Wind Energy Fundamentals

9TH MARCH 2015

JONATHAN J. MILES, PH.D.
DEPT. OF INTEGRATED SCIENCE AND TECHNOLOGY
CENTER FOR WIND ENERGY
JAMES MADISON UNIVERSITY

What is Energy?

ENERGY?

ENERGY FORMS?

ENERGY CONVERSION?

CONVERSION EFFICIENCY?

The Ubiquitous American Windmill

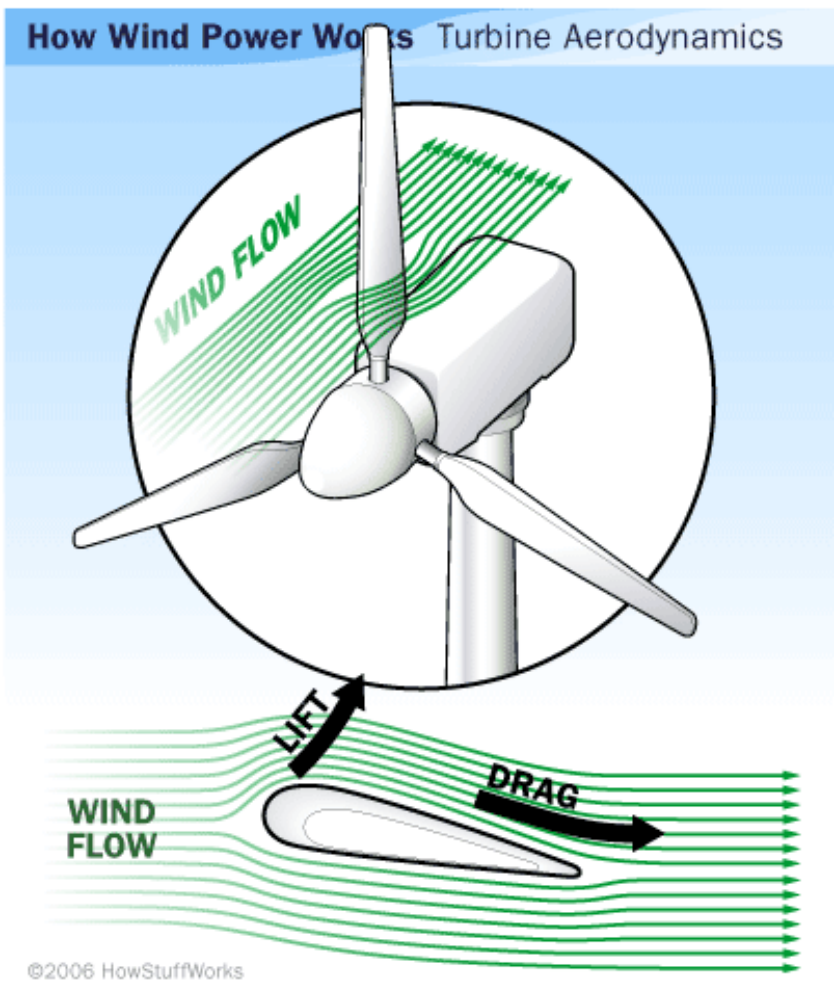
The Ubiquitous American Windmill

- Relies mostly on the wind's force to push the blades into motion.

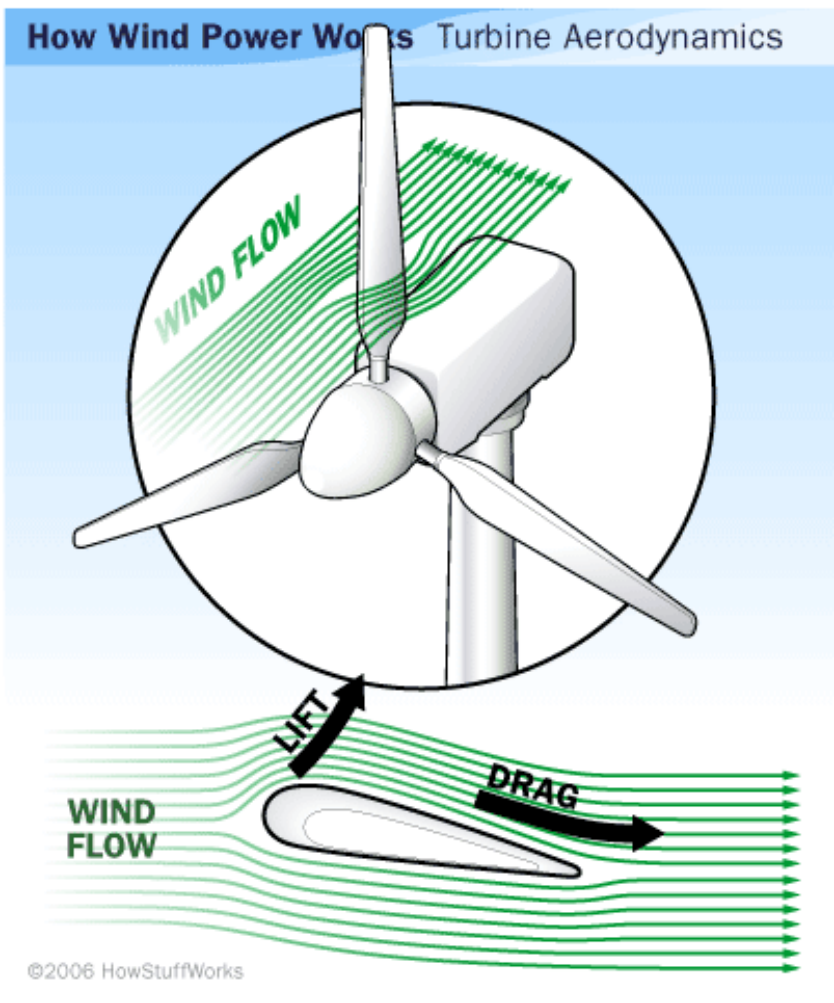
The Ubiquitous American Windmill

- Relies mostly on the wind's force to push the blades into motion.
- High torque, Low efficiency.

The Modern American wind turbine

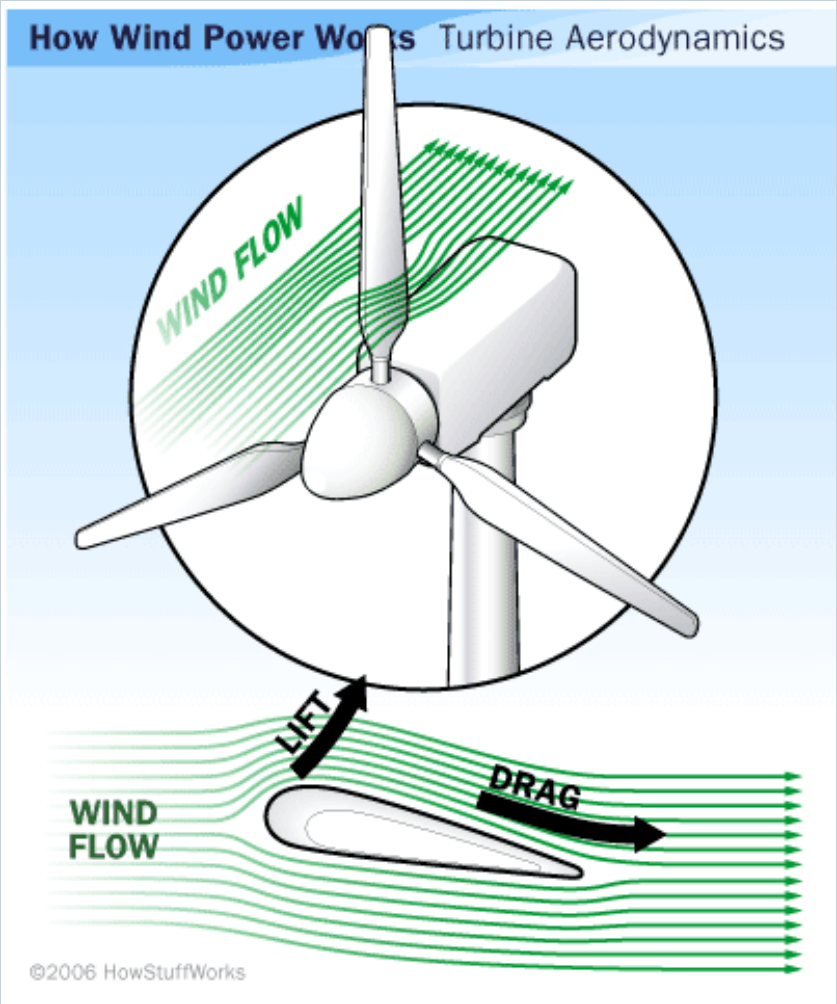


The Modern American wind turbine



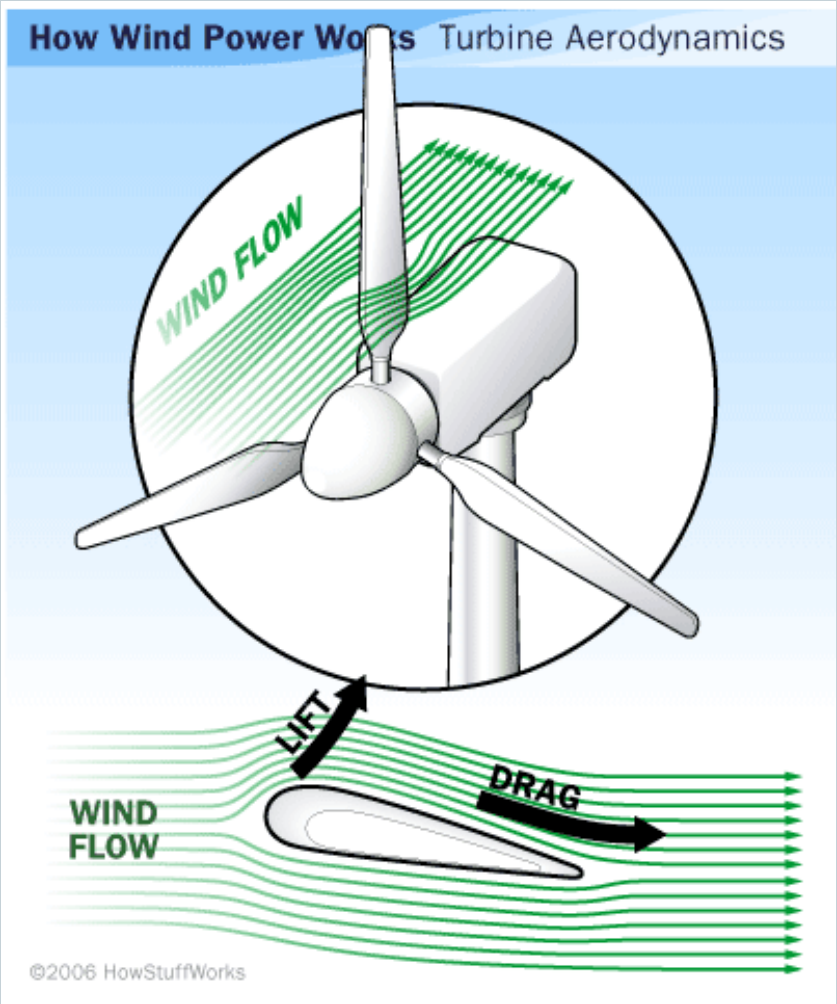
- Modern wind turbines use more sophisticated **aerodynamic** principles to capture the wind's energy most effectively.

The Modern American wind turbine



- Modern wind turbines use more sophisticated **aerodynamic** principles to capture the wind's energy most effectively.
- The two primary aerodynamic forces at work in wind-turbine rotors are **lift**, which acts perpendicular to the direction of wind flow; and **drag**, which acts parallel to the direction of wind flow.

The Modern American wind turbine



- Modern wind turbines use more sophisticated **aerodynamic** principles to capture the wind's energy most effectively.
- The two primary aerodynamic forces at work in wind-turbine rotors are **lift**, which acts perpendicular to the direction of wind flow; and **drag**, which acts parallel to the direction of wind flow.
- High conversion efficiency.

