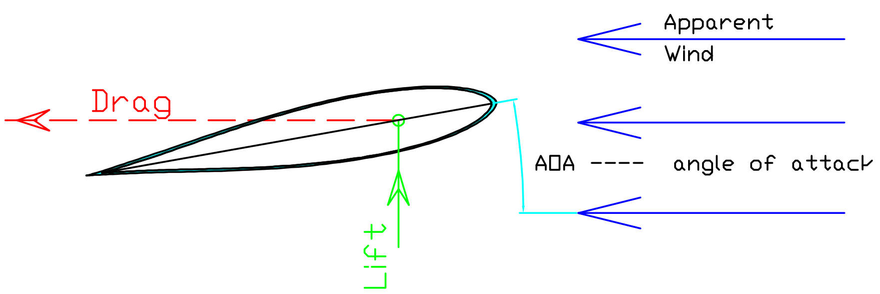
Aerofoils in wind turbines

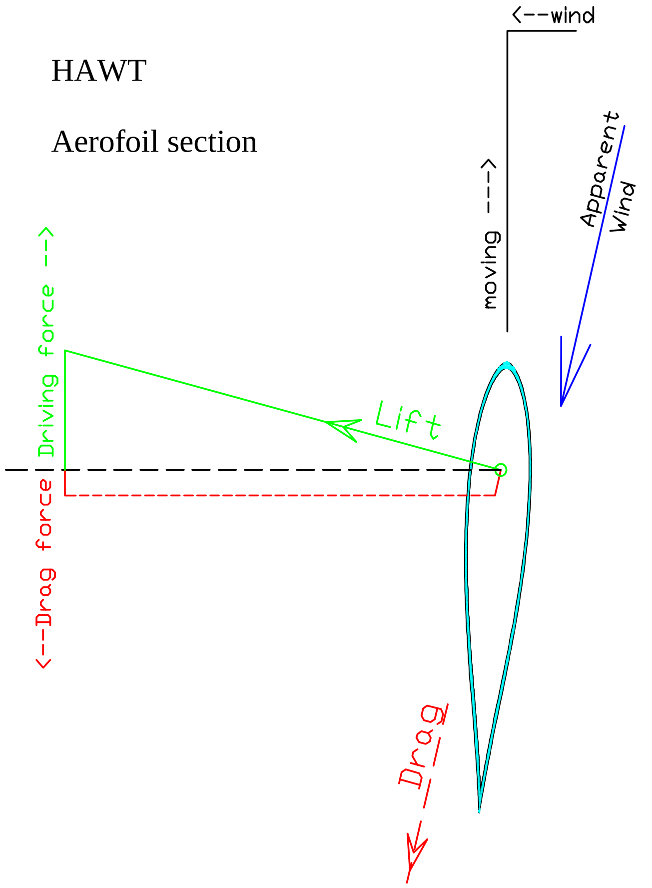


Making use of the lift forces that can be produced by an aerofoil angled to the apparent wind flow is the best way of obtaining energy from the wind.

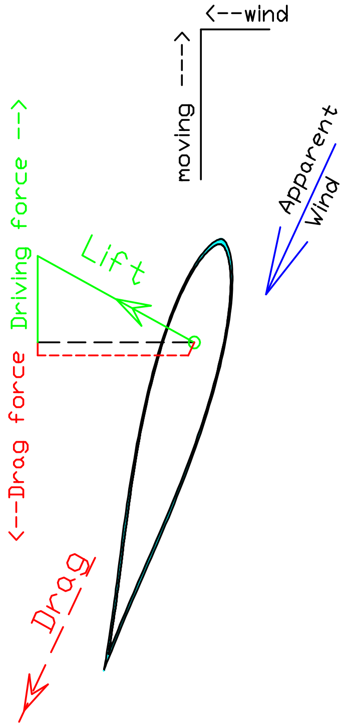
Currently the most developed method is the use of a horizontal axis of rotation:
The wind is always @ 90° to the direction of movement of the aerofoil. Twisting the blade along its length is used to optimise the angle of attack to allow for variation in the apparent wind at different radii.
The diagrams below indicate how the aerofoil is pitched along its length.

