Wind Turbines

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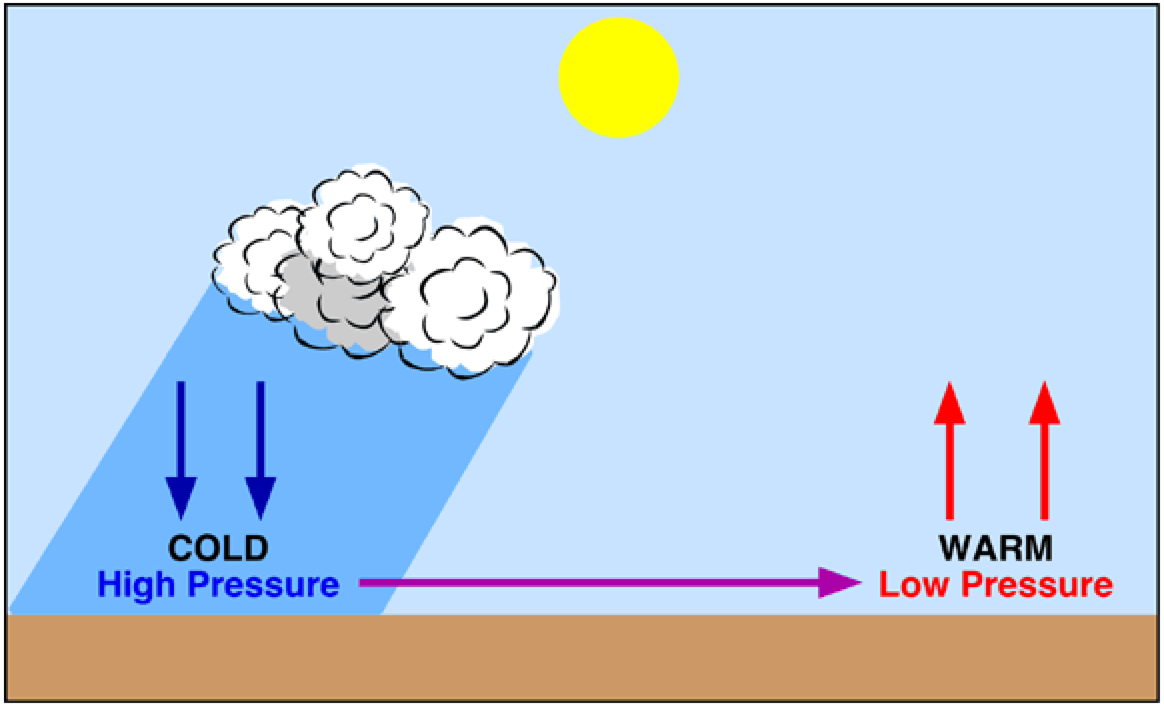
wind



