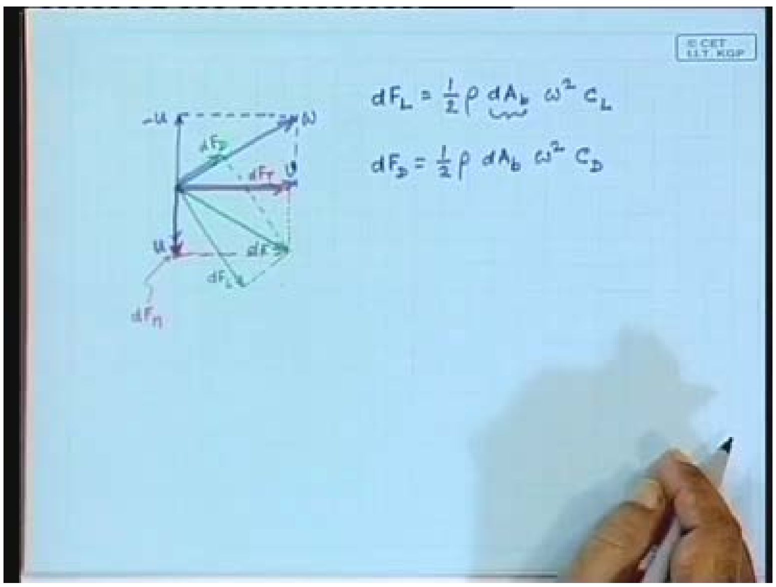
Energy Resource and Technology
Prof. S. Banerjee
Department of Electrical Engineering
Indian Institute of Technology - Kharagpur

Lecture - 23
Wind Energy – III

Today, let us show you how to solve problems in this area. That means given the adequate data, how to calculate how much will be the power output of a wind turbine, how much will be the thrust that will be experienced by the wind turbine? How to do that? But before doing that, I suppose we will need to refer to certain things. So, let us recall, recapitulate what we did in the last class.

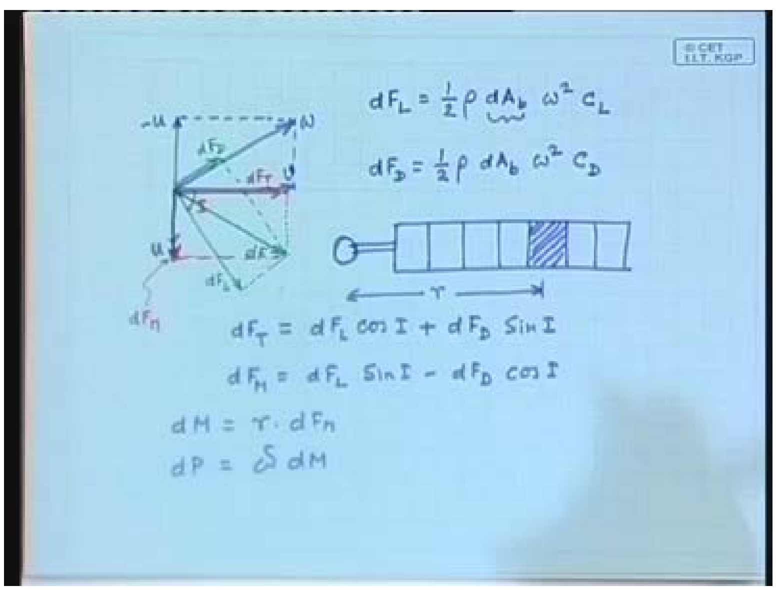
(Refer Slide Time: 1:27)



We said that let this be the velocity of the wind v, let this be the linear speed of the aerofoil and then we will have to obtain the relative wind, w and then there will be a force in the same direction as w that is F D and since all these are referring to blade elements rather than the whole blade, we will call it dF D and there will be one force perpendicular to it. That will be, what is it? dF L and then, the parallelogram again has to be completed to obtain the resultant force that is dF, fine and finally we obtain the different forces that are meaningful to us by getting the projections onto these two coordinates. So, this was your, sorry, this was your u, this was your u and this was your minus u. So, in that direction, I will put the u as a shorter one, so that this is something different.

So, here you have, this particular force would be the moment producing force dF M and here this force, this coordinate is your dF T, that you have seen already. So, this is the velocity, velocities and the forces as represented here and then we have seen that these two forces dF L and dF D that comprise, that actually make up, all these other forces are given by dF L is equal to half rho dA b, dA b because this is together, because we are talking about a blade element and its area, then w square, then your C L, the lift coefficient. Similarly, the drag force is equal to half rho dA b w square C D. So, these are the two forces that are produced, rho is the density of air, dA b is the blade element that we are talking about.

(Refer Slide Time: 5:10)

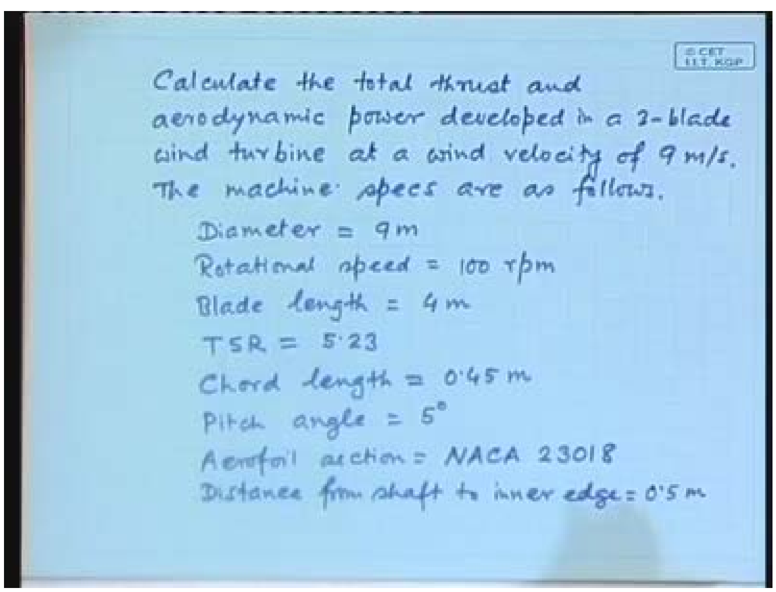


So, if you are thinking of a blade something like this, we will divide it into some elements and here we are talking about each of these blade elements. So, if consider that we are talking about this blade element, then dA b is this area and when we talk about the w square, we are talking about this particular blade element's w square, which is not difficult to see that it will be different from element to element. Why? Because, though v is the same, u the linear speed at which it moves will be different. It will be smaller towards the inner edge, it will be larger towards the outer edge.

So, this is the shaft and this is the blade, say and then we have seen that the forces, thrust force and the moment producing force, these are, these forces are written as, it will be, thrust force is, this angle is your I, so you have this as dF L cos I plus dF D sin I and we saw that the moment producing force is dF L sin I minus dF D cos I. Minus because, when it comes to the moment producing force, this force has its projection this side and this force has projection that side, so we have to subtract and then we saw that this is the moment produced by this particular blade element and the power actually, actual moment dM is r, this distance is r, r times dF n and power is, power is moment times the angular velocity. So, your omega times …, so this was the essential thing on the basis of which we do the calculation.

So, this is the omega times dM, so when we actually want to calculate the power we will put omega, then dF M will take all these and in place of dF M we substitute here that is it. We will refer to this particular slide later. So, let us come to a problem.