HAWT

Aerofoil section



Closer to the hub:



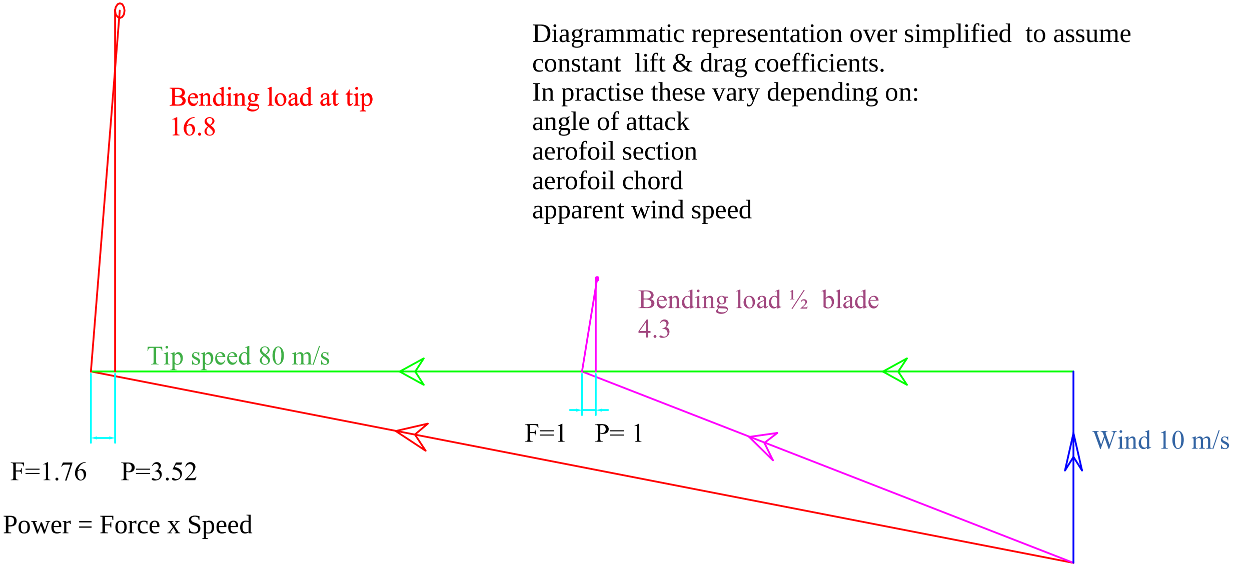
There are 2 main loads imposed on the blades:
1 The lift force, driving the rotation and bending the blades
2 The alternating force due to gravity as the blades rotate.
As diameters increase the lift forces increase over a longer span requiring substantially stronger sections which will be heavier resulting in even bigger alternating loads.

Tip speeds can not be increased substantially. This allows proportionally more undisturbed air to pass between blades as the diameters increase resulting in a reduction in energy per unit of swept area.

Loads on & power from HAWT blades

The cyclic loads due to gravity are not shown.
The speed of the aerofoil section changes along the blade proportionally to the radius of rotation. This changes the apparent wind resulting in changes to the lift & drag forces along the length.
The lift force is 90 degrees to the apparent wind, resolves into a driving force F and a bending load.

Diagrammatic representation over simplified to assume constant lift & drag coefficients.
In practise these vary depending on:
angle of attack
aerofoil section
aerofoil chord
apparent wind speed



Power = Force x Speed

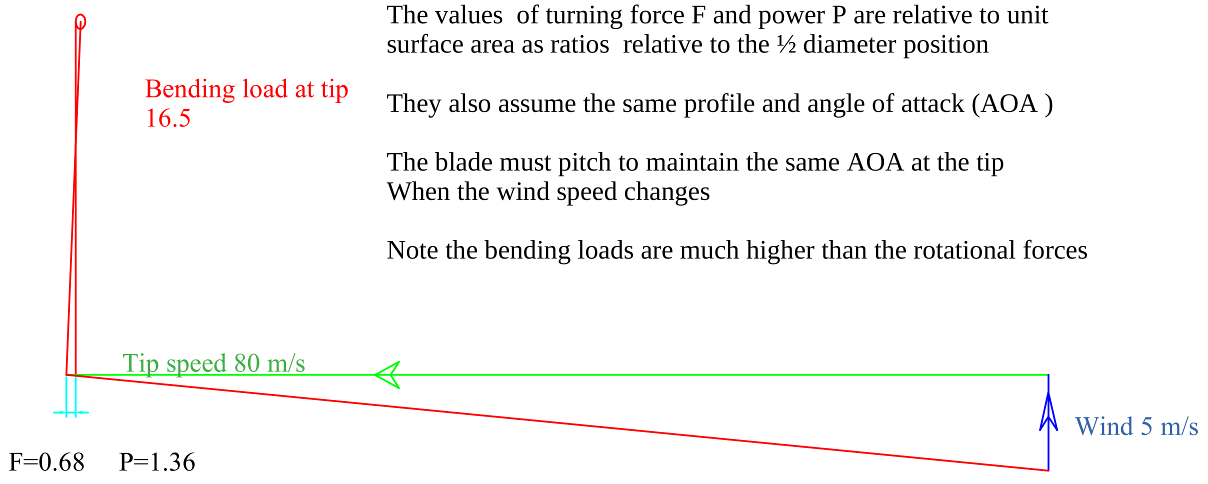
The forces on the blade are dependent on (speed of apparent wind)^2
The apparent wind is a vector of the wind and blade speed