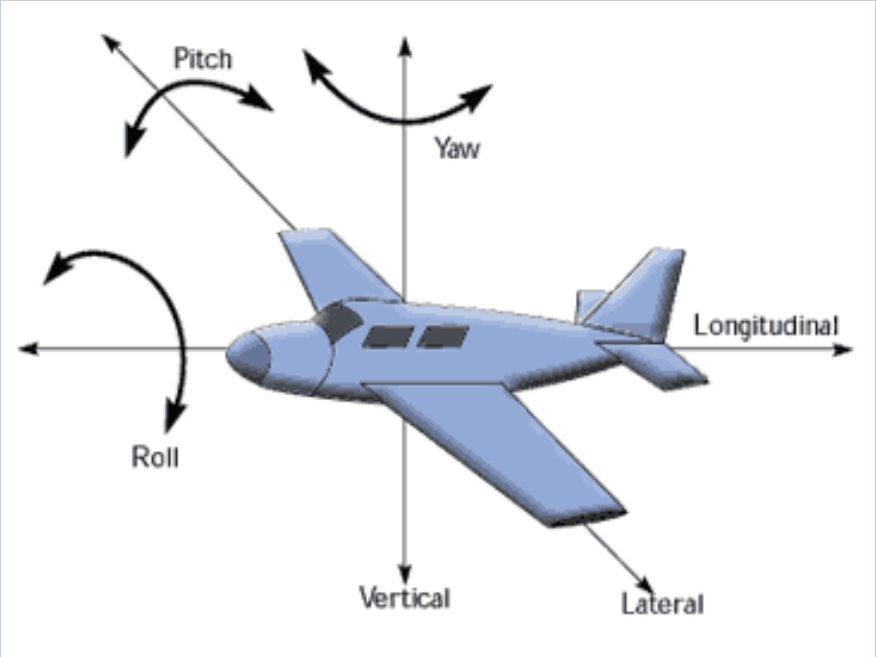
Fundamental Concepts

Lesson 1: Axes of rotation

What are the axes of rotation pertinent
To the motion of an airplane?

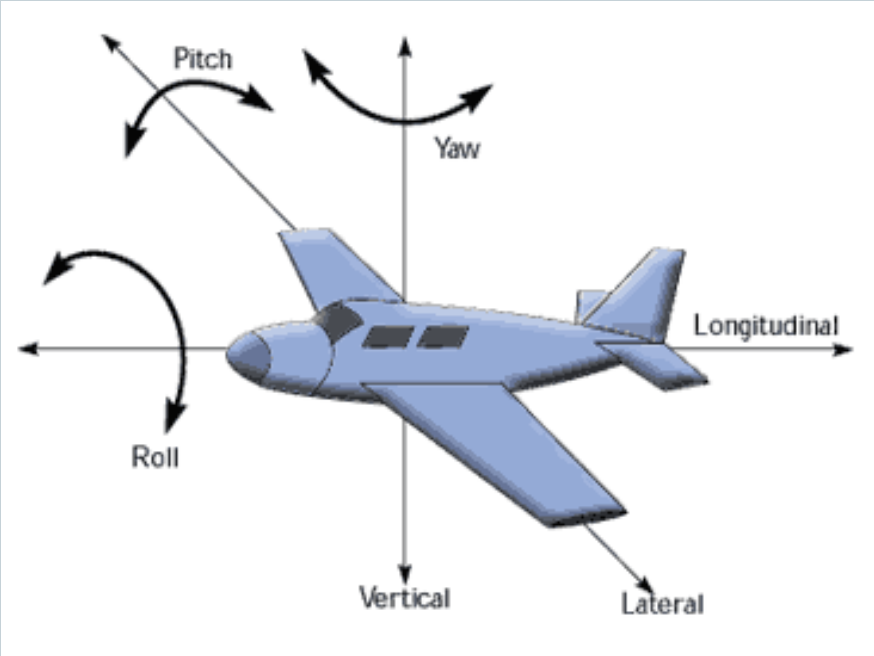
Lesson 1: Axes of rotation

What are the axes of rotation pertinent To the motion of an airplane?



Lesson 1: Axes of rotation

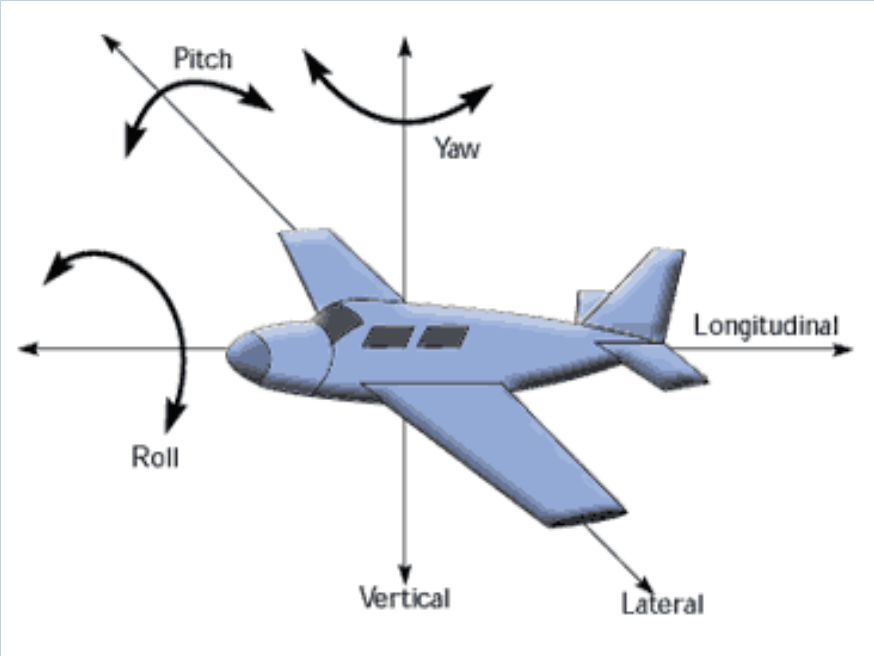
What are the axes of rotation pertinent To the motion of an airplane?



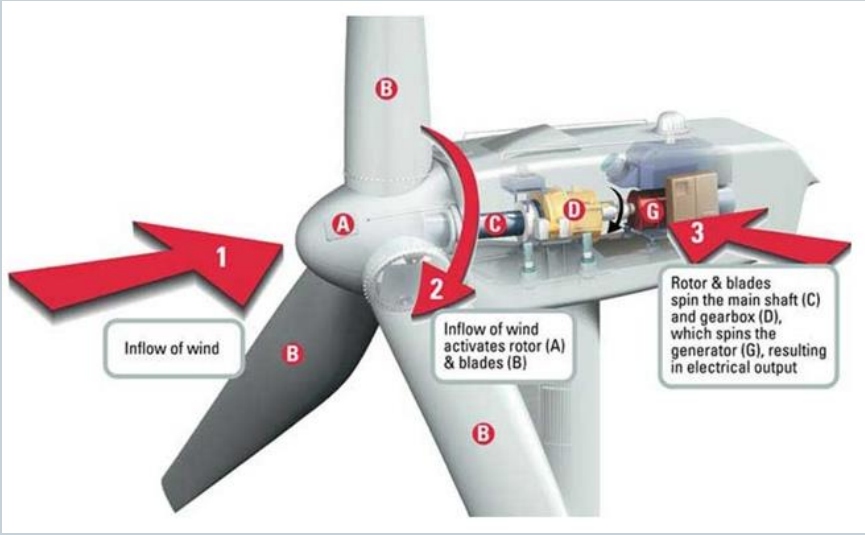
What are the axes of rotation pertinent To the motion of a wind turbine?

Lesson 1: Axes of rotation

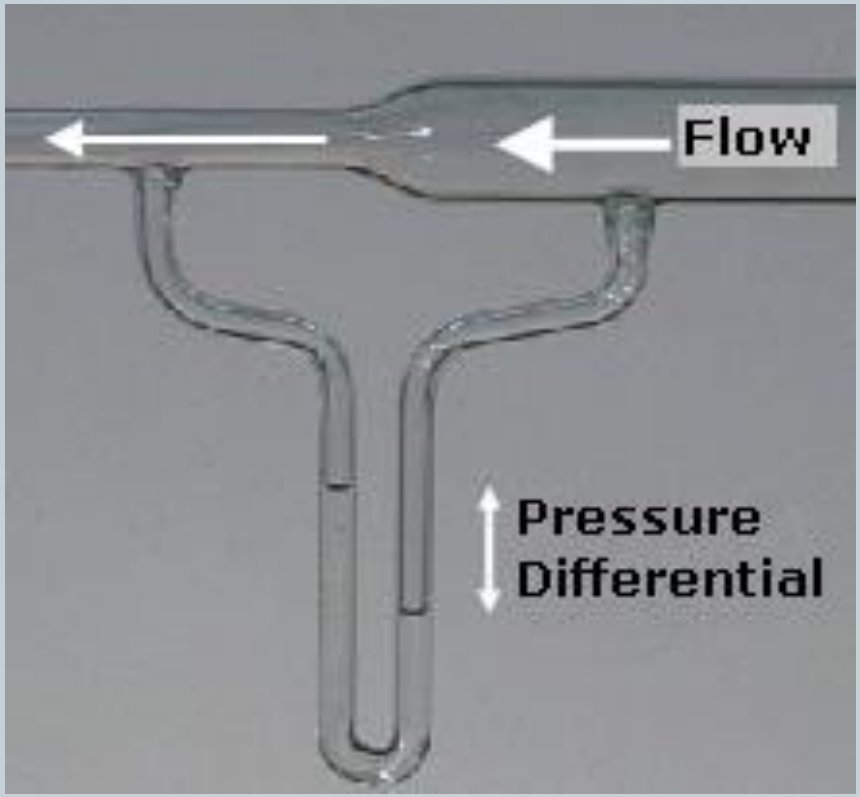
What are the axes of rotation pertinent To the motion of an airplane?



What are the axes of rotation pertinent To the motion of a wind turbine?