Wind power calculation

- Power= work / time

$= \text{Kinetic Energy} / t$

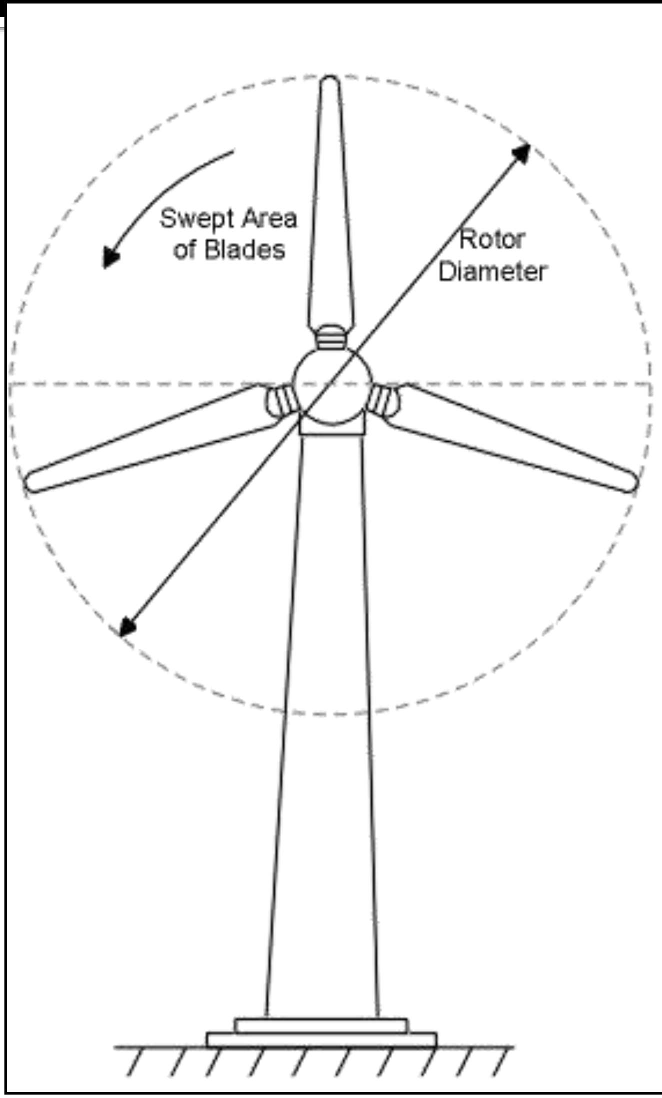
$= \frac{1}{2} m V^2 / t$

$= \frac{1}{2} (\rho A d) V^2 / t$

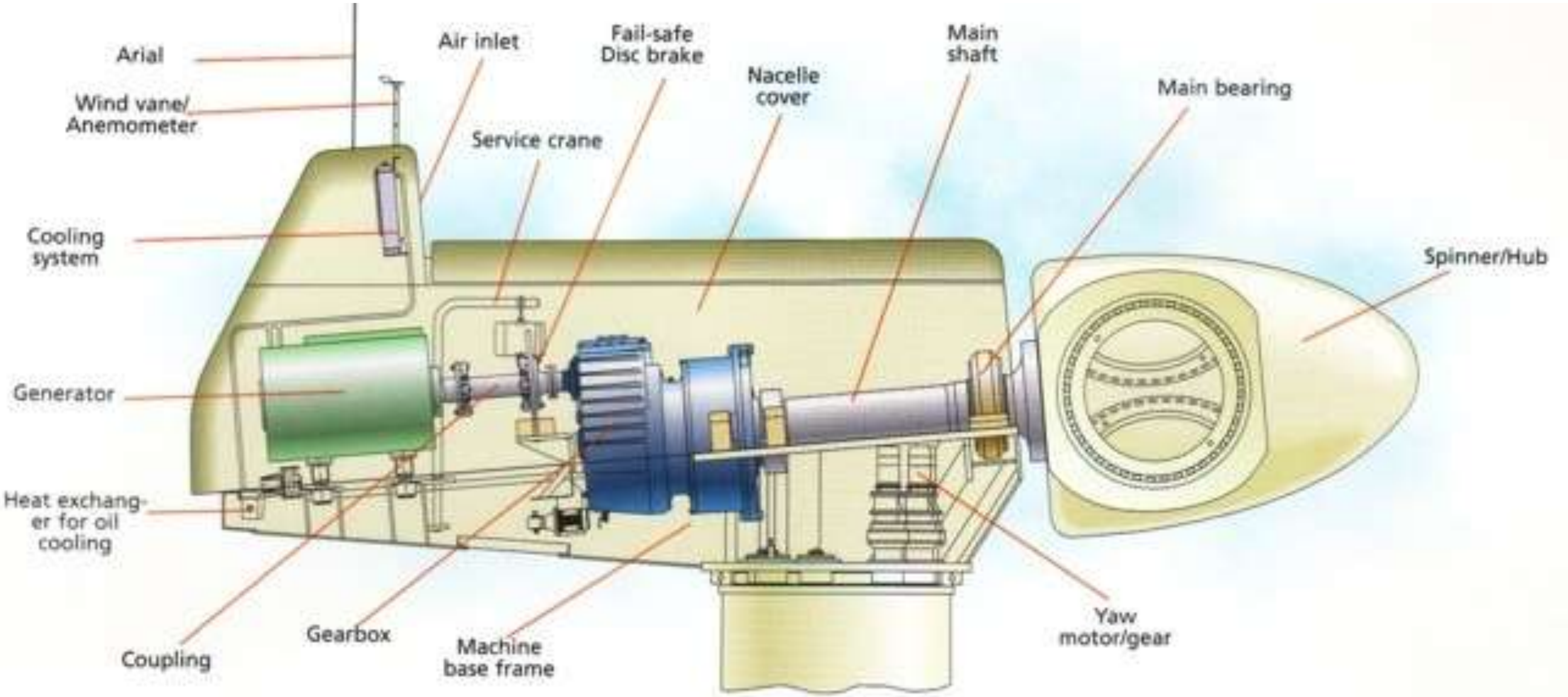
$= \frac{1}{2} \rho A V^2 (d/t)$

$= \frac{1}{2} \rho A V^3$

