**Energy Resources and Technology**
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**Lecture - 21**
**Wind Energy - 1**

Today onwards we will start the topic of wind energy.

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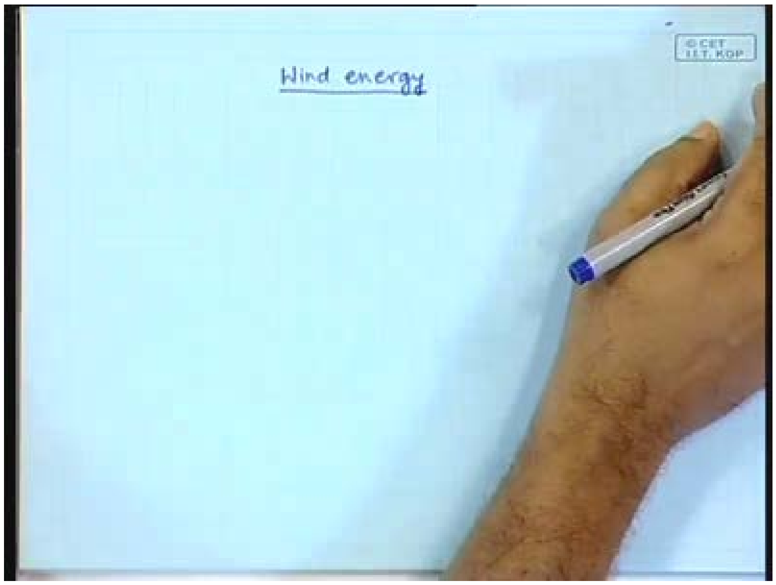


As you know, wind energy out of all the different possible energy sources, is the most exploitable form of renewable energy. As you know, there are many conventional sources of energy. Out of that, you may have learnt about the coal that is thermal power generation, tidal power generation, nuclear power generation and now we are entering the various types of renewable sources and out of them the two that are now seriously coming to the market are the photovoltaic power conversion and wind power conversion.

So, wind energy is a very serious affair. Probably you would know that in India, India happens to be one of the leading countries in wind energy exploitation. In India, out of the, right now we have about 6000 megawatts of wind power generation install capacity, while the nuclear power generation is 3.5. So, it is, it is quite large, large amount and that is why it becomes very important to understand the technical details of wind energy conversion. That is what we will be learning in the next few classes.

Now, before going into the subject, a historical background will be in order, because wind energy is not really recent. Wind energy has been exploited for centuries and in the olden times, especially since the renaissance onwards, especially since the renaissance onwards it is, it used to be employed, wind energy used to be employed in what you know as windmills. Those windmills have entirely different structure then what you see today and the structure was something like this.

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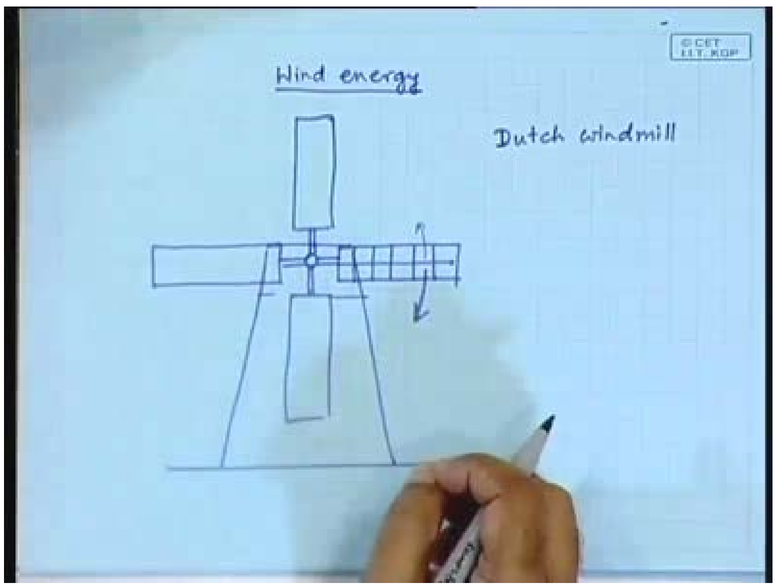


You have a building, which is normally tapered to the top and at one point there would be a shaft coming out connected to four blades in the four sides like this. Now, these four blades are normally wooden slabs; that means flat plates of wood. Normally, this would be divided into a few compartments in such a way that you can have a frame and in it these wooden slabs are connected and the whole thing is inclined at an angle, both through the plane of rotation and through the direction of the flow of wind. The wind goes in this direction, the plane of rotation is like this, but this would be inclined at an angle like this.