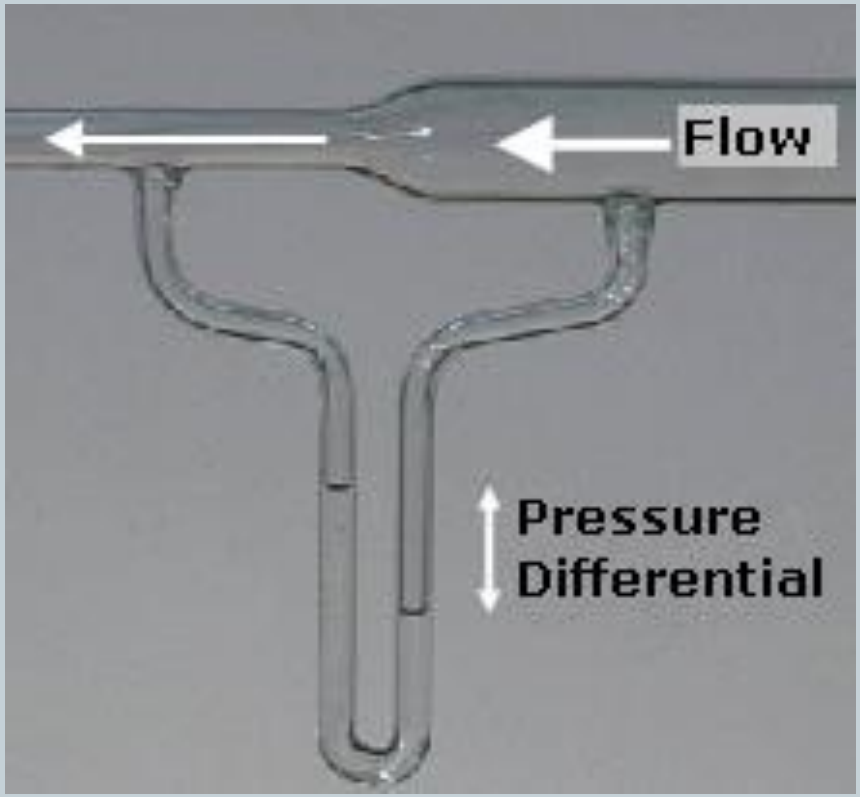


Lesson 2: Venturi flow



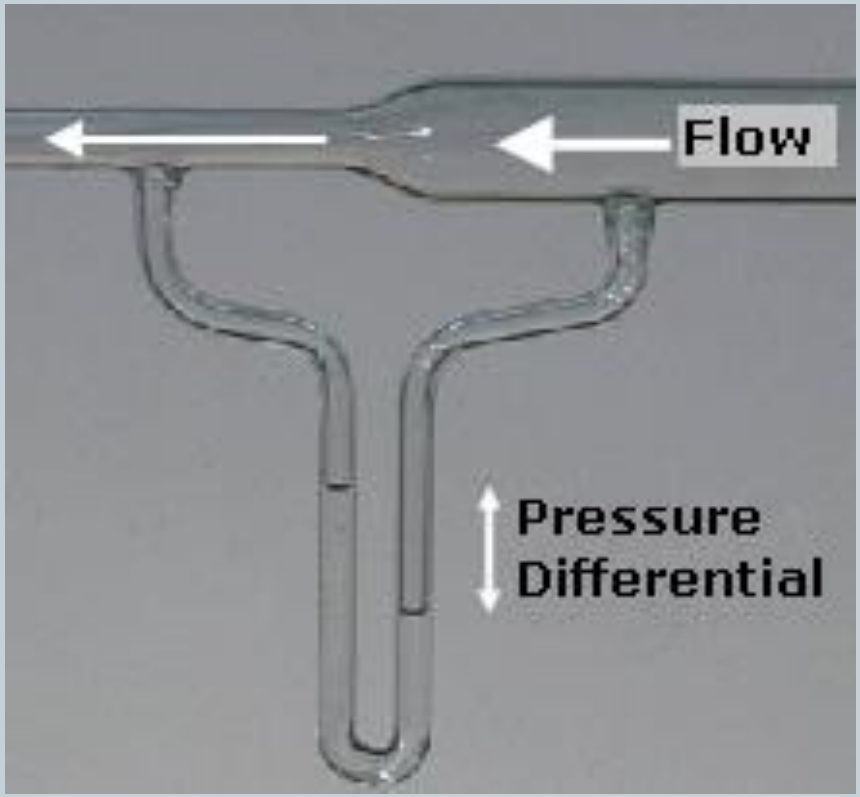
Lesson 2: Venturi Flow

- Bernoulli's equation
  - In fluid dynamics, **Bernoulli's principle** states that for an inviscid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.



Lesson 2: Venturi Flow

- Bernoulli's equation
  - Conservation of energy requires that in a steady flow, the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline.



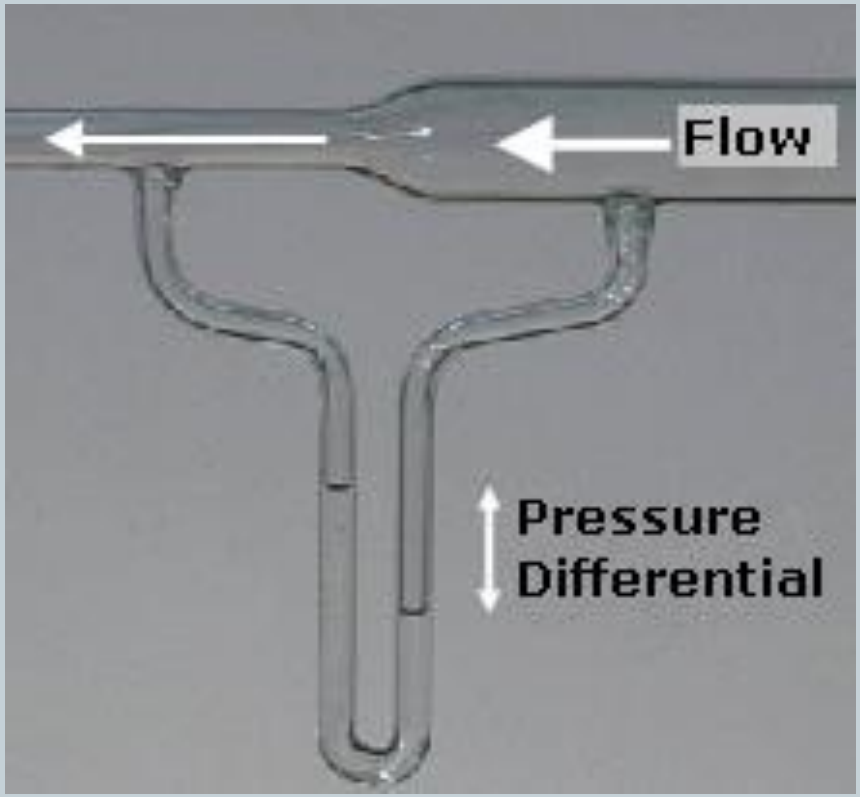
Lesson 2: Venturi Flow

- Bernoulli's equation
  - A common form of Bernoulli's equation, valid at any arbitrary point along a streamline where gravity is constant, is:

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

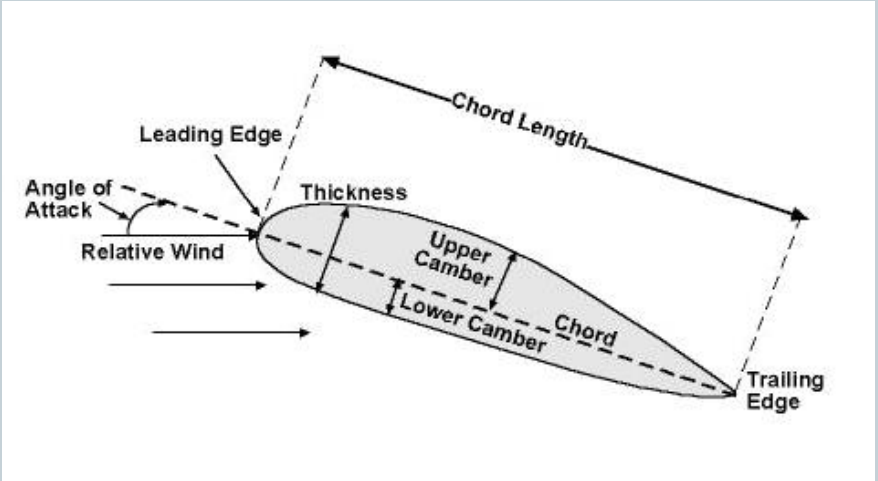
where:

v is the fluid flow speed at a point on a streamline,
g is the acceleration due to gravity,
z is the elevation of the point above a reference plane, with the positive z-direction pointing upward – so in the direction opposite to the gravitational acceleration,
p is the pressure at the chosen point, and
ρ is the density of the fluid at all points in the fluid.



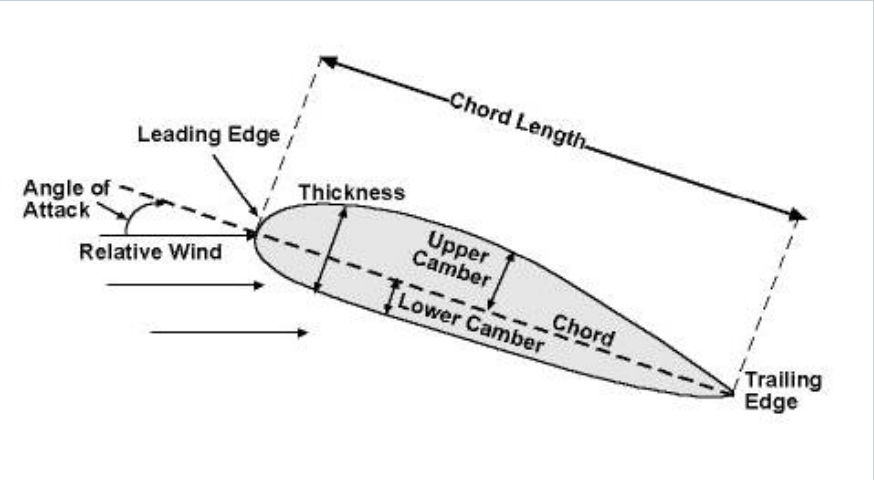
Lesson 3: Forces

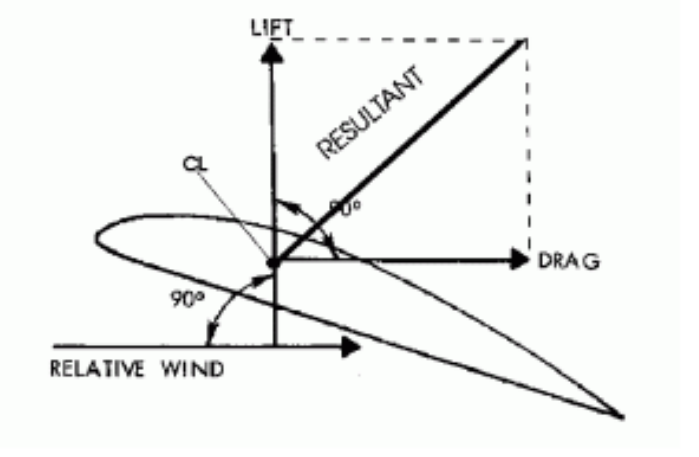
- Defining characteristics of an airfoil



Lesson 3: Forces

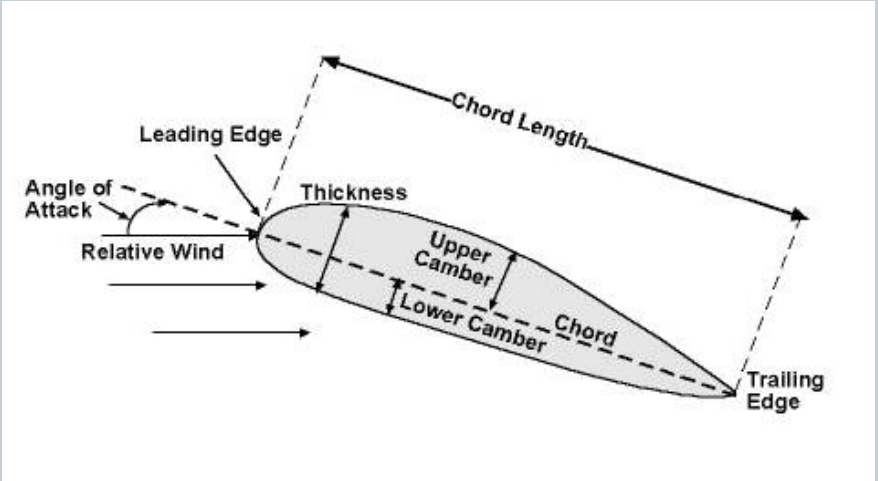
- Defining characteristics of an airfoil
- Force components acting on an airfoil





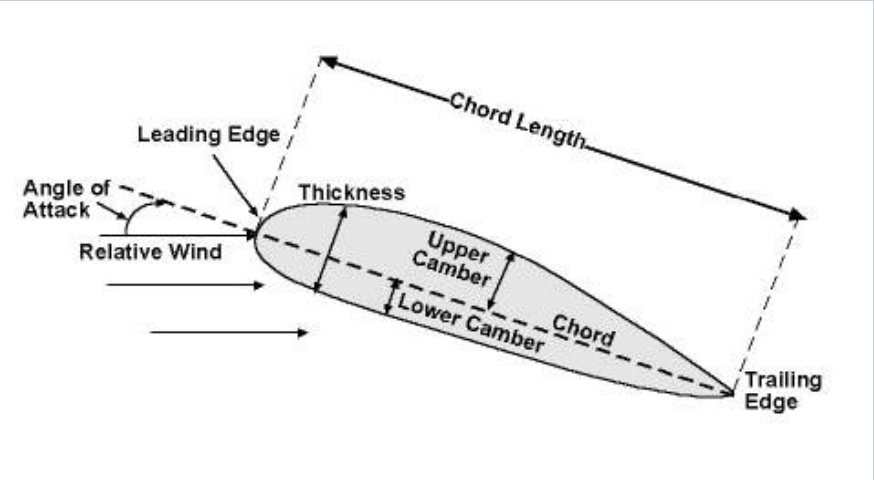
Lesson 4: Relative wind

- What do we mean by relative wind?

