**Wind Energy**

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# Lecture 27: Airfoil nomenclature

welcome come back so, let us continue the discussion on this, horizontal axis their momentum theory so what we have talked about momentum theory one dimensional momentum theory momentum theory with weak rotation beam theory and what we have established the criteria for maximum power coefficient, maximum thrust coefficients and some of the design consideration of the code or the solidarity and all these things. An important aspect which has kind of come out of that discussion is that how one can have this design of the blades but obviously at the different section of the turbine blades or the rotor blade you will have different section of the profiles and those airfoils are going to be different because the twist solidarity all these are in different locations are different these things are more going to be import i mean more important or clear when we'll be talking about the dynamics part of it. So, each segment of the rotor blade, how they contribute to the overall system dynamics on the rotor blade dynamic. And, when you talk about those dynamic or that aspect of it, so that also kind of lead to the design. So, what we are trying to do here is that see the wind energy of the wind which is kind of coming to this particular what do you call on the blades or the rotor blades then the rotor due to this lift and it rotates and the main shaft which is connected with the gearbox that transmit that to the high speed shaft and then there the generator is connected which is converting that to electricity so that's the overall mechanism of these things but this is what is going to coming to the aerodynamics design and all this having said that the important aspect of it is looking at some of this nomenclature of airfoils and things like that so that is what we are going to talk about here so, airfoils which are well known streamline structure okay, so, which is known for uh so this used for generating lift force usually define the lift force is defined the perpendicular to the direction of the oncoming air flow And, the lift force is, we'll see that. So, there are, it can use the blades, wings.

So, if you see this particular airfoil, this is called leading edge. This is trailing edge. Then you have the line which is connecting the leading and trailing edge called the chord line. Or, that's what the chord length is.

and the one which is dividing the airfoil into two equal segments called the camber and in between you have the thickness. So, that's the typical airfoil nomenclature that you have. So, what is there is now  If we look at, so these are all kind of a cambered airfoil. These are called cambered airfoil. If you see here in this picture, you have leading edge, trailing edge, then quad length, you have a lower camber.

So, the quad which is connecting between the leading edge and trailing edge,  That divides the thickness into two segments. One is called the upper camber and this is the lower camber. So, camber is the asymmetry between the two acting surfaces of the airfoil. The airfoil which doesn't have camber is called the symmetric airfoil. The benefits of cambering were long back which is 19th century discovered.

now the airfoil can be positive cambered if the upper surface is more convex the airfoil could be and the camber is complex property that is can be more fully characterized by the camber line and then one can define the thickness at different location of the airfoil in this direction which kind of describes the thickness of airfoils at any given point so the upper point you can let's say this and the lower point so this is the camber line in curve the z with i mean function of x and the thickness by two so this is how the upper and lower point one can be estimated now there are different kind of airfoils which are used so there are some conventional airfoils there are so if you see this is used for high lift producing devices. So, it is used wherever you would like to produce high lift. This is more like a general purpose airfoil. These are again high speed airfoil. That means these are used in some vehicle or aircraft or somewhere where you are encountering high speed.

Again, this airfoil, if you see, this is a zero camber. This is upper surface is more convex. This is negative camber because the lower surface having more convex. So, the camber curvature usually dictates the positive or negative camber and things like that. Now, conventional airfoils if you see this particular airfoil it has some property.

It's low camber  Low drag, high speed, thin wind section suitable for race planes, fighter, interceptors. You have very deep camber. This is used for high lift but at the low speed operating condition. Thick wind section suitable for transport, fighter, bombers and all this. Similarly you have deep camber which is used for high lift and low speed.

Thin wind section suitable as above. This is for low lift high drag system. The reflex trailing edge with section. Very little movement of center of pressure. Good stability.

This is symmetrical wind section. Pretty much similar to the above. This is a thicker for better structure and lower weight. Good stall characteristics. This airfoil chamber is maintained.

which increases lifting capacity over more and decreases drag. So, this is what you can have. when you have different kind of airfoils provide different nomenclature and different advantage, disadvantage and their uses. So, obviously these are all based on the use of the airfoil, what kind of airfoil one would like to choose and that sort of dictates the  Now, when you talk about the nomenclature of the airfoil, this was given by the NACA, which was National Advisory Committee of Aeronautics. And, it defines airfoil shapes and also aircaps wing.