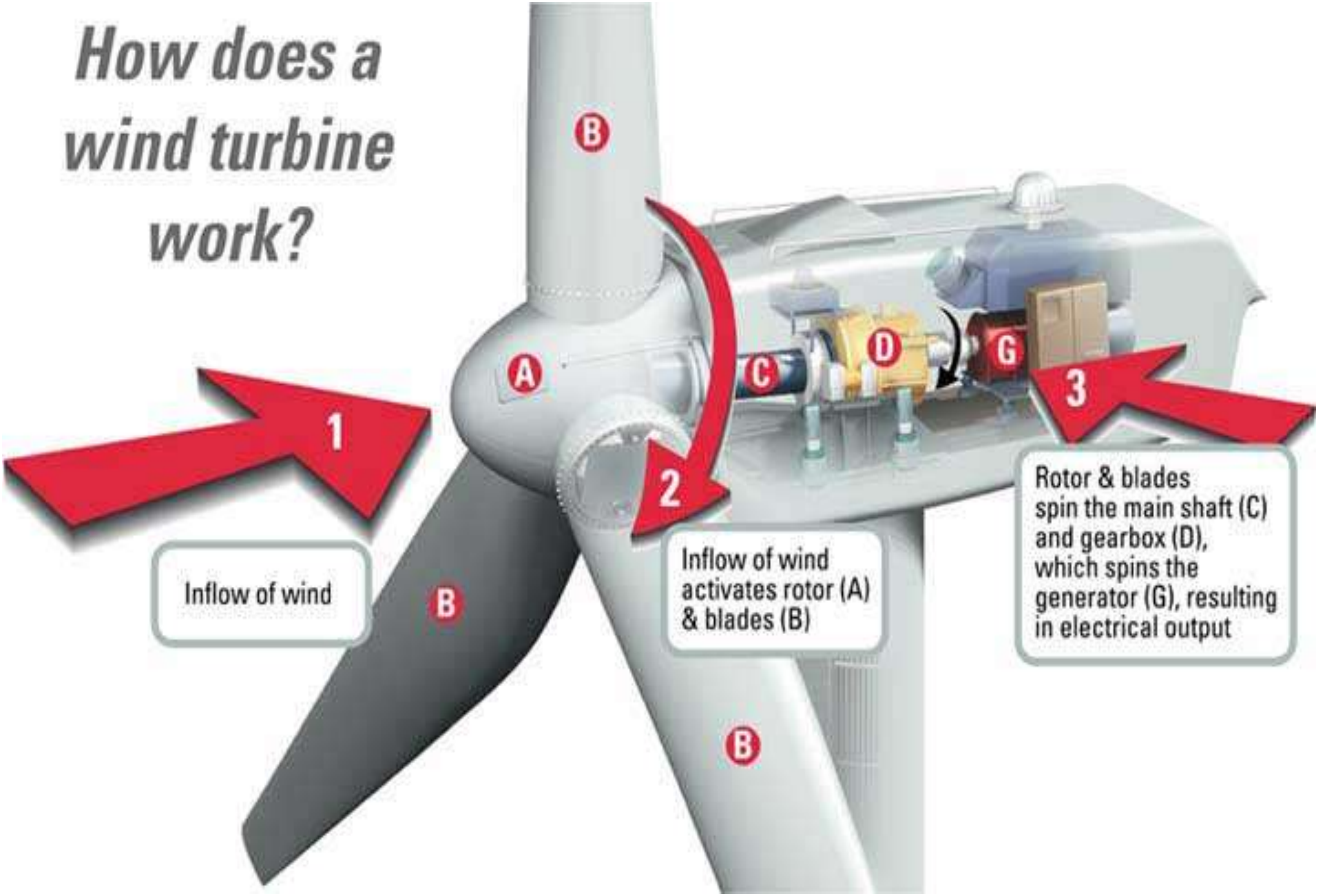
- Power in the Wind = $\frac{1}{2} \rho A V^3$



Inside a Wind Turbine



How does a wind turbine work?



Types of wind turbines according to power

Small (≤10 kW)

- Homes
- Farms
- Remote Applications

(e.g. water pumping, telecom sites, icemaking)