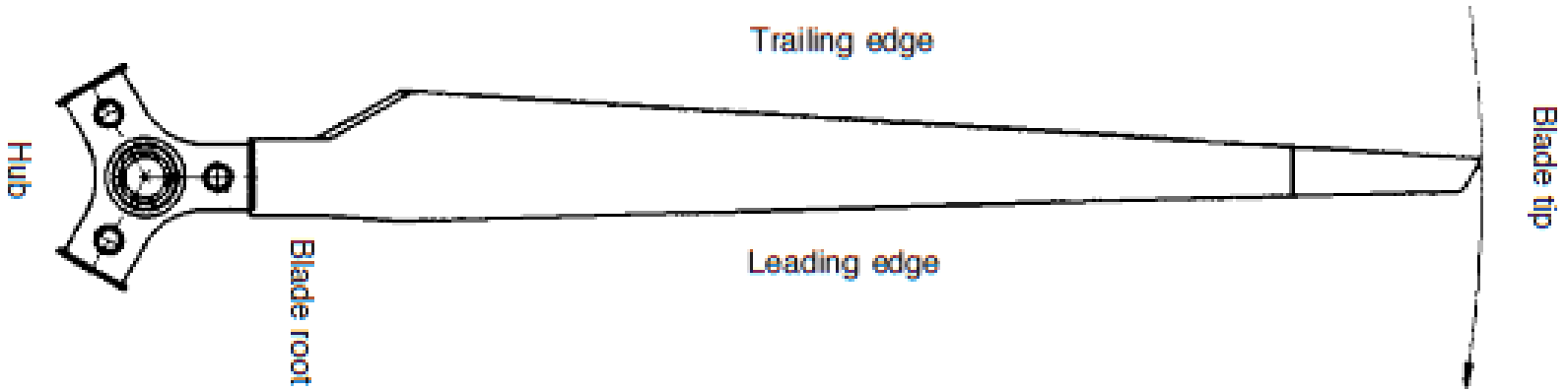


Lesson 4: Relative wind

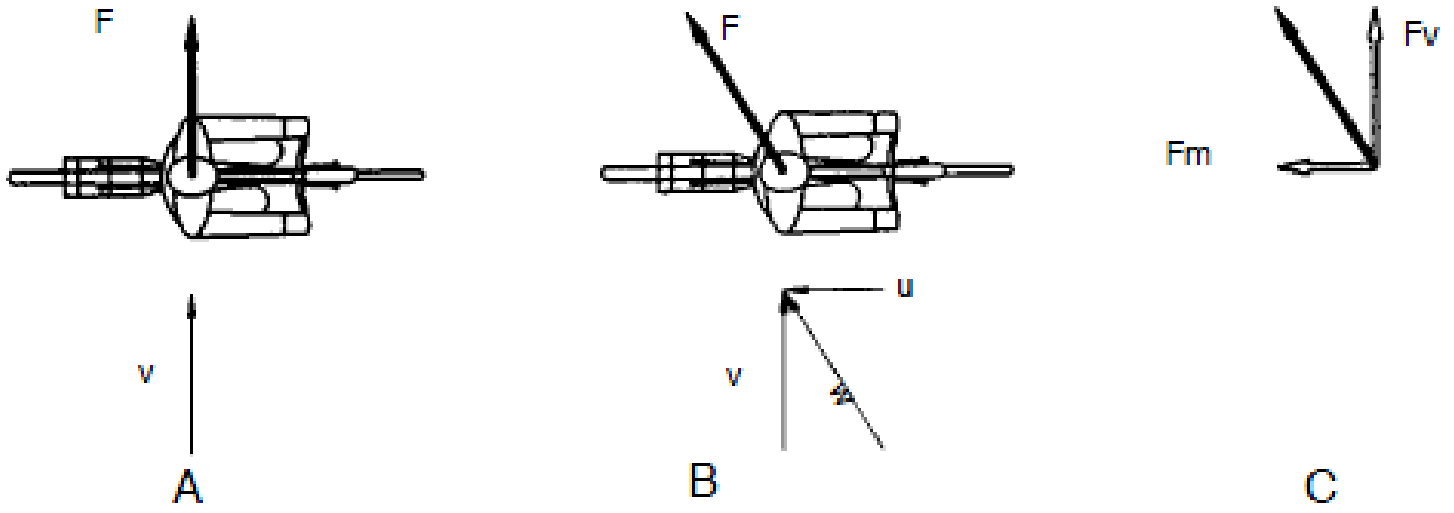
- What do we mean by relative wind?
- Offer examples!



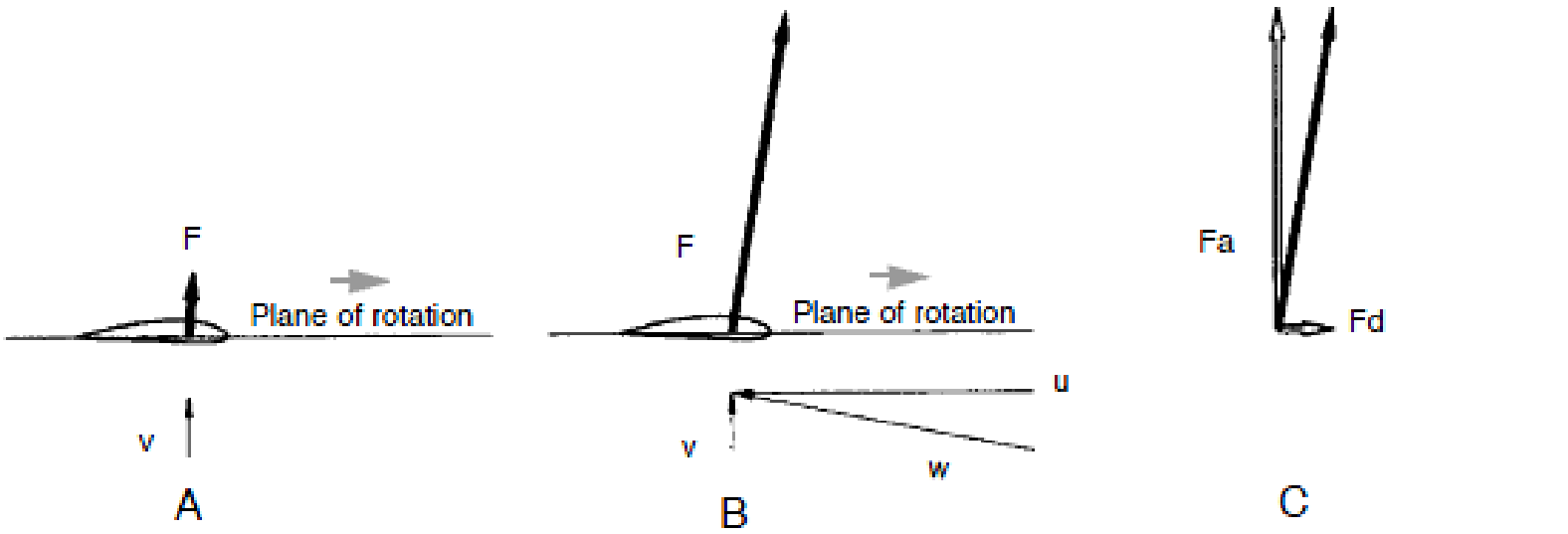
Components of a wind turbine blade

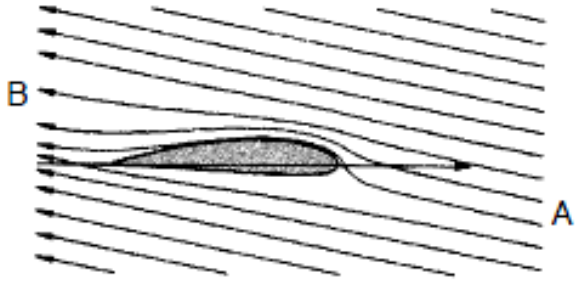


Air flow around a person on a bicycle

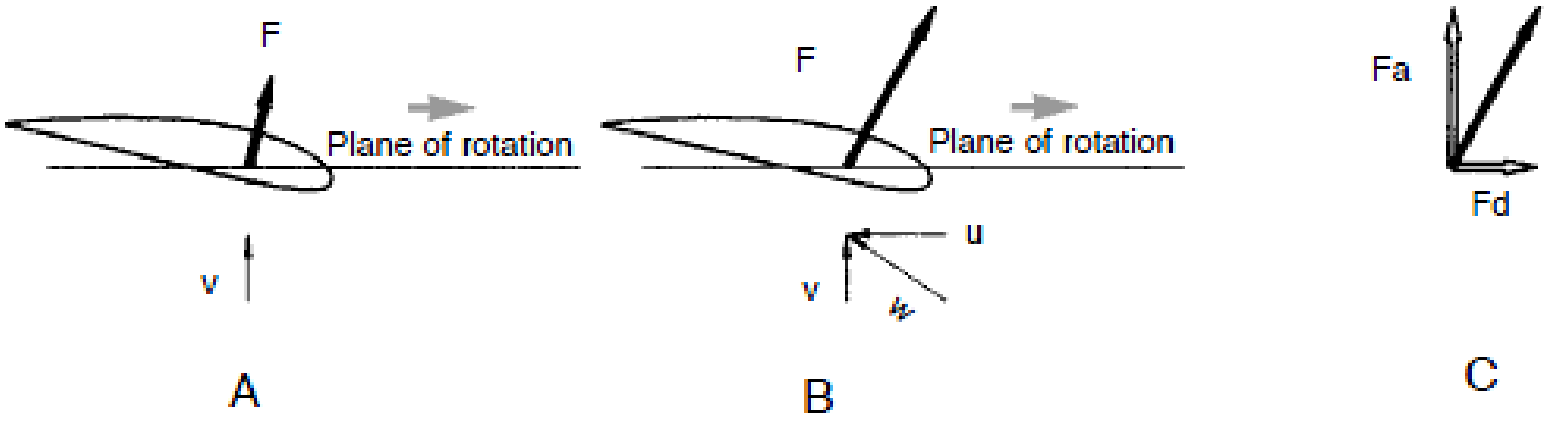


Air flow around a blade profile, near the blade tip

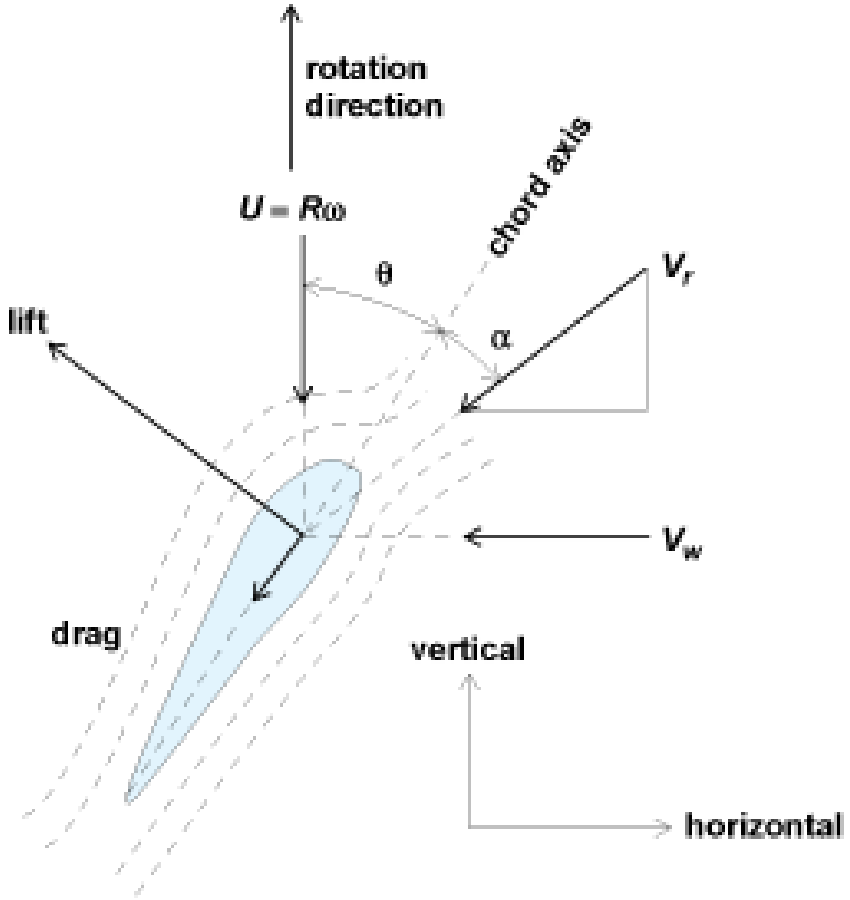




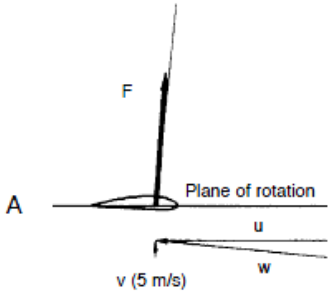
Air flow around a blade profile, near the blade root

