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:

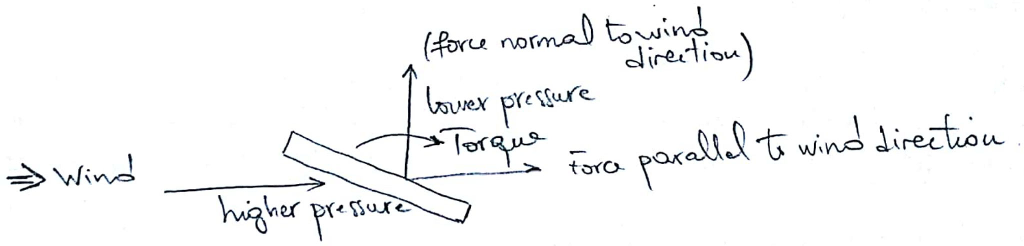
- Aerodynamic forces
- Airfoils
- Wind energy technology concepts.
- Wind Turbine Terminology.

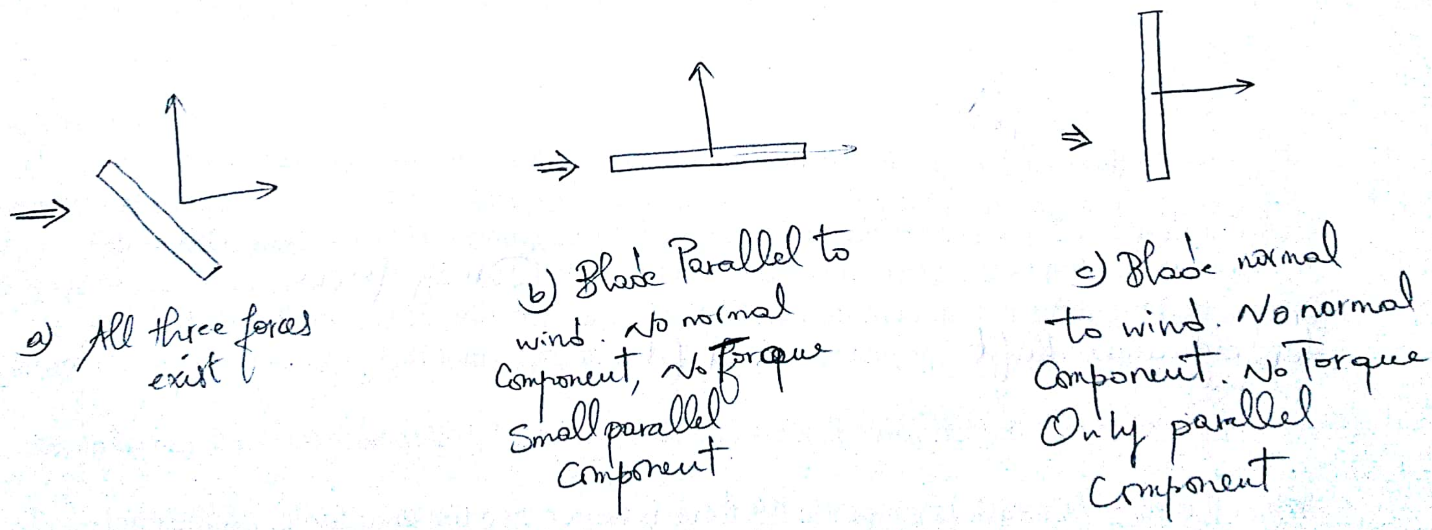
1 . Aerodynamic Forces

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.