As a result, as the wind strikes it is deflected like this and the whole blade itself will be deflected in the opposite direction like that. So, the whole thing will rotate. That was the essential idea. These used to be used for water pumping as well as mainly for grain grinding. So, grain grinding was the major employment of this kind of wind turbines and obviously you can easily see that this would have to be oriented to the direction of the wind. So, the wind has to come from this direction. It will not work if it comes from the other direction. So, it has to be oriented and this orientation used to be done by means of manual device. That means the whole top portion would be turnable like the big turntable and one has to physically move, to orient it to the direction of the wind. So, this was essentially the structure of the old, which is known as Dutch windmill, because the Dutch had developed this.

Coming to the essential point, what is the principle of operation? The thrust given by wind, the push given by wind, right, that was the essential principle of operation. When the use of steam engine came, then slowly these windmills went out of operation, became obsolete and so, since the industrial revolution we do not see much of windmills though many of the advanced countries where these things were invented, like the Holland, like Germany, still you will find these things in operation as sort of a museum piece, antique thing, that is still made operational, kept operational, but these are no longer used. The reason, I will come to it.

There was another type of windmill that was used and that is sort of still used, which is very simple in construction. It is, it can even be made out of local things in a rural setting.

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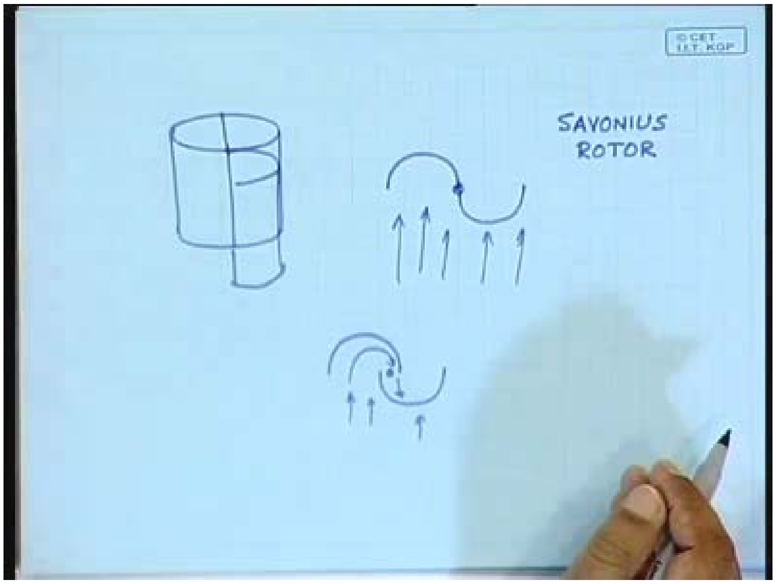


For example, if you have a, say you have a drum, the starting point is the drum. You cut it into half. That means you get a half circle or half a cylinder and half a cylinder and then you reconnect it in a different way, which I will show as a plane view, plane view means looked from the top. When you have one of the half circles, you view from the top here and the other half circle here, so what has, what has happened? This half circle has been moved to a position like this. That means I will draw the total view later, but you can easily see that if this is the plane view and if wind is coming and hitting it, what do you expect to happen? Because this fellow is concave and this fellow is convex, there will be a difference in the pressure and if here is a, you know, shaft, then it will rotate around this shaft. Is it clear? This design is called the Savonius rotor. You remember these words, because we will need it later.

