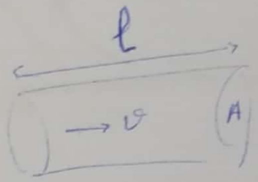
Chapter 2: Wind Resources

1. Energy and power of wind

(*) For a stream tube of length l and surface A applies:(A, v, $\rho Air = const.$)

. C'est les différences de pressions qui causent la variation de la vitesse du vent en surface terrestre.



$$\boxed{P_{wind} = \frac{1}{2} \rho A v^3}$$

$$\Uparrow$$

1) Volume $V = A \times l$

2) masse de l'air $= \rho_{air} . V = m_{air}$

3) l'énergie cinétique $E = \frac{1}{2} m_{air} v^2 = \frac{1}{2} . \rho_{air} . V . v^2 = \frac{1}{2} \rho . A . l . v^2$

$$\Rightarrow P_{wind} = \frac{dE}{dt} = \frac{d(\frac{1}{2} \rho . A . l . v^2)}{dt} = \frac{\frac{1}{2} \rho . A . dl . v^2}{dt} \; ; \; \frac{dl}{dt} = v$$

$$\Rightarrow \boxed{P_{wind} = \frac{1}{2} \rho . A . v^3}$$

<u>Exp 1</u> : . $\rho = 1{,}225 \ kg.m^{-3}$ (the value at sea level à $15°C$)

. $v = 10 \ m/s$

a) Calculate the power of wind in this air flow for $R = 2 \ m$

$A = \pi R^2 \Rightarrow P_{wind} = 7{,}697 \ kW$

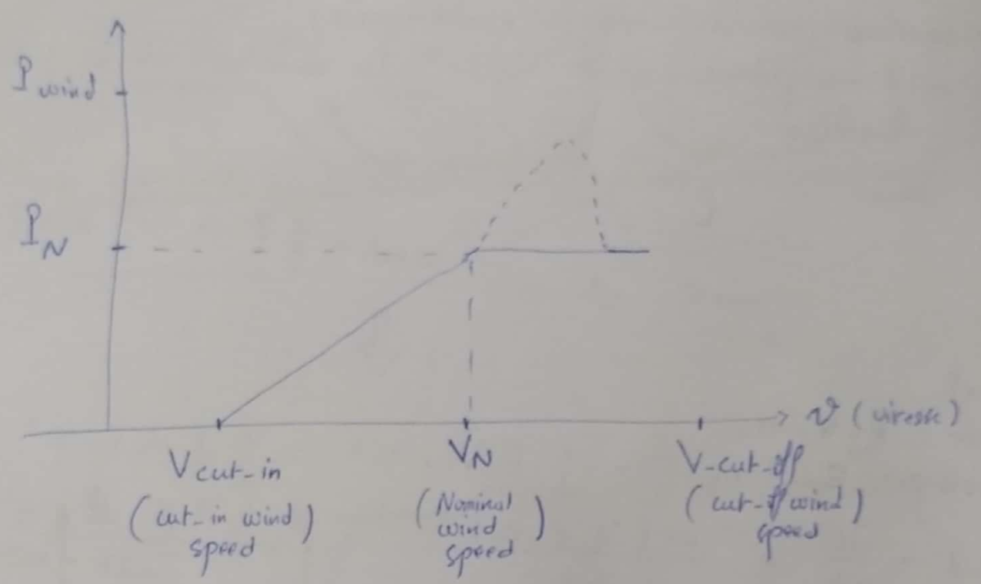
b) for $R = 60 \ m \Rightarrow P_{wind} = 6{,}927 \ MW$

Power Curve

- Let's consider the wind turbine with $C_p = 0,4$: $P_N = (\frac{1}{2} \rho \cdot A \cdot v^3) \cdot C_p$

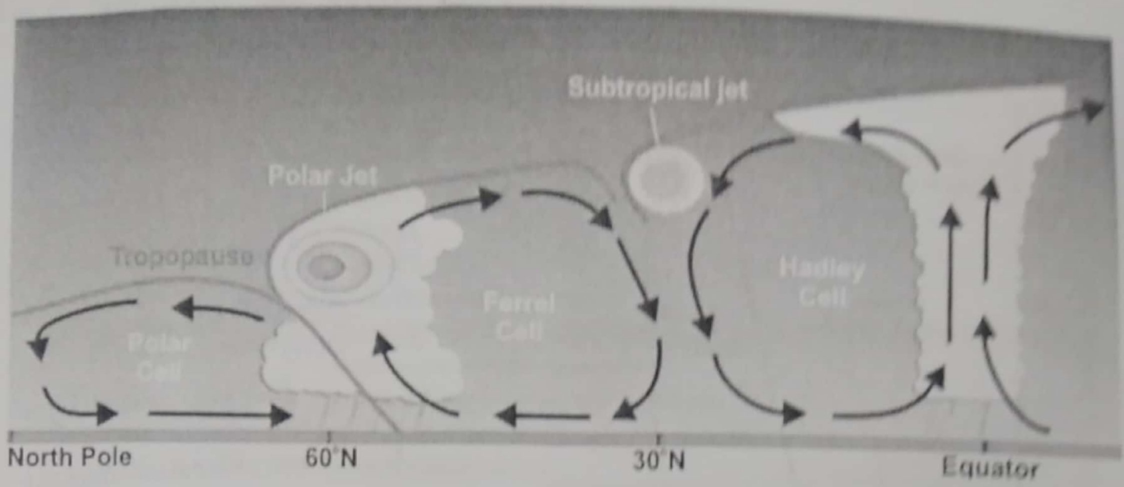
for exp 1 pour $R = 60$ m $\rightarrow P_N = P_{wind} \times 0,4$

