POWER PLANT (ME-403)

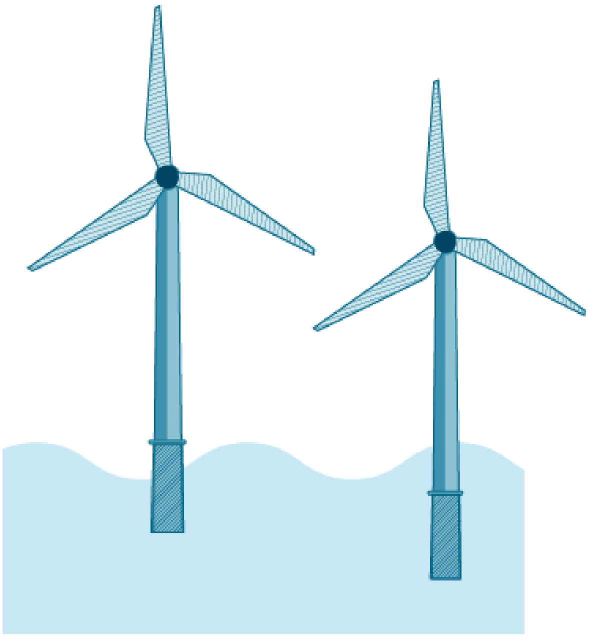
Lecture Topic : Wind Energy

MANSOOR ALI ZAHEER
Assistant Professor
Mechanical Engineering Department
University of Sargodha

Wind Energy

- Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth.

- Wind energy (or wind power) describes the process by which wind is used to generate electricity.



Process of Wind Creation

- Wind “current of air (air moving from an area of high pressure to an area of low pressure)
- Hot air rises, it expands, becomes less dense, and is then replaced by denser, cooler air
- Heated air rises from equator, moves north and south in the upper levels of the atmosphere and circulates above cooler air.

Wind Energy Terminology

- **Angle of attack:** The angle of relative air flow to a wind turbine’s blade.
- **Average wind speed (velocity):** The mean wind speed over a specified period of time
- **Chord :** The width of a wind turbine blade at a given location along the length.
- **Cut-in speed:** The wind speed at which the turbine blades begin to rotate and produce electricity, typically around 10 miles per hour.
- **Cut-out speed:** The wind speed, usually around 55 to 65 miles per hour, at which some wind turbines automatically stop the blades from turning and rotates out of the wind to avoid damage to the turbine.

How Wind Power Is Generated:

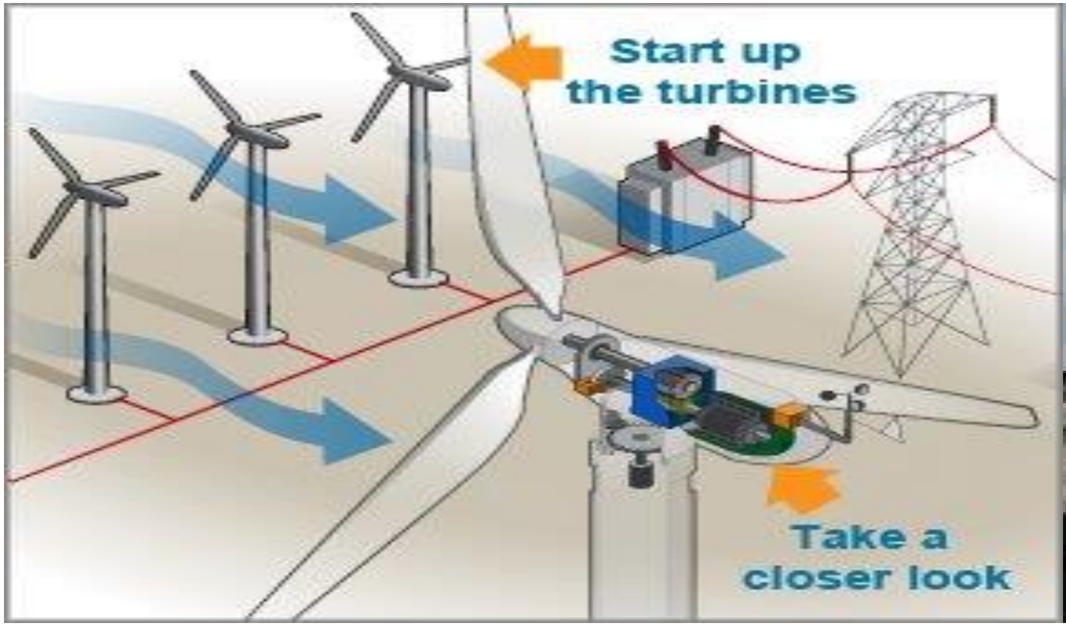
- The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity.
- Wind turbines convert the kinetic energy in the wind into mechanical power.
- This mechanical power can be used for specific tasks such as a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

Wind Turbines

- Wind turbines, like aircraft propeller blades, turn in the moving air and power an electric generator that supplies an electric current.

- Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity.