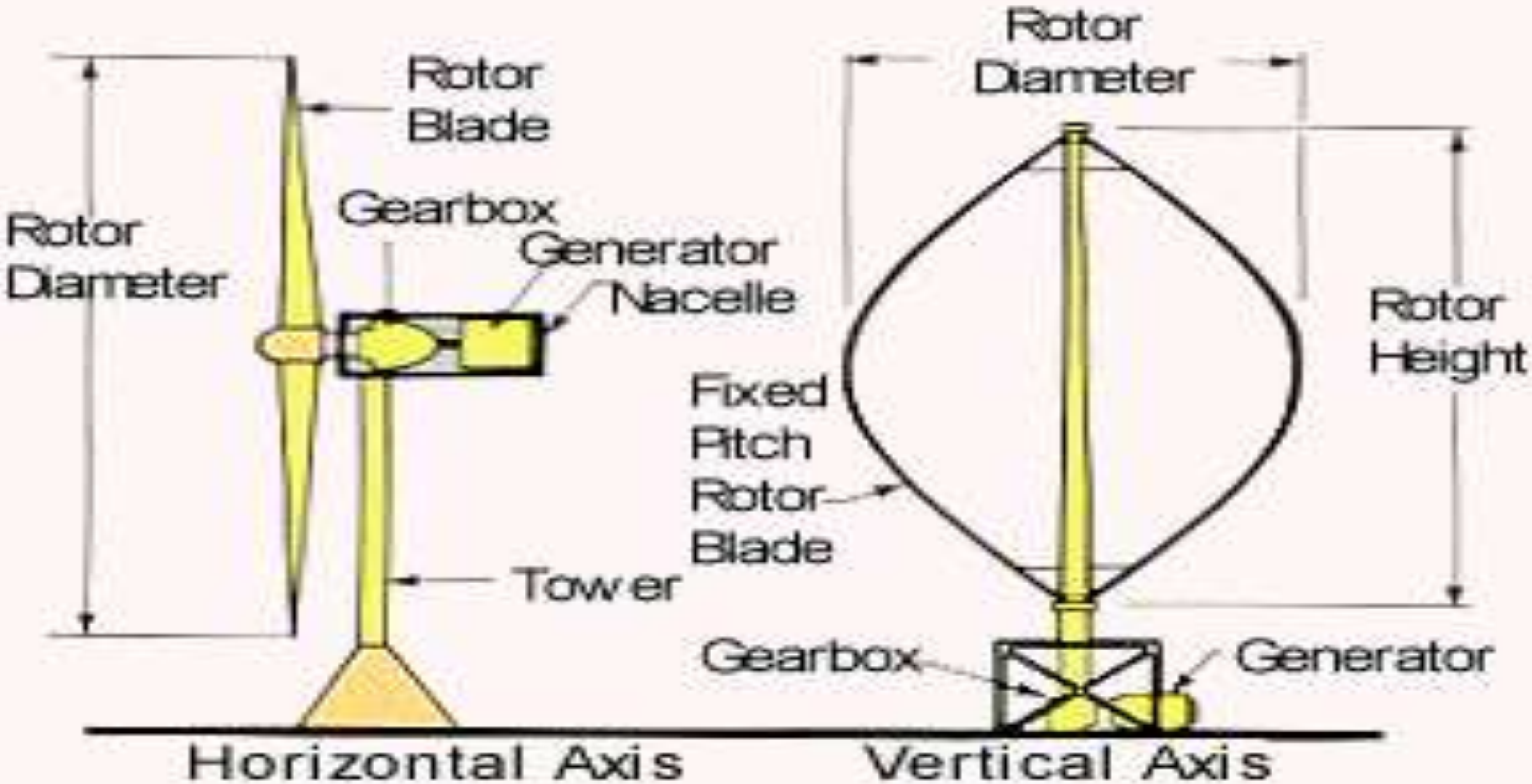
Intermediate (10-250 kW)

- Village Power
- Hybrid Systems
- Distributed Power

Large (250 kW - 2+MW)

- Central Station Wind Farms
- Distributed Power

Types of wind turbines according to design



Wind Turbine Configurations

Horizontal axis turbines

ADVANTAGES

- Variable blade pitch, which gives the turbine blades the optimum angle of attack
- The tall tower base allows access to stronger wind in sites with wind shear.
- High efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation.

DISADVANTAGES

- Tall towers and blades up to 90 meters long are difficult to transport. Transportation can now cost 20% of equipment costs.
- Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators
- Massive tower construction is required to support the heavy blades, gearbox, and generator

Vertical Axis Turbines

Advantages

- Omnidirectional
  - Accepts wind from any angle
- Components can be mounted at ground level
  - Ease of service
  - Lighter weight towers
- Can theoretically use less materials to capture the same amount of wind

Disadvantages

- Rotors generally near ground where wind poorer
- Centrifugal force stresses blades
- Poor self-starting capabilities
- Requires support at top of turbine rotor
- Requires entire rotor to be removed to replace bearings
- Overall poor performance and reliability
- Have never been commercially successful

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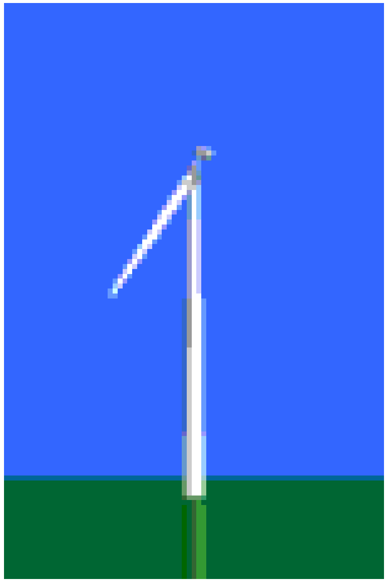
Classification according to number of blades