And, that's what the series are most of the time, this airfoil which are used, they are called in the namingly NACA series. And there are, I mean, nomenclature has certain aspect of it. So, here if you see the one is the zero lift line, two leading edge, three no circle, four maximum thickness, five camber, six upper surface, seven trailing edge, eight camber mean nine lower surface. If, you kind of remember this, then how we define these things, the other things like NACA initially developed the number of the airfoil system. So, what happened is that during 1920 and into 30, the NACA developed the series, thoroughly tested airfoils and devised a numerical designation of each airfoil.

So, they had four digit series, they have five digit series, they have six digit series. So, that's how the digit came up. 1929 Langley had developed the system to point where the numbering system was complemented by an airfoil cross section. And, the complete catalog of 78 airfoils appeared in the annual report of 1933. So, engineers could quickly see the particularities of airfoil shape and the numerical designator.

For example, NACA 2415, it's specified camber lines, maximum thickness, things like that. Obviously, this provides that when you try to design the system, you know what kind of airfoil you would like to use and also what would be the nomenclature. Let's start with the four-digit series. So, the first digit here, that is 2,  describe the maximum camber as a percentage of quads. So, this 2 is the 2% maximum camber of 2%.

Second digit describes the distance of maximum camber from the airfoil leading edge to intents of quads. So, here the 4 is that the maximum camber located at 40% or 0.4 of quads from the leading edge. and last two digit defines the thickness with a maximum thickness of 12 percent similarly so this is two four one two this is probably zero zero one five zero zero stands for this is a symmetrical arrow curl so that means there is no camber so there is no point of maximum camber only thing that you get the thickness issue So, you get only the, so as soon as somebody sees this 00 series, immediately you would be able to identify that this is a thickness which is there. Then you have five digit series.

So, the five digit series kind of the format is LPSTT. L, a single digit which representing the theoretical optimum lift coefficient and ideal angle of error, which is the 0.5, 1.5 times of the L. P, a single digit for x coordinate of the point of maximum camber, so maximum camber at 0.

05 P. S, a single digit number which is, which talks about whether it's a simple camber or reflex camber. 80 again the maximum thickness in percentage of chord like what you have in 4 digit series. For example, 23112, the lift coefficient is 0.3 because 0.515 into 2, the point of maximum camber is 15% of the chord, so 5 into 3.

reflex is reflex number 1 and 12 is the thickness. So, that's what you have in 5 digit. Similarly, you can have 6 digit series. So, those series are so every series has this kind of number filter. Now, talking about the aerodynamic forces So the aerodynamic force is generated when the blade actually rotates through the air.

So, the lift and drag act through the centre of pressure which is the average location of the aerodynamic forces on an object. These are mechanical forces and they are generated due to the interaction of the blade or contact of the blade with the air. lift force which is kind of a defined a perpendicular to the direction of the oncoming airflow and this is a consequence of the unusual sequential pressure difference across the upper and lower surface of the airfoil and drag force is usually and this is due to both interaction. So, these are some, then you have pitching moment and all these things. So, the lift generation is kind of what we get using the fundamental principle of Newton's first law of motion and second law of motion.

So, it's then third law of motion which says, so, Bernoulli's principle also increasing the speed of the fluid simultaneously, so, these we have what it says the Newton's second law the force causes a change in velocity with intangence another force, so, when the flow passes by the airfoil there is a pressure difference, so that, so if you see this air coming and this is the kite so the resultant portion allow the kite to go up same thing happens with the wind there is air coming, the wind having this same difference. This generates a downward flow. Now, obviously, when there is a pressure difference, it is obvious effect of the geometry. Important when you have a higher turning, that is in this case, you get better stability. Now, we can see a volume where expand is so high because of that you get so increased air flow decreases in pressure.