Obviously, this construction is very simple. It requires only a drum. You cut it into half and connect it in a proper way and naturally it can be constructed on site in rural areas. Not very efficient, used mainly for water pumping purposes, used mainly for water pumping purposes and the whole structure, before coming to the whole structure, later there was one bit of improvement to this design in which the two semicircles were connected not like this, but like this and the shaft will be somewhere here in the symmetrical position.

Now, the reason is that when wind comes and hits, this wind will be deflected like this and as a result, it would exert some additional pressure to this side. So, here, there would be some pressure, because the wind is also coming to this side, but this pressure experienced by this other half has to be reduced which is obtained, achieved by deflecting some of the wind to the concave portion of this half. As a result the whole torque goes up, clear.

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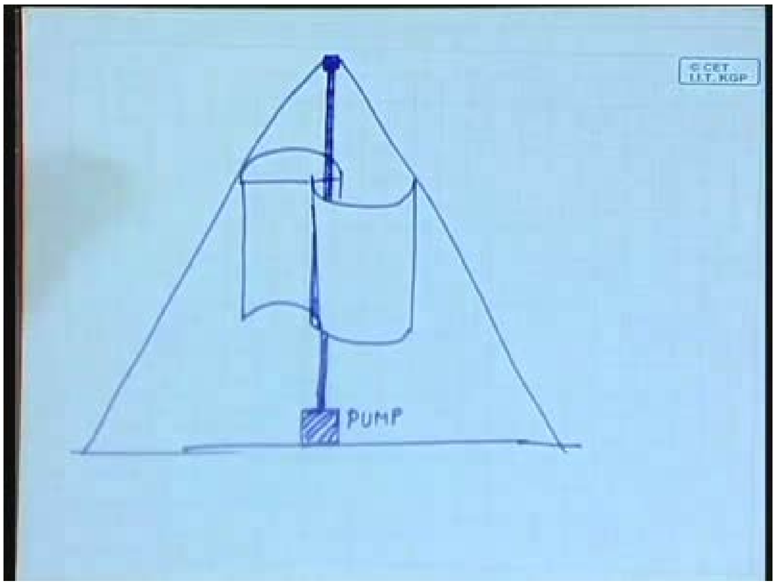


So, the total structure of this kind of Savonius rotor would be, if I draw, it would be something like this and here would be a long shaft. At the bottom there would be the pump. Now, the whole thing has to be, I have drawn it badly it seems, yes. The whole thing has to be, you know, kept vertical and for that purpose at the top end there would be a hinge here with …. connected. These are simply wires to pull it in three different directions and if these three are symmetrically arranged, then the whole thing remains vertical. So, that is the essential construction of the Savonius rotor. There is another.

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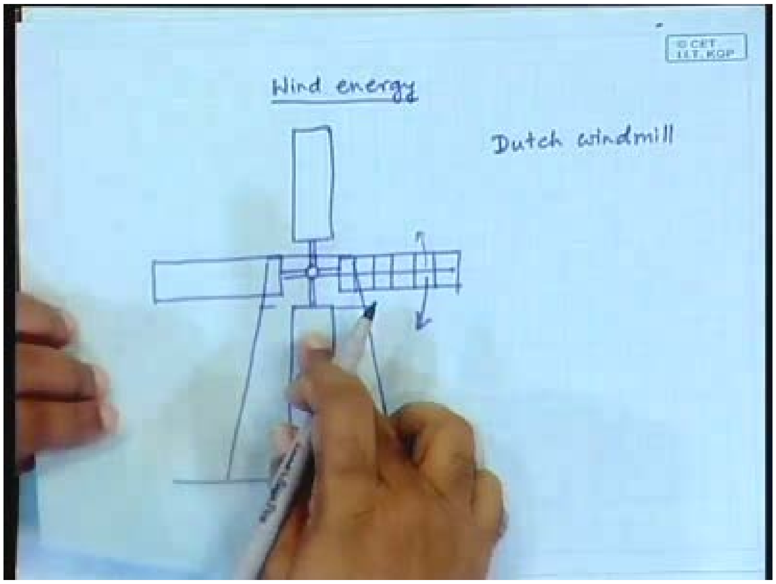


This is the difference between this type and that type, this type and that type is that this one is a horizontal axis, axis is horizontal. So, it is a horizontal axis wind turbine, while this is a vertical axis wind turbine. There is another type of vertical axis wind turbine which we will study. It is a bit complicated construction and we will study in one of the later classes, but in essence this and that, this and that both work on which principle? The principle of thrust, given push, because of the push it works. Later it was realized that the essential principle of the push is inefficient. Why, I will come to that now, but before I come to that, I suppose another discussion of another issue would be in order.