- The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity



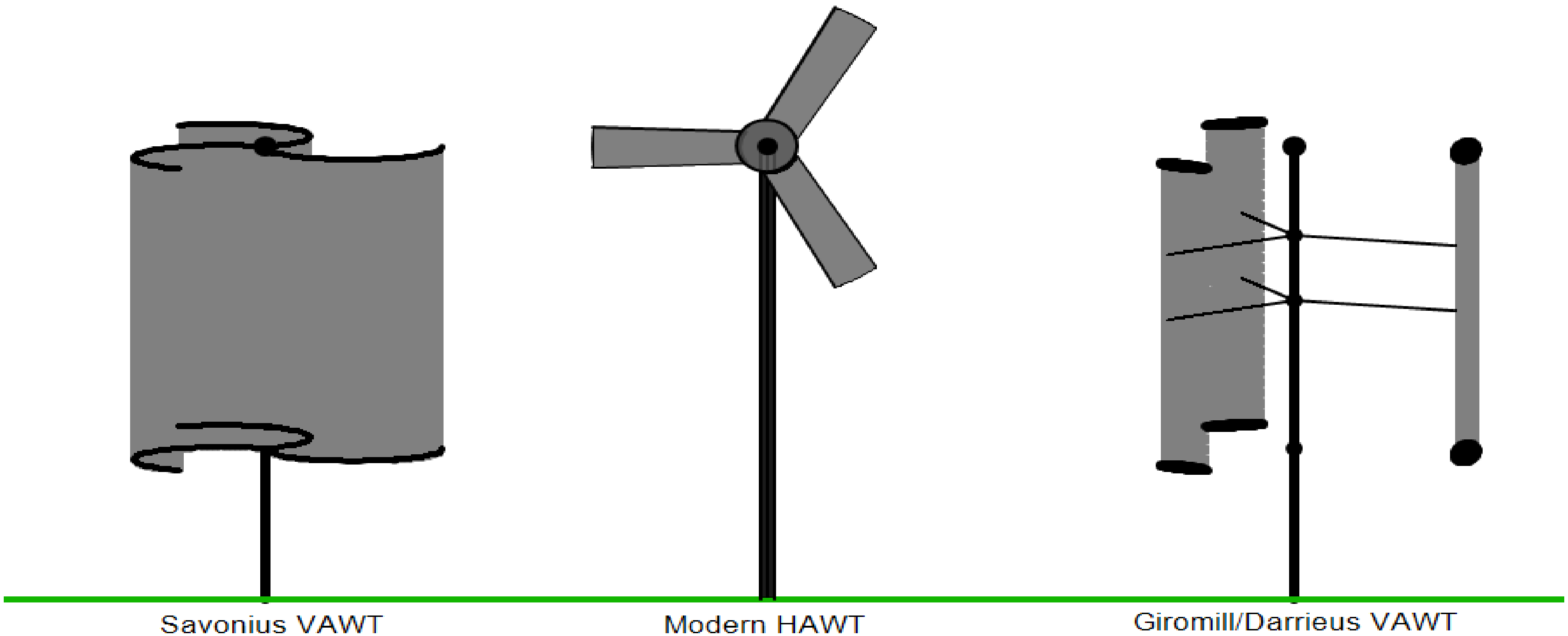
Windmill vs Wind Turbine

Comparison Chart

Windmill	Wind Turbine
It is a wind-powered machine that converts the energy of wind to pump water or grind or mill grains.	It is a mechanical device that converts the kinetic energy of wind to generate large amounts of electricity.
It uses the power of wind directly and converts it into mechanical energy by means of vanes called sails or blades.	It is one of the most effective and low-cost sources of renewable energy that use wind power to generate electricity.
A pressure difference is created when the wind blows over the blades causing the blades to rotate.	The blades of a wind turbine operate on the principle of lift and drag just like airplane wings.
Used for pumping water and from crushing to shredding rocks and agricultural material.	Commercially used to generate electricity to power homes, schools, or businesses.

❖ Types of Wind Turbines

- **Horizontal axis**
- **Vertical-axis**

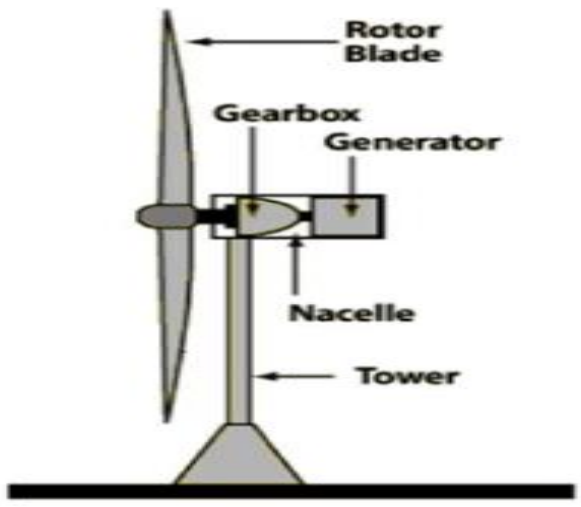


Types of Wind Turbines

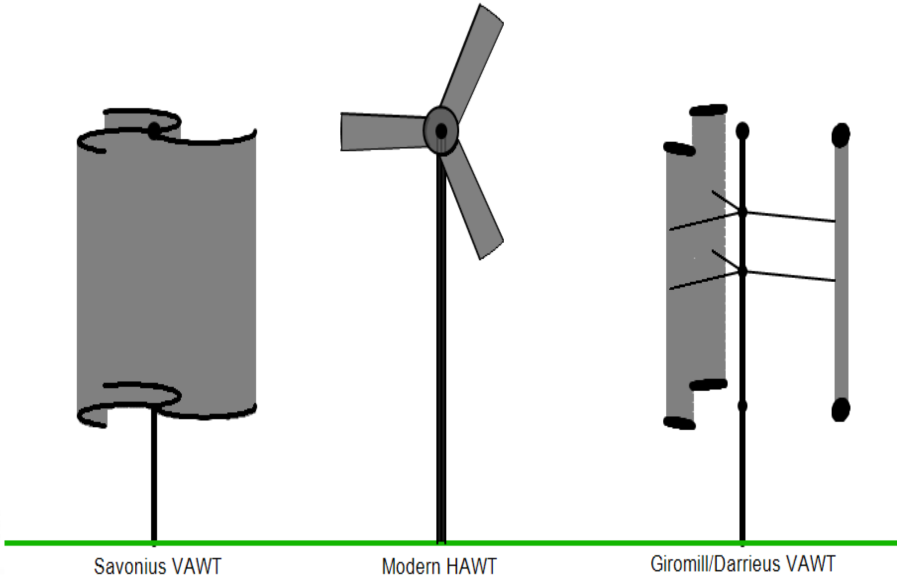
- **Horizontal axis**

  – Horizontal axis means the rotating axis of the wind turbine is horizontal, or parallel with the ground.

  – In big wind application, horizontal axis wind turbines are almost all you will ever see. However, in small wind and residential wind applications, vertical axis turbines have their place.

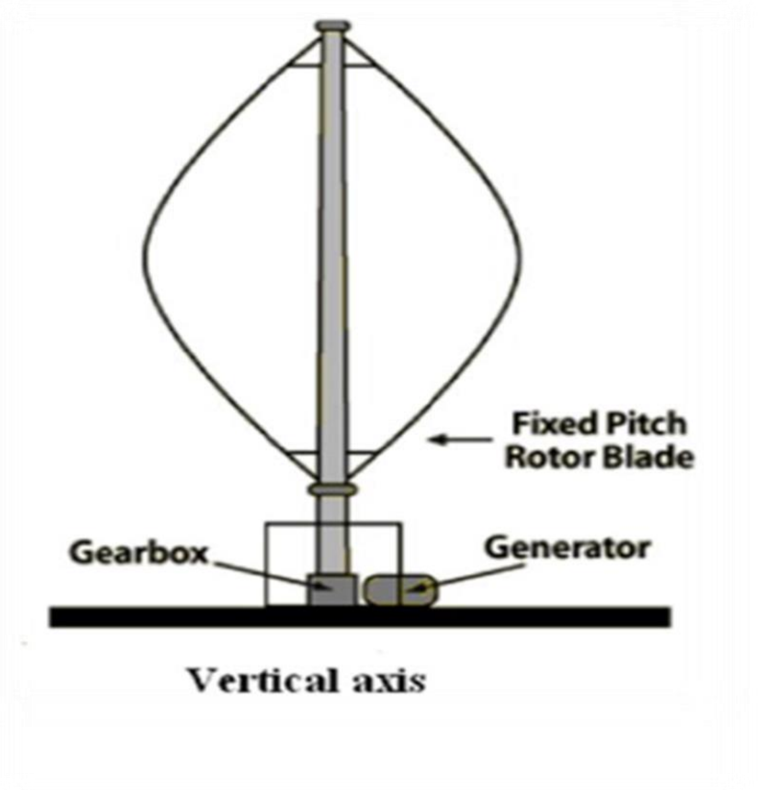


Horizontal axis



Types of Wind Turbines

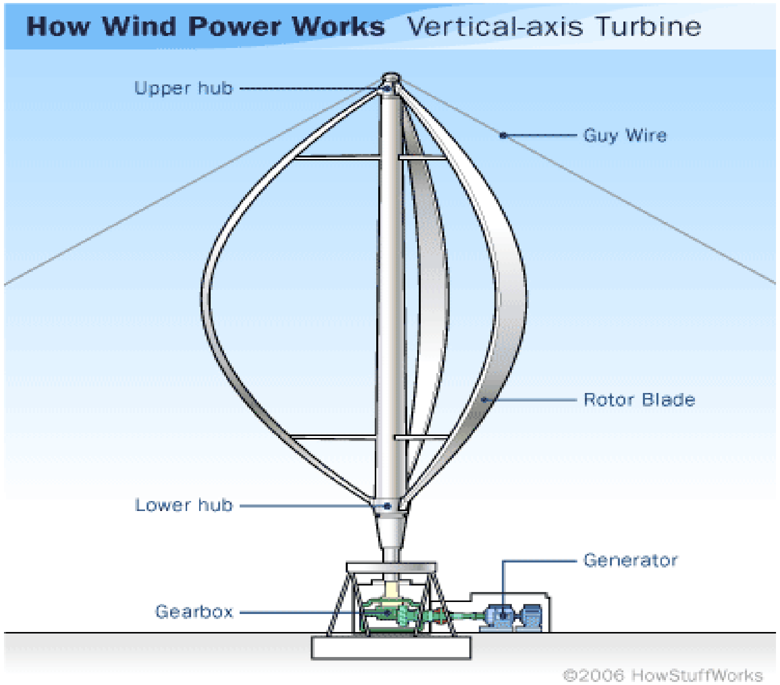
- **Vertical axis**
- With vertical axis wind turbines the rotational axis of the turbine stands vertical or perpendicular to the ground.