So, the air flowing over the surface of moving speeds up happens when the air flow comes and the flow moving less pressure which is going to contribute towards the increase in speed reduces pressure above and then produces that. So, how does an airfoil produces an lift, so, if you see this is a typical flat plate or here you see the airfoil so the flow velocity over top of the airfoil is faster than on the bottom surface so you can have some kind of a steam tube let's say a senses upper portion of the airfoil as an obstruction and steam tube A squares to smaller cross-section area, whether in the lower surface, steam tube B is a higher cross-section area, so the flow expands, slows down, so the pressure builds up there. So, that's how you get this kind of pressure difference over the airfoil surface. And this pressure distribution, you can see that generates this force, which is normal to the system.

So, this is how it generates. Now, you have relative wind effect on flight. Relative wind has both speed and direction. So, when a plane flies, relative wind blows in nearly an exact opposite direction. So, this is what the relative wind, because the airfoil having an angle of attack. So, this is what is going to have a relative wind.

Now angle of attack plays an important role. Also, not only for airplane, we can see the example of the airplane. But, here is an example of the airplane. if a plane alters its pitch which you can see here, the up and down movement of the plane nose, the angle of attack on the wings will increase. So, when the angle of attack increases, the blade produces more lifting force.

So, there is a typical CL versus angle of attack curve for generally airfoil. So, with the increasing alcohol of attack, you can see the CL is increasing up to a certain angle of attack. So, this is a point where what happens is that if your angle of attack is too much, then flows tend to separate. And once flow tend to separate, then you have a lot of loose speed zone and all these things. There will be more viscous effect which is going to be dominant.

It increases the drag. So, that is why beyond a point actually where it stalls and the seal starts dropping and that can be easily visible here. So, point at which plane stalls around 15 degree because these are standard airfoil but this is not something. So, what you can see when you are at the lower alpha or angle of attack, the floor remains attached so nicely you can get lift, you have drag. But, as soon as you increase the angle of attack, you see the flow like that.

So, this is the separated flow region. So, more and more you have separated flow region, obviously your lift decreases because lift is primarily delta P. between the upper surface and the lower surface. But, here this is going to be a problem. When separation occurs, you have adverse pressure gradient, not favorable pressure gradient. So, lift actually, in this case, lift actually starts decreasing.

So, what happens is that, so this lift and drag are primary forces that act on the aerodynamic body. This is a measure of usefulness of the device. Drag is the force which retains the motion. So, basically even for your rotor blade, the drag force is going to increase your losses.

Power production is going to be less. So, one has to understand the relationship between lift and drag. And with fundamental relationship is developed relating force and aerodynamic coefficients. then you can so if you look at those thing you have lift coefficient so this is a lift force divided by area into dynamic head drag coefficient pitching moment coefficient, so, these are fundamental aerodynamic coefficient then one needs to have for design and things like that now what creates these aerodynamic forces, so, aerodynamic forces are exerted by air flow and come only two sources one is pressure that is how this gets distributed over surface so this is x normal to the surface then shear stress friction on surface which acts tangentially failure on the surface. Net unbalance in the force creates the aerodynamic force. No matter how complex the flow field, no matter how complex the shape of the body, the only way nature has of communicating an aerodynamic force to a solid object or surface is through the pressure and shear stress distribution that exists on the surface.

# Summarizing primary coefficients

- $C_L = \frac{\text{Lift}}{\frac{1}{2}\rho v^2 S}$ = lift coefficient
- $C_D = \frac{\text{Drag}}{\frac{1}{2}\rho v^2 S}$ = drag coefficient
- $C_M = \frac{\text{Pitching moment}}{\frac{1}{2}\rho v^2 S\bar{C}}$ = pitching moment coefficient

So, now you can see how the relative to the, so, this is an airfoil which has an angle of attack alpha, so, this is the relative wind and this is the component of the forces okay, so, total resultant forces are and you have two component one is lift component which is perpendicular and drag component which is parallel to the system and then aerodynamic moment, so, The total lift force on airfoil is summation of F1 and F2. Lift is obtained when F2 is greater than F1. Misalignment of F1 and F2 creates the moment which tend to rotate the airfoil or wheel. Value of induced moment depends on the point about which moments are taken. Moments of the leading edge, a quarter quad, In general, this is MC by 4 where it acts.