Is wind energy a high quality energy or a low quality energy?

Students: Low quality energy.

It is a low quality energy. Why?

Students: …

Yeah, because it is far more disorderly than the known high quality energy forms like the motion of a rotational shaft or the electrical energy and that disorderliness is on account of the disorderly motion of the individual air molecules in all sorts of directions. Wind means that statistically there is, if you take a statistical average there will be a resultant component in one direction that is all. But, if a very strong wind is flowing in one direction, that does not mean there is no molecule flowing in the opposite direction. There will be some flow in the opposite direction. So, in that sense it is a low quality energy.

Now, you have also learnt in the first few classes that whenever there is a conversion from a high quality energy, low quality energy to a high quality energy, there has to be a limit; there has to be efficiency limit. So, mostly in thermodynamic classes you will learn only about the heat to mechanical energy conversion, but that is exactly why I wanted to impress upon you that the idea, the concept is not related to heat. It is a general concept applicable to any form of energy and so, the moment you realize that wind is a low quality energy, you should immediately, it should struck, it should strike that there must be a limit. So, what is the limit? Let us work that out.

First, in order to work it out, you remember, when we considered the conversion of heat energy into mechanical energy, we sort of considered an ideal Carnot engine, right; ideal in the sense that we will really not be able to ever make such a thing and the details, the nitty-gritty of where the piston is, where the, you know, all these things we did not consider. We considered some kind of an idealized engine. Here also we will do the same. Wind is coming and some amount of energy is being extracted from it by some kind of ideal engine. What that engine is we will come to that later, but initially we will not need to consider that; we will consider some ideal engine and wind flows off.

So, okay, before we come to that, yes, I think we should talk about how much energy is contained in wind. How much power is contained in wind? After all, the power is in the kinetic energy of the wind, so half mV square.

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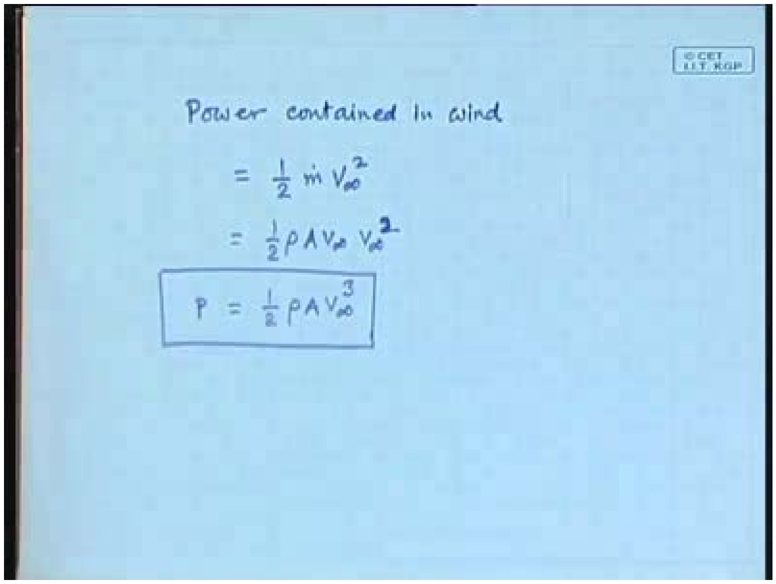


So, power contained in the wind, yeah, we need to talk about this, because we are essentially talking about how much of that power can we really extract. So, we need to understand how much is there. So, this is half power, so it has to be m dot, so V infinity square. V infinity is the speed of wind when it is undisturbed by anything. That means if you are placing a wind turbine, obviously that causes a disturbance, changes the wind speed and we are not talking about that. We are talking about the undisturbed wind and the energy contained in it and in that sense the V infinity, subscript is in the, in the sense that idea, the idea is that it is ideally at infinite distance from any obstacle, in that sense. So, obviously you do not place it something at an infinite distance, because then you will be outside the Earth. We are not talking about that, it is just a concept.