Types of Vertical Axis Wind Turbines

- **Darrieus wind turbine**

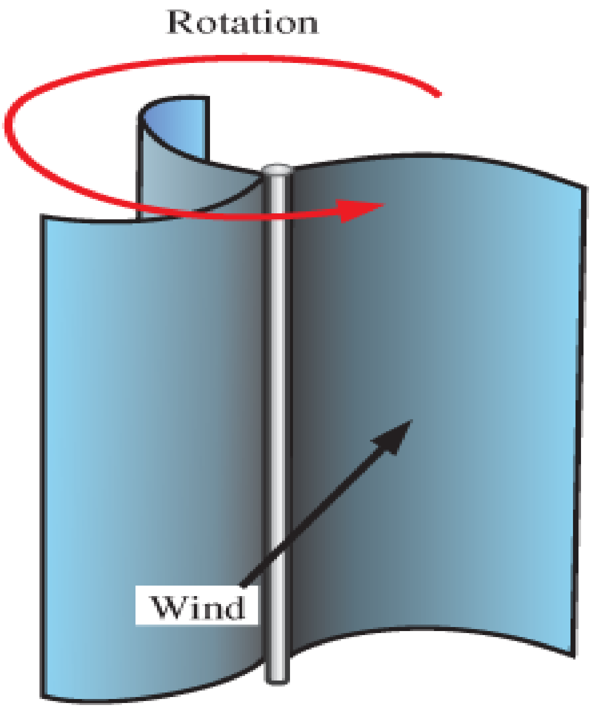
- The Darrieus wind turbine is a type of vertical axis wind turbine (VAWT) used to generate electricity from the energy carried in the wind. The turbine consists of a number of curved aerofoil blades mounted on a vertical rotating shaft or framework. The curvature of the blades allows the blade to be stressed only in tension at high rotating speeds.

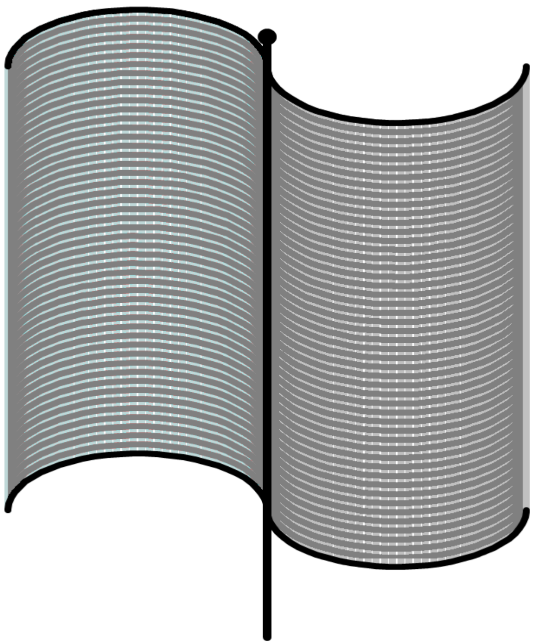


Types of Vertical Axis Wind Turbines

- **Savonius wind turbine:**

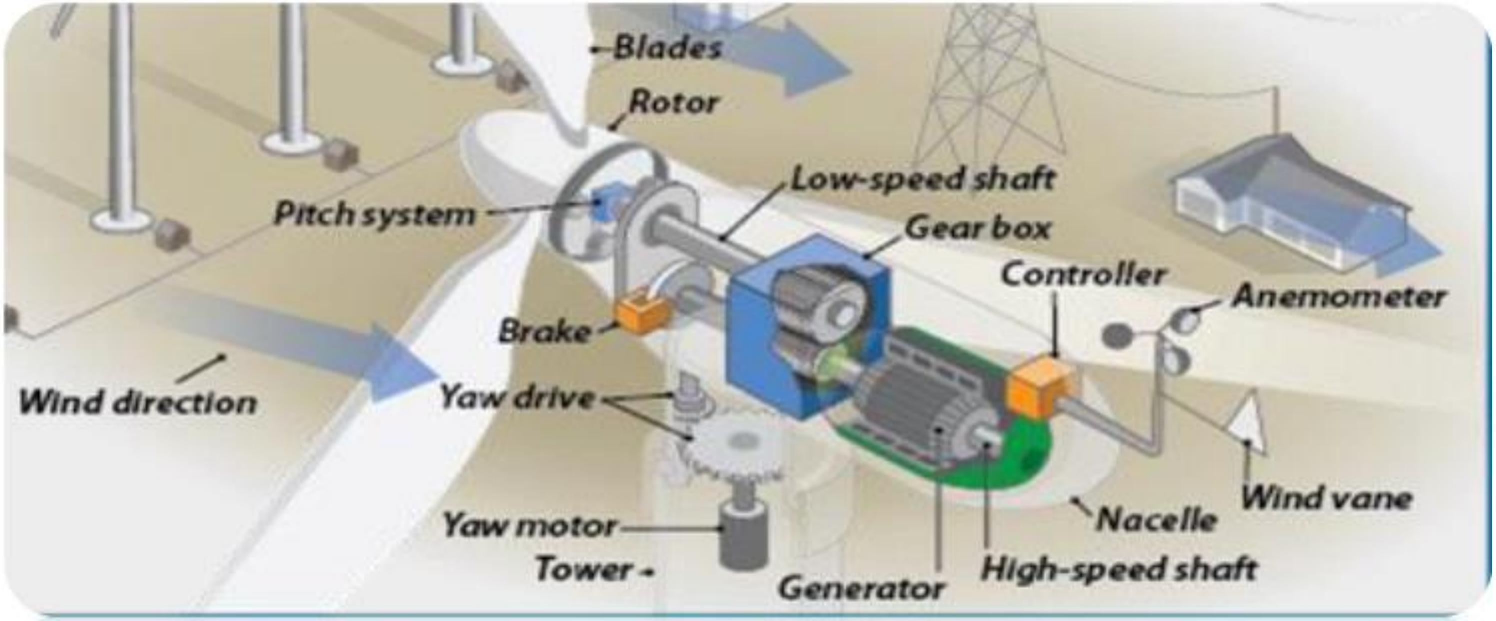
The Savonius turbine is one of the simplest turbines. Aerodynamically, it is a drag-type device, consisting of two or three scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" shape in cross section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin.