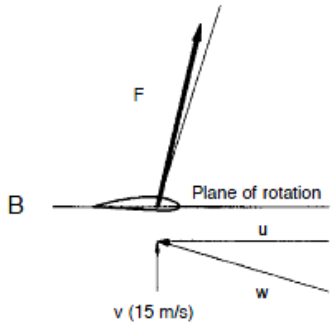


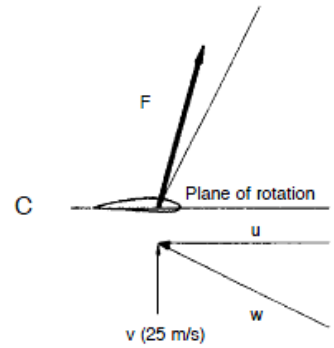
Components of velocity and force acting on turbine blade

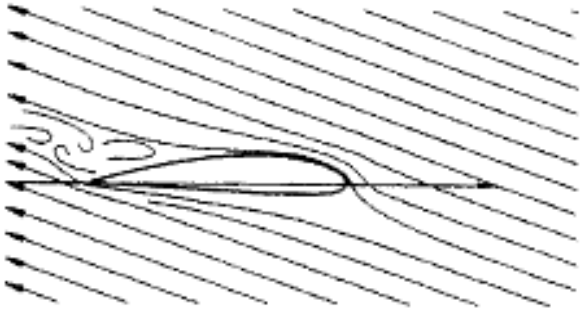


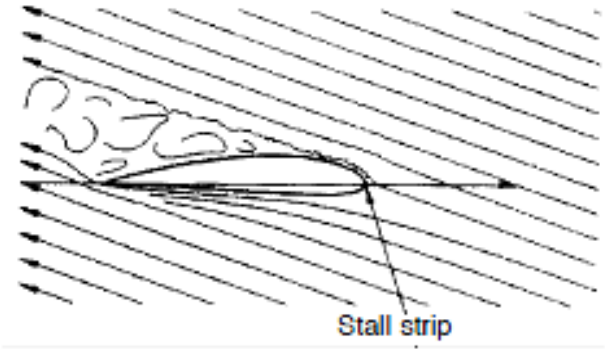
Relationship between lift and drag coefficients and angle of attack



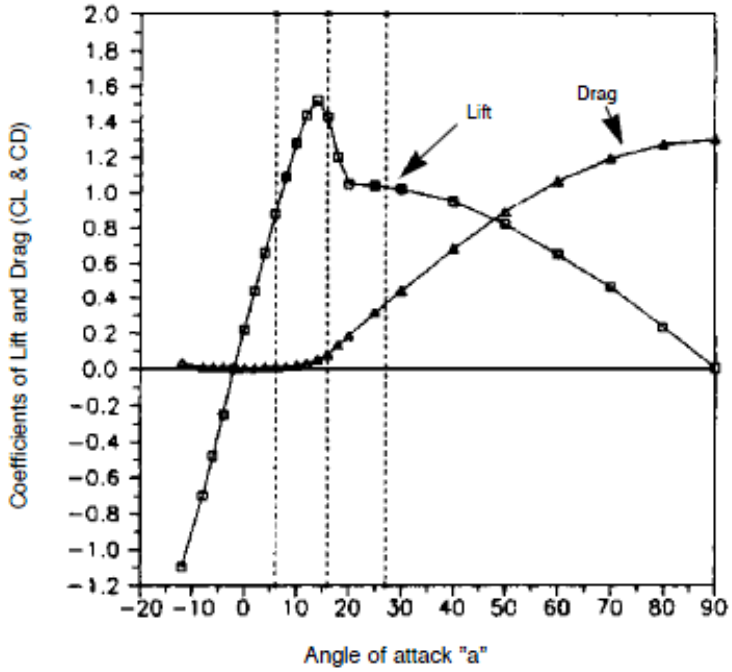


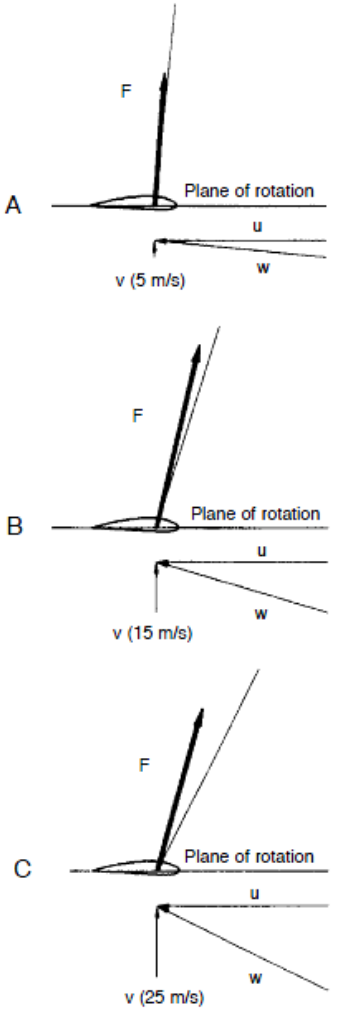


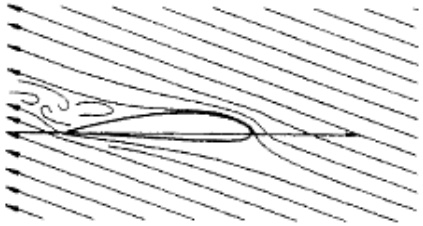


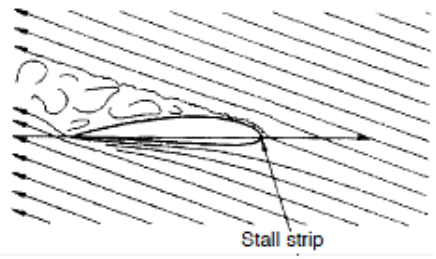


Relationship between lift and drag coefficients and angle of attack



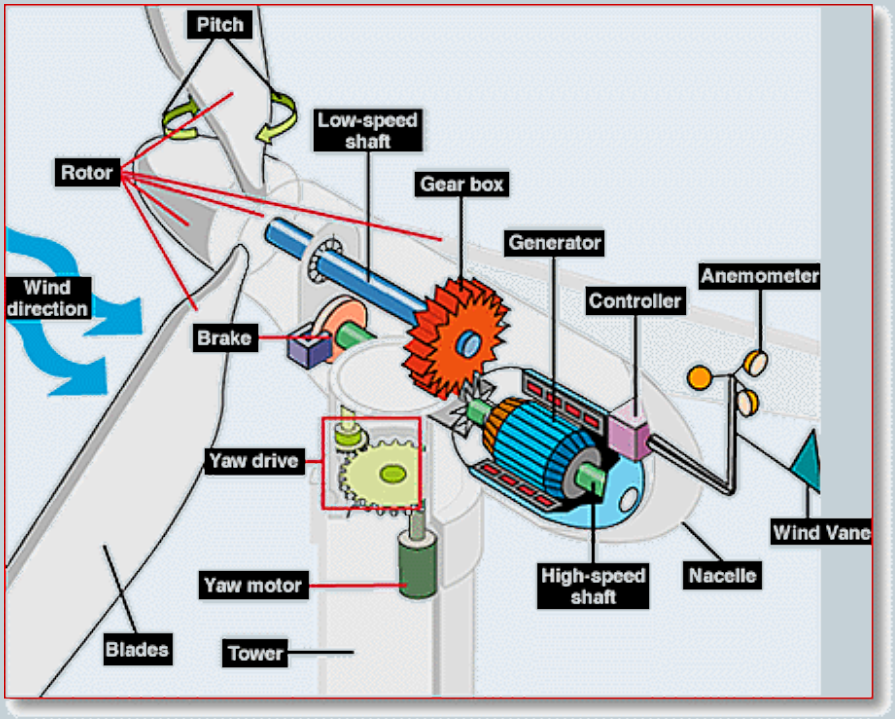






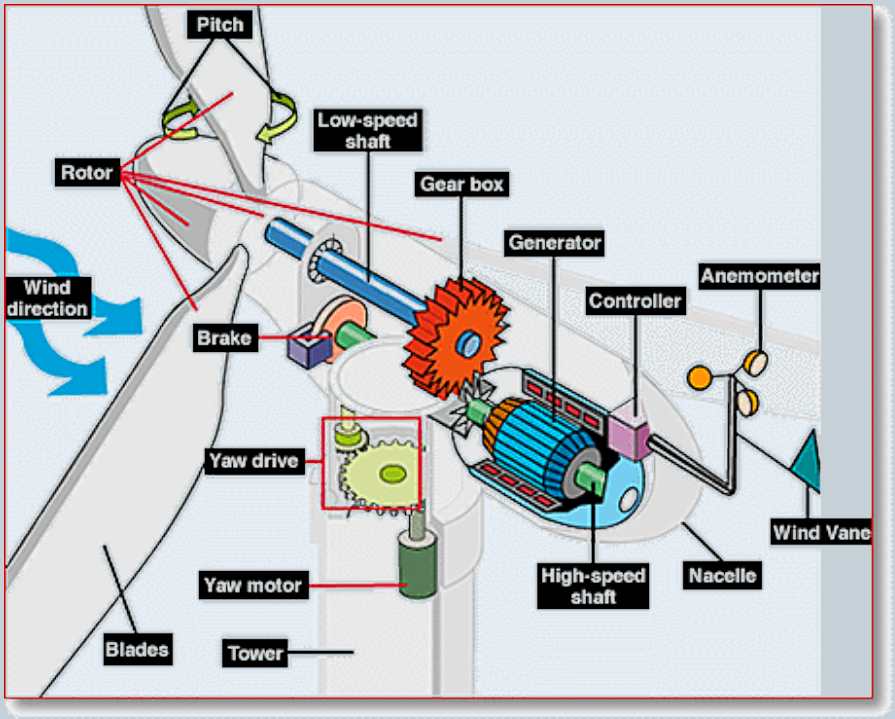
Wind Turbine Components

Inside the Wind Turbine



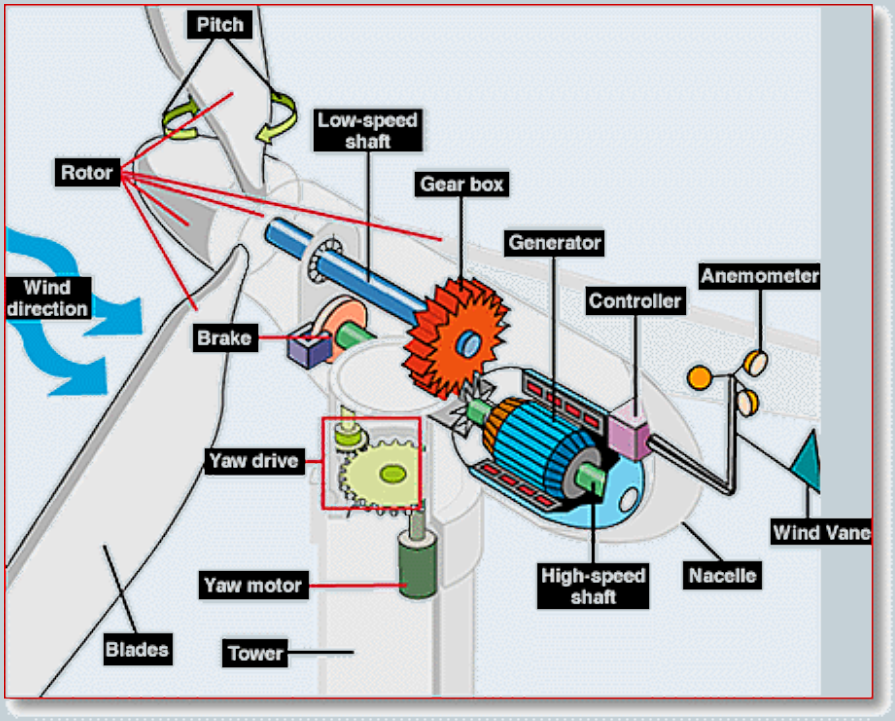
- Anemometer
  - Measures the wind speed and transmits wind speed data to the controller.
- Blades
  - Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate
- Brake
  - A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.
- Controller
  - The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