(Refer Slide Time: 8:42)

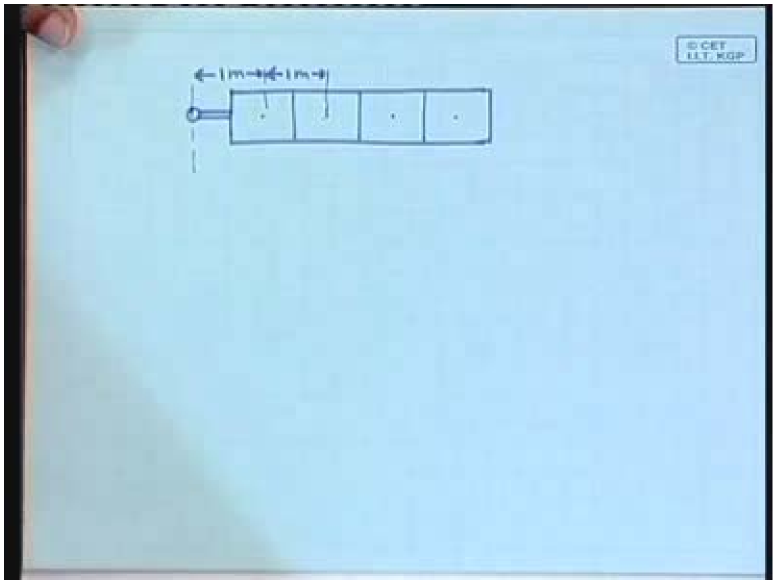


Write down the problem. Calculate the total thrust and aerodynamic power developed in a 3-blade wind turbine at a wind velocity of 9 meters per second. The machine specs are as follows. Machine specs means what will you need? You will need the diameter, rotational speed 100 rpm, blade length 4 meters, tip speed ratio, you have learnt about the tip speed ratio, the ratio between the wind speed and the tip of the blade which is 5.23, chord length, assume that it is uniform through the blade, so the blade is actually something like this, the chord is this and that is uniform through the blade. Later we will learn that it is actually not made in that way, but presently let us assume for the sake of simplicity that the chord length is uniform. Pitch angle 5 degree, again we assume that is uniform through the blade, presently for solving the first problem.

Later we will see that it could also be variable and the aerofoil section, now aerofoil section as I told you, can be different kinds of available aerofoil designs and many people have constructed such aerofoils with certain geometries and people have tested in wind tunnels and the data are made available. I will show you how the data are. Now, say we are now using NACA 23018. That is a particular aerofoil; it goes by this particular name.
So, we will need to retrieve the data for this particular aerofoil to obtain the results and the shaft to inner edge … First let us, have you, have you written down, because I will have to move this and this will not be displayed when you actually solve the problem. So, you will need to write it down.

So, let us first understand the structure, the construction of the blade. It has a, it has a diameter of 4 meters, which means it has a radius of 4.5. Out of that, the distance from the shaft to the inner edge is 0.5. The actual blade is then 4 meters, actual blade is 4 meters.

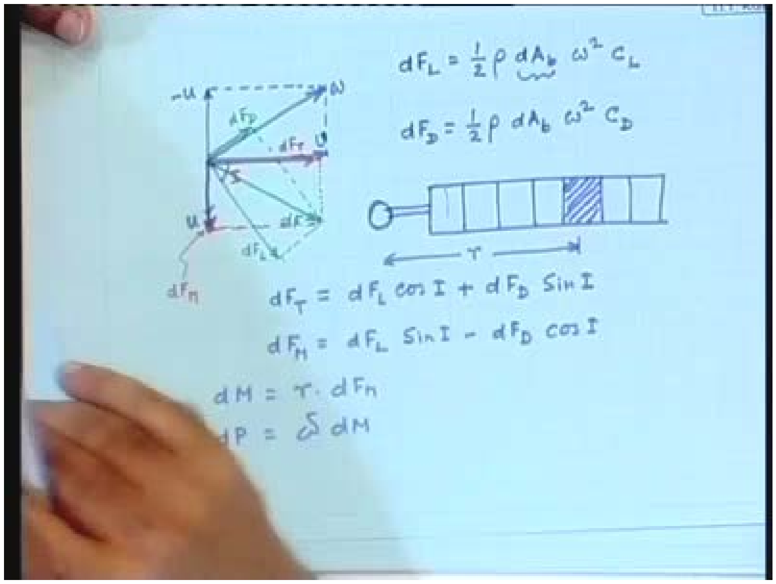
(Refer Slide Time: 13:58)



So, it is like this. You have got the shaft, you have got the connecting shaft and then, it is something like 4 meters, straight blade. Now, as I told you, in order to solve such a problem, we cannot take the whole blade together. We have to break it up into blade elements. So, given this kind of structure, it will be convenient for us to break it up into 4 blade elements, because it has a length of 4 meters. So, let us break it up into 4 blade elements of 1 meter each. If we do so, we will need to consider the midpoint of each blade element and what is the distance from the shaft to the midpoint of this one? 1 meter. What is the distance to this one? 2 meters; so, it becomes convenient to handle the number. That is why I did it, did break it that way.

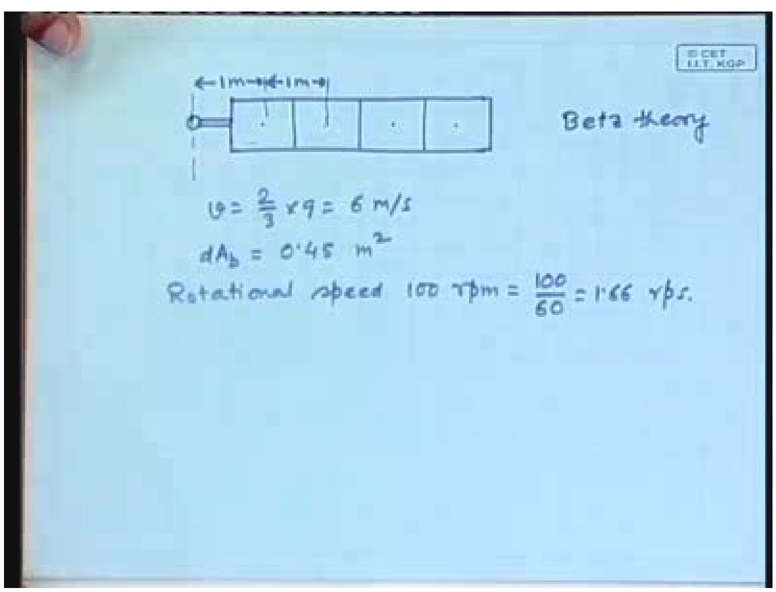
So, this distance is 1 meter distance, distance is again 1 meter and so on and so forth, good. Now, one thing it has been said that the wind velocity of 9 meters per second, this is the undisturbed wind velocity, in our language it was v infinity.