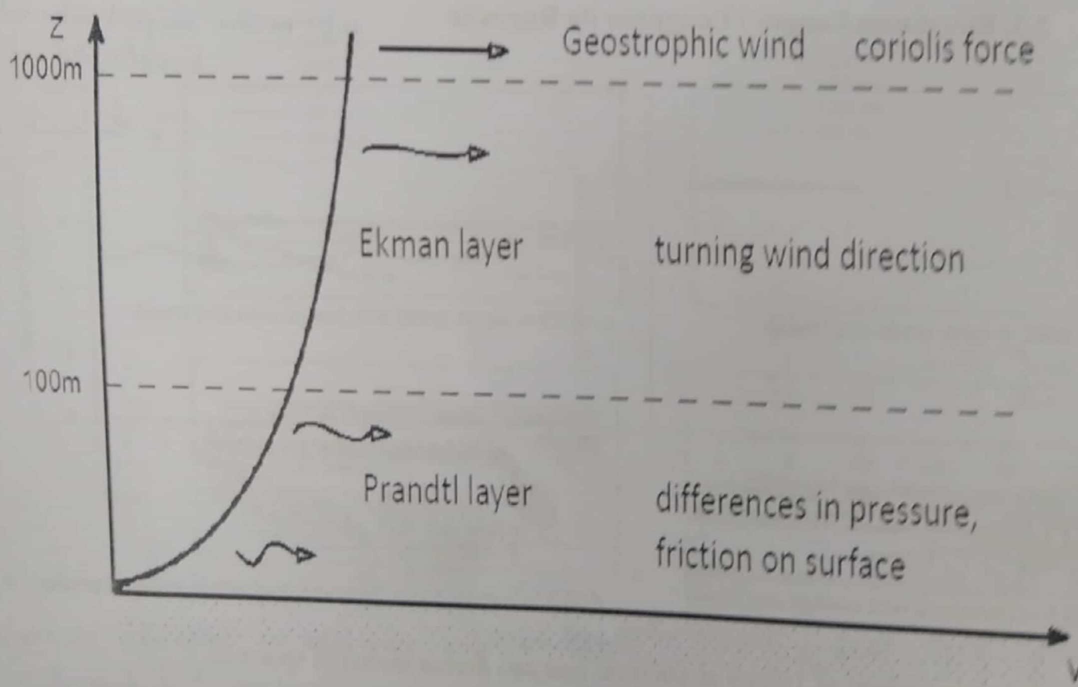
$v_N = 10 m/s$



2. Wind Profiles

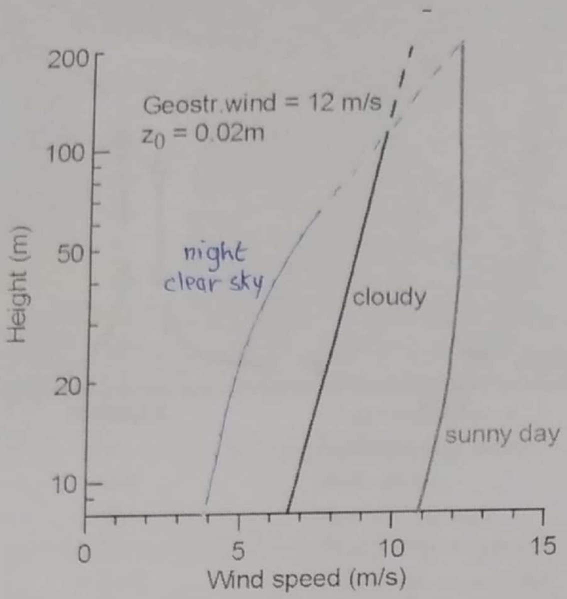
2.1. What causes the air to move (diapo)





Dependence of Wind Speed on Height above ground (wind shear)

2.2. Logarithmic Profile of the Wind



[DTU Courses]

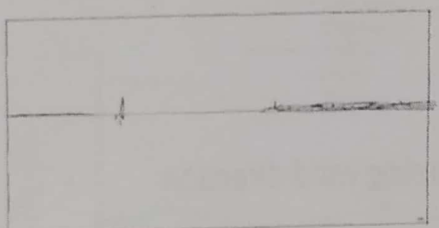
La vitesse du vent est régit par cette équation :

$$u(z) = \frac{u_*}{k}\left(\ln\left(\frac{z}{z_0}\right) - \psi\right)$$

u : wind speed
z : height
z_0 : roughness length
u_* : friction velocity
k : von Karman constant (~0.4)
ψ : atmospheric stability function
$\psi > 0$: day
$\psi < 0$: night.

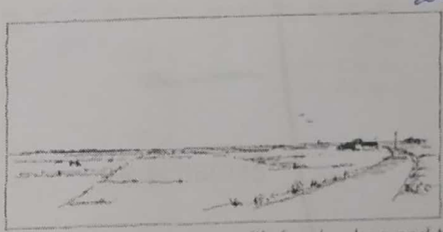
- la variation de la vitesse du vent est moins importante ds une journée ensoleillé q cloudy
- la nuit est plus importante

2.3. Roughness Length / Longueur de Rugosité



z_0=0.0002 m (sea, fjords and lakes)

→ u ↗



z_0=0.03 m (open areas with few bushes and trees)

z_0=0.1 m (farm land with bushes and trees)

z_0=0.4 m (urban, forest and farm land with many wind breaks)

→ u ↘

Assuming a wind speed of 10 m/s at 1000 m, one can derive the wind speed in…

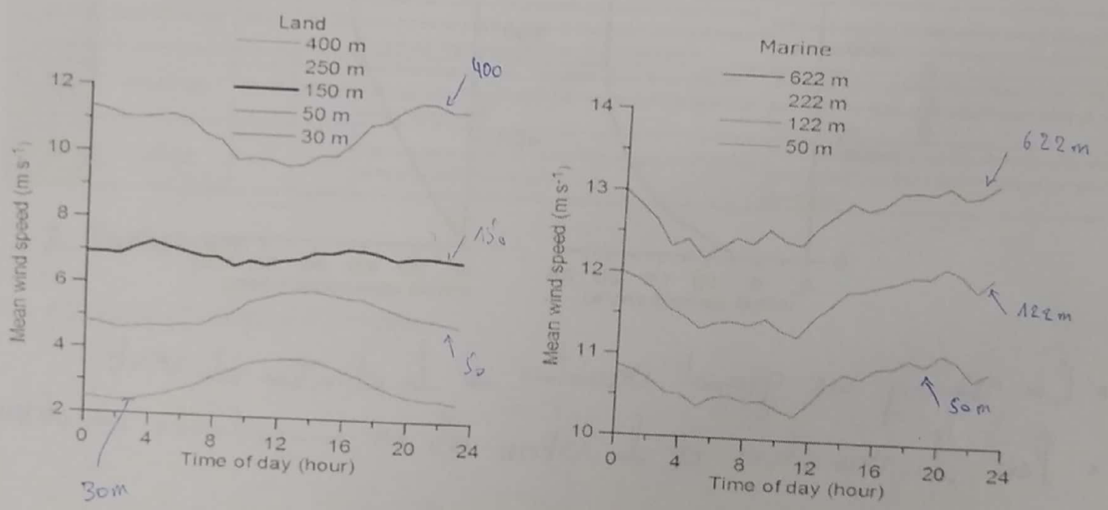
	Water	Forest
in 50 m	v_1 = 7.8 m/s	v_2 = 6.3 m/s
in 100 m	v_1 = 8.3 m/s	v_2 = 7.2 m/s

Relevant heights for wind turbines are 50–200 m

• The higher the roughness Z_0 the smaller the wind speed $u(Z)$ at a given height Z.