The values of turning force F and power P are relative to unit surface area as ratios relative to the ½ diameter position

They also assume the same profile and angle of attack (AOA)

The blade must pitch to maintain the same AOA at the tip
When the wind speed changes

Note the bending loads are much higher than the rotational forces

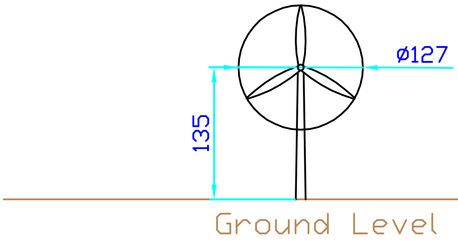


It is possible to have twist built into the blades such that the AOA is optimised along its length for a designed wind speed. The angle of the apparent wind to the blade changes along its length by different amounts at different wind speeds, which makes it impossible to maintain the same AOAs along the blade with a constant rpm at different wind speeds.

In the example above assuming the tip has a constant AOA of 10 such that when the wind dropped the blade was pitched to maintain this for optimum tip power. The AOA at the ½ diameter point would drop to 6.6

Since power is proportional to speed it is desirable to maintain a high operational rpm.
An example of the many design options is the reduction of the amount of twist in the blade such that the inner section has greater than optimal AOA at the designed wind speed with more lift but a lower lift to drag ratio but resulting in a higher AOA and more power in the central zone at the lower wind speed.

Comparing Large wind turbines (HAWT)



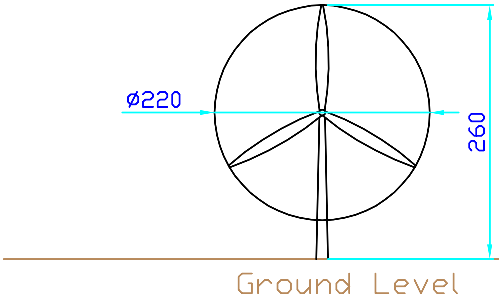
Enercon E-126   7.580
7,58 MW
12668 m^2 swept area
598,4 W/m^2

Cp 0.22 @ wind of 16.5 m/s   Tip speed 80 m/s
Cp 0.47 @ wind of 11 m/s   (4.85MW)

$$Cp = \frac{\text{Collectable wind energy}}{\text{Total wind energy}}$$

Being developed

General electric Haliade-X
12 MW
38000 m^2 swept area
315,8 W/m^2



Very few HAWTs have tip speeds exceeding 180 mph (80 m/s) because dust in the air causes erosion of the leading edge of the aerofoil blades.

Since power at any zone along the blade equals turning force x speed, it is advantageous to have as high a speed as practical.

For tangential rotational speed (S) and wind velocity (U) The lift force, which is proportional to the square of the apparent wind speed (A^2) can be used to get a power factor (P) related to velocity for different sections along a blade

$P = A \times U \times S$ where $A = (U^2 + S^2)^{0.5}$ and P_{zone}/P_{tip} can be used as a power ratio P_R

Power ratios for 80 m/s @ 127 & 220   (U & S in m/s)

diameter (m)		127	100	75	50	220	127	100	75	50
U	S	80	63	47	31	80	46	36	27	18
20	P_R	1	0.63	0.37	0.18	1	0.35	0.23	0.14	0.07
10	P_R	1	0.62	0.35	0.16	1	0.34	0.21	0.12	0.06
20	P_R						35%	36%	38%	41%
10	P_R						34%	34%	35%	36%

Due to the lower rotational speed to maintain a constant tip speed the power factor of the central area (1/3 of swept area) is down to 35%.

Note this is relative to power per unit surface area (offset by bigger aerofoil sections) but does indicate a potential for diminishing returns for increasing diameters much further.

The above is simplified and does not include the power reduced by drag.

The corresponding drag factor $D = A \times S^2$ but the coefficient of drag is small compared to the coefficient of lift.

The 220 diameter HAWT has a lower power /m^2 but it can with 3 times greater swept area generate more power at lower wind speeds