(Refer Slide Time: 15:31)



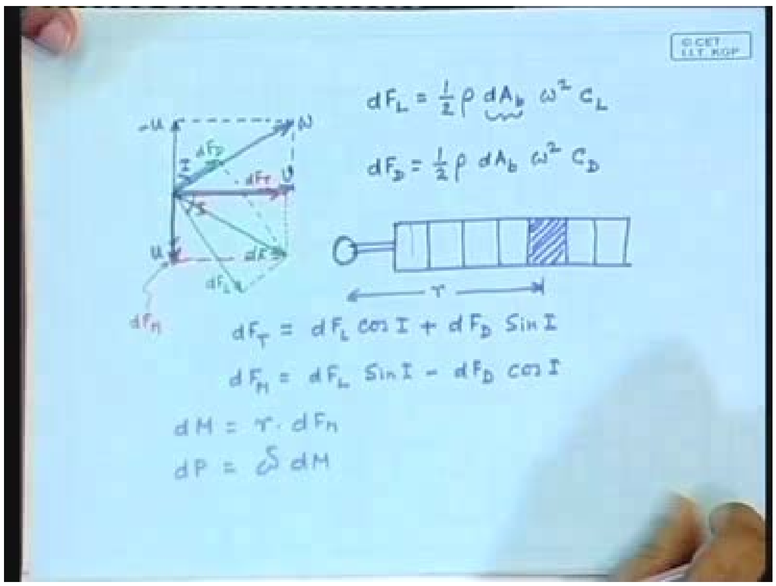
So, in order to calculate all these, we will need to use v, right, we cannot use that velocity. So, what is this v? It is the velocity of the wind as it passes over the blade. How much should it be? Yes, right, right. We have seen earlier when we were, we were calculating the maximum possible efficiency that is achievable, we found that that is attained at, yeah, beta is not necessary now. It is clear that the speed should be two third of the v infinity; that is what we have.

(Refer Slide Time: 16:14)



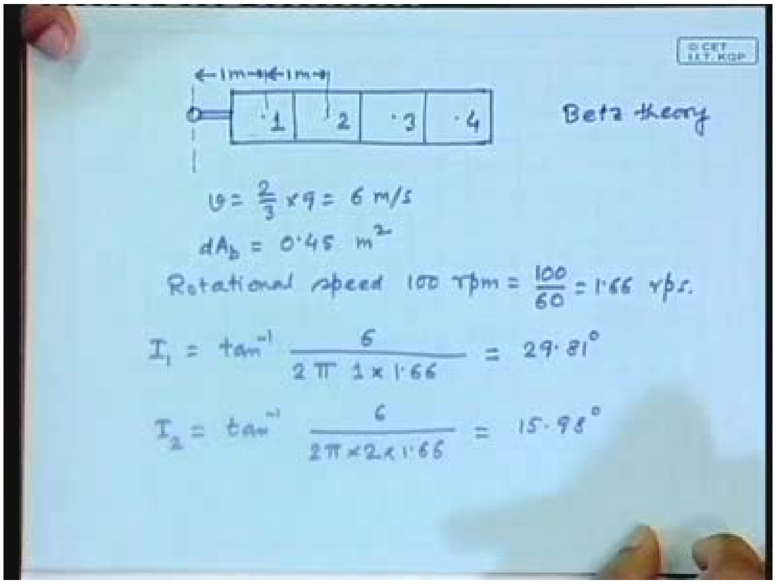
That follows from Betz theory. That calculation that we did was due to Betz and so, it is called, that limit 16 by 27 is called the Betz limit and the fact that the velocity of wind through the blade should be two thirds of the undisturbed wind velocity also then follows from the Betz theory. So, we will say v is two third of 9, clear, fine. Now, what is the area of each blade element? This side is 0.45 and this side is 1. So, dA b for all the blade sections would be 0.45. Now, what is the rotational speed? 100 rpm is equal to 100 by 60 is equal to something like 1.66 rps. That is what we will need, clear; so, this much rps.

(Refer Slide Time: 17:56)



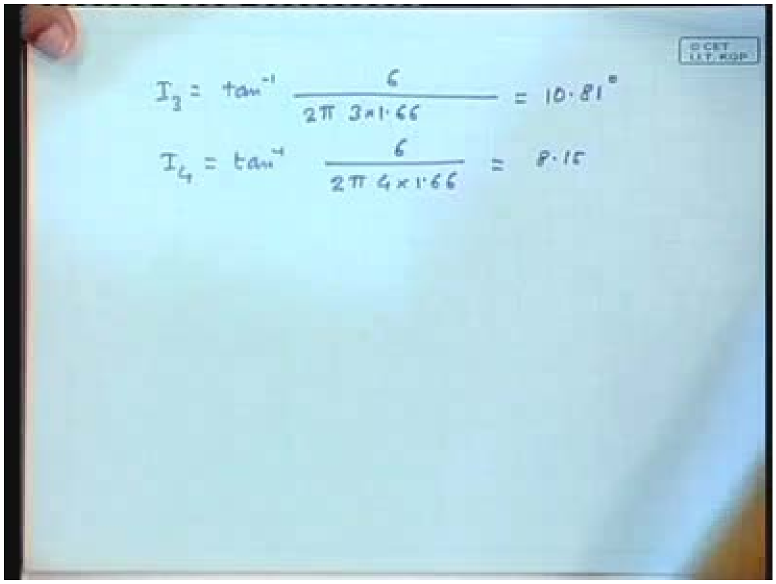
Now, in order to apply these, in order to apply these, what are the things that we really need? We need I. What is I? I is this angle and that angle this I or say tan I. What is this angle? This angle is also equal to this angle. Can you see that? This is 90 degree, this is 90 degree, so therefore this should be equal to that. So, it is the angle between u and w. So, that angle we need to calculate and that angle you can easily see it is, it is this angle I is tan I is v by u, right so, tan inverse v by u is I. So, we will calculate it for each of the blade element.

(Refer Slide Time: 18:49)



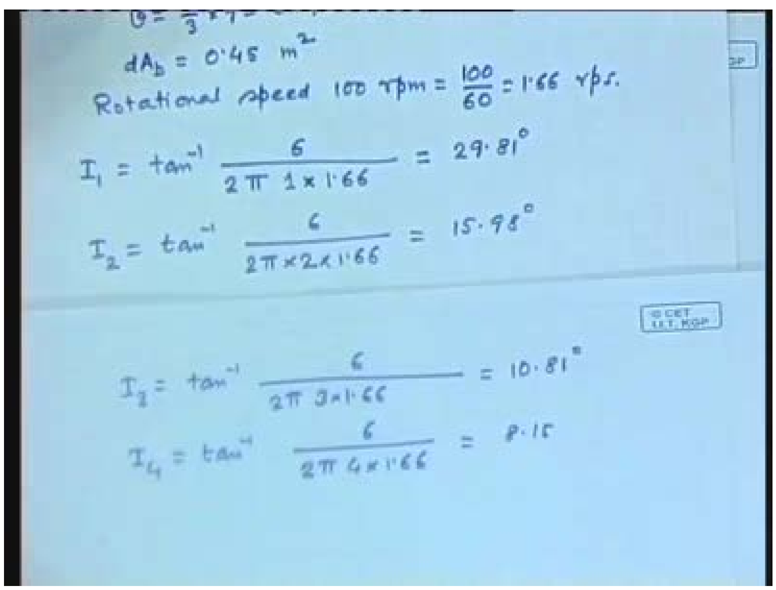
So, first one, I 1, we will skip the subscript depending which blade element we are considering; this is blade element 1, 2, 3, 4. How will you do this? I 1, it will be tan inverse of v by u. So v is 6, we have already done that divided by u, u is the linear velocity of this based on, so how will you do that? It is 2 pi the r, so in this case it is 1 and 1.66. How much is this? It is, if you have a calculator you calculate, else I have already done, so let me write it 29.81. Similarly, you have to calculate it for all the other elements; 6 by it will only be 2 pi into 2, in this case the distance is 2 into 1.66 is equal to 15.98 degrees.