Inside the Wind Turbine



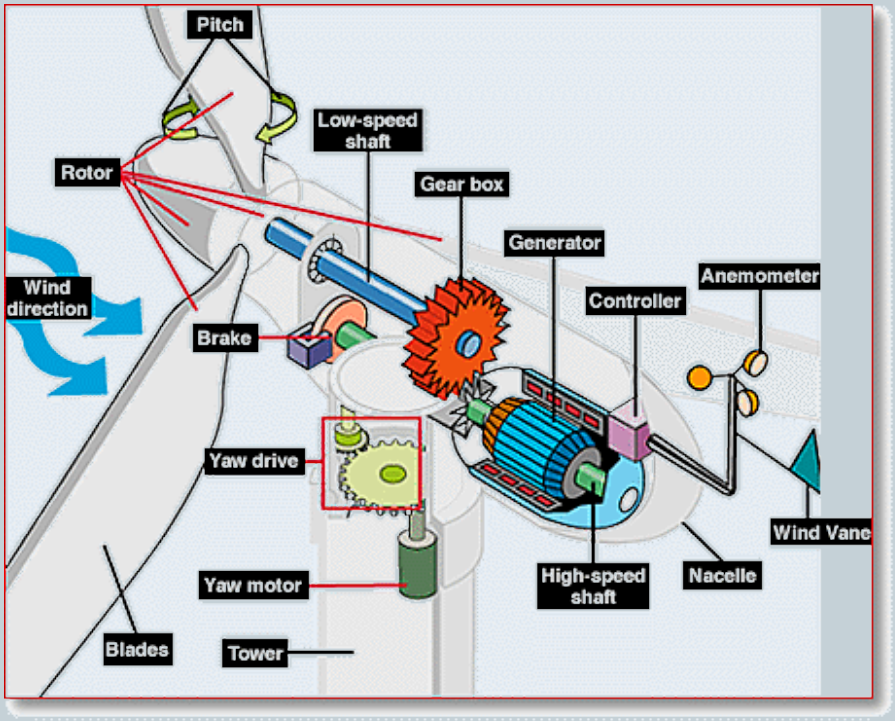
- Gear box
  - Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.
- Generator
  - Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.
- High-speed shaft
  - Drives the generator.
- Low-speed shaft
  - The rotor turns the low-speed shaft at about 30 to 60 rotations per minute

Inside the Wind Turbine



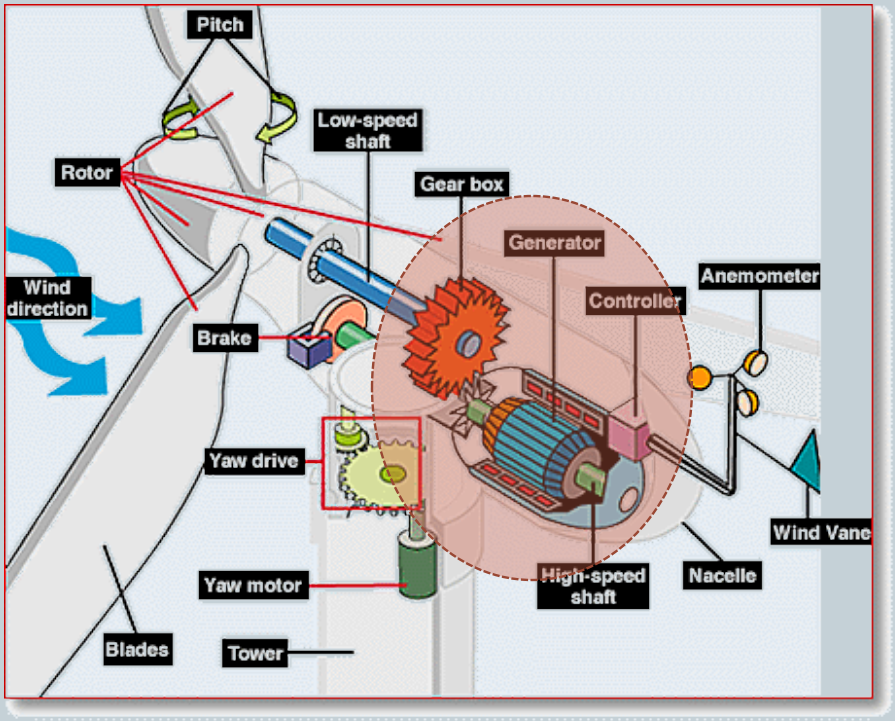
- Nacelle
  - The nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.
- Pitch
  - Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity
- Rotor
  - The blades and the hub together are called the rotor.
- Tower
  - Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Inside the Wind Turbine



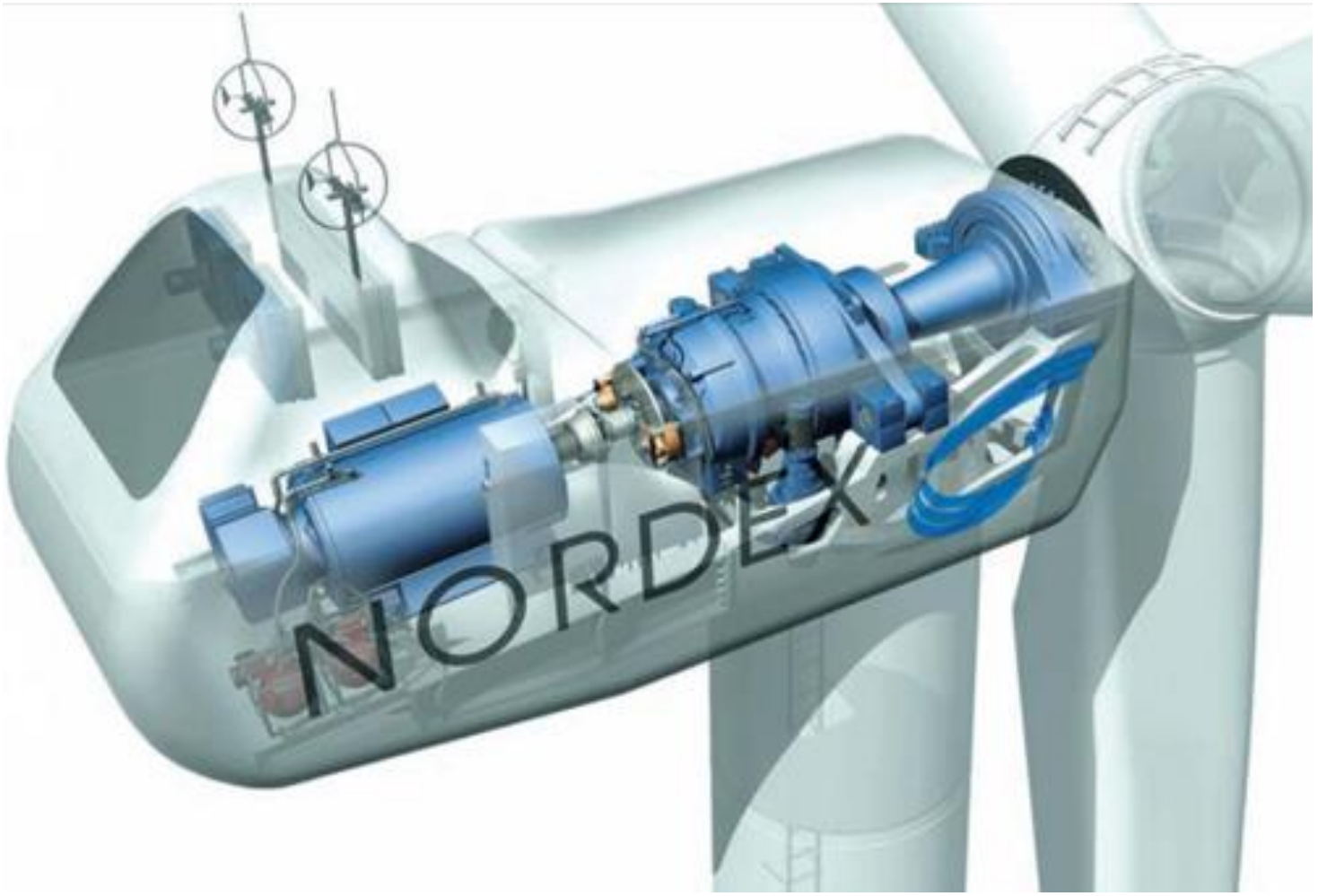
- Wind direction
  - This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.
- Wind vane
  - Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
- Yaw drive
  - Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.
- Yaw motor
  - Powers the yaw drive.

Inside the Wind Turbine



- **Gear box**
  - Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.
- **Generator**
  - Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