Z_0 [m]	Terrain surface characteristics (land use)
1.50	Sparse forest
1.00	City
0.80	Dense forest
0.50	Suburbs
0.40	Shelter belts
0.20	Many trees and/or bushes
0.10	Farmland with closed appearance
0.05	Farmland with open appearance
0.03	Farmland with very few buildings/trees
0.02	Airport areas with some buildings and trees
0.01	Airport runway areas
0.008	Mown grass
0.005	Bare soil (smooth)
0.001	Snow surfaces (smooth)
0.0003	Sand surfaces (smooth)
0.0002	Water areas (lakes, fjords, open sea)

2. 4. Daily Variation of the wind



• À une hauteur de 150 m, les variations de vent la vitesse du vent ne sont pas importantes (le jour q la nuit) ≃ constantes.

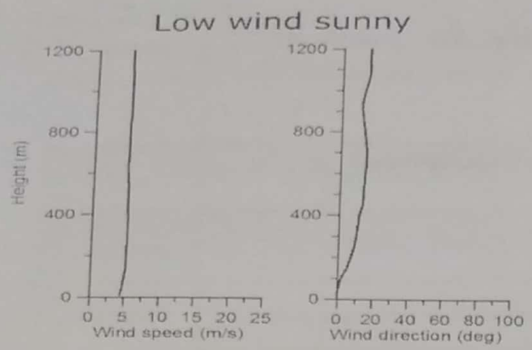
• Pour une hauteur de 30 m, les variations de la vitesse du vent sont très importantes pendant le jour.

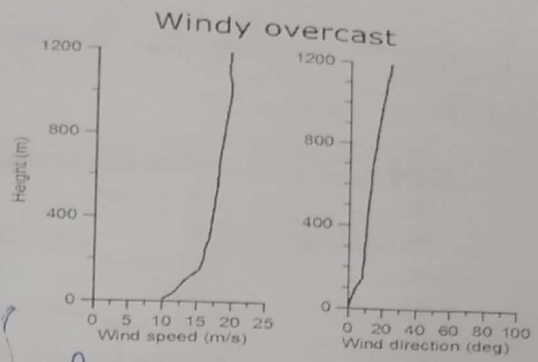
• Pour une hauteur de 400 m, les variations de la vitesse du vent sont plus importantes pendant le jour sauf qu'ils vont vers la baisse qd il y a bcp d'ensoleillement.

• Sur une surface de la mer, les vitesses du vent sont tjrs plus importantes q sur la surface terrestre ; cela est dû au paramètre de rugosité Z_0.

- ∀ la hauteur Z considérée sur une surface marine la variation de la vitesse du vent est plus importante pendant la journée et les vitesses sont plus faibles pendant la journée.

2.5. Variation of the wind speed and its direction depending on height - DAY



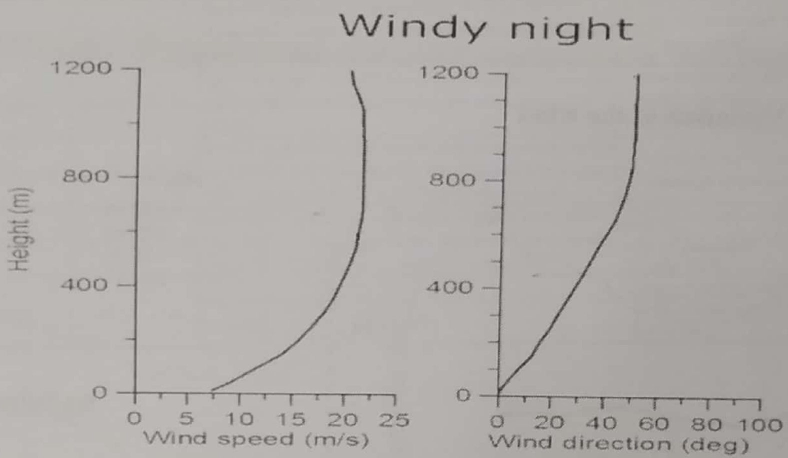


• pour une journée ensoléillé, on ne remarq pas de grands variations sur la vitesse du vent, ni sur la direction

• Pour un temps nuageux ; la variation de la vitesse du vent est importante en f°(hauteu

• la variation de la direction du vent est ± importante .

2. 6. Variation of the wind speed and its direction depending on height – Night



• On remarq une grand variation de la direction du vent

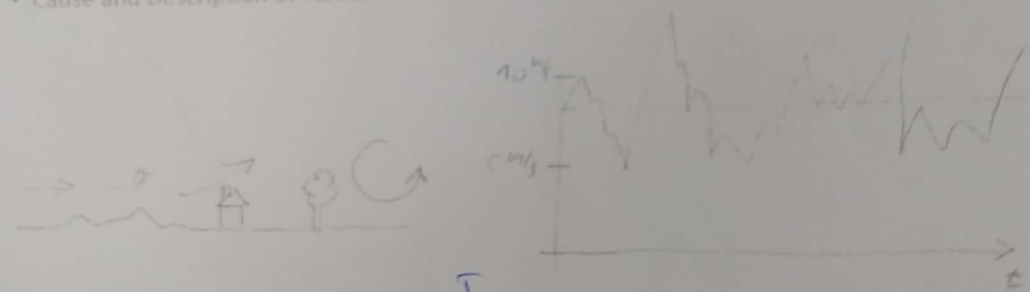
• Pour la variation de la vitesse elle est importante au dessous de 400 m

2.4. Wind speed table/ Beaufort table

Beaufort number	Description	Wind speed		Sea conditions	Land conditions
		kts	km/h		
0	Calm	<1	<1	Flat.	Calm. Smoke rises vertically.
1	Light air	1–2	1–5	Ripples without crests.	Wind motion visible in smoke.
2	Light breeze	3–6	6–11	Small wavelets. Crests of glassy appearance, not breaking	Wind felt on exposed skin. Leaves rustle.
3	Gentle breeze	7–10	12–19	Large wavelets. Crests begin to break, scattered whitecaps	Leaves and smaller twigs in constant motion.
4	Moderate breeze	11–15	20–28	Small waves with breaking crests. Fairly frequent white horses.	Dust and loose paper raised. Small branches begin to move.
5	Fresh breeze	16–20	29–38	Moderate waves of some length. Many white horses. Small amounts of spray.	Branches of a moderate size move. Small trees begin to sway.
6	Strong breeze	21–26	39–49	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
7	High wind, Moderate gale, Near gale	27–33	50–61	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind. Swaying of skyscrapers may be felt, especially by people on upper floors.
8	Gale, Fresh gale	34–40	62–74	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
9	Strong gale	41–47	75–88	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over. Damage to circus tents and canopies.
10	Storm, Whole gale	48–55	89–102	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
11	Violent storm	56–63	103–117	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread vegetation damage. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
12	Hurricane	≥64	≥118	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.