(Refer Slide Time: 20:15)



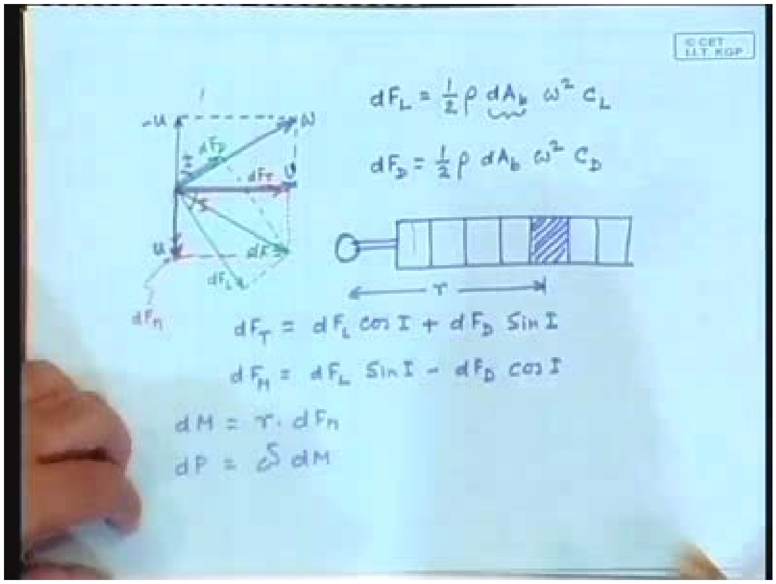
I 3 is tan inverse 6 by 2 pi 3 1.66 is equal to 10.81 degrees and I 4 is tan inverse 6 by 2 pi 4 into 1.66 is equal to 8.15.

(Refer Slide Time: 20:49)



So, you will notice that it varies quite a lot; it varies quite a lot, 29.81, almost 30 degrees to 8 degrees.

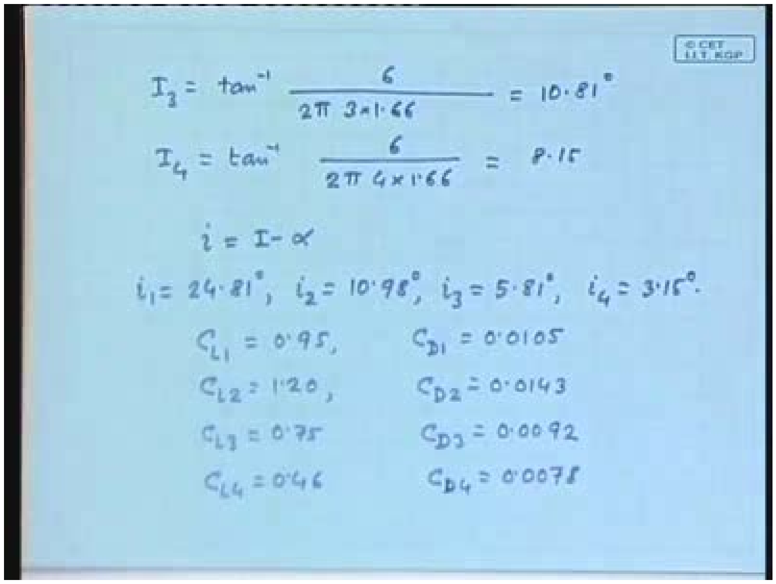
(Refer Slide Time: 21:01)



So, this, construction of this one will vary quite a lot as you go from the inner edge to the outer edge, good. So, we have calculated this. On the basis of that we will not be able to calculate the C D and C L, because we need to calculate C D and C L; we need to calculate C D and C L and as I told you, the C D and C L are to be obtained from yes, aerofoil data and the aerofoil data how is it measured? It is measured by keeping the aerofoil in an air stream and then depending on the angle of attack, depending on the angle of attack, you measure how much is the drag, how much is the lift? That is how you obtain it. So, in this case it is dependent, it is available as a function of the angle of attack.

Here, what you have? Here you have calculated the I’s which are not the angle of attack, right. So, this angle is not the angle of attack. Angle of attack is, no, this minus the pitch angle, because this is what? This is the angle between the relative wind and the direction of rotation. We want to find out the angle between the actual position of the, actual angle with the relative wind and that is the angle of attack, clear. So, the actual position as different from the direction of the relative wind that is the angle of attack and that is what we need to calculate and we have calculated not that, we have calculated the I’s, capital I’s which is the angle between this and that. So, we will need to subtract what is the angle of the chord, say if the chord is say at this angle we have to subtract this angle in order to get the angle between the chord line and the relative wind. So, what was the pitch angle? I have already given in the problem, I will bring this, so we have to subtract five datas, clear.

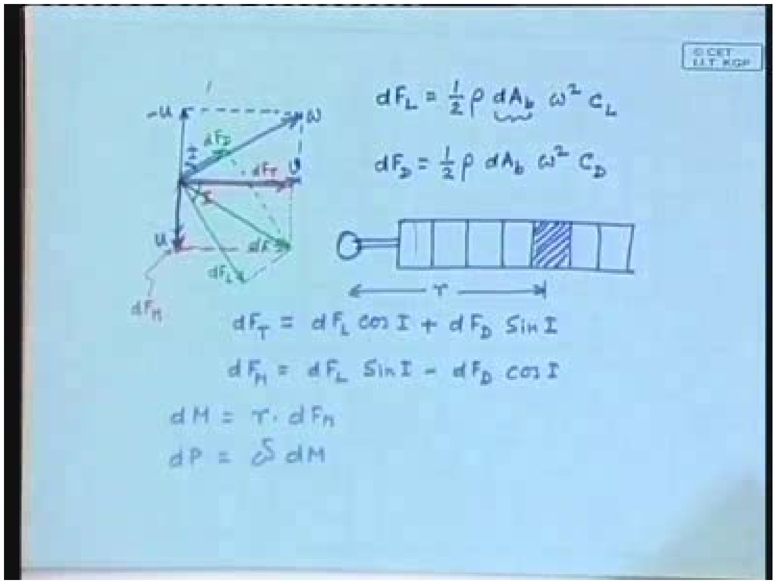
(Refer Slide Time: 23:23)



So, i, small i the angle of attack is capital I minus the pitch angle and this gives i 1 is if you subtract you will get 24.81 degrees, i 2 is 10.98 degrees, i 3 is 5.81 degrees and i 4 is 3.15 degrees. Yes, now we will have to refer to the aerofoil data that is available. This exercise I have already done. So, I will, these data are available in form of I's and another column there would be for the C L, another column there will be C D. For each value of i you can read off and if your i is not exactly there, you have to interpret it that is it. So, what we have found is C L1, the first one is 0.95, C D1 is 0.0105, C L2 is 1.20, C D2 is 0.0143, C L3 is 0.75, C D3 is 0.0092, C L4 is 0.46, C D4 is 0.0078.

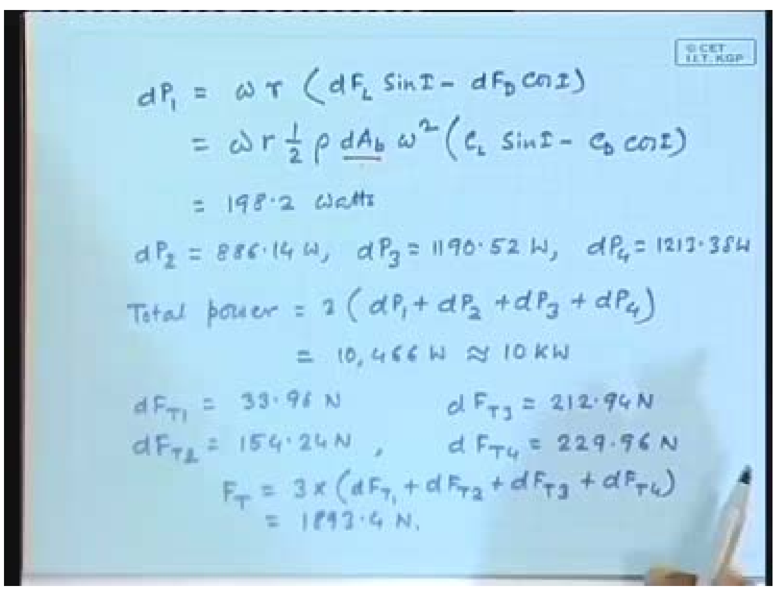
Notice the difference in the order of magnitude of these quantities. The C D is normally about a couple of order of magnitude smaller that C L. So, after having obtained the angles of attack, these have been obtained from the data sheets. That I have already done, so I have given you. How do you proceed after that? After that we have actually everything that we need in order to proceed with the calculation.