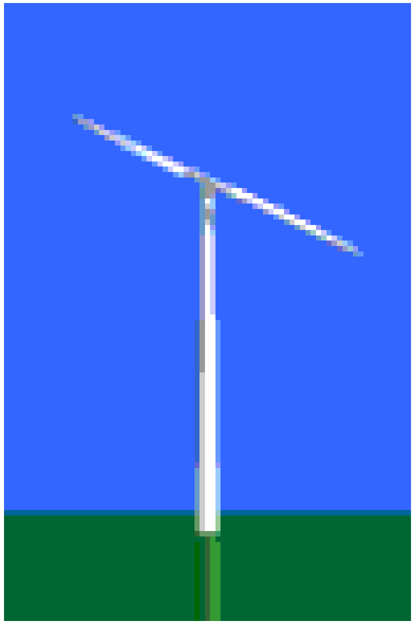
Number of Blades – One

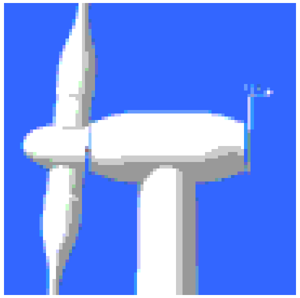
- Rotor must move more rapidly to capture same amount of wind
  - Gearbox ratio reduced
  - Added weight of counterbalance negates some benefits of lighter design
  - Higher speed means more noise, visual, and wildlife impacts
- Blades easier to install because entire rotor can be assembled on ground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



Number of Blades - Two

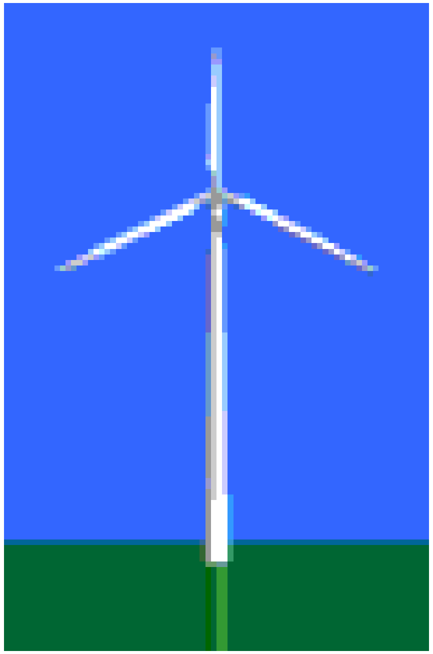
- Advantages & disadvantages similar to one blade
- Need teetering hub and or shock absorbers because of gyroscopic imbalances
- Capture 5% less energy than three blade designs