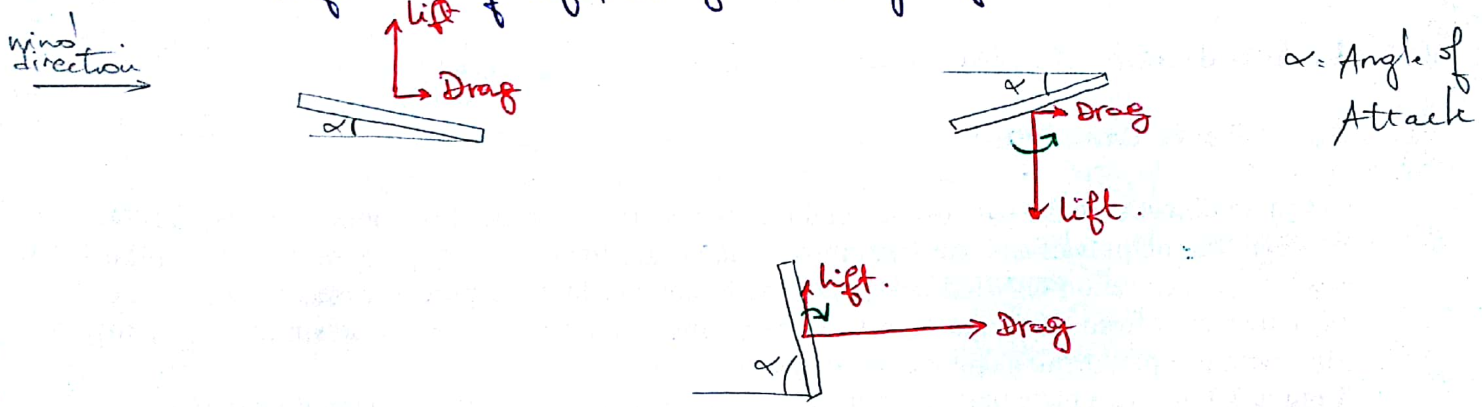




In figure 3.1, three cases are shown in which the angle of the plate with the wind direction are different.

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 The angle of attack In order to understand that better, refer to **Figure 3.2.** Definition of lift, Drag and angle of Attack.



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 Drag force..... or just simply Drag., and the force component perpendicular to the direction of the wind is called Aerodynamic lift.. or just simply lift 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 Aerodynamic force... 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,

$$\text{Force} = \text{Area} \times \text{Pressure} \quad (3.1)$$

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

$$\frac{1}{2} \text{Density} \times (\text{wind speed})^2 \quad (3.2)$$

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.

Force = Area × Pressure

Pressure $= \frac{1}{2} \rho V^2 = 1,225 \times \frac{1}{2} \times (7,5)^2 = 34,45$ bar.

$\Rightarrow F = 3 \times 0,5 \times \frac{1}{2} \times 1,225 \times (7,5)^2 = 51,67$ 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 coef × Aerodynamic force (3.3)
Drag force = Drag coef × 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 coef = lift force / Aerodynamic force (3.5)
Drag coef = 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."

1.4. 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 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 larger than the lift one. 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 ..airfoil............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).

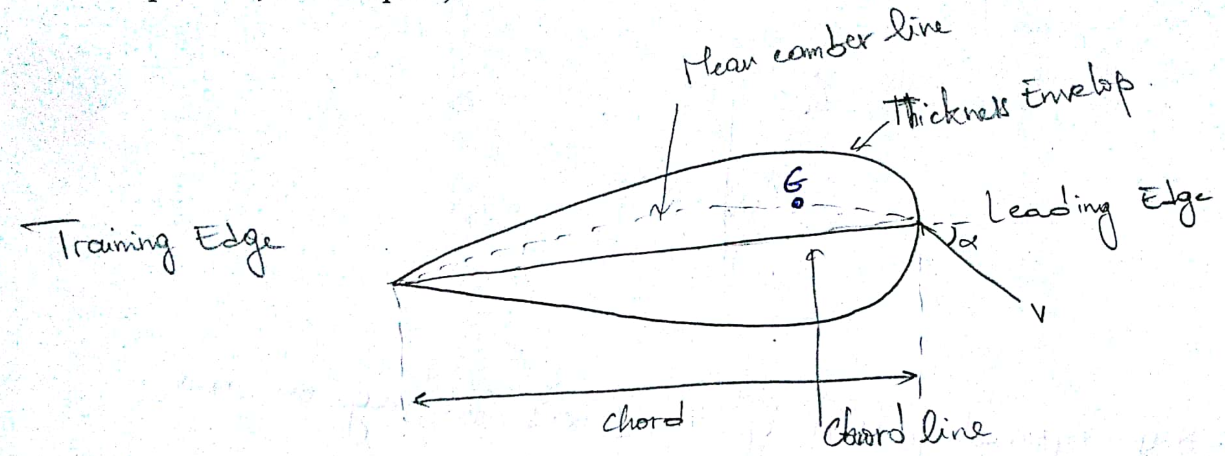


figure 3.3: Typical Pattern of an airfoil and the definition of Various terms.

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 ..Airfoil......................
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 defi ne 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.**

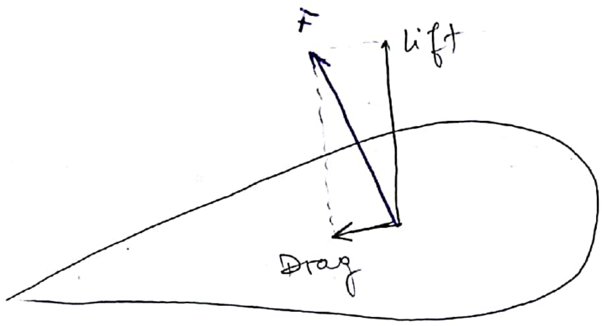


figure 3.4: Typical pattern of the forces acting on an airfoil section.

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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