(Refer Slide Time: 25:54)



What do you needed? We needed omega we have, we needed r we have, for each of the blade element, we needed in order to calculate dF M dF L dF D, which you have, so I have here. So, we can go ahead with the calculation, clear. So, how will actually do it?

(Refer Slide Time: 26:21)



For the first blade element, d P1 it will be, let us write down the expression and then let us proceed; omega r dF L sin I minus dF D cos I and if you substituted, you get omega r dF L would be half rho dA b w square, these are the different things, w square and yeah, this will be common, so it will be C L sin I minus …, fine and so, was have all these, we substitute, clear. Can you do that? Simple stuff, really. If you, if you do that that means you know for this, for the particular blade element, first one, I we know, C D we know, C L we know and the w we know, w is you know u, you know I, you know w. So, you can calculate everything and if you do so, you get this one as 198.2 watts.

Similarly for the other blade elements you can calculate in a similar manner and you will get dP 2 is 886.14 watts, dP 3 is 1190.52 watts, dP 4 is 1213.38 watts. So, how much will be the total power? Add them up, that will be the power produced by one blade and there are three blades, so three times. So, total power if you do that, you get in this case approximately 10.466 watt or approximately equal to 10 kilo watts. So, this is how you calculate. There is another important thing that you would like to calculate. How much should be the strength of the tower that holds the whole wind turbine and that is dependent on the thrust that tries to topple the tower and there is another engineering calculation one needs to do and so, in that case how will you do that? Here we already have that, so again in this case you substitute this and you obtain.

Similarly, dF T1 you have understood how to do that? So, simply the relevant quantities for the specific blade element, which is, you substitute and you obtain and then you will get in this particular case, 33.98 Newtons, similarly dF T2 is 154.24 Newtons, dF T3 is 212.94 Newtons and dF T4 is 229.96 Newtons. So, the total, so F T is again three times, times this dF T1 plus dF T2 plus dF T3 plus dF T4. Visible? Yes, it will come to be 1893.4 Newtons.

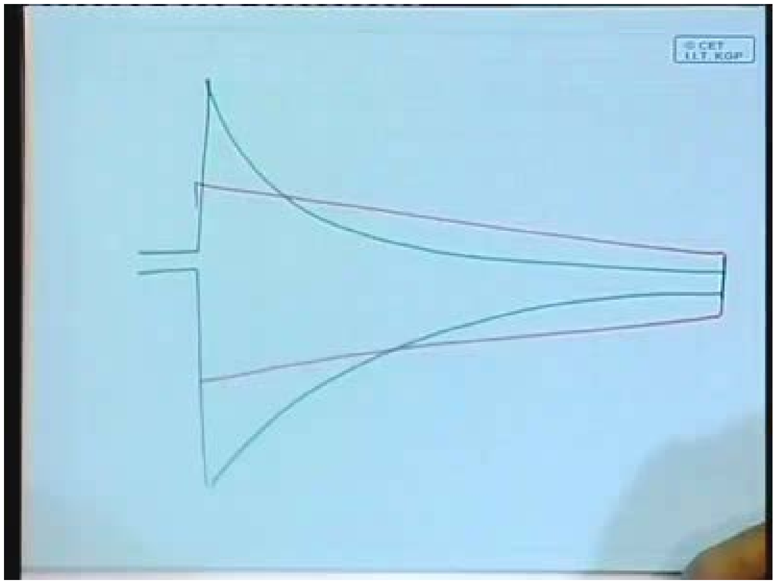
Notice a few things, the reason I actually wrote the results of the computation; I could have left it to you to be done. The reason is that notice the amount of power produced by the inner side and the outer side, widely different. The amount of thrust that is experienced by the inner side and outer side, widely different and that is one of the reasons why the blades tend to break, because the inner edge experiences a lesser thrust, outer edge experiences a bigger thrust, which means that there will be a bending stress.

That bending stress tries to break it. Similarly the torque produced, torque experienced by the inner edge and the torque produced by the outer edge are different. That is again something tries to break it. Since that is so, then how to, how to avoid that? How to avoid that?

No, the reason for the pitch angle variation is not that. I will, I will, I will come to, but logically in the expression you find that there is a term here, dA b. Can that be varied? Yes, that can be varied by changing the width of the blade from the inner edge to the outer edge, which means if the blade can be given a taper, then this problem can be avoided. Now, you might say that then in that case, I know how to do that. What I will do is I will design, so that all the power or the torque experienced by all the elements would be the same. Then, there will be no bending stress. Similarly, if you calculate it, so that the thrust are the same, in that case there will be no stress that way. But, you will find that these two calculations will contradict each other.

If you set at as your criterion that these should be equalized, then you will get one kind taper and if you set this to be equalized that means that the thrust, you will get different result. That is one problem. The other problem is that in both these calculations you will find, because these are so hopelessly different, the width of the blade in the inner edge will be hopelessly larger than that in the outer edge, the blade will look awkward. If you, if you, do it that way then, actually you will land up with the blade that is shaped something like this.

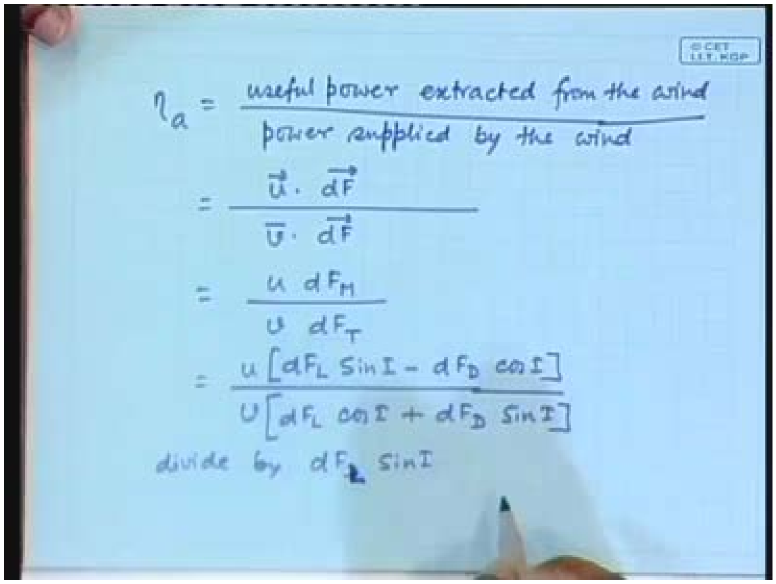
(Refer Slide Time: 34:32)



So, this is somewhat awkward shaped blade. That is why nobody really does it. What instead people do is because of the limitations of the manufacturing process, suppose we have understood that we can only make it like this, this much taper we can give, then we give that that much taper, but in that case we know that the inner edge will experience a bigger torque and bigger thrust than the, sorry, lesser torque and lesser thrust than the outer edge. So, accordingly the strength has to be taken into account. That means, even if that kind of stress difference is produced, the blade will not break, clear.