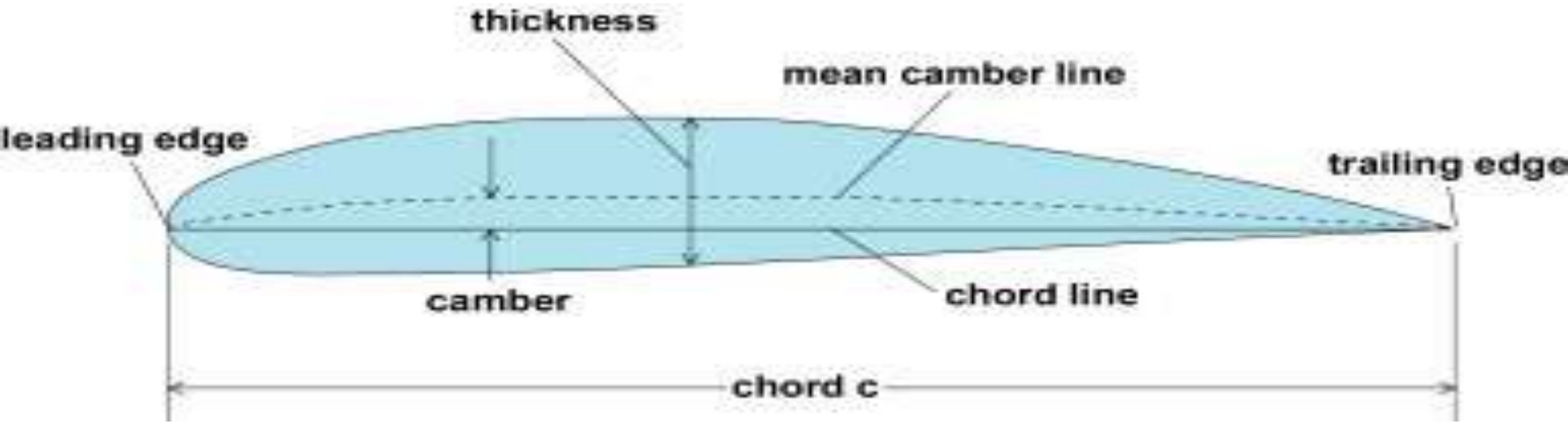
Number of Blades - Three

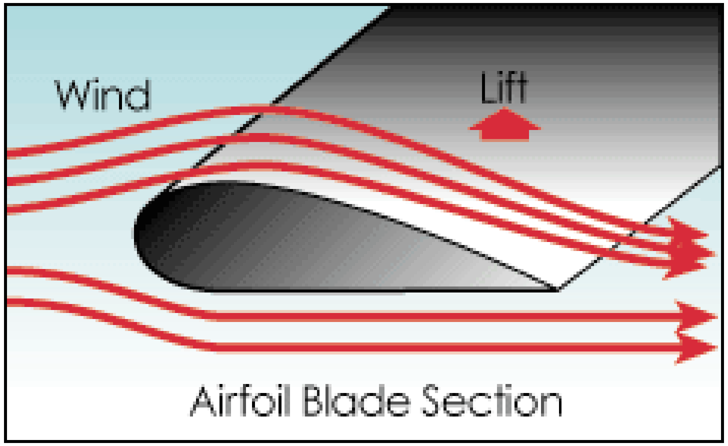
- Balance of gyroscopic forces
- Slower rotation
  - increases gearbox & transmission costs
  - More aesthetic, less noise, fewer bird strikes



Airfoil Nomenclature

Wind turbines use the same aerodynamic principals as aircraft





Lift & Drag Forces

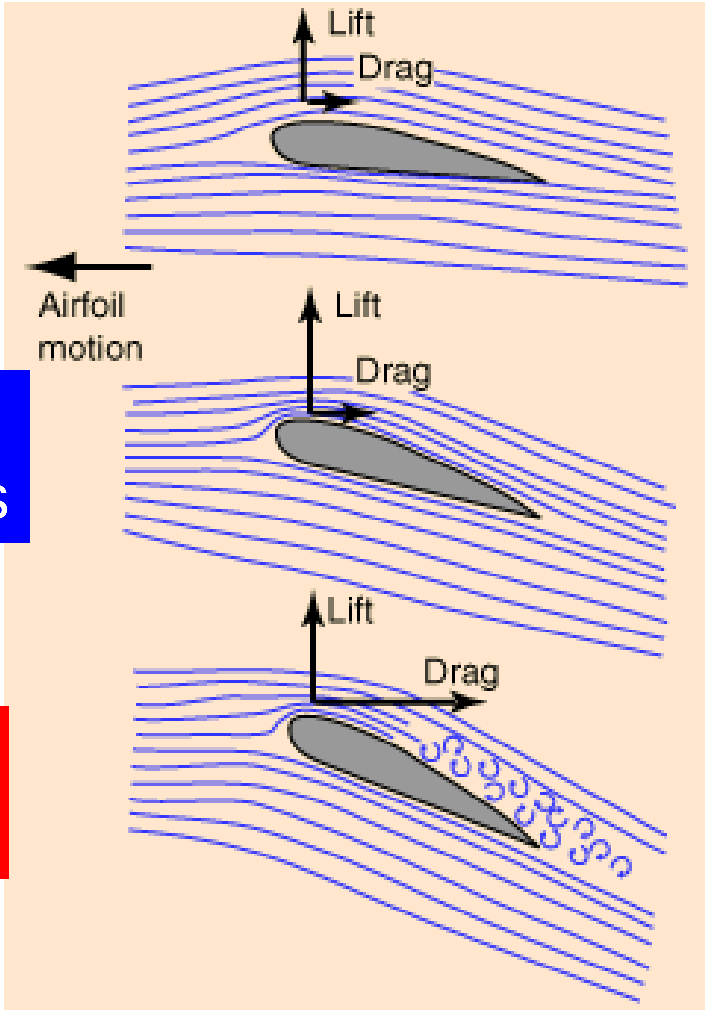
- The *Lift Force* is perpendicular to the direction of motion. We want to make this force BIG.

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

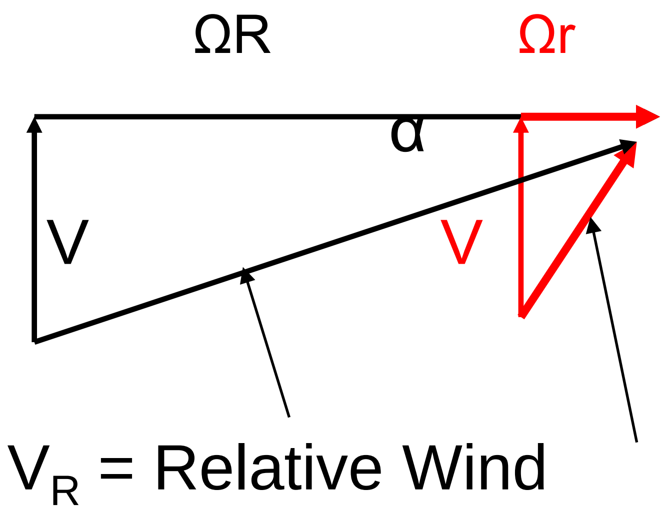
α = low

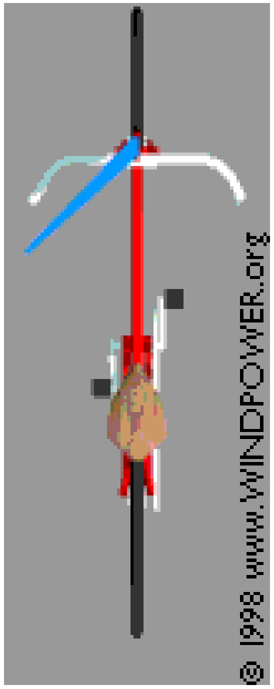
α = medium <10 degrees

α = High Stall!!



