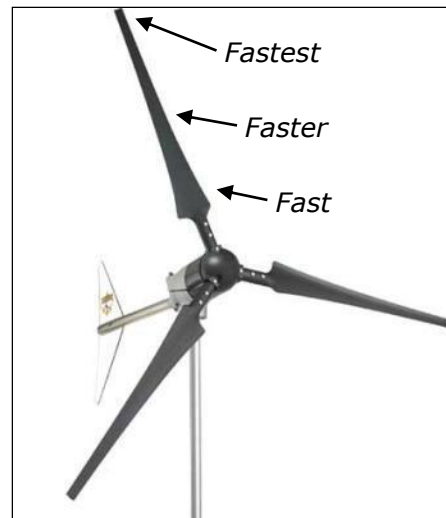
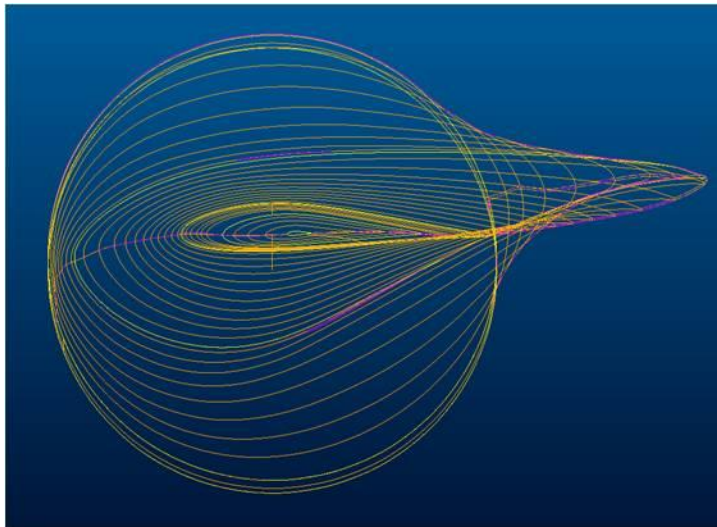
Just like the wings of an airplane, wind turbine blades use the airfoil shape to create lift and maximize efficiency.



The Bernoulli Effect

Twist & Taper

- Speed through the air of a point on the blade changes with distance from hub
- Therefore, tip speed ratio varies as well
- To optimize angle of attack all along blade, it must twist from root to tip



Tip-Speed Ratio

Tip-speed ratio is the ratio of the speed of the rotating blade tip to the speed of the free stream wind.

There is an optimum angle of attack which creates the highest lift to drag ratio.

Because angle of attack is dependant on wind speed, there is an optimum tip-speed ratio

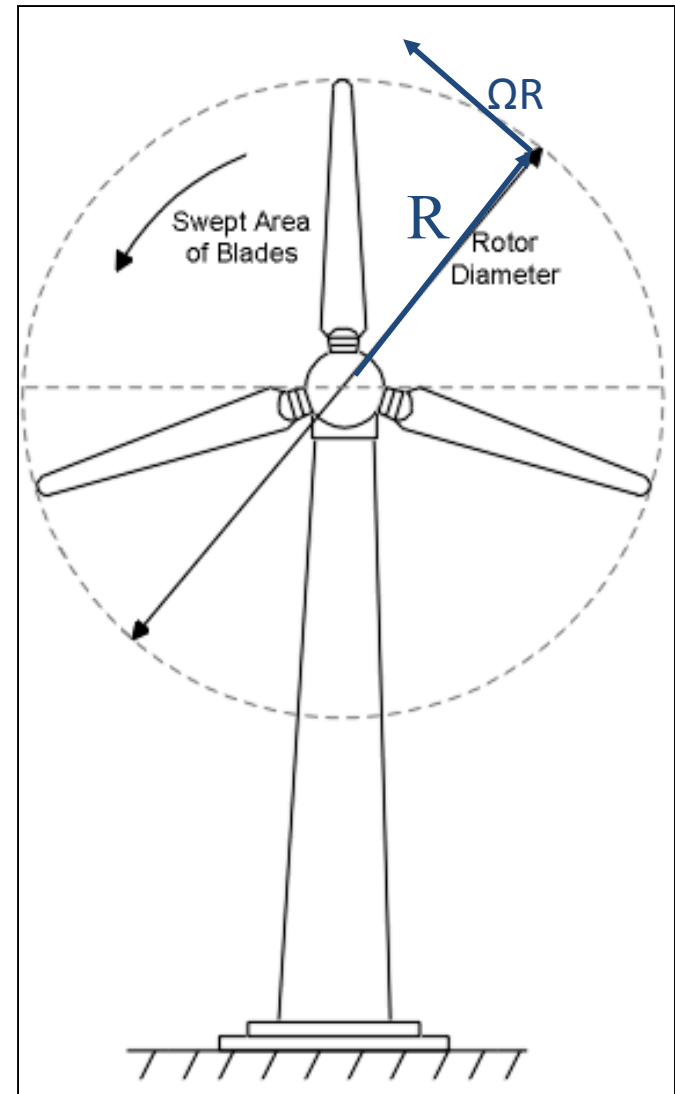
$$\text{TSR} = \frac{\Omega R}{V}$$

Where,

Ω = rotational speed in radians /sec

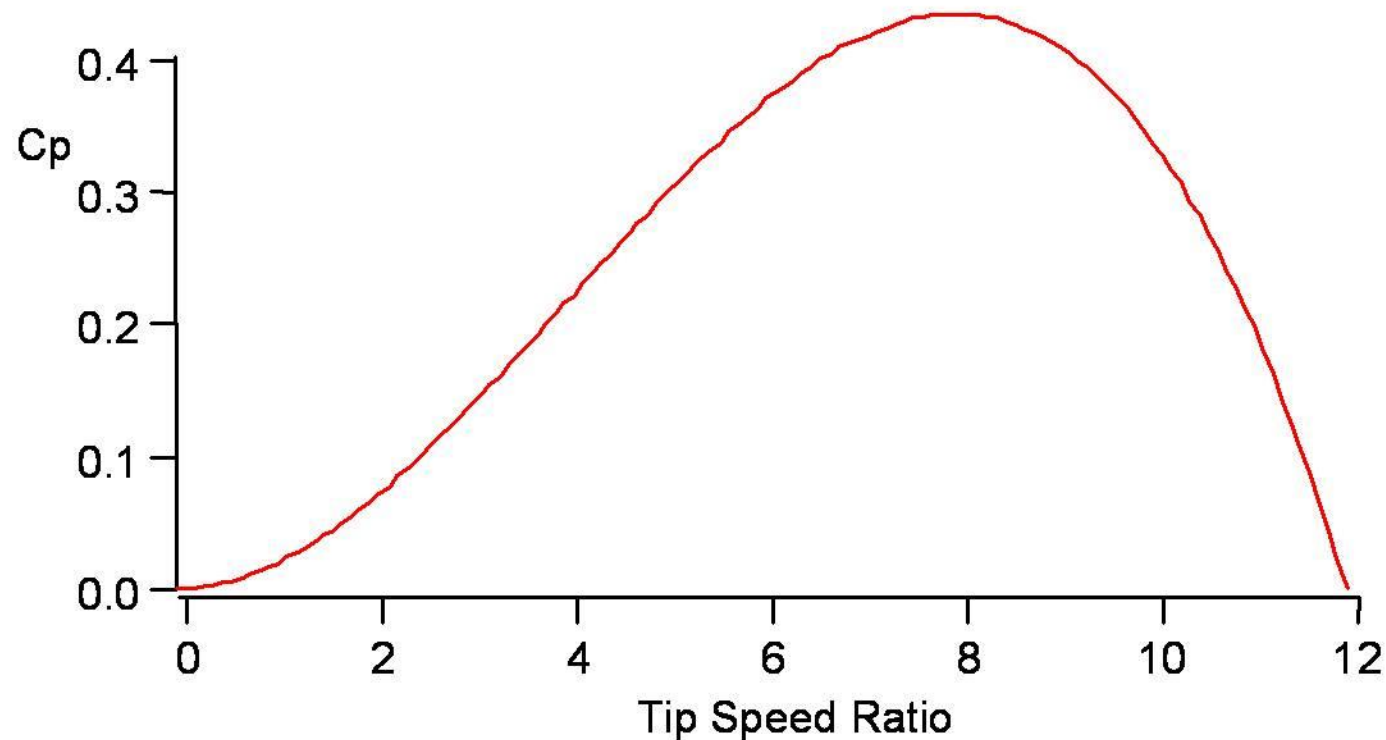
R = Rotor Radius

V = Wind “Free Stream” Velocity

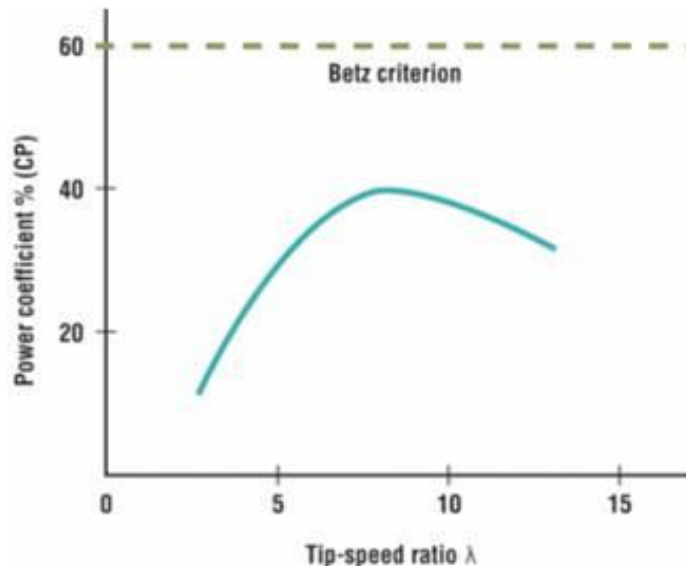
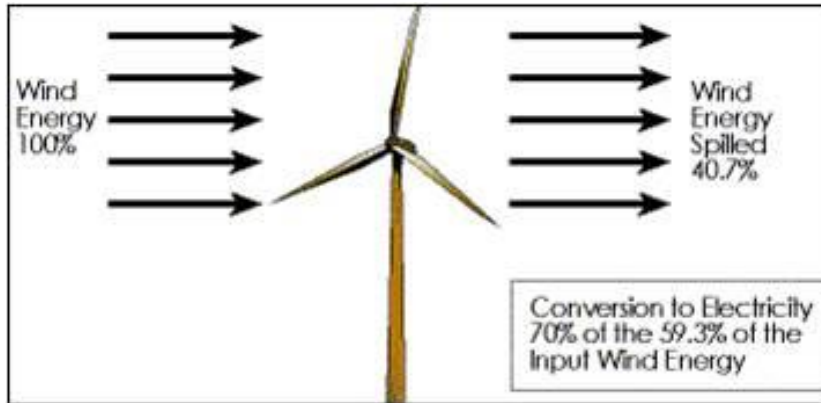


Performance Over Range of Tip Speed Ratios

- Power Coefficient Varies with Tip Speed Ratio
- Characterized by C_p vs Tip Speed Ratio Curve



Betz Limit



All wind power cannot be captured by rotor or air would be completely still behind rotor and not allow more wind to pass through.

Theoretical limit of rotor efficiency is 59%

Most modern wind turbines are in the 35 – 45% range

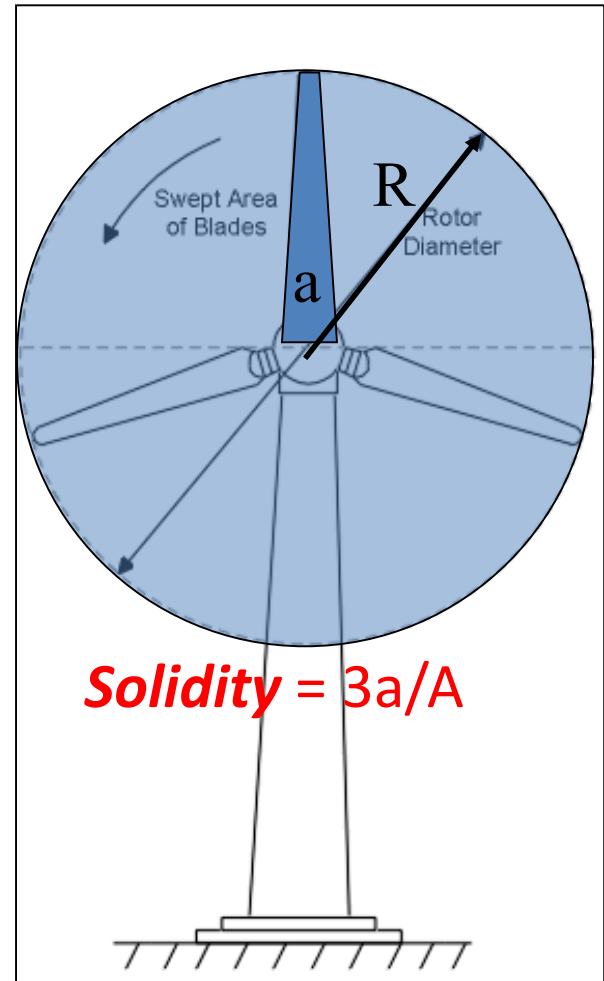
Rotor Solidity

Solidity is the ratio of total rotor planform area to total swept area

Low solidity (0.10) = high speed, low torque



High solidity (>0.80) = low speed, high torque



Manufacturing Blades



The blade mold (left) is lined with layers of fiberglass, then injected with epoxy resin. To enhance stiffness, a layer of wood is placed between the fiberglass layers. The two molds are joined and adhered together using a special liquid epoxy, which evenly joins the two sides of the blade.

Finally, the whole mold is baked like a cake! 8 hours at 70 degrees C.

Manufacturing Blades



Before delivery, samples of the rotor blades have to go through a variety of static and dynamic tests. First, they are subjected to 1.3 times the maximum operating load. To simulate 20 years of material fatigue, the blades are then mounted on special test beds and made to vibrate around two million times, before the endurance of the material is again tested with a final static test.

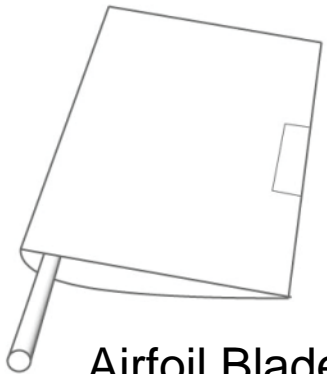
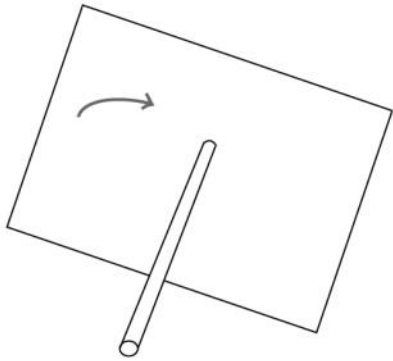
The blades are painted white, then shipped to wind farms all over the world.

Wind Turbine Blade Challenge

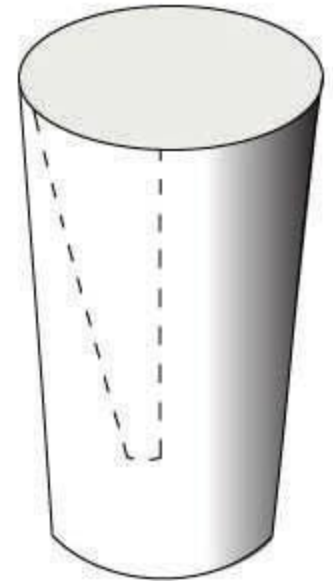
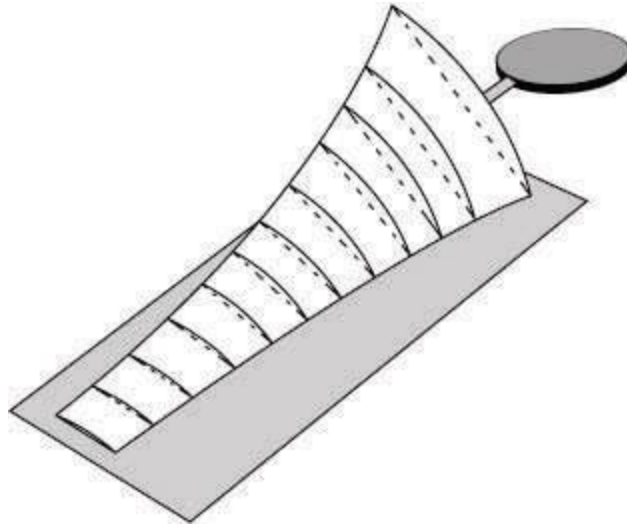
- Students perform experiments and design different wind turbine blades
- Use simple wind turbine models
- Test one variable while holding others constant
- Record performance with a multimeter or other load device
- Goals: Produce the most voltage, pump the most water, lift the most weight
 - Minimize Drag
 - Maximize LIFT
 - Harness the POWER of the wind!



Advanced Classroom Blades



Airfoil Blades




Cardboard Tube
for twisted blades

Questions?



Joe Rand
KidWind Project
joe@kidwind.org

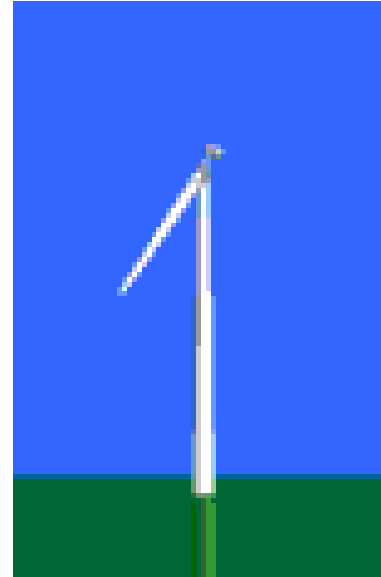


Wind Turbine Number and Pitch of Blades Design

Joseph Rand
The Kidwind Project
joe@kidwind.org
877-917-0079

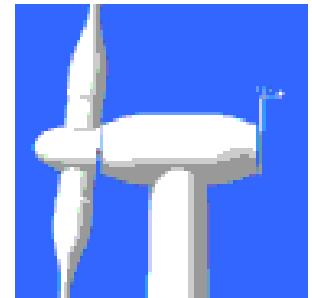
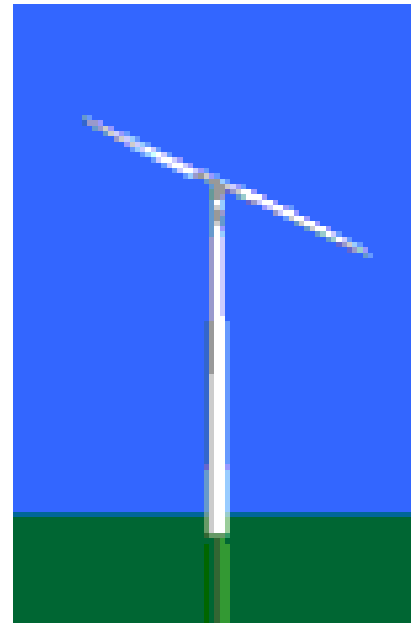
Number of Blades – One

- Rotor must move more rapidly to capture same amount of wind
 - Gearbox ratio reduced
 - Added weight of counterbalance negates some benefits of lighter design
 - Higher speed means more noise, visual, and wildlife impacts
- Blades easier to install because entire rotor can be assembled on ground
- Captures 10% less energy than two blade design
- Ultimately provide no cost savings



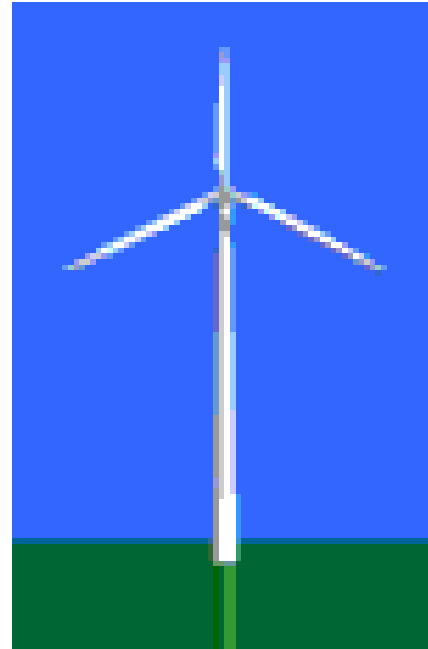
Number of Blades - Two

- Advantages & disadvantages similar to one blade
- Need teetering hub and or shock absorbers because of gyroscopic imbalances
- Capture 5% less energy than three blade designs



Number of Blades - Three

- Balance of gyroscopic forces
- Slower rotation
 - increases gearbox & transmission costs
 - More aesthetic, less noise, fewer bird strikes



Lift & Drag Forces

- The Lift Force is perpendicular to the direction of motion. We want to make this force **BIG**.



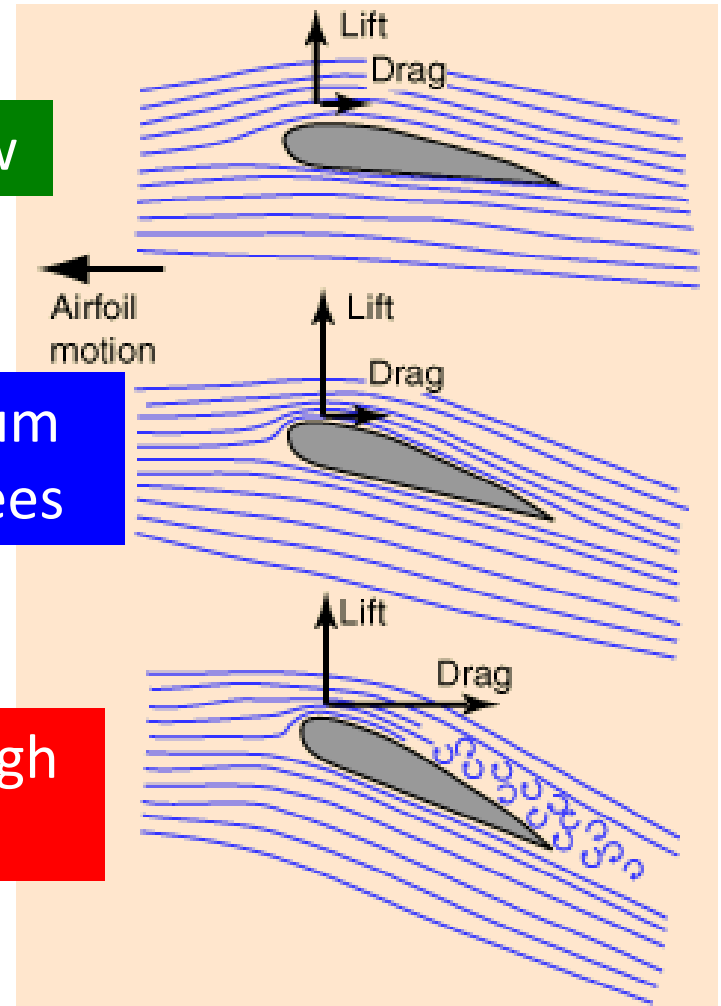
© 1998 www.WINDPOWER.dk

- The Drag Force is parallel to the direction of motion. We want to make this force small.

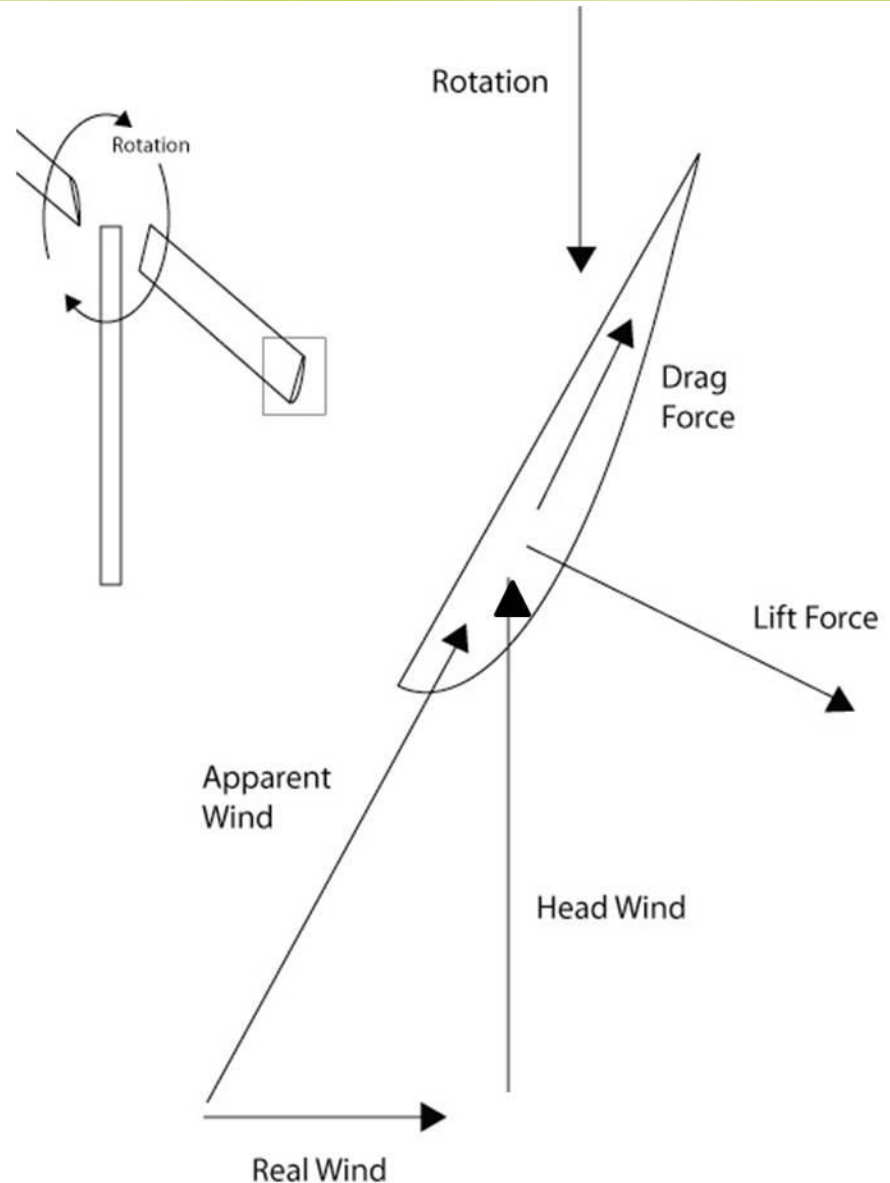
$\alpha = \text{low}$

$\alpha = \text{medium}$
<10 degrees

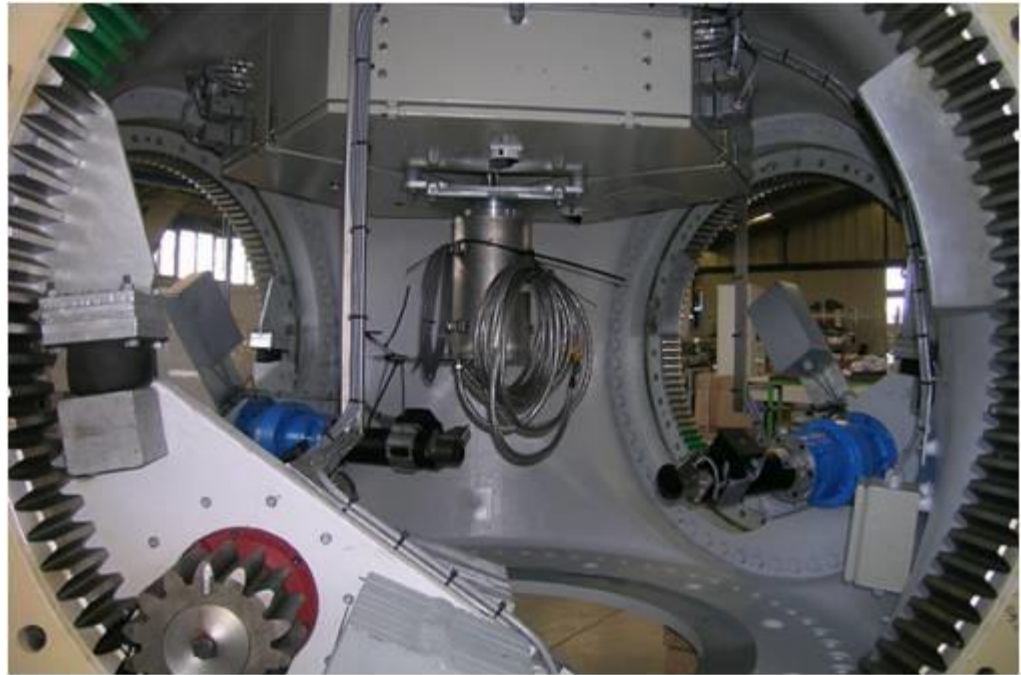
$\alpha = \text{High}$
Stall!!



Lift/Drag Forces Experienced by Turbine Blades



Pitch Control Mechanisms



Some Wacky Ideas...