3. Turbulence

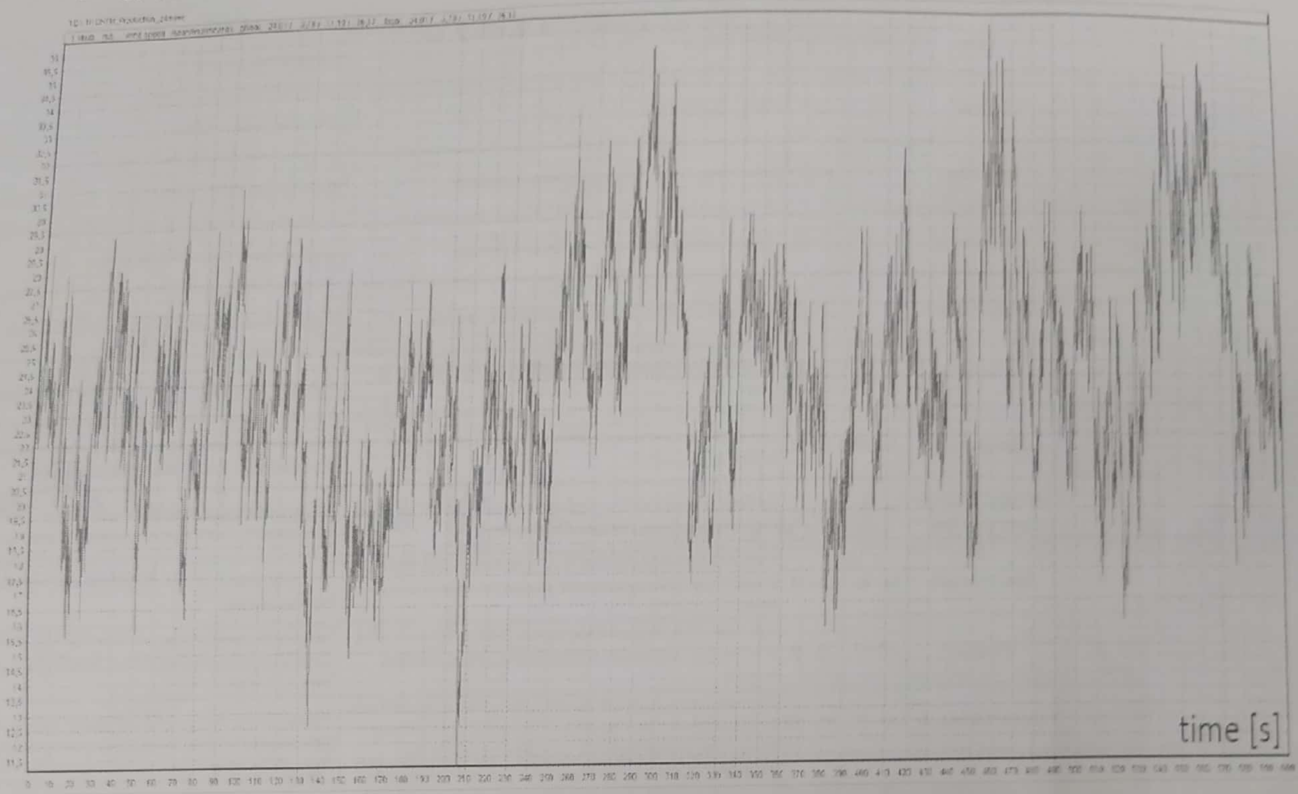
- Cause and Description of Turbulence



→ Sur T

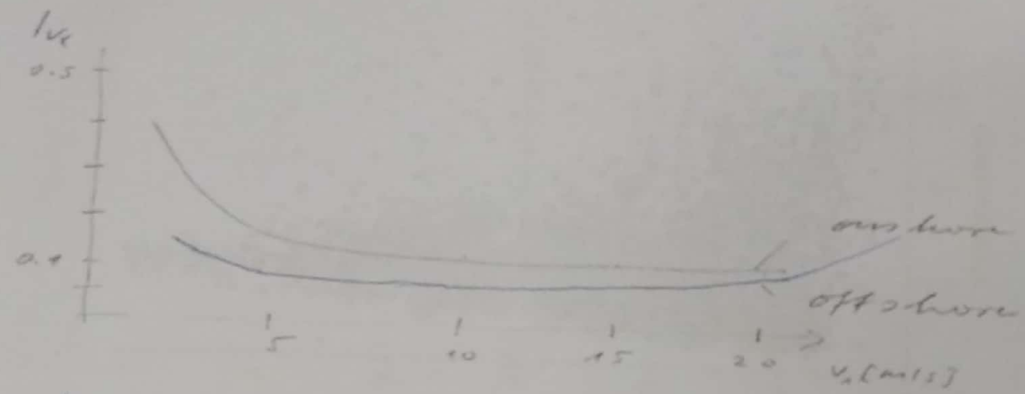
- Mean : $\bar{v} = \frac{1}{T}\int_0^T v(t)\,dt$
- Variance : $Var(v) = \frac{1}{T}\int_0^T (v(t) - \bar{v})^2\,dt$
- Standard déviation: $\sigma_v = \sqrt{var(v)}$
- Turbulence Intensity : $I_v = \frac{\sigma_v}{\bar{v}}$

- **10-Minute-Mean 24 m/s** [Ritschel Courses]



- I_v decreases with ~~e~~ increasing wind speed and height above the ground.
  ($I_v \searrow$ wind speed $\nearrow$ height $\nearrow$)

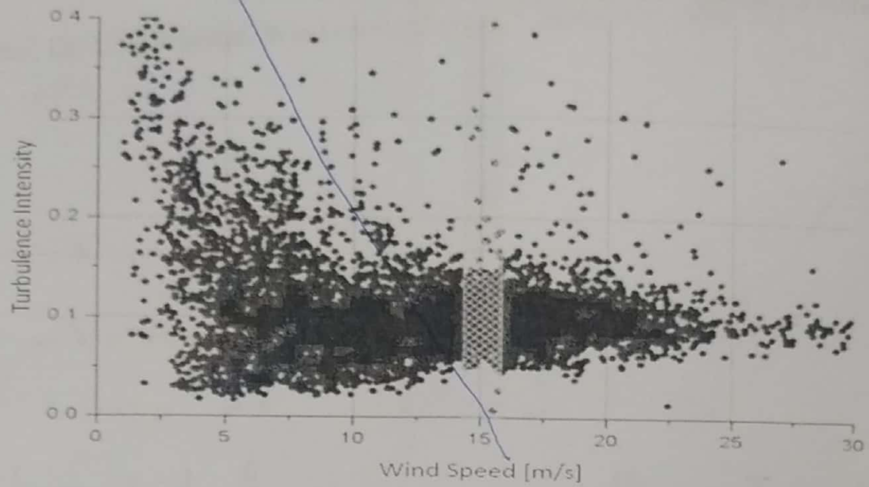
- **Turbulence intensity (On and Offshore)** [Ritschel Courses]



⇒ the turbulance I_v on offshore increases for high wind speed due to waves.