So, half m dot V square and what is m dot? m dot is the rate of flow of the air. This is equal to half, it will be rho AV, so A times V infinity is a volume flow, rho is a mass flow times V infinity cube, sorry square. So, this is equal to half rho AV infinity cube. Rho is the density of air, A is the area through which it is passing, V infinity is the wind speed at infinite distance from any obstacle. So, this is the expression for the power contained in wind. Now, it is easy to see that the power contained in wind goes as a cube of the wind speed and that is why it is very strongly dependent on the wind speed.

Slight change in the wind speed will make a lot of change in the power contained in it and that often many people do not understand. It is very, very strongly dependent on the wind speed and that is exactly why it makes no sense to try to extract energy from a less windy place. People try to look for more windy place, because of this reason that the energy content is more. So, if you are to trying to obtain energy from it, you get more. So, this is the power, something that you should remember for the rest of the classes, because we will refer to it again and again. So, here is the total amount of power that is contained in wind out of which we are trying to get some amount of output. So, here again, what is the, okay, what is the value of rho?

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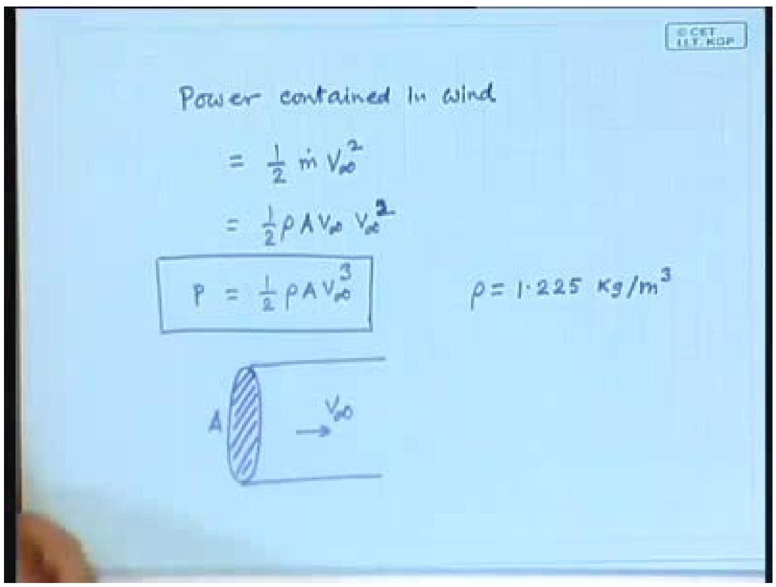


Now, the rho is a variable quantity really and that is what the barometer reads; barometer reads the pressure and depending on the pressure the rho also changes. So, the rho is not really constant quantity, but for your purposes, for the purpose of calculation you can take something like this, as some kind of an average value. Sometimes when I give a problem I might give 1.125, do not say it is wrong, because it is a variable quantity, fine. So, you are essentially assuming that there is an area through which wind is blowing and this is the area we are talking about, A, rho is this and the speed at which it is blowing is V infinity, then this pertains.

Now, we are coming to the question that out of that how much is the maximum extractable quantity?