So, the actual calculation takes into account the strength of the blade, so that even with the maximum possible stress produced and that has to be calculated this way even with the maximum possible stress produced, it is not, it will not break. But, you have understood that it is deserved to give a taper, clear. It is also desirable to give a twist. Why? Okay, I will come to that issue now in a slightly different context. What should actually be the logic behind giving a different pitch angle to different places? You just said that it will, it will be different. All right, it will be different, but why? Why and how much? In order to understand that, let us proceed this way. What is the aerodynamic efficiency?

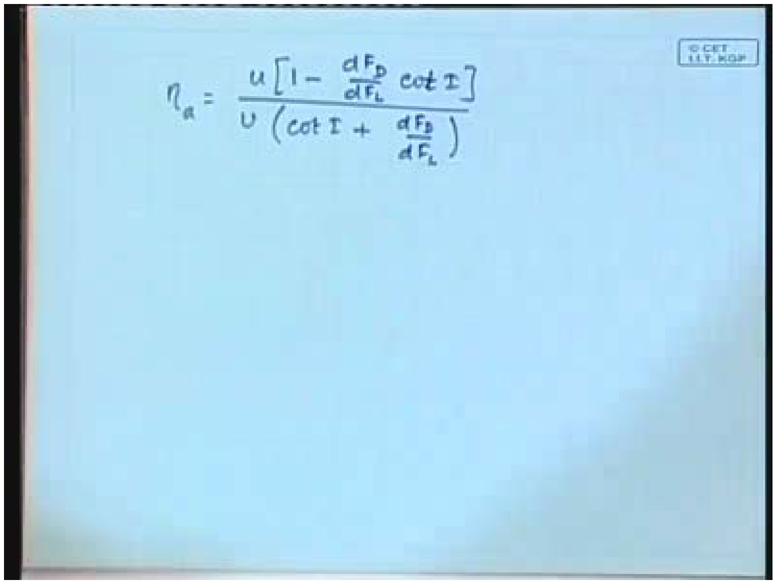
(Refer Slide Time: 36:35)



Aerodynamic efficiency eta a is useful power extracted from the wind divided by the power supplied by the wind. Now, how much is the useful power extracted from the wind? It is u as a vector dot product with dF and how much is the power supplied? That is v dot product dF and if you now forget about this dot products, we can write it as u dF M and v dF T, right. This is the, in a dot product you will have to take a component, so, that component is dF M and this component dF T, so you can write in this way. Now, substitute these values. We have already learnt what these values are, just substitute them. You will get u, then we substitute the value, dF L sin I minus dF D cos I divided by v, dF T is dF L cos I plus dF D sin I.

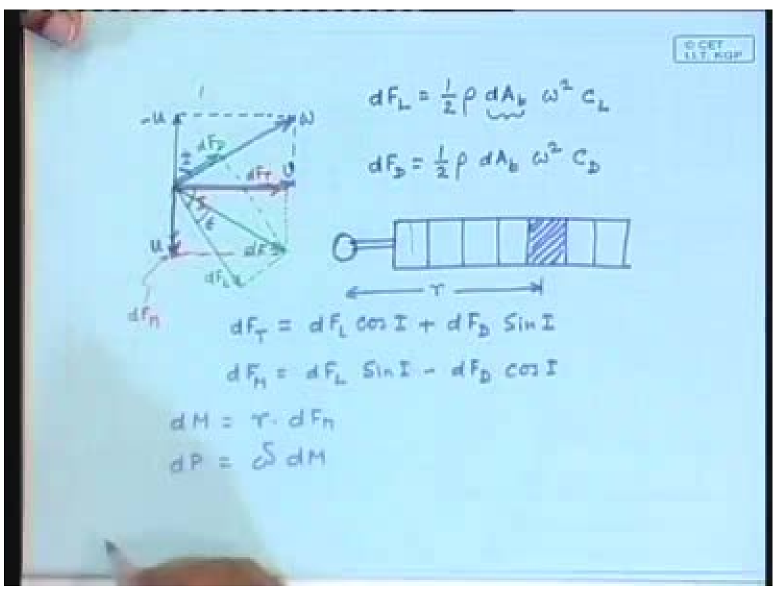
Now, divide both top and bottom by dF D, sorry, dF L sin I.

(Refer Slide Time: 39:11)



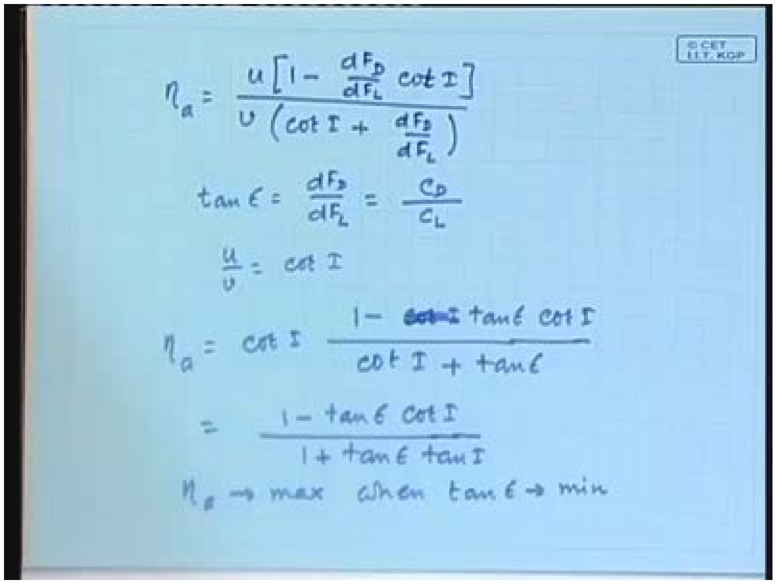
If you divide both top and bottom by dF L sin I, you get aerodynamic efficiency as u by v, but this becomes 1 minus dF D by dF L cot I divided by cot I plus dF D by …

(Refer Slide Time: 40:03)



Now, in this diagram, in this diagram, this angle is called epsilon, which means epsilon is, tan epsilon is dF D by dF L; tan epsilon is dF D by dF L.

(Refer Slide Time: 40:23)

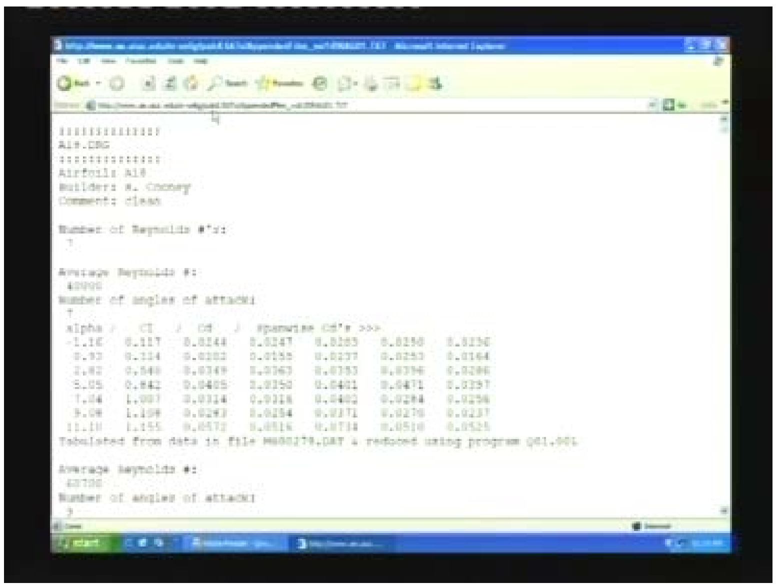


So, tan epsilon is this one and if you substitute the values dF D by dF L, you will get simply … Your other things will cancel off, because the coefficient of these are the same in the numerator as well as the denominator, so you get this and what is u by v? There was a u by v here, what is u by v? Na, cot I, cot I. So, if you substitute these into this, just do that, substitute in place of this one, tan I, tan epsilon and in place of this, cot I and do a bit of simple trigonometry, you will get eta a is, in the first stage we will write cot I 1 minus this is cot I, no, tan I, tan epsilon cot I and here it is cot I plus tan epsilon and then you will just bring it in. You get 1 minus tan epsilon cot I 1 plus tan epsilon.