Wind Vector

- **Measured turbulence Intensity as Function of Wind Speed**



4. Wind Ressources : Weibull Distribution

- Pour des périodes allants de qqs semaines jusqu'à une année, la fonction de Weibull représente les vitesses observées, il s'agit d'une f° de densité de probabilité s'exprimant sur la forme suivante.

$$P(V) = \left(\frac{K}{c}\right)\left(\frac{V}{c}\right)^{K-1} \cdot \exp\left(-\left(\frac{V}{c}\right)^{K}\right)$$

Probabilité

$P(v)$: densité de probabilité de la vitesse V

K : c'est le facteur de forme de la courbe (sans unité)

C : c'est le facteur d'échelle de la courbe $[m/s]$

- Rmq : pour $K = 2$ → distribution de Raylegh.
- La vitesse moyenne du vent : $V_{moy} = \int V \times P(V)\, dV$

References

[DTU Courses] DTU, Wind Energy courses, Coursera, 2016

[Ritschel Courses] Dr. Uwe Ritschel, Wind energy Course, Tunisia , December 2017 .
ATLAS

TD 2 : Wind Profiles and Weibull Distribution

Exercice 1 : Variation à l'échelle annuelle du vent

Mois	J	F	M	A	M	Jn	Jt	A	S
Vit. Vent à 100 m (m/s)	11.9	12.9	12	11.9	11.9	12,1	12.1	11.7	11.4

Mois	O	N	D
Vit. Vent à 100 m (m/s)	11.2	11.6	12.4

Tableau 1. Variations mensuelles de la vitesses du vent à Oujda (Maroc)

1/ donner l'expression de densité de probabilité relative à la distribution du vent.
2/ Calculer la Fonction de distribution cumulative de Weibull pour différentes valeurs du facteur de forme K = (2, 3, 4) , C=7,2 m/s. $V_{moyenne} = \sum x\, P(V)$

Exercice 2 : THE ANALYSIS OF WIND DATA WITH RAYLEIGH DISTRIBUTION [2]

In this study, Elmadağ region which is district of Ankara is selected. Elmadağ is in the Central Anatolia Region in Turkey, has 39°54'N ve 33°23'E coordinates, and its altitude is 1178 meters. Hourly wind speed data obtained from State Meteorological Station which belongs 2012- 2013 years is gotten at 10 meter from the ground surface. According to these measurements, the mean speed data of twelve months are calculated as in Table 2.

Months	Mean Wind Speed (m/s)	Months	Mean Wind Speed (m/s)
January	6.78	July	4.95
February	5.86	August	6.08
March	3.71	September	1.89
April	4.67	October	2.14
May	4.98	November	2.65
June	6.41	December	7.29

Table 2. Monthly mean wind speed data

Mean wind speed of region at 10 meter measurement height is 4.78 m/s. The lowest mean wind speed data is calculated in September and highest mean wind speed data is calculated in December.
The results using only mean wind speed data are given in Table 3.
1/ Calculate Weibull distribution for each month
2/ You are asked to draw the Rayleigh probability density function diagram for a wind speed between 0 m/s and 25 m/s. $K=2$

Months	V_{mean}	c	E_v(W)
January	6.78	7.65	364.61
February	5.86	6.61	235.41
March	3.71	4.19	59.74
April	4.67	5.27	119.15
May	4.98	5.62	144.49
June	6.41	7.23	308.12
July	4.95	5.59	141.89
August	6.08	6.86	262.94
September	1.89	2.13	7.90
October	2.14	2.42	11.47
November	2.65	2.99	21.77
December	7.29	8.23	453.23
Annual mean	4.78	5.40	127.77

Table 3. Rayleigh analysis results

References

[2] Yağmur ARIKAN1, Özge Pınar ARSLAN 1, Ertuğrul ÇAM, « THE ANALYSIS OF WIND DATA WITH RAYLEIGH DISTRIBUTION AND OPTIMUM TURBINE AND COST ANALYSIS IN ELMADAĞ,TURKEY", Yağmur ARIKAN et al./ IU-JEEE Vol. 15(1), (2015), 1907-1912.

TD 2

Exercice n° 1 :

1)
$$P(V) = \left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1} \cdot \exp\left(-\left(\frac{V}{C}\right)^K\right)$$

P : probabilité

V : vitesse du vent

K : facteur de forme de la courbe

C : facteur d'échelle de la courbe (m/s)

+ K = 2 → distribution de Rayleigh

2) pour K = 2 , C = 7,2 m/s ; V = 11,9 m/s

$$P(V) = \left(\frac{2}{7,2}\right)\left(\frac{11,9}{7,2}\right)^1 \exp\left(-\left(\frac{11,9}{7,2}\right)^2\right)$$

$= 0,029 = 2,9\ \%$

- pour V = 12,9 m/s

$P(V) = 0,020 = 2\%$

- pour V = 12 m/s → $P(V) = 0,028 = 2,8\%$

Exercice n° 2 :

1)
$$P(V) = \left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1} \exp\left(-\left(\frac{V}{C}\right)^K\right)$$

$$P(V)_J = \left(\frac{2}{7,65}\right)\left(\frac{6,78}{7,65}\right) \cdot \exp\left(-\left(\frac{6,78}{7,65}\right)^2\right)$$

$= 0,105 = 10,5\ \%$

$$P(V)_F = \left(\frac{2}{6,61}\right)\left(\frac{5,86}{6,61}\right) \exp\left(-\left(\frac{5,86}{6,61}\right)^2\right)$$

$= 12,2\ \%$

$$P(V)_M = \left(\frac{2}{4,19}\right)\left(\frac{3,71}{4,19}\right) \exp\left(-\left(\frac{3,71}{4,19}\right)^2\right)$$