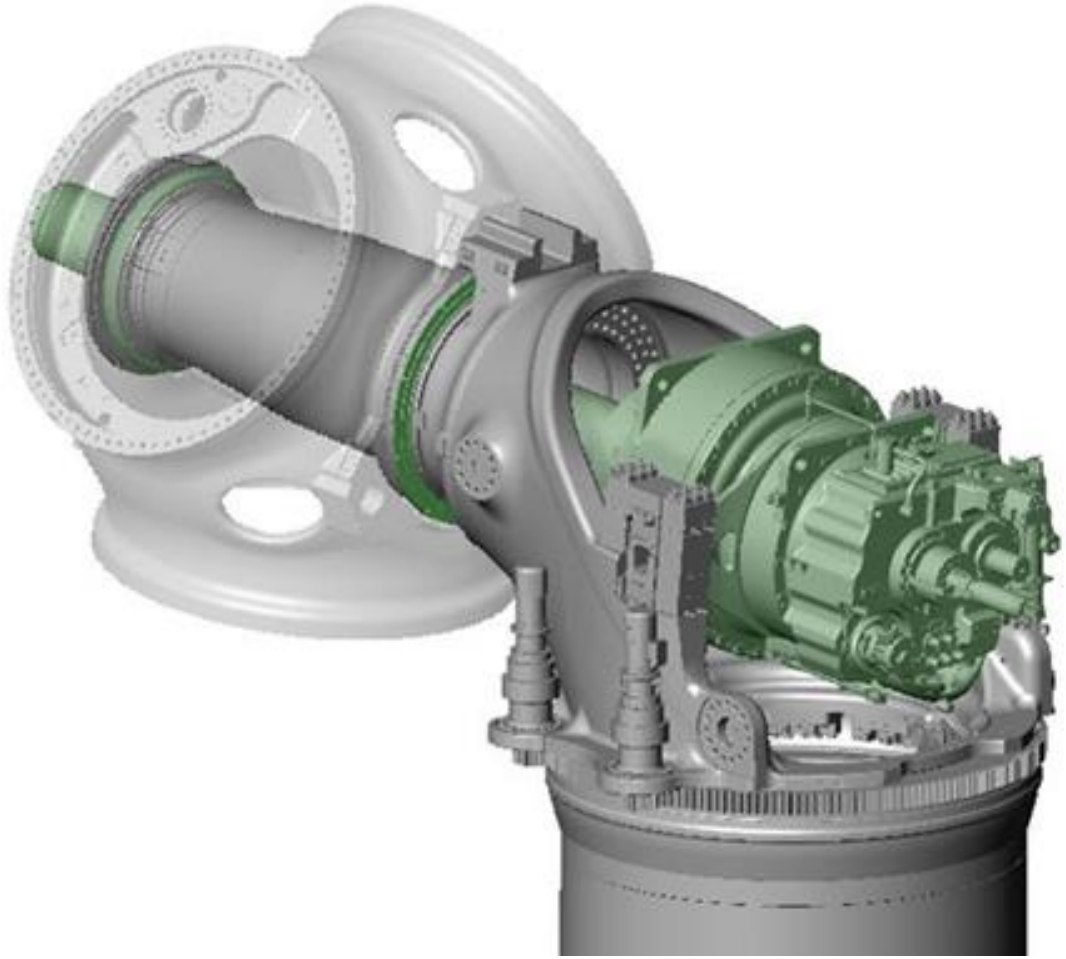
Nordex turbine



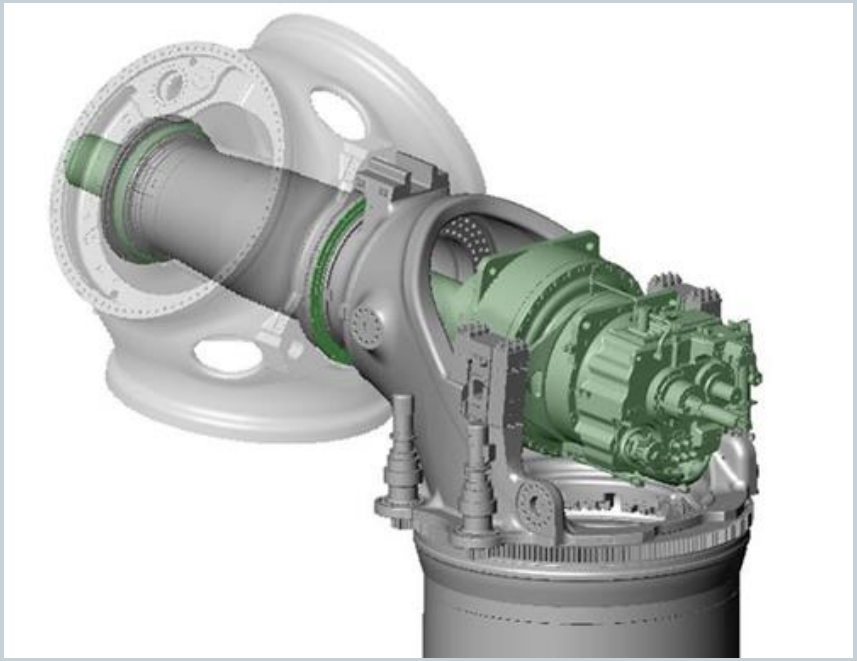
Nordex turbine

- The three-bladed rotor proliferates and typically has a separate front bearing, with low speed shaft connected to a gearbox that provides an output speed suitable for the most popular four-pole (or two -pole) generators.
- Commonly, with the largest wind turbines, the blade pitch will be varied continuously under active control to regulate power in higher operational wind speeds.

Ecotècnia (Alstom) 100 turbine

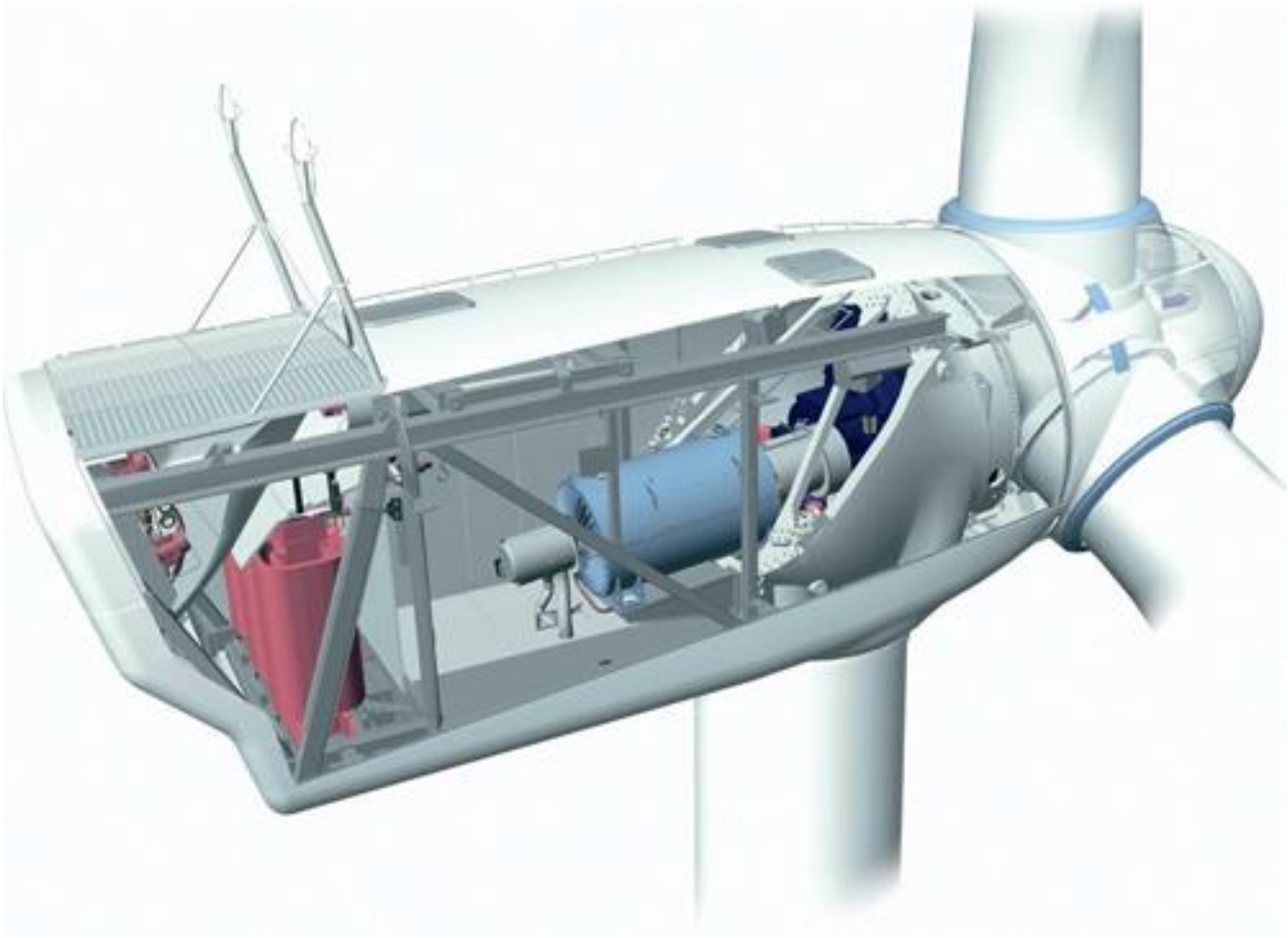


Ecotècnia (Alstom) 100 turbine

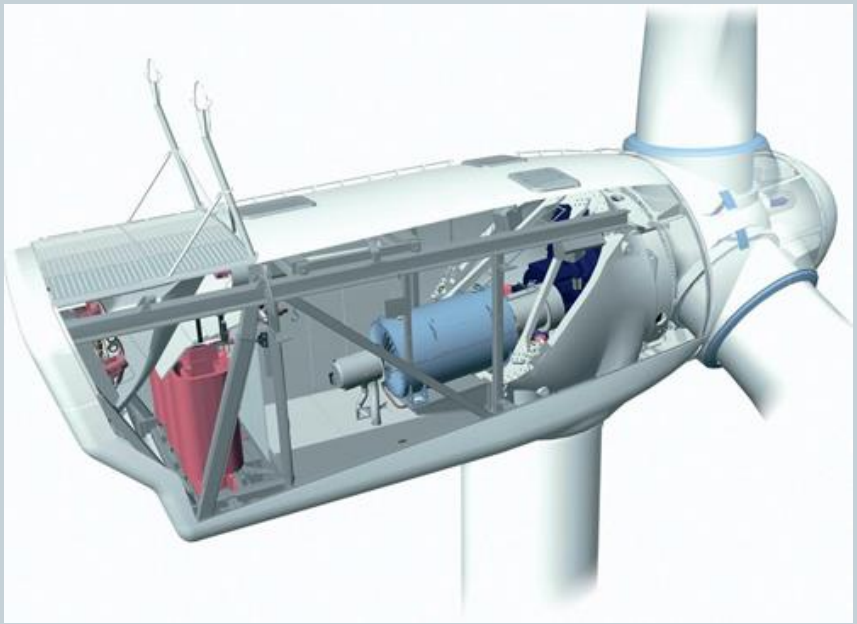


- The drive train of the Nordex turbine shows the rotor attached to a main shaft driving the generator through the gearbox. Within this essentially conventional architecture of multi-stage gearbox and high speed generator, there are many significant variations in structural support, in rotor bearing systems and in general layout.
- A distinctive layout has been developed by Ecotècnia (Alstom), which separates the functions of rotor support and torque transmission to the gearbox and generator. This offers a comfortable environment for the gearbox, resulting in predictable loading and damping of transients, due to its intrinsic flexibility.

Vestas V90 turbine



Vestas V90 turbine



- Among the more innovative of a large variety of bearing arrangements is the large single front bearing arrangement adopted by Vestas in the V90 3 MW design (Figure 3.8). This contributes to a very compact and lightweight nacelle system.

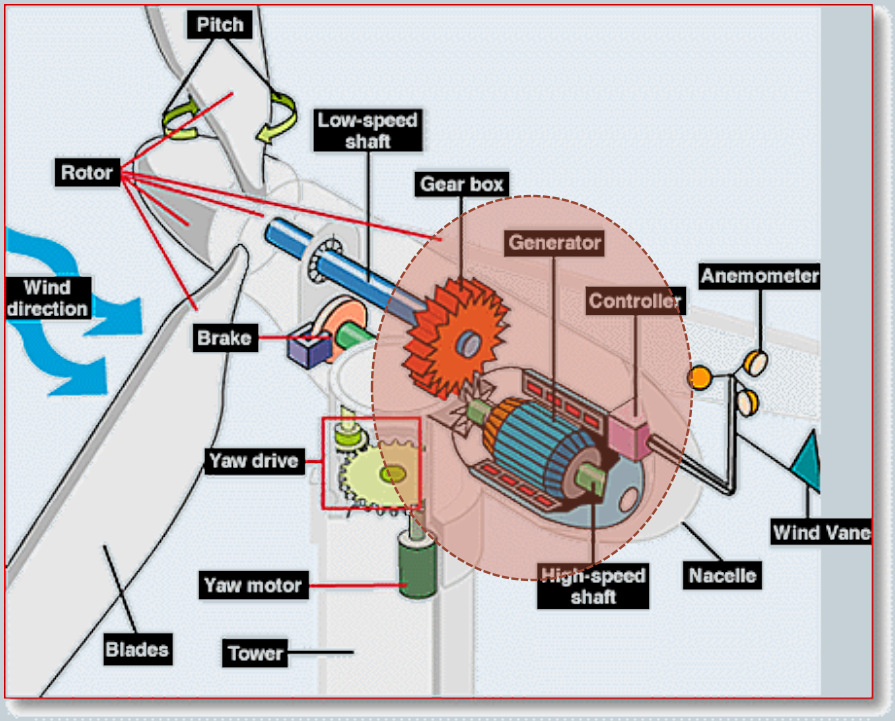
Enercon E126

- The direct drive systems of Enercon are long established, and many direct drive designs based on permanent magnet generator (PMG) technology have appeared in recent years.

Enercon E126

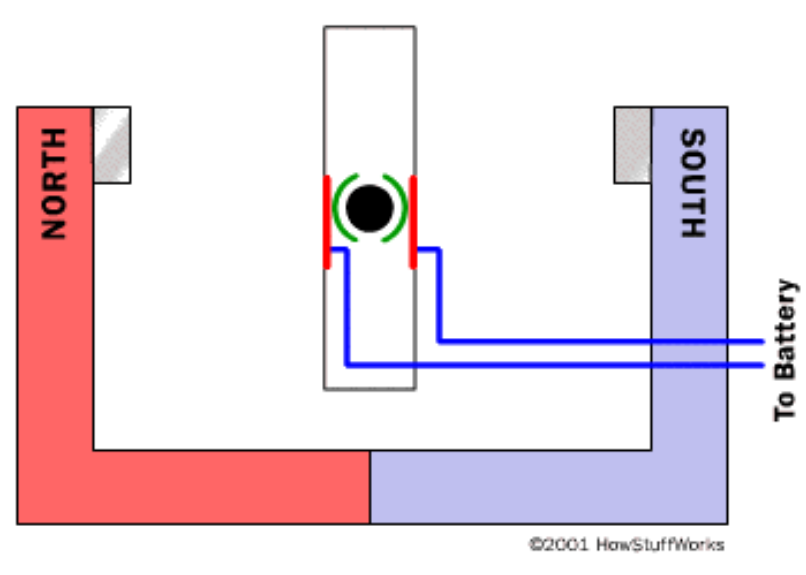
- The direct drive systems of Enercon are long established, and many direct drive designs based on permanent magnet generator (PMG) technology have appeared in recent years.
- The world's largest wind turbine is currently the Enercon E-126 installed in Emden, Germany, in February 2008. The new E126 has a rating of 6 MW and may be up-rated to 7 MW.