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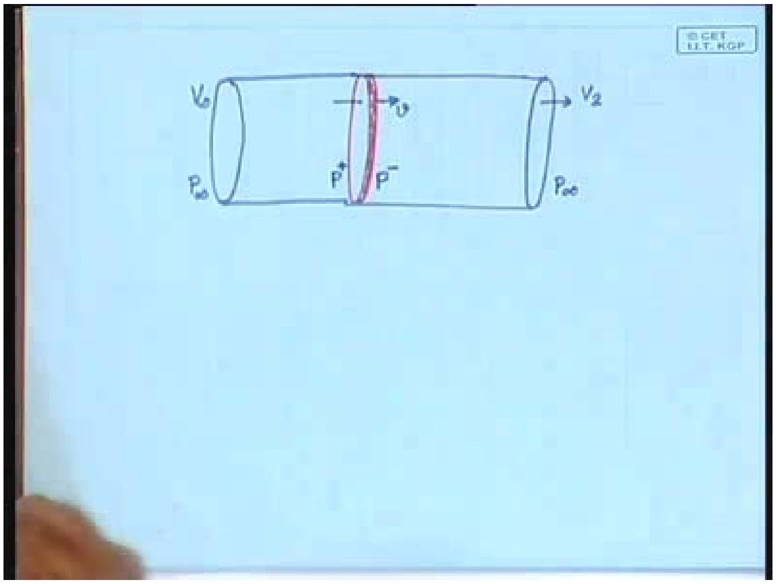

So, for that as I told you, we will consider the situation where you have a power coming through a similar cylindrical area and then, here at this point we will have something that extracts the power. So, we will have some kind of an idealized machine here. We will, I have drawn in form of just a disk, just a disk, but what the disk is, what it does, I will come to that later and then, the air flows out and then it reaches ideally an infinite distance, say here. Now, we will have to put the various velocities and pressures. So, here the velocity is it is ideally at infinite distance from this, so here the velocity is V infinity. It goes through the … and here there should be another velocity, right, say that velocity is small v and when it reaches here what should be the velocity?

Students: V infinity.

No, it will not be V infinity, because had it been V infinity there is no energy that has been extracted. You have extracted some amount of energy and so, here when it reaches the velocity should be something different. If it is V infinity, then obviously it contains the same amount of energy that it did when it was here; some amount of energy has been taken out, fine.

Now, let us talk about the pressures. When you talk about the pressure, here at this place it is again the normal atmospheric pressure at infinite distance. When it goes through, obviously when it has to go through this, there has to be a pressure difference between the two sides, else it will not go. So, here let the pressure be P plus and here let the pressure be P minus and when it reaches again infinite distance, what will be the pressure? Back to P infinity. Is this diagram understood clearly? On that basis we can proceed. Now, so far as the wind has proceeded from this point to this point, just before this converter, we can apply the Bernoulli's principle. If we apply the Bernoulli's principle, what do you get? You write down the equation for that.

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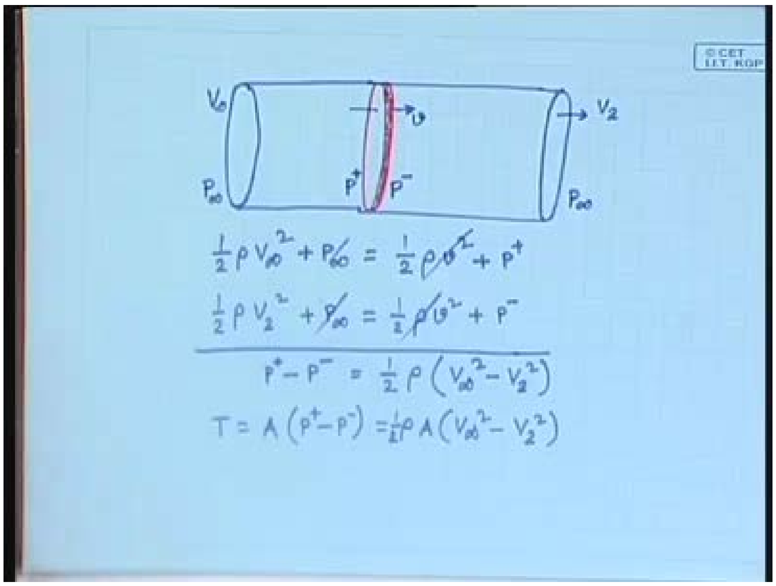


You will have half rho V infinity square plus P infinity is equal to half rho V square plus P plus. Again, we can write the Bernoulli's principle from here to here, right. So, since we will have to do some manipulation here, we will write this one first and this one later. So, we will write it as half rho V 2 square plus P infinity here is equal to half rho V square plus P minus, right. So, having written these two equations, we can subtract this from this and as a result we get, this cancels off, this cancels off, we have P plus minus P minus is equal to half rho V infinity square minus …, good. This is one expression for the pressure difference between the two sides. If the pressure difference is known, then what is the thrust? Thrust is pressure difference times area. So, thrust is A times P plus minus P minus is equal to half rho A V infinity square minus V 2 square. The thrust, the thrust is also given by the change of momentum, right. So, we have got one expression for thrust like this.