Apparent Wind & Angle of Attack



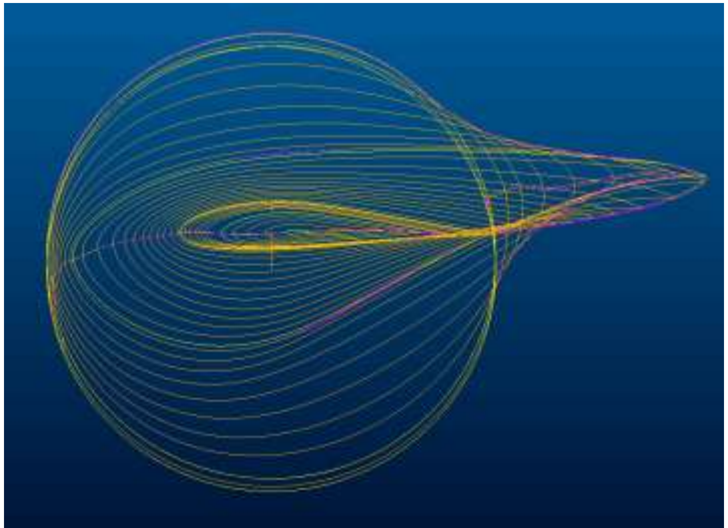


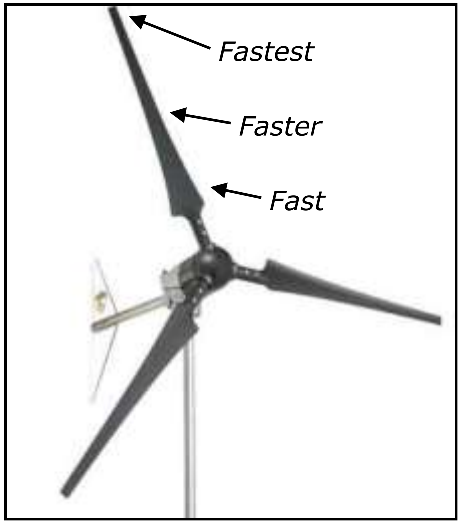
α = angle of attack = angle between the chord line and the direction of the relative wind, V_R .

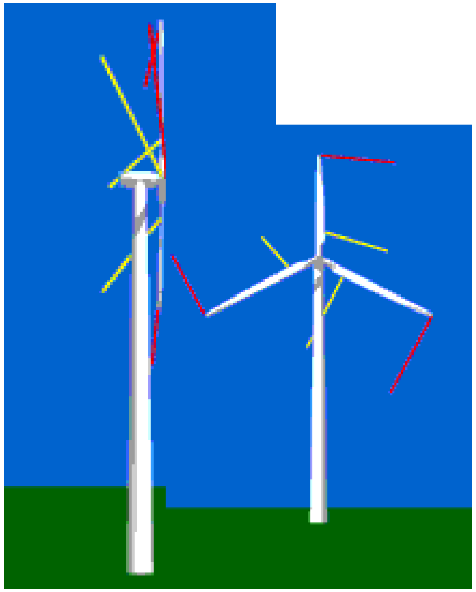
V_R = wind speed seen by the airfoil – vector sum of V (free stream wind) and ΩR (tip speed).