Inside the Wind Turbine



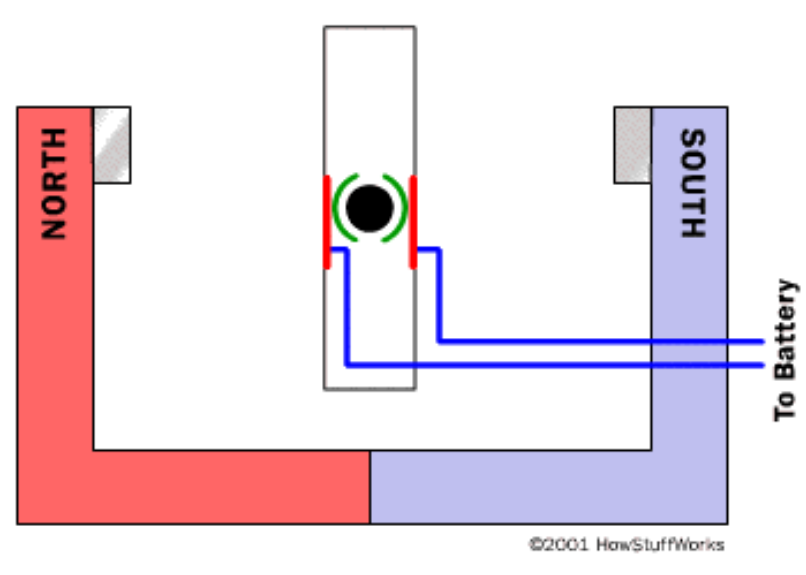
- **Gear box**
  - Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.
- **Generator**
  - Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

Generators



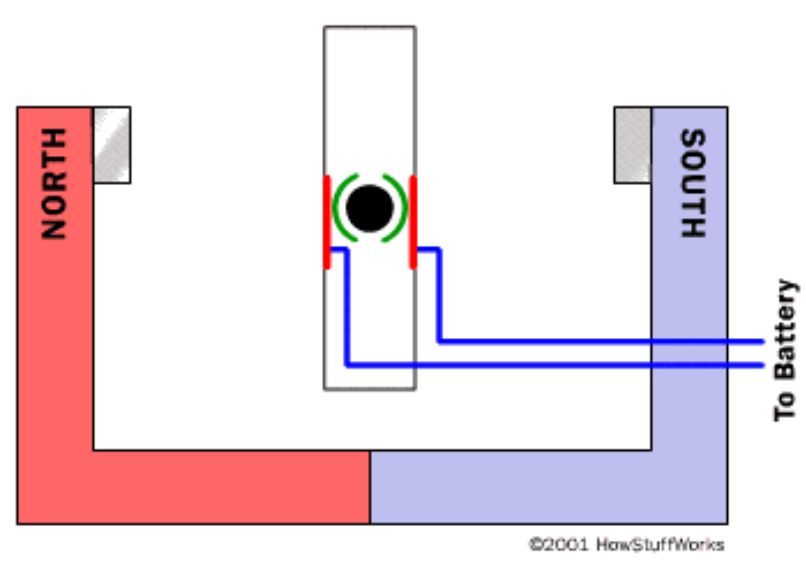
- If you allow electrons to move through a metal wire, a magnetic field will form around the wire.
- A **generator** is simply a device that moves a magnet near a wire to create a steady flow of electrons.

Generators



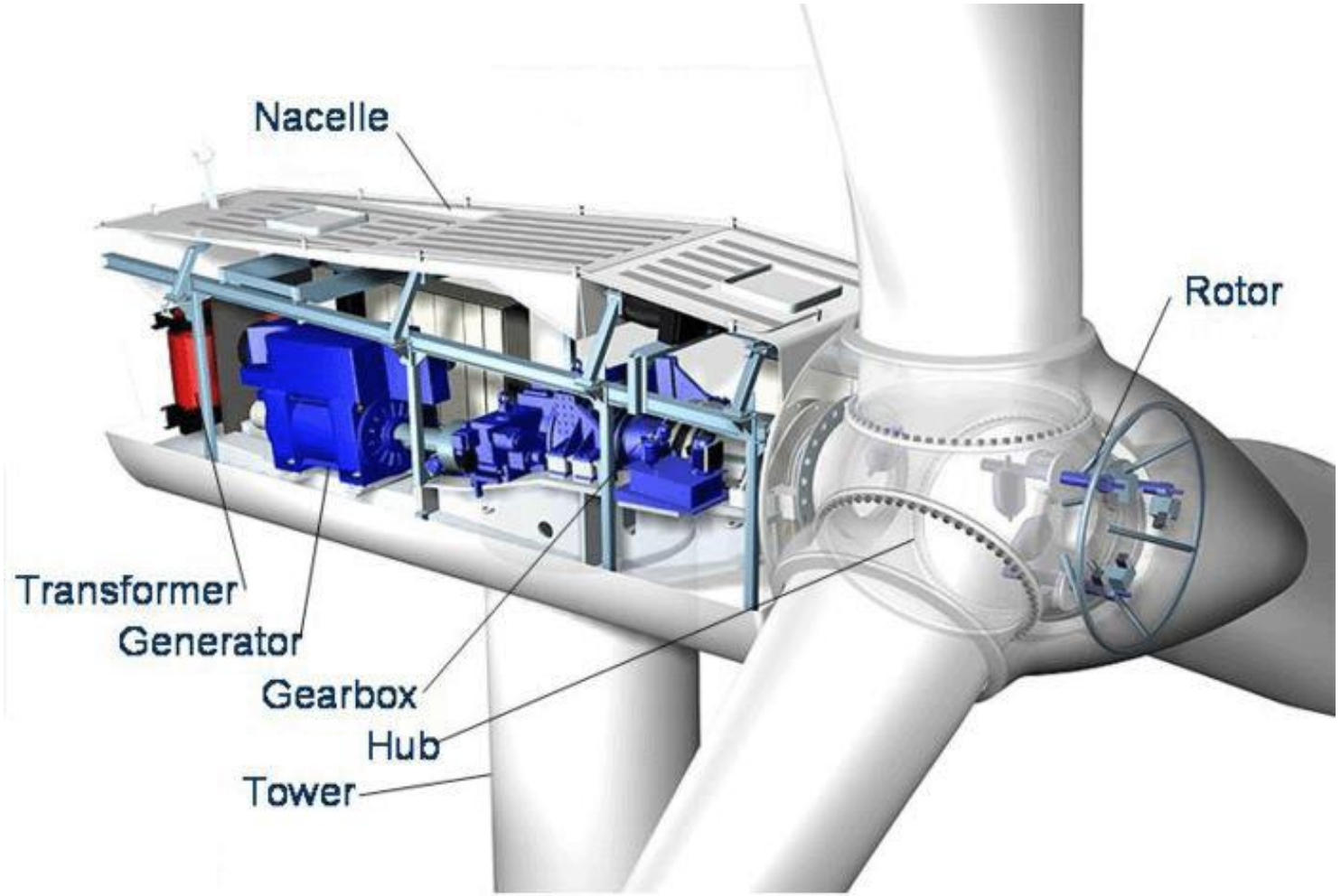
- One simple way to think about a generator is to imagine it acting like a pump pushing water through a pipe. Only instead of pushing water, a generator uses a magnet to push electrons along. This is a slight oversimplification, but it paints a helpful picture of the properties at work in a generator.

Generators

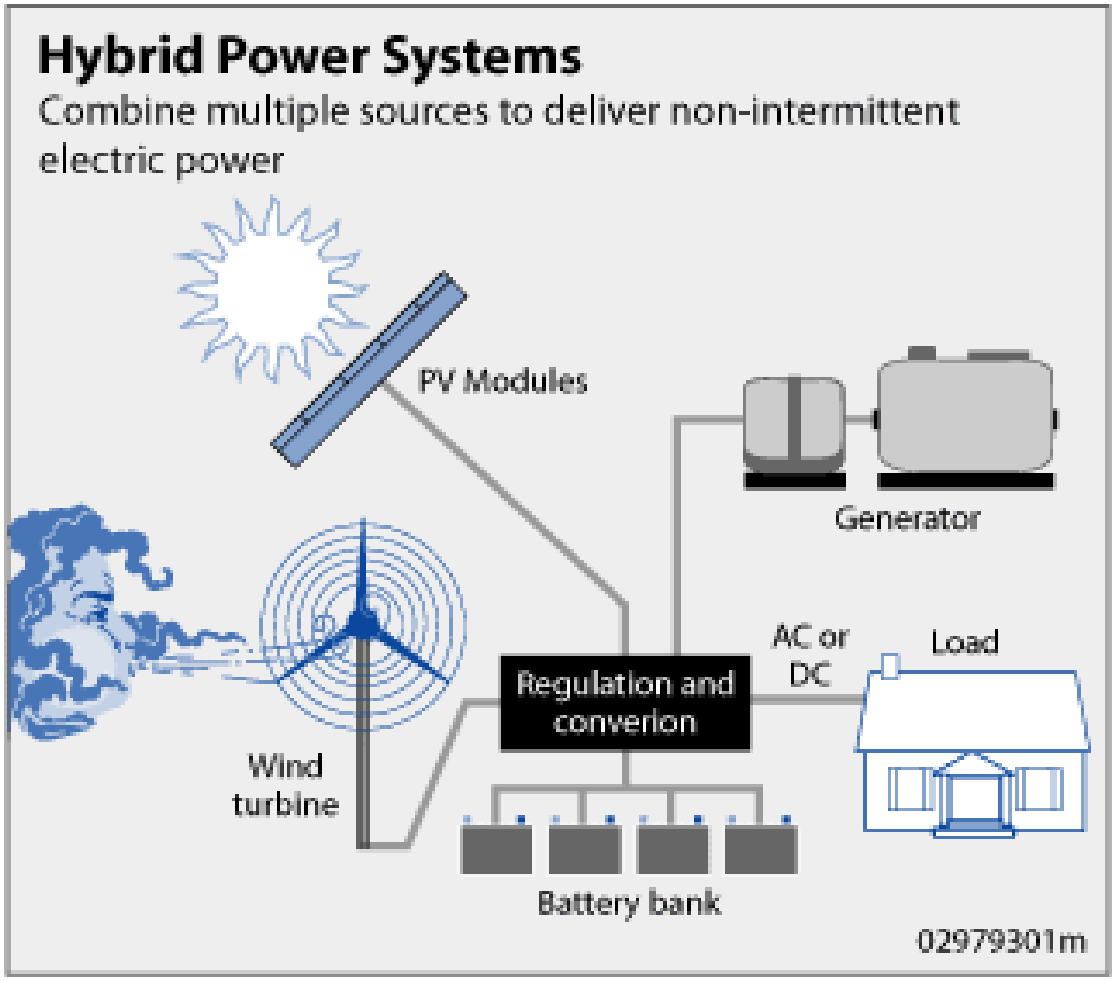


- In an electrical circuit, the number of electrons in motion is called the **amperage** or **current**, and it's measured in **amps**.
- The "pressure" pushing the electrons along is called the **voltage** and is measured in **volts**.
- For instance, a generator spinning at 1,000 rotations per minute might produce 1 amp at 6 volts. The 1 amp is the number of electrons moving (1 amp physically means that 6.24×10^{18} electrons move through a wire every second), and the voltage is the amount of pressure behind those electrons.

Drive Train



Hybrid Systems



Questions ???