Now, what is there? You have this variation of the lift force, drag force and moment with alpha. So, lift drag moment on an aerofoil or wheel will change as alpha changes. Variation of these quantities are some of the most important information that airfoil designer has. so, one is the aerodynamic center point about which movement essentially do not vary with alpha that's called mac constant independent of alpha flow low speed airfoils aerodynamic center is nearly quarter quite much so this is nearly c but yes it depends also the airfoil so how one would Find the lift coefficient. So, you get the pressure distribution over this airfoil surface.

This is along the pod. The pressure coefficient would be the PL minus P naught by rho V square by two. Cp is the difference between the local pressure between lower and upper surface. So, the area between the upper and lower surface distribution is proportional to the lift. And, once you find the lift, then you can find out the lift coefficient, which is CP.

So, now one can find out the lift on a blade. So, this is a typical aerofoil. this is leading edge this is telling it, so, this would be finite length in this side, so, there is an finite aspect ratio, so, this is small infinite similar strip and the angle is given, so the lift per unit span and something very very important so, that is due to the pressure differences all these that you get so one can find out by integrating lift force between leading edge to trailing edge and the component of these forces. So, one is PL cos theta minus Pu cos theta of ds. ds is this small segment here.

So, you go from leading edge to trailing edge. So ds cos theta is dx. So one can convert this to zero to see Pl dx minus Pu dx. lift per unit span so adding and subtracting p infinity so there is some kind of an algebraic manipulation that one can do and what you can do is that 0 to c p l minus p infinity, so, p u minus p infinity x, so, now our definition of lift coefficient is l by q infinity s square Q infinity is half rho U infinity square. Then we write L by Q infinity into C because it's an unit span. So, combining these two quantities, so what we get Cl is 1 by C 0 to C P 1 minus P infinity P lower and P upper minus.

So Cpl, this is a lower surface coefficient. This is upper surface coefficient. So, what you get Cl as an one by C, Cpl minus difference of the upper and lower surface coefficients and this thing. So, if you look at the lift coefficient versus angle of attack, you have zero lift angle of attack, which is alpha zero. The slope of the linear region gives the infinite wing lift coefficient, the reference lift coefficient is given the point zero. So, this is the case where flow remains attached And this is where the flow gets separated.

So, that is where it goes to the stalling point of the system and things like that. So, lift is not pushing force. It makes the rotor to rotate. So, this is where when you talk about the context of the turbine blade. So, when you talk about the context of the turbine blade, so, as we said the blade rotates so obviously every section there are airfoils and they are having angle of attack so, due to this wind and the relative pressure difference the lift force this allows this to rotate okay so obviously the commonality is that you get lift and drag so you try to minimize the drag for the account for the losses and things like that so If you try to make a connectivity of this blade, so this is your center point and this is how the blade goes, so this is your tip, this is at the root close to the half, this is how the radius varies and this is where the rotation is.

Now, this particular segment if you look at it, this is having an airfoil section and this is the wind speed. Now, that airfoil if we take it separately and try to, basically it's a zoomed in view and this is the wind speed, So what happens, this is coming to the airfoil and airfoil having an angle of attack of alpha, there is a twist of beta and this is the flow angle. So, you get lift in this direction, you get drag in this direction, then you have all these component L sine phi, d cos phi and the W which is the relative wind speed. So these are the calculation that we have already seen that taking an airfoil, and taking these angles and their concept and finding out the rest of the component. So, if I summarize that, so the pressure difference across the airfoil surface, that actually generates the lift coefficient.

So, you can always find out by doing the integration pressure across this. One can represent in different ways, like lower surface lift coefficient, upper surface lift coefficient, and that way. but if you increase the angle of attack one point of time there could be a flow separation so more and more self flow separation happens so, there is a drop in the lift obviously drag increases okay so this is the same concept which needs to be used while designing the rotor blade also because the rotor blade the lift causes it to rotate and the rotation is the main component here where you are converting your wind energy so the wind flow hitting the rotor blade, because of their airfoil sections at different planes and different things, it rotates. That rotation goes to the low-speed shaft to high-speed shaft to generator and produces the electricity.

So, we will stop here. We will continue the discussion on weak and all these things in the next session.