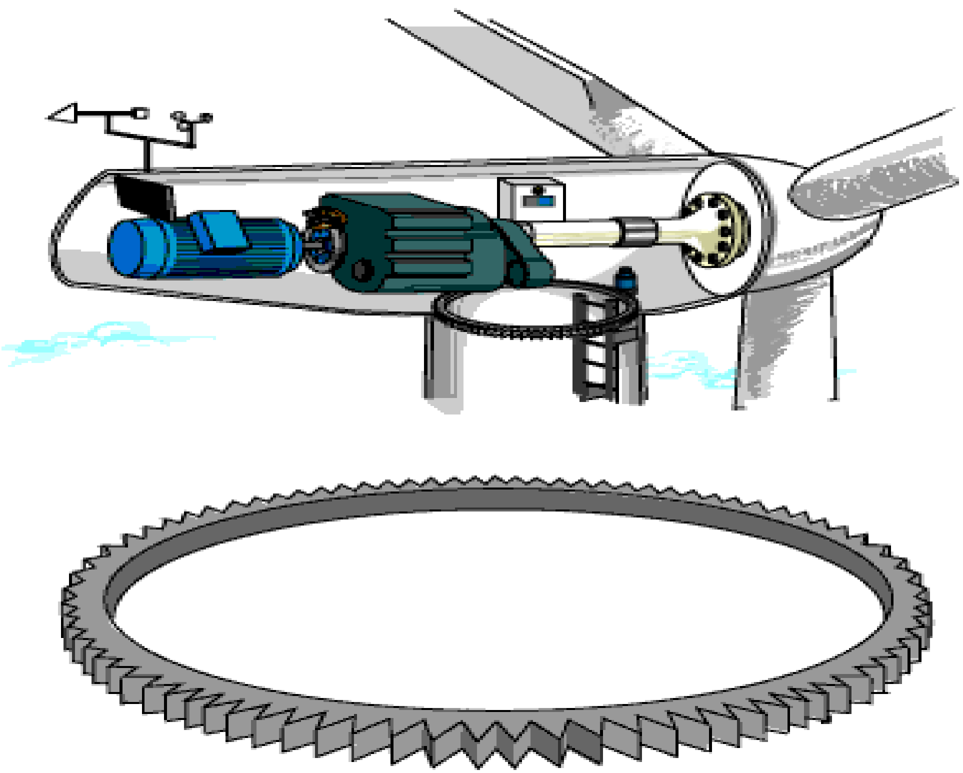
Wind Turbine Components

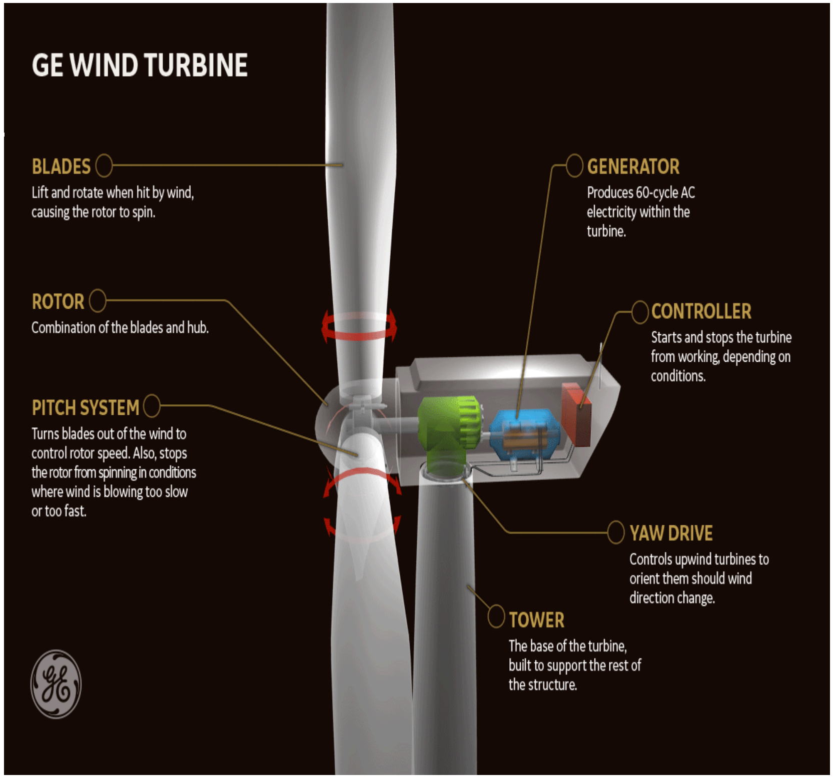
- Yaw
- Pitch
- Drivetrain
- Cooling unit
- Nacelle
- Rotor blades
- Electronic controller
- Wind Turbine Tower



YAW

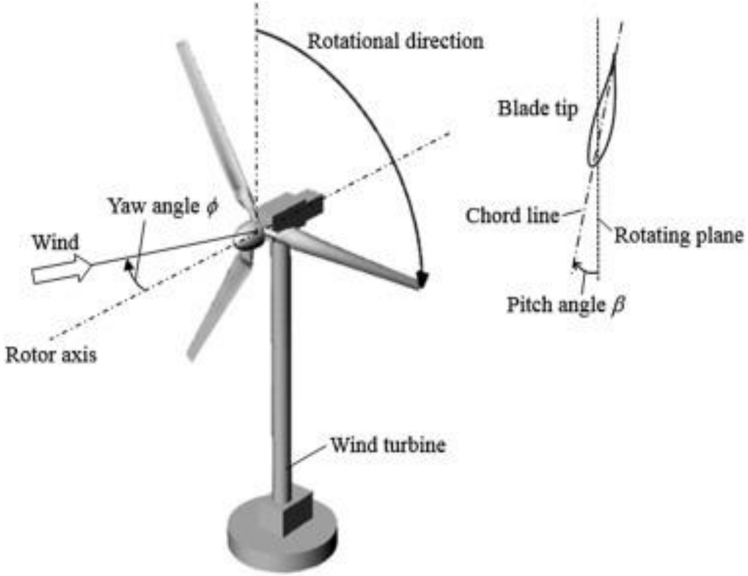
- The yaw drive is an important component of the horizontal axis wind turbines' yaw system.
- To ensure the wind turbine is producing the maximal amount of electric energy at all times, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes.