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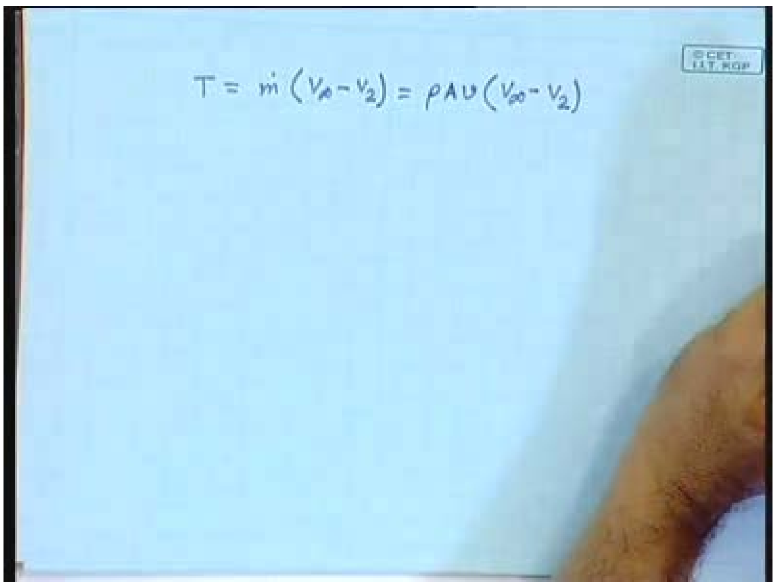


The thrust can also be written as m dot V infinity minus V 2. So, this is, m dot is rho A small v that is the rate at which it is passing. What is the rate of flow? It is through this, right and so, you have rho A small v times V infinity minus V 2.

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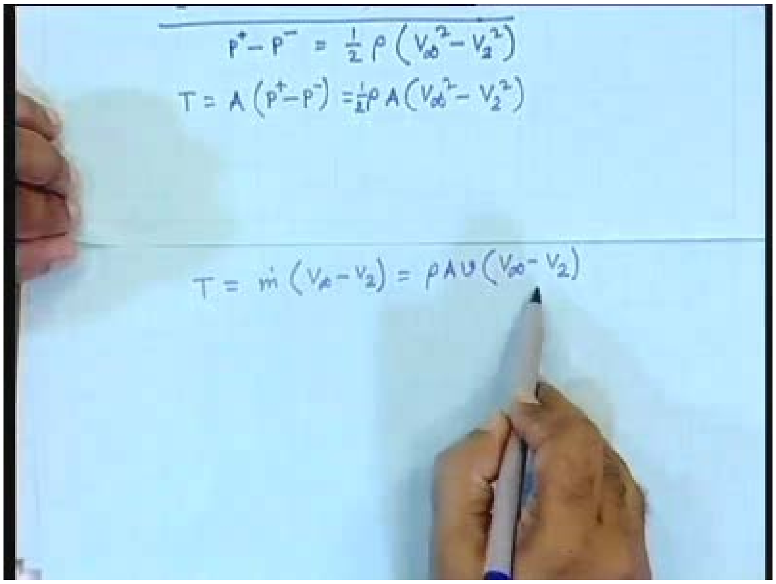


Notice that we have already obtained one expression for thrust here. We have got another expression for thrust here and this should be equal.