$= 19,3\ \%$

$P(V)_{Avril} = 15,34\ \%$; $P(V)_{Juin} = 11,17\%$

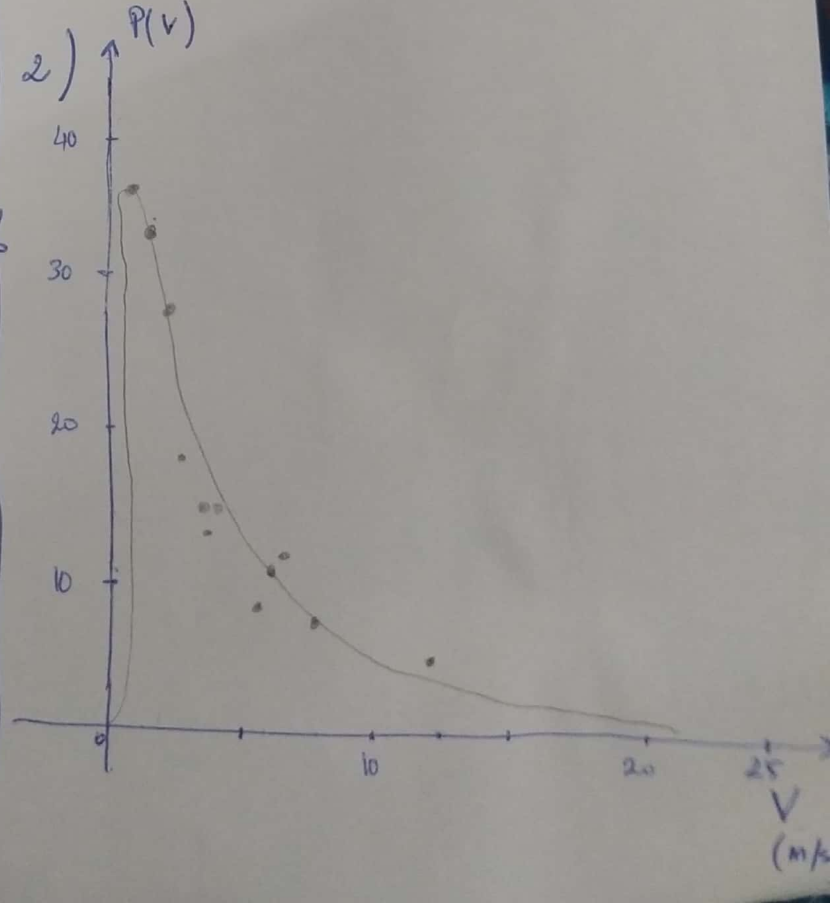
$P(V)_{Mai} = 14,38\%$; $P(V)_{Juillet} = 14\%$

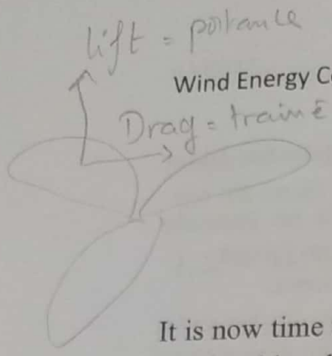
$P(V)_{Aout} = 11,78\%$; $P(V)_{Sep} = 37,91\ \%$

$P(V)_{Octb} = 33,44\%$; $P(V)_{Nov} = 27,03\%$

$P(V)_{Dec} = 9,8\ \%$

2)





Chapter 3: Wind Turbine Technology

It is now time to focus on the wind turbine itself. In this module you will learn about different wind turbine designs including the modern three-bladed turbine. Four parts are introduced in this lesson:

- Aerodynamic forces
- Air foils
- wind energy technology concepts
- wind turbine terminology.

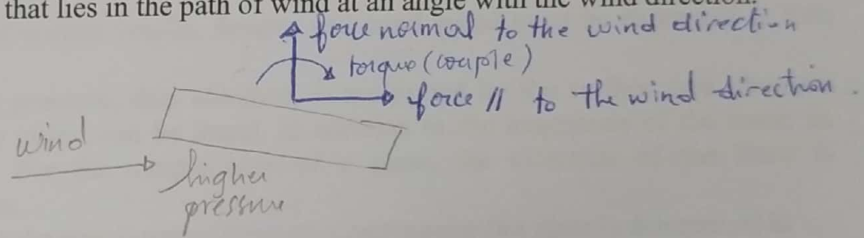
1

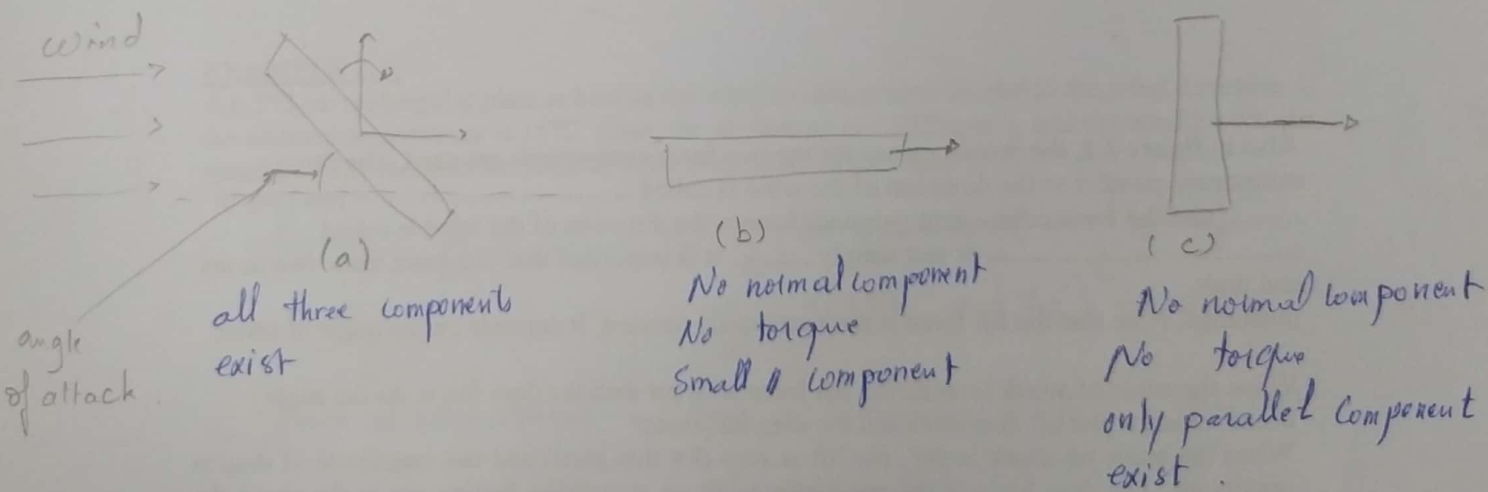
1 . Aerodynamic Forces

1.1. Force from Wind

When an object is in the path of the wind it is subject to two forces from wind. This is true for an object in the path of any fluid that moves, like water flowing in a pipe or in a river. For the sake of concentration on wind only, here we do not consider the general case and emphasize only the force from wind. An object can be of any shape and any size. The simplest case to start with is a plate with a rectangular shape.

Figure 3.1 shows a plate that lies in the path of wind at an angle with the wind direction.





In figure 3.1, three cases are shown in which the angle of the plate with the wind direction are different.

In (a) the general case is shown, where all three components—two force components and a torque—exist.
In (b), the plate is parallel to the direction of wind and, as a result, there is no pressure difference on the two sides of the plate. Consequently there is no side force and no torque. There is only a small force pushing the plate in the same direction as the wind blows.
In the third case, (c), the plate is normal (perpendicular) to the wind direction. In this case, again, there is no side force or torque. There is only a pushing force that is in the direction of wind.

The important thing is to realize the effect of the plate angle on the forces.
This angle is called the angle..of.attack. In order to understand that better, refer to **Figure 3.2.**

Also in **figure 3.2**, the proper names for the two force components are used. The force component parallel to the direction of the wind is called ……………………... or just simply …….., and the force component perpendicular to the direction of the wind is called …………………………... or just simply ……. . It is important that you learn these two terms and their
meanings. Note that the lift force is not necessarily upward. It depends on the angle of attack.