What is the purpose of all these? The purpose of all this is that we are trying to maximize this and we want to see very clearly and any person with a reasonably good mathematical intuition will see how this can be maximized. How can this be maximized? By minimizing tan epsilon, because if tan epsilon becomes zero, what is the aerodynamic efficiency? 1. So, can you really bring it to zero? Why? If you do bring it to zero, look at this. Tan epsilon being zero means there is no dF D; that cannot be possible, but ultimately we are trying to, we should be trying to reduce this. That also follows from common sense, because tan epsilon is C D by C L. We should actually try to minimize C D and maximize C L, so that is also logically correct. So, ultimately we are trying to, eta a goes to max when tan epsilon goes to min. How to minimize tan epsilon? That is the problem then.

Now, this fellow tan epsilon is essentially dependent on epsilon. Epsilon minimized means tan epsilon is also minimized, epsilon has to be minimized. As I told you, the data, let me show you the data. As I told you, they are available on the net, people have tested and those things are right now available on the net and right today, I have logged into one of the sites and I have brought in the data. See how it looks. Can you see? Yeah.

(Refer Slide Time: 44:41)

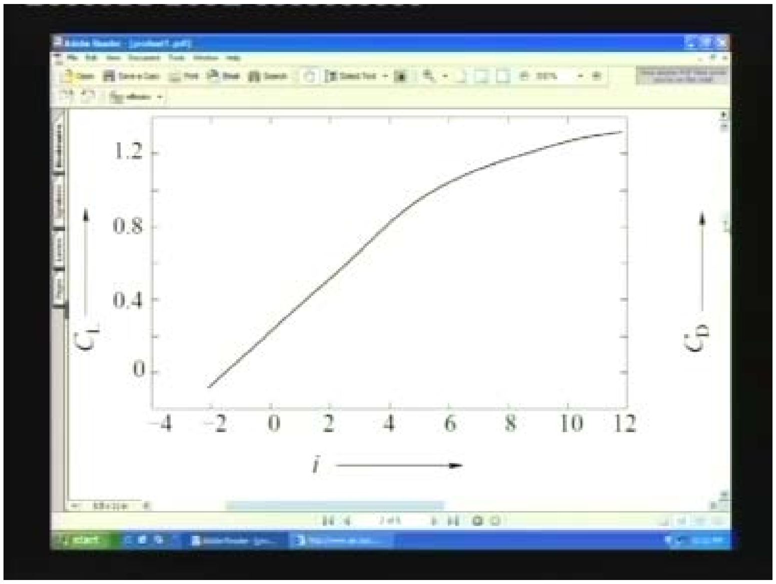


Probably you will also be able to see the sites location. It is UIUC, university of Illinois at Urbana-Champaign site, in the specific site of Professor Michael Sellick, M Sellick and you have to do some search in order to get in here. Here for example, it gives the data for something like 1500 different aerofoil. It is a huge data site. So, let me just go to the first one. It is the aerofoil A 18 that is again some aerofoil number, the way here we were doing for NACA 2 some number, similarly here it is A 18. Then it is available. This particular data was available or calculated at 40,000 Reynolds number, Reynolds number of 40,000.

Now, remember one thing. For all these aerofoils, you will find that the data are given for different Reynolds numbers. Out of that, which one will be important for us? The one that is at the least Reynolds number. Why? Because, imagine the flight of an aircraft which often flies at 20,000 feet. In that case, much rare flight atmosphere, the density is much less, the speed is much more, so the viscosity of air is less, the speed is more and therefore, that pertains to very high Reynolds number. In case of an electricity generation wind turbine, even though these are faster than the slow speed water pump, in the wind turbine these are not fast enough in comparison to the flow of air across it as compared to that in the aircraft or the helicopter blades. So, obviously in this case, the viscosity as compared to the speed will be larger, viscosity of air. As a result, it will be at a less Reynolds number.

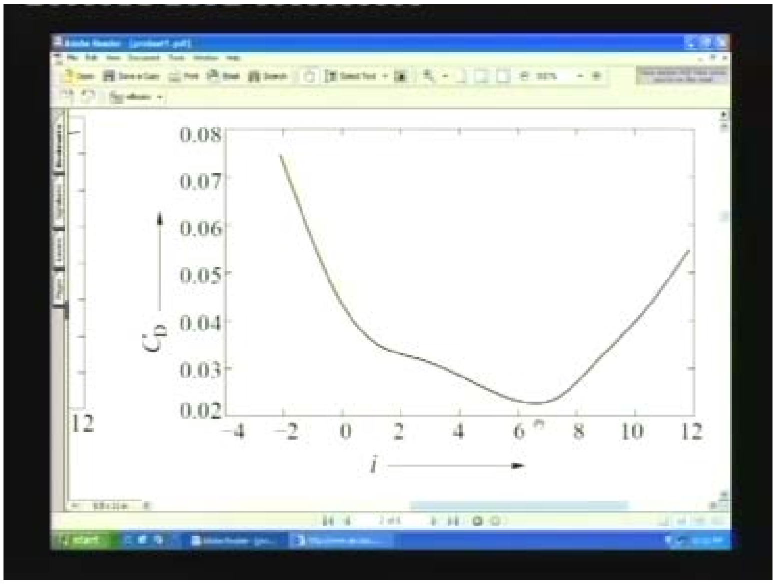
So, as you can see here, this particular aerofoils characteristic was calculated for different Reynolds number and all these data are available now. But, we will look at the first one. As you can see, the alpha is given. In this case it is the angle of attack really; not our nomenclature, in their nomenclature they are calling it alpha, but it is the angle of attack, I for us and C L C D are given. These are not necessary for us. We only need these amount of data, so the data for alpha versus C L versus C D. For every alpha, we can plot the value of C L and we can get a graph and the graphs would be of this kind of structure. I will make it bigger.

(Refer Slide Time: 48:02)



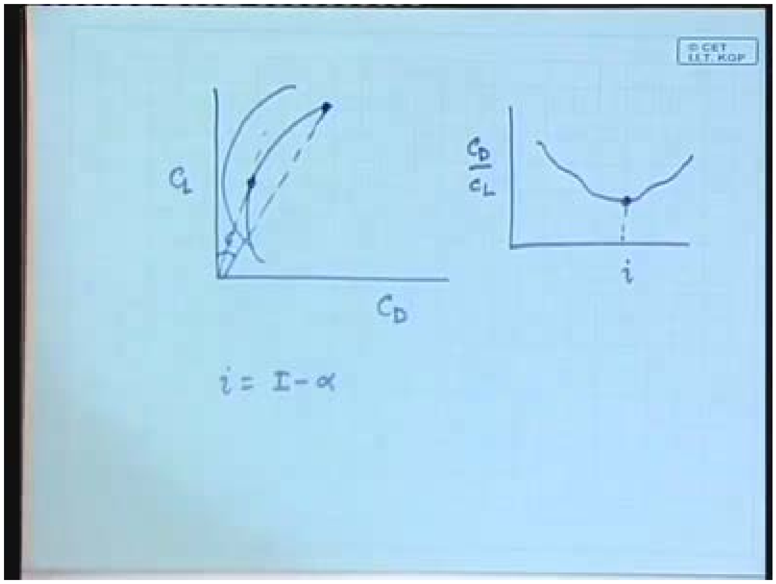
If you, if you draw the C L versus I, it will get a curve like this and if you draw the C D versus I, you will get a curve something like this.