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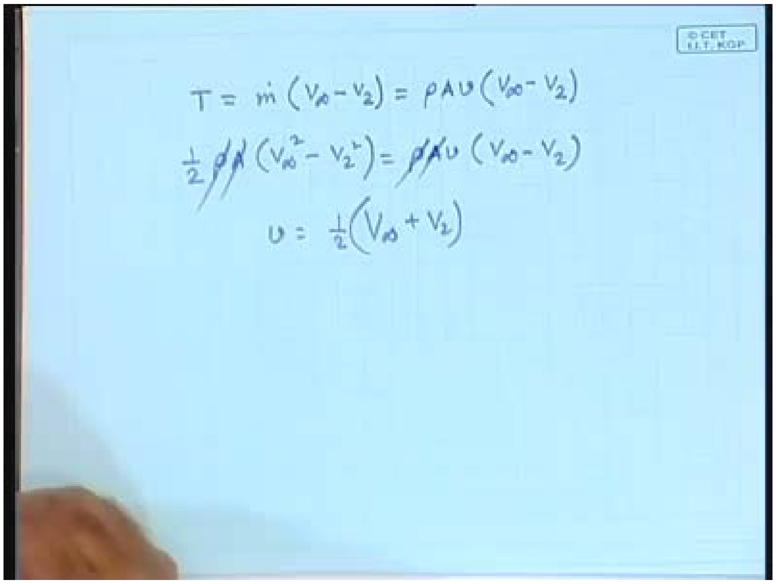


So, if you equalize them, you immediately get half rho A V infinity square minus V 2 square is equal to rho Av V infinity minus V 2. Cancels off, cancels off, this can be broken into V infinity plus V 2 and V infinity minus V 2. Minus cancels off, so what do you get? So, this was not evident right in the beginning. See, something, something, somewhat additional we have obtained that the velocity, when it passes through that wind turbine, should be the average of the velocity at infinite distance before and at infinite distance after. So, this is a somewhat strong result we have obtained, good, we will use this.

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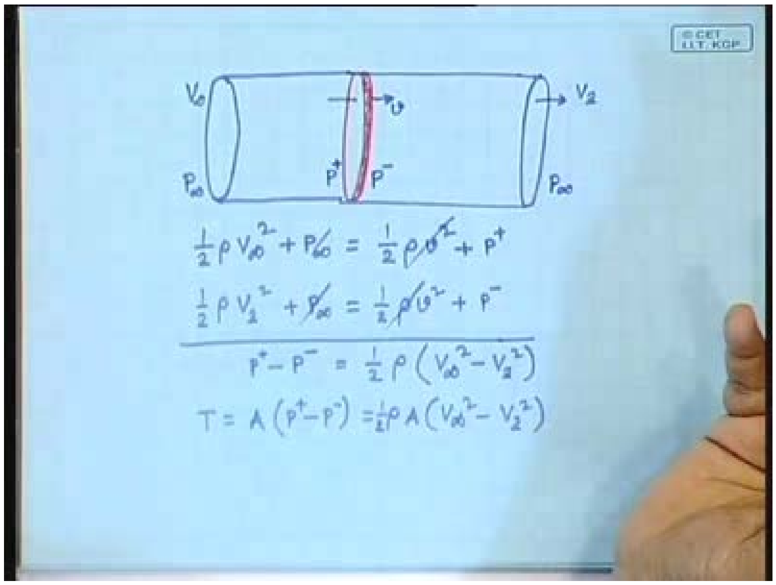


But, now here you see that we are trying to find out some kind of a maximum. What is the maximum amount of energy that I can extract and the maximum depends on what this fellow is doing. Imagine that this fellow, imagine the two extremes. This fellow allows the air through without any hindrance. As a result, your V is equal to V infinity and V 2 is also equal to that. In that case, how much is the power extracted? Zero. Imagine that this offers very large obstacle to it like a wall, so that all the V infinity is stopped here. What is the power extracted? Again zero, again zero. So, in both cases we have zero power output. In between, there must be some value that where it will maximize.

So, whenever we encounter such situations, we try to define a quantity that sort of tells how this fellow is performing and we try to differentiate the total power output, we just go to that quantity. What should that quantity be? Logically it is called axial interference factor.

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