Twist & Taper

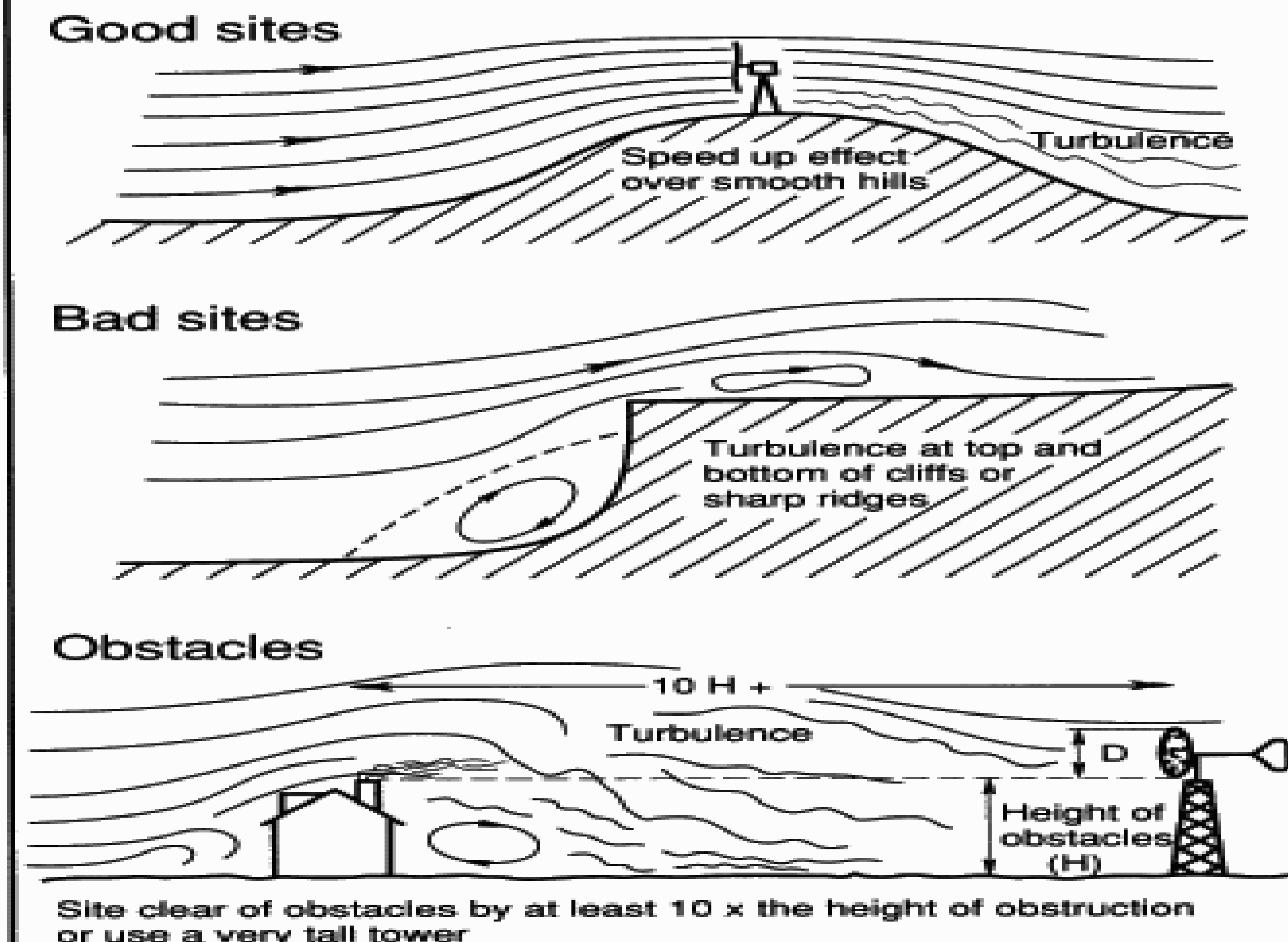
- Speed through the air of a point on the blade changes with distance from hub
- Therefore, tip speed ratio varies as well
- To optimize angle of attack all along blade, it must twist from root to tip







Wind turbines sites

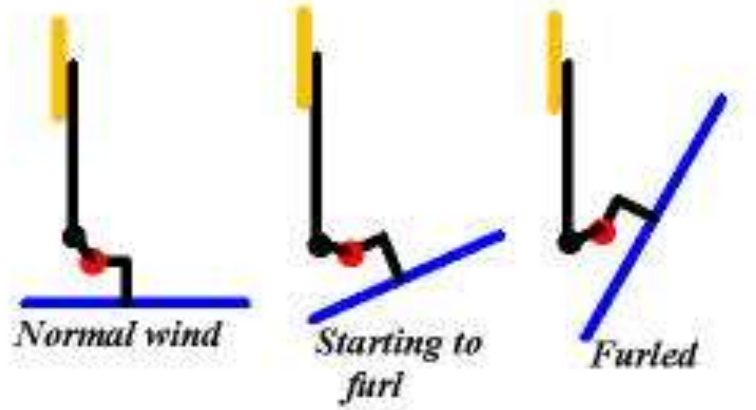


Flow over hills and obstacles

Rotor Controls

"The rotor is the single most critical element of any wind turbine… How a wind turbine controls the forces acting on the rotor, particularly in high winds, is of the utmost importance to the long-term, reliable function of any wind turbine." Paul Gipe

- Micro Turbines
  - May not have any controls
  - Blade flutter
- Small Turbines
  - Furling (upwind) – rotor moves to reduce frontal area facing wind
  - Coning (downwind) – rotor blades come to a sharper cone
  - Passive pitch governors – blades pitch out of wind
- Medium Turbines
  - Aerodynamic Stall
  - Mechanical Brakes
  - Aerodynamic Brakes



Turbine Power Limited By

- Power in the wind
- Betz limit (air can not be slowed to zero)
- Low speed losses - wake rotation
- Drag losses – aerodynamics and blade geometry
- Generator and drivetrain inefficiencies

Thank you