When the angle of attack is small the lift force is larger than the drag force. As the angle becomes larger the lift decreases and the drag increases.
When the angle of attack is 90°, the lift is zero (for this plate) and the magnitude of drag is maximum. The drag force is the resistance of air on something that moves in the air or the force from air when wind flows over an object. On the other hand, lift is a force that moves an

object to a side (it can be upward). For example, the force that keeps an airplane in the air is the lift on its wings.

1.2. Aerodynamic force

The force from wind on a plate, just studied in the previous section, is called .... We referred to the two aerodynamic force components as lift and drag. In fact, any force can be broken into two components. Here the lift force and the drag force are the two components of the aerodynamic force on the plate under consideration. These two components are perpendicular to each other; that is, they make an angle of 90° with each other, as shown in figure 3.1.

Recall that force exerted on a surface (the plate surface, in our discussion) is always the product of the area and the pressure on the surface. That is,

Force = Area x Pressure ...(3.1)

Thus, if the area of a plate is known (when the shape and dimensions of the plate are known), we need to find the pressure from wind and multiply that by the area of the plate in order to determine the aerodynamic force.

As you may be able to guess, the pressure from wind on a surface initially depends on the wind speed and the air density at the temperature under consideration.

The exact relationship is

Pressure from wind = $\frac{1}{2}$ x (density) (wind speed)^2 ...(3.2)

Note that in order to get correct results, density and wind speed must be expressed in their proper units.

If the magnitude of the pressure, thus obtained, is multiplied by the surface area, then the force from wind on any object can be found. In addition to the magnitude of the force, its direction is important. For the simple case of a plate, the direction of the force is perpendicular to the plate.

In the following example the aerodynamic force on a rectangular flat plate is determined in order to give you an idea about the amount of force expected.

EXAMPLE 3.1:

A 0.5*3-m rectangular plate is held in the wind stream, perpendicular to the wind direction. If the ambient temperature is 15°C (thus, the air density is 1.225kg/m^3), and the wind blows at a speed of 7.5m/sec, find the force exerted from wind on the plate.

$\frac{Kg}{m^3} \cdot \frac{m^2}{s^2}$

Kg/m^1.s^2

- Pressure from wind $= \frac{1}{2}$ (air density)(wind speed)^2

$= \frac{1}{2} \cdot 1{,}225 \times (7{,}5)^2 = 34{,}45$ Pa. (Kg m^{-1} s^{-2})

- Force airodynamique = Area x Pressure $= 1{,}5 \times 34{,}45$

$= 51{,}67$ N.

1.3. Lift and drag coefficients

In the previous sections you learned about aerodynamic force and lift and drag, which are the two components of aerodynamic force on an object in the path of wind. You also learned that the values of lift and drag are not constant and can change. In this section, two more terms are defined, which are used in determining the lift and drag force components for a given object (a flat plate, for example) and in the ratio between them (usually the lift -to-drag ratio), which is very important, as we will see later.

These new terms are .lift coefficient..... and .Drag..coefficient...

The magnitudes of the lift and drag forces depend on the angle of attack (see figure 3.2), but at each angle their values can be defined in terms of the aerodynamic force; that is,

Lift..force..=..lift..coefficient.x.Aerodynamic (3.3) force

Drag ~~coeff~~ force.....=...Drag.coefficient.x.Aerodynamic..force....(3.4)

where the aerodynamic force depends on the shape of an object. Based on the above formulas, the definition for **lift coefficient** and **drag coefficient** are as follows:

lift coefficient..=..lift.force../.Aerodynamic...force... (3.5)

Drag.coefficient..=...Drag force.../Aerodynamic..force..(3.6)

Although the "lift " and "drag" coefficients change with the angle of attack, they are highly dependent on the shape of an object. Moreover, they are the same for objects of the same shape, since these two quantities are "ratios."

2. Airfoils

The importance of drag and lift forces is their contribution to the active action in the operation of a wind turbine. So far we have talked about an object, in general, and a flat plate, in particular, inside a wind stream. In certain turbines it is the drag force that turns the turbine and in others it is the lift force.

We learned in the previous section that the aerodynamic force depends on the shape and size of an object and that if at any angle of attack the lift and drag coefficients are known, one can determine the lift and drag forces on the object.

In a wind turbine we like to have the maximum power drawn from wind at each wind speed.

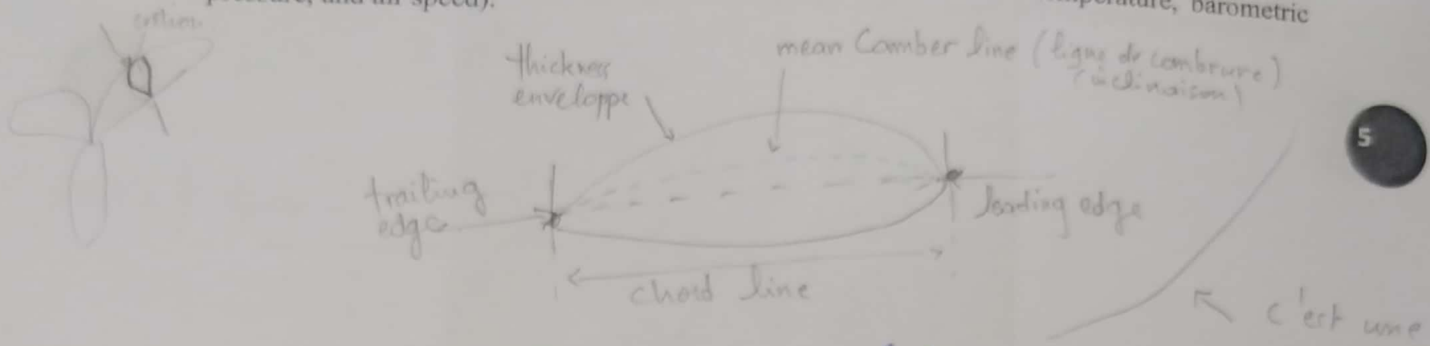
For this reason, if the turbine works based on .lift...force........, we like the lift force to be much larger than the drag force.

If, on the other hand, a turbine works based on the .Drag..force...., we like the drag force to be ...much..large..than..the..lift. You will see later that the turbines that work based on lift force are more efficient and preferred to those based on drag force.

It may be worth mentioning here that airplanes work based on the lift force on their wings. When an airplane moves, it behaves as if it is stationary and air flows around it, like an object in the wind stream. In the case of an airplane, the drag force is opposite to the airplane motion and it is not desirable; thus, its value must be as small as possible. On the contrary, lift is the force that keeps the plane in the air; so, it is desirable that its magnitude is large.