(Refer Slide Time: 48:11)



When I say that all these data are read from the available data sheet, it is essentially, for a given value of I you find out what is the corresponding value of C D. But now, at the present moment, our problem is how to minimize i, small i. How to, so, no, not small i, epsilon. We are trying to minimize epsilon. What is epsilon? Epsilon is the angle is the ratio between C D and C L and here we have a graph for C D and C L, both. All we need to do is to draw a graph C D versus C L.

(Refer Slide Time: 49:01)



So, if you draw from this data, a graph C D versus C L you will get, C D C L, you will get something like this say. Then, how to find out, say I take a point like this and what is the angle epsilon? CD versus CL, tan epsilon is this. Here is epsilon and that is what we are trying to minimize, but we will do, will go for the tangent, right; we will go for the tangent. So, the moment we have identified the tangent, we have identified this particular point and this point refers to a certain value of i, so that is the value of i we have to take. You get the point. That is how we have to actually go for the proper design.

Now, one difficulty is there. As I told you, the C D is a couple of magnitudes less than the C L. As a result, this graph will be very close to like this and it will often be very difficult to draw; it will often be very difficult to draw. For many of the well designed aerofoils, it is very difficult to draw. In that case, what you have to do is from the data that I just showed, you just find out what is C D by C L and plot that versus i. You will get something like this and the minimum point gives the right value of i, clear. So, that should be the proper choice of angle of attack and you have already seen that your i is capital I minus alpha. This is the pitch angle and this is the angle of incidence, the angle that we showed in the graph. Where is that picture I took? I refer to it all the time, yeah here (Refer Slide Time: 51:15).

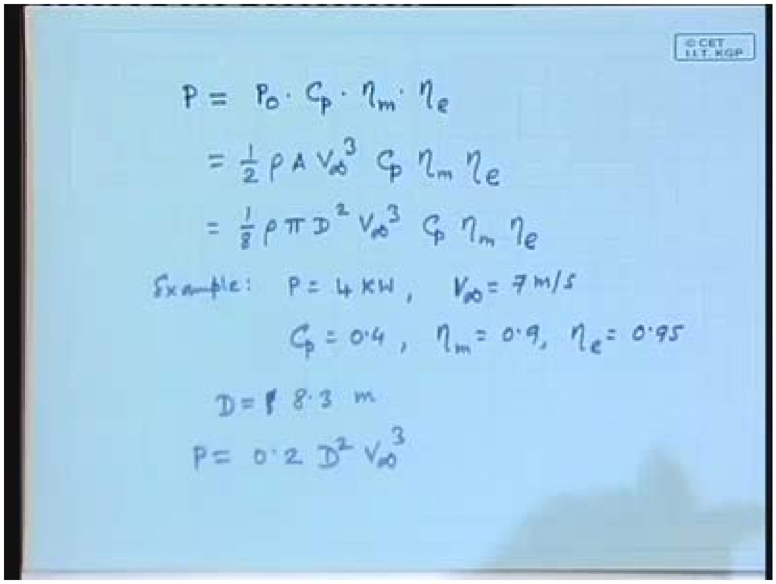
I is here. So, since you need to keep small i constant at this value, therefore as capital I changes, you have seen that it changes by a large extent, you will have to also vary the alpha from the inner edge to the outer edge, in such a way that the i becomes constant, right. If you do that you will actually see that it needs a very large twist and a twist means a shear in the blade. The inner edge and outer edge goes like this, it goes like this. To some extent it is possible to do that, to give that kind of shear in the design itself, manufacturing process itself, so to the extent that is possible we do give and accordingly we will ….. So, the blade is not just like this, it is like that, where this side has one angle and that side has another angle. The angles are different. Is that clear now?

There is another problem that we will face when you actually try to solve problems like the way that I have given. What did you do? You had obtained the capital I's and then you had obtained that small i's depending on alpha. If it is, if it is a flat blade without any twist, if it is a flat blade without any twist, then what happens? Then, all these, you subtract the same number from this in order to get i. As a result, the small i's will be widely different and the data you will find are available for only certain range from say minus 2 to in this case, 12. It will go out of that range and you do not know the data then. That is another reason you need to actually give the twist. Is that clear?

So, when we, when we design the wind turbine rotor, we have to keep these in mind that a good, well designed blade should have a taper, should have a twist and in some cases, people additionally give a, people additionally consider the possibility that the aerofoil section may not be the same throughout the blade; inside it can be one aerofoil section, the outside can be another aerofoil section. So, these are also possibilities that people do consider.

Now, how big will a wind turbine be? Big means the radius, the diameter. You have to have some idea, because nowadays we find wind turbines of the size of 1 megawatt, 2 megawatts, 3 megawatts; huge wind turbines now are available. Also for the households, for the relatively smaller requirements, you also have the smaller wind turbines. What will be the size like? How you will calculate that? Simple.

(Refer Slide Time: 54:40)



The power is equal to, power will be equal to the power contained in wind times firstly the power coefficient C P times there will be one mechanical efficiency eta m and there will be one electrical efficiency eta e. That will be the final power of it. What have we done? First we have taken the amount of power that was contained in the wind. Then, we said that we will multiply with a power coefficient which is the amount of aerodynamic power extracted. From that, we will have to multiply by a factor that is the efficiency of the mechanical system, because there has to be the transmission, gear box and stuff like that and you will have to multiply the electrical efficiency and we know that this term is given by half rho A V infinity cube, fine. Then you will have all these terms C P, eta m, eta e.

A is, area is, in terms of diameter one fourth pi D square, right. So, it will be one eighth pi D square V infinity cube, again C P eta m eta e. Now, if you know the power and if you know these, then you can find the diameter. Suppose, suppose you have, you are trying to design a 1 kilowatt wind turbine for example. P is equal to 1, sorry, something like say 4 kilowatts, 1 kilowatt is too small, V infinity is say 7 meters per second, a moderate wind speed and C P, C P is maximum would be 16 by 27, 0.59. So, let us assume that a reasonable number is 0.4, eta m let it be 0.9, eta e let it be 0.95. Can you calculate, can you calculate D? It will come out to be 8.3 meters approximately.

So, you will know that in order to calculate, in order to obtain a power something like 4 kilowatts, you need a diameter of 8.3 meters, 8.3 meters will be how big? Bigger than this, the height of the room. How big will it be, if you want to produce 1 megawatt? Use similar data, use similar data and can you calculate? Make it 1 megawatt. There is a square here. It is not, because there is square here, you have to, you know finally you have to take a root, so it does not scale. So, it will be of the size approximately of a football field. So, that big would be the rotor diameter and naturally the whole thing scales up. It is a huge thing and often the problem of constructing such thing is the transport of such a big blade across the field.

One thing you can say that if all these things are not given, very approximately you can say for a good, well designed turbine, you can write it like this, 0.2 D square V infinity cube, all these taken together. So, this is a, it is a very easy and quick way of calculating how much should be approximate size of the turbine, fine. Let us stop, stop here now and we will continue in the next class.