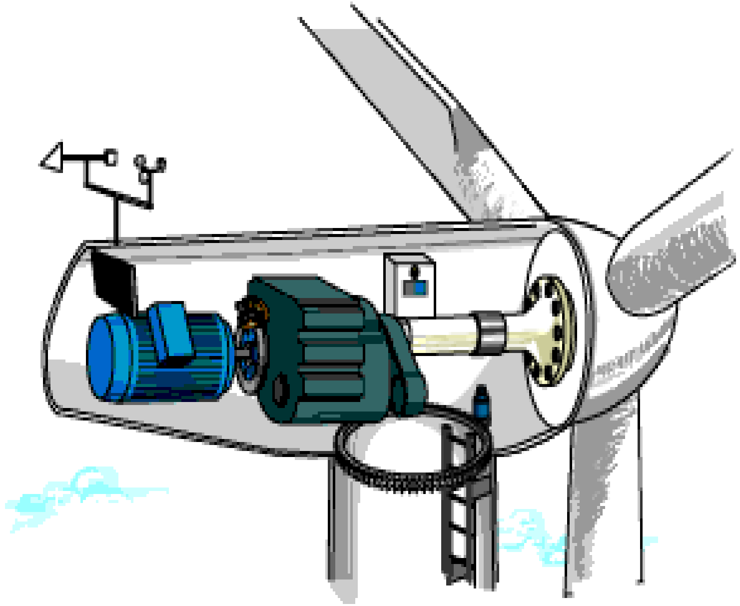
Pitch

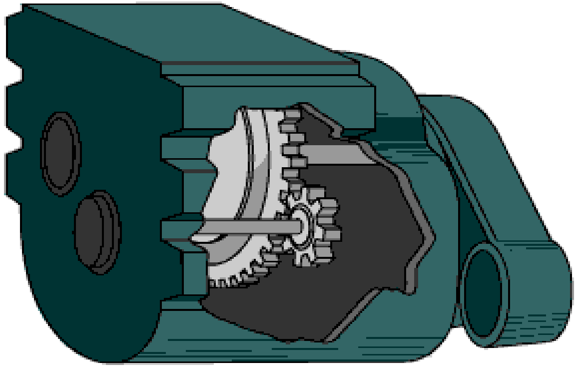
- On a pitch controlled wind turbine the turbine's electronic controller checks the power output of the turbine several times per second.
- When the power output becomes too high, it sends an order to the blade pitch mechanism which immediately pitches (turns) the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again.
- The rotor blades thus have to be able to turn around their longitudinal axis.

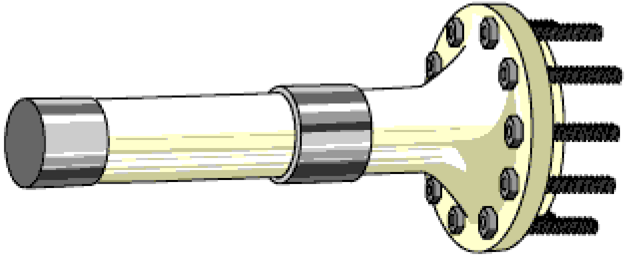


Drivetrain

- The drivetrain of a wind turbine is composed of the gearbox and the generator, the necessary components that a turbine needs to produce electricity.
- The gearbox is responsible for connecting the low-speed shaft attached to the turbine blades to the high-speed shaft attached to the generator.

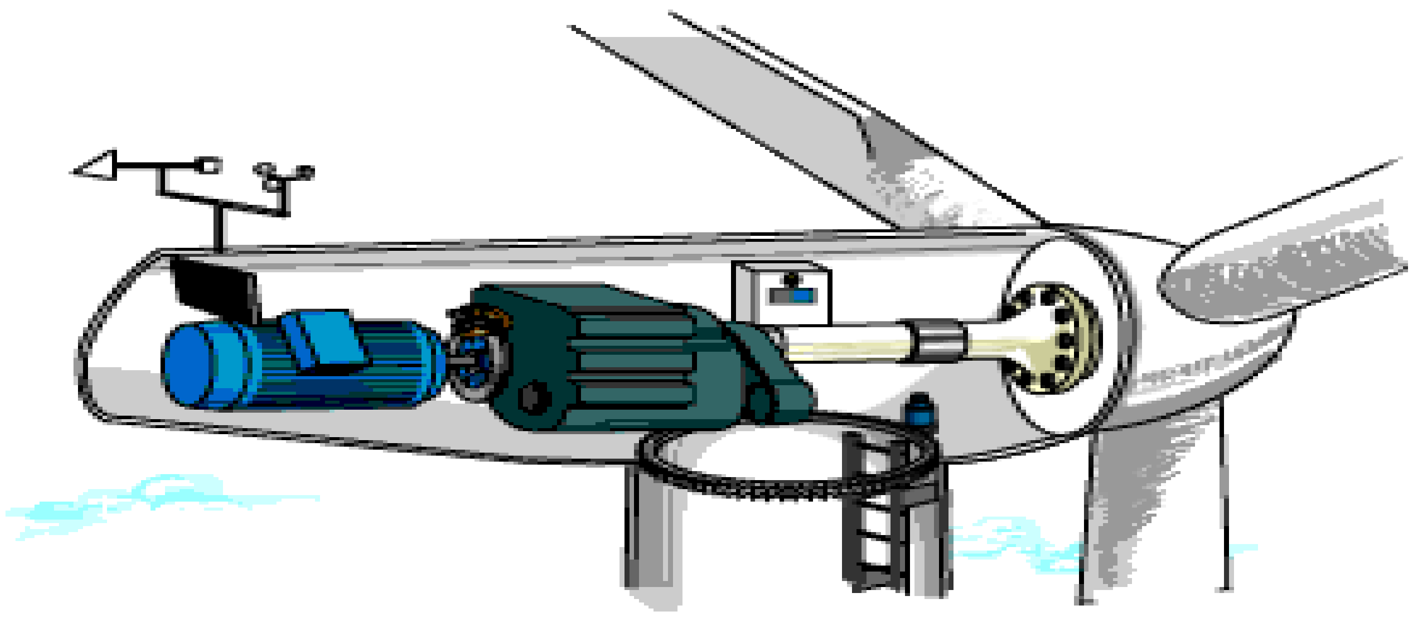






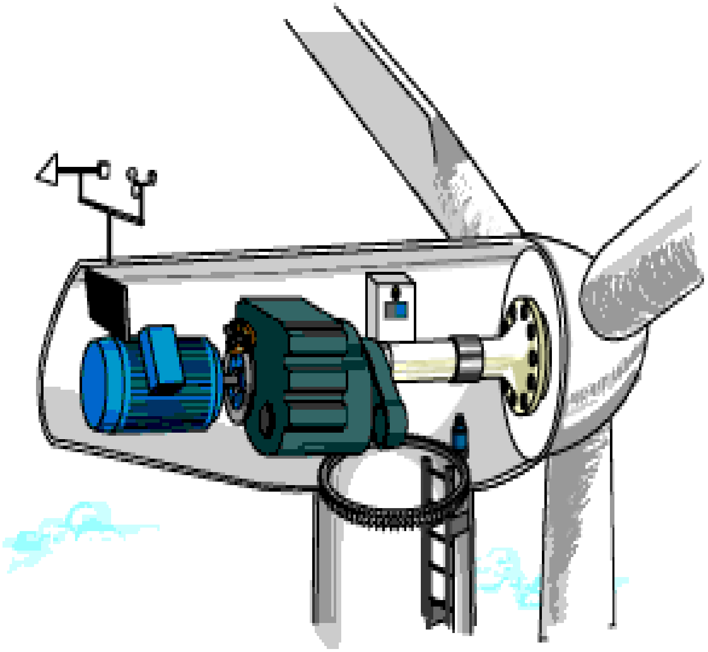
Nacelle

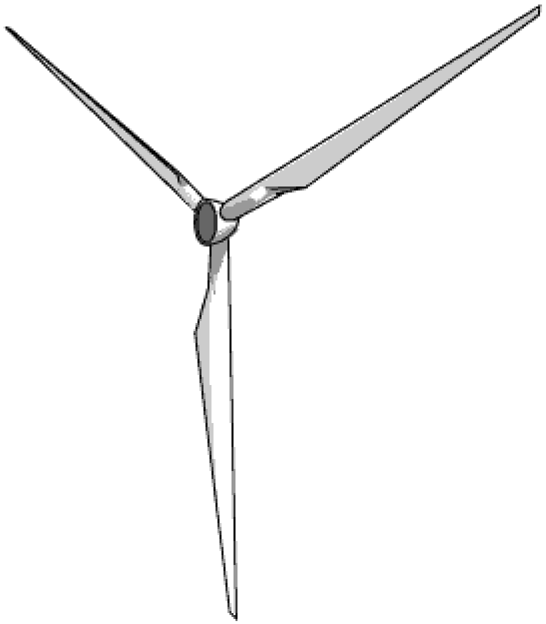
- The nacelle contains the key components of the wind turbine, including the gearbox, and the electrical generator.
- Service personnel may enter the nacelle from the tower of the turbine. To the right of the nacelle we have the wind turbine rotor, i.e. the rotor blades and the hub.



Hub and Rotor blades

- Hub is the central part of the wind turbine, which supports the turbine blades on the outside and connects to the low-speed rotor shaft inside the nacelle.
- The rotor blades capture the wind and transfer its power to the rotor hub. On a modern 1000 kW wind turbine each rotor blade measures about 27 metres (80 ft.) in length and is designed much like a wing of an aeroplane





Rotor and Hub Design

Main Rotor Design Method (ideal case):

1. Determine basic configuration: orientation and blade number
2. take site wind speed and desired power output
3. Calculate rotor diameter (accounting for efficiency losses)
4. Select tip-speed ratio (higher → more complex airfoils, noise) and blade number (higher efficiency with more blades)
5. Design blade including angle of attack, lift and drag characteristics
6. Combine with theory or empirical methods to determine optimum blade shape

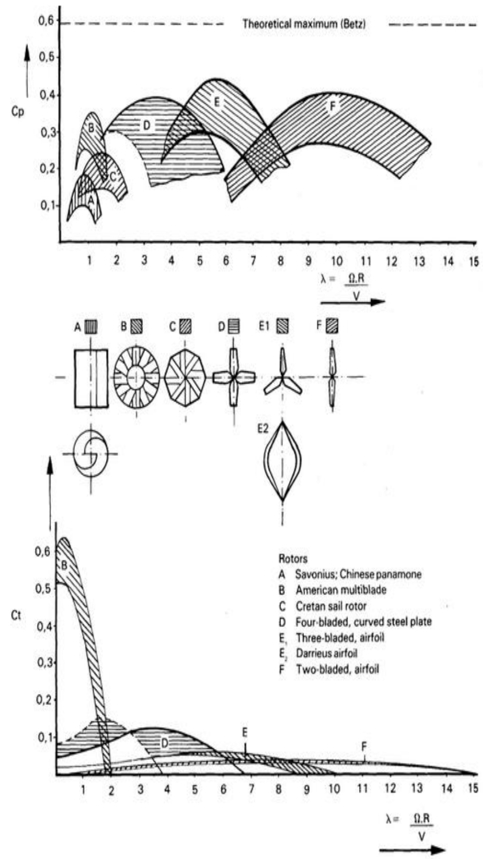
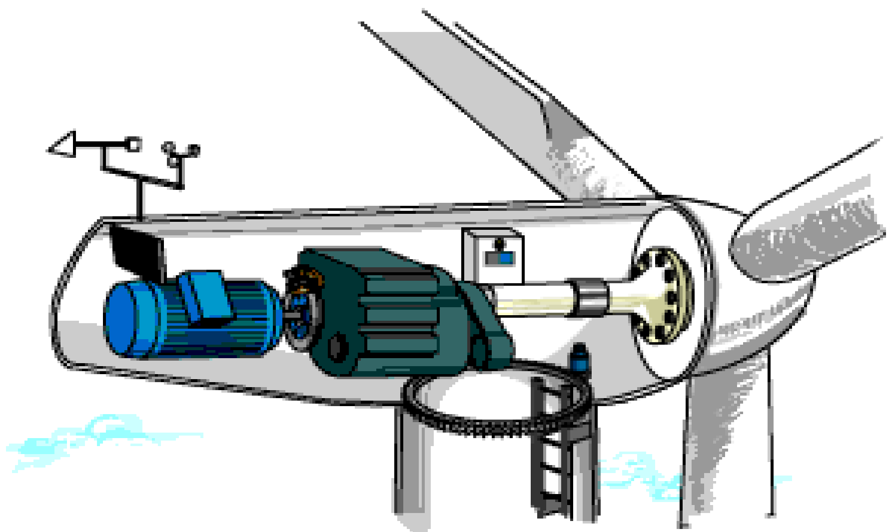
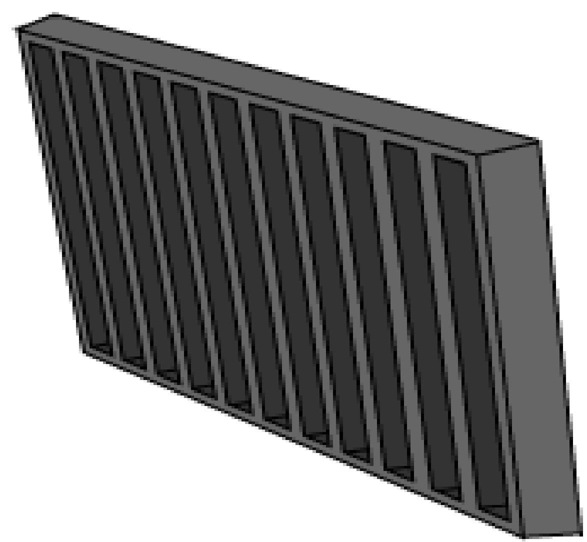


Fig. 121 The power coefficients (Cp) (above) and the torque coefficients (Ct) of various types of wind turbine rotor plotted against tip-speed ratio (λ) (after Lysen/CWD [45])

Cooling unit

- The cooling unit contains an electric fan which is used to cool the electrical generator.
- In addition, it contains an oil cooling unit which is used to cool the oil in the gearbox.
- Some turbines have water-cooled generators.





Wind Turbine Tower

- Since velocities close to the ground are very low and there must be good clearance between the lower part of the blades and the ground, the wind turbines are placed on top of a tower at a significant height above the ground. The height of the tower depends on the diameter of the blade and is of the order of magnitude of the blade diameter, D, allowing a clearance of D/2, between the ground and the lower part of the blade. Thus, towers are between 30 and 100 m high. The tower is a simple structural element, usually made of reinforced concrete, which is designed to withstand the axial force and resulting moment generated by the wind turbine. It is typically thicker at the lower part and is usually designed as a hollow structure to allow easy access to the top for engine repairs at the turbine hub.

Wind Efficiency

- Wind efficiency is the amount of kinetic energy in the wind that is converted to mechanical energy and electricity. Laws of physics described by Betz Limit says the maximum theoretical limit is 59.6%. The wind requires the rest of the energy to blow past the blades. This is in fact good. If a turbine trapped 100% of energy wind would stop blowing and the blades of a turbine cannot turn to produce electricity.
- It is, however, not possible for any machine, at present to convert all of the trapped 59.6% of kinetic energy from wind to electricity. There are limits due to the way generators are made and engineered, which further decrease the amount of energy that is finally converted to power. The average at present is 35-45% .

Wind Capacity Factor

- The **capacity factor** is the average power generated, divided by the rated peak power.
- Let's take a five-megawatt **wind** turbine. If it produces power at an average of two megawatts, then its **capacity factor** is 40% ($2 \div 5 = 0.40$, i.e. 40%).

Capacity Factor = Average Output / Peak Output

❖ **Factors Improve Capacity Factor:**

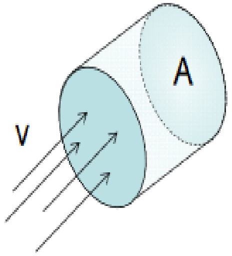
- **Wind speed**
- **Air density**
- **Larger and taller turbines**

Wind Turbine Efficiency

- For the wind turbine, one standard of perfection would be the ability to convert all of the power available in the wind passing through its blades, at a specific velocity, into useful mechanical power ‘

$$\text{Wind turbine efficiency} = \frac{\text{Shaft power out of turbine into gear box}}{\text{Wind power into turbine blades}}$$

Wind Physics
Available wind power



- Wind power depends on:
  - Amount of air (volume)
  - Speed of air (velocity)
  - Mass of air (density)
  - Flowing through area of interest (flux)
- Kinetic energy: $KE = \frac{1}{2}m\mathrm{v}^2$
- Power: P$= \frac{1}{2}\dot{m}\mathrm{v}^2$
- Particles of air have low mass, so must look at mass flow in a specific area
- Fluid mechanics gives mass flow rate $\dot{m} = \frac{dm}{dt} = \rho A\mathrm{v}$
- Thus power can be written as: $P = \frac{1}{2}\rho A\mathrm{v}^3$

Wind power basics

- Power in the wind:

  $P = \frac{1}{2}\rho A \mathrm{v}^3$

  - Effect of wind speed, **v**
  - Effect of air density, $\boldsymbol{\rho}$
  - Effect of swept area

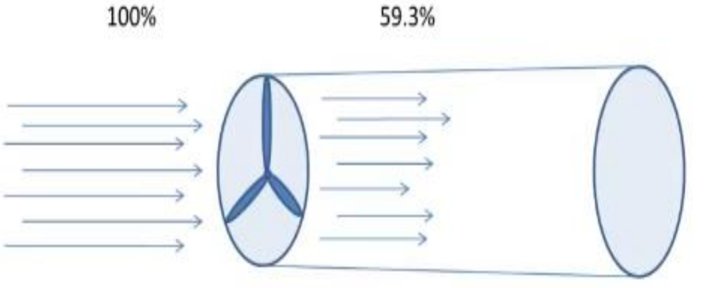
    $\boldsymbol{A} = \pi \mathrm{r}^2$

Faster wind lots of power

Bigger turbine more power

~1 for air, nearly constant

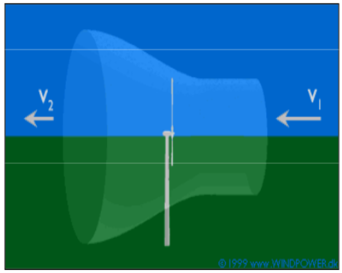
Betz limit, Tip Speed, Efficiency



- Spinning blades cause wind behind turbine to rotate. Faster spinning blades cause less rotation and have less wake rotation losses
- Rule: Faster the tip of the blade, the more efficient turbine

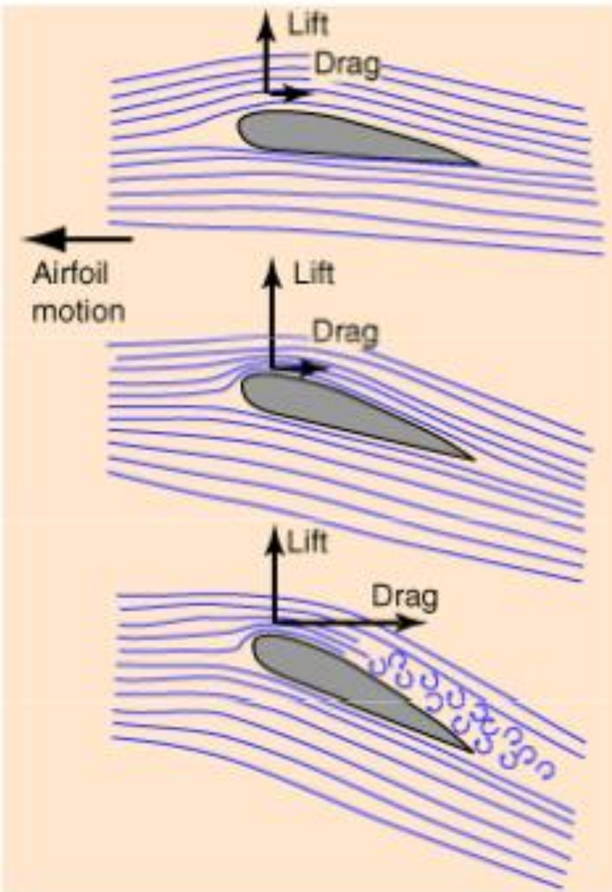
Efficiency in extracting wind power

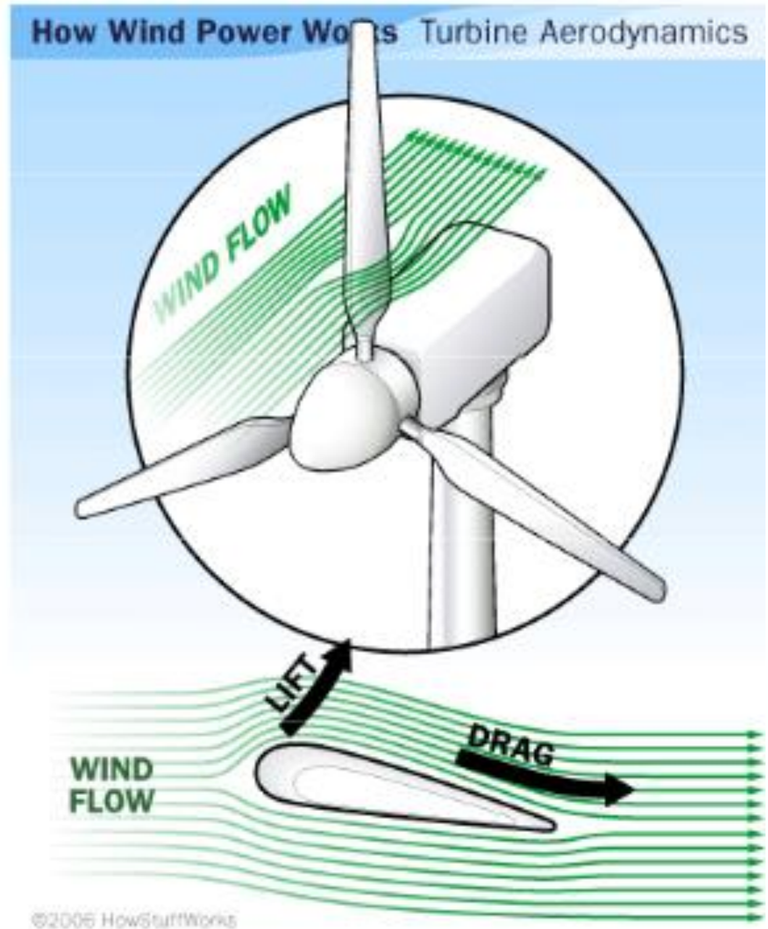
- Power coefficient, C_p, is the ratio of power extracted by turbine to the total contained in the wind resource $C_p = \frac{P_T}{P_W}$



- Turbine power output: $P_T = \frac{1}{2}\rho A\, \mathrm{v}^3 \mathrm{C_p}$
- Tip speed ratio, $\lambda = \omega R/\mathrm{v}$, ω being rotational speed of the tip of blade having radius R and v is the velocity of air
- 59 % efficiency is the BEST a conventional wind turbine can do in extracting power from the wind.

Lift and drag forces





LIFT AND DRAG FORCES

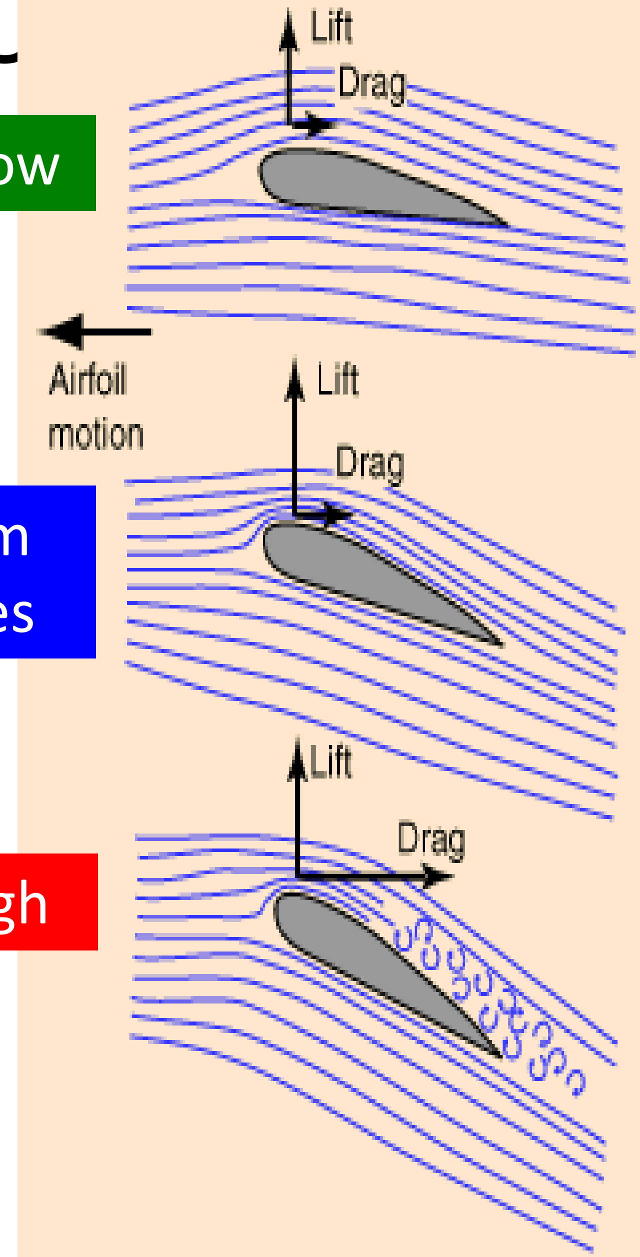
The Lift Force is perpendicular to the direction of motion. We want to make this force big.

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

α = low

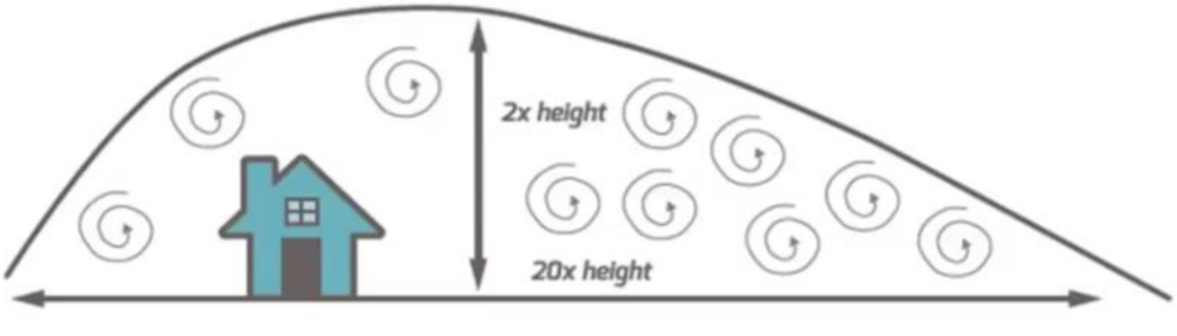
α = medium
<10 degrees

α = High



Wind power basics

- Avoid slow wind
- Avoid turbulent wind
- Never on buildings



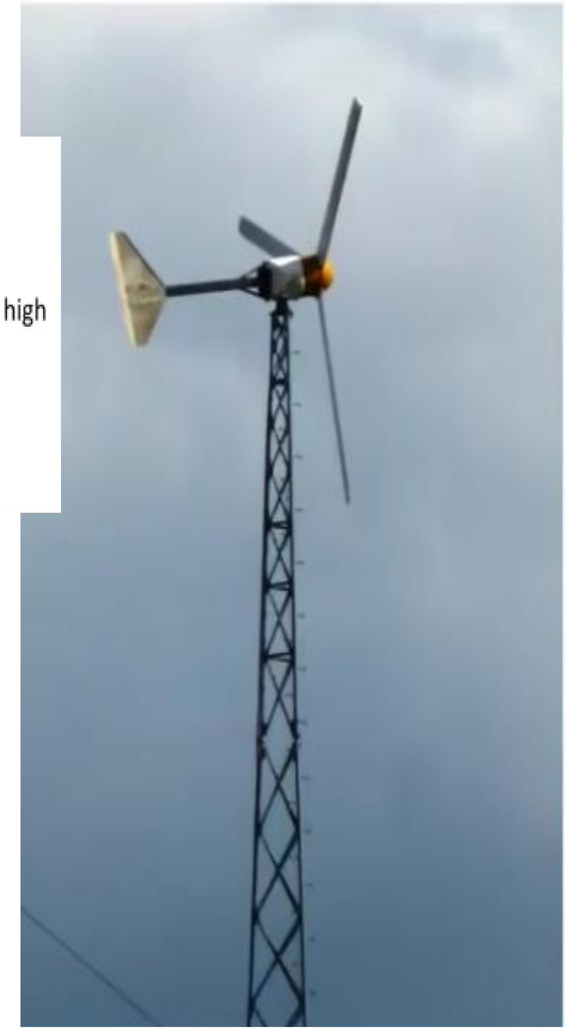

BAD!
Lincoln, NE
- Inefficient Design (savonious)
- Turbulent Wind
- Slow Wind
- Annoying due to vibrations causing noise in building!


Portland, Oregon


BAD!
- Design is OK
- Turbulent Wind
- Slow Winds (even though they are high the winds are slowed in urban settings)
- Annoying due to vibrations causing noise in building!
Portland, Oregon

Good!

- Design OK
- Clear winds up high
- Tall Tower



Advantages of Wind Energy

- Clean & Environment friendly Fuel source
- Renewable & Sustainable
- Cost Effective
- Industrial and Domestic Installation
- Job Creation

Disadvantages of Wind Energy

- Fluctuation of Wind and Good wind sites
- Noise and aesthetic pollution
- Not a profitable use of land
- Threat to wildlife

Conclusion

- Wind energy is probably the solution for our energy demands. It has great potential and is easy to manage. All you have to do is build the turbine and everything else is going to be free.
- With only 1 turbine, you can power over 200 homes. Every wind turbine lasts for about 20-25 years. As long as the wind blows, wind turbines can harness the wind to create power. Wind power only makes up a tiny percent of electricity that is produced.
- Unlike coal, wind turbines don't create greenhouse gases and are completely renewable source.
- Many people believe that the wind energy could soon be our main source of energy.
- Though wind turbines can cause complaints and fatalities of wildlife, it could be the energy solution we have been looking for.

ANY QUESTIONS..?