In order to increase the lift and reduce the drag, an .air.foil.............is employed instead of a flat plate. **This is true for an airplanes wings as well as for the blades of the majority of the wind turbines.**

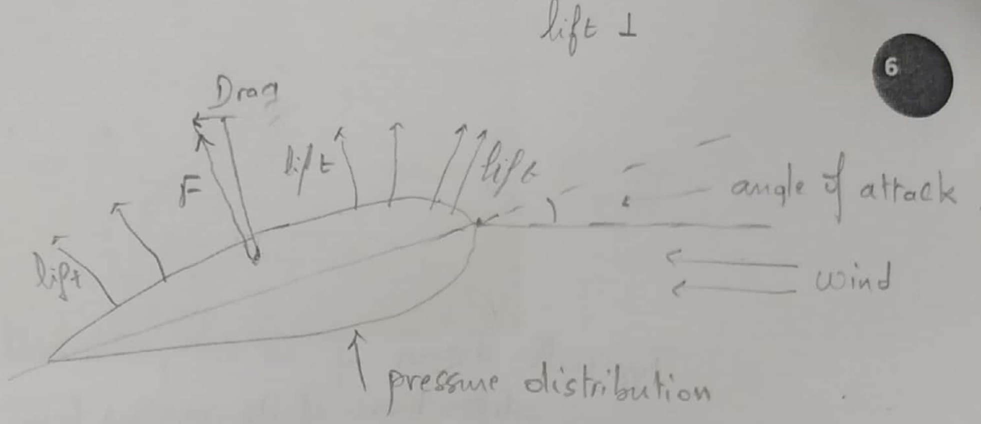
An airfoil has a cross section as shown in **Figure 3.3.** There is not only one airfoil, but many designs exist that are different from each other and have different characteristics.
It is quite important to note that many different sizes of airfoils can be made from one airfoil profile. In other words, if the relative sizes of various parts of an airfoil are kept the same we can have many different scales of the same airfoil.
For all the different sizes, the lift and drag coefficients will be the same, but the lift and drag forces will increase with the area of the airfoil. If the area doubles, so does the aerodynamic force; and, thus, the lift and drag forces double (under the same temperature, barometric pressure, and air speed).



Typicall Pattern of an air foil and the definition of its various terms.

What is shown in figure 3.3 is the section of an airfoil. You can imagine a flat plate over which certain parts are added to shape it as having curved surfaces. These curved surfaces considerably change the aerodynamic property of the flat plate.
The thin flat surface extends from the extreme point in the leading edge... to the extreme point in the trailing edge....... The extent between these two extreme points is called the "Chord"
The imaginary flat thin plate represents the Chord line......., a line connecting the leading edge to the trailing edge. The leading edge is a smooth curve, whereas the trailing edge is a sharp point. An airfoil can be symmetric, that is both sides have the same curve, or the upper and lower curves can be different. In the latter case the airfoil is said to be cambered air foil.......................
As you can see in figure 3.3, the upper and lower surfaces make a profile that defines the airfoil. The thickness of the airfoil at various points along the chord varies. At one point it has the thickest cross section. The midpoints between the upper and the lower curves of the airfoil section, when connected together, form the mean camber line..... This is a curved line connecting the leading edge to the trailing edge. The mean camber line and the chord line define an area that can be thin or thick. The thinness (or thickness) of this area affects the aerodynamic properties of an airfoil. Figure 3.3 also shows the center of gravity of the airfoil section (**point G**).
The important property of an airfoil is that it possesses larger values of lift force and smaller values of the drag force for most angles of attack that arise in practice. This property is usually represented by the lift and drag coefficients and the lift -to-drag ratio, which is the ratio of the lift coefficient to the drag coefficient. Whereas with a flat plate the maximum

possible value for this ratio can be a small number, with airfoils this ratio can reach values over 20.
Because of the desirable aerodynamic property of airfoils, in all the turbines for which the active force is "lift " the structure of the blades has the profile of a selected airfoil.
When a turbine blade (or an airplane wing) with an airfoil profile is inside a wind flow, various parts of it are subject to pressures of different values. The resultant of all this pressure surrounding it translates into one single force *F*, which has a component in the direction of wind (drag) and another component normal to the wind direction (lift). This force *F* acts at the center of gravity of the blade (wing). This is as schematically shown in **Figure 3.4.**



typical pattern of the forces acting on a airfoil section

It is this lift force and the drag force that exhibit the effect of wind on the blade in a wind turbine and finally contribute to the rotation of the turbine and the amount of power it draws from the wind (see **Figures 3.5** and **3.6**).
A good airfoil is required to have the following properties:

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FIGURE 3.5 *Cross section of a 41-m (134.5-ft) wind turbine blade, seen from the tip.*

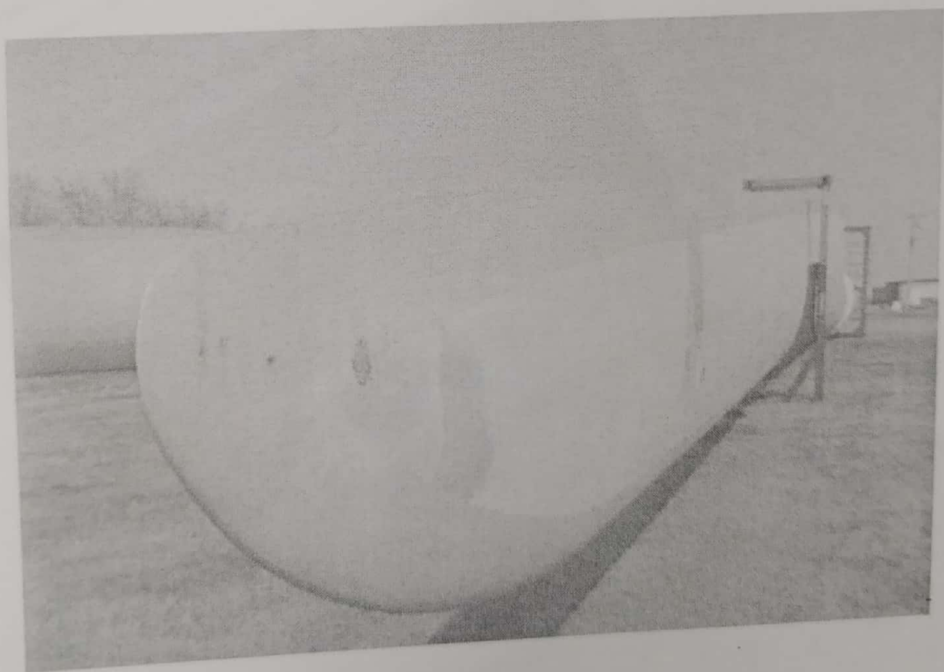

FIGURE 3.6 *Picture of the 134.5-ft blade whose cross section is shown in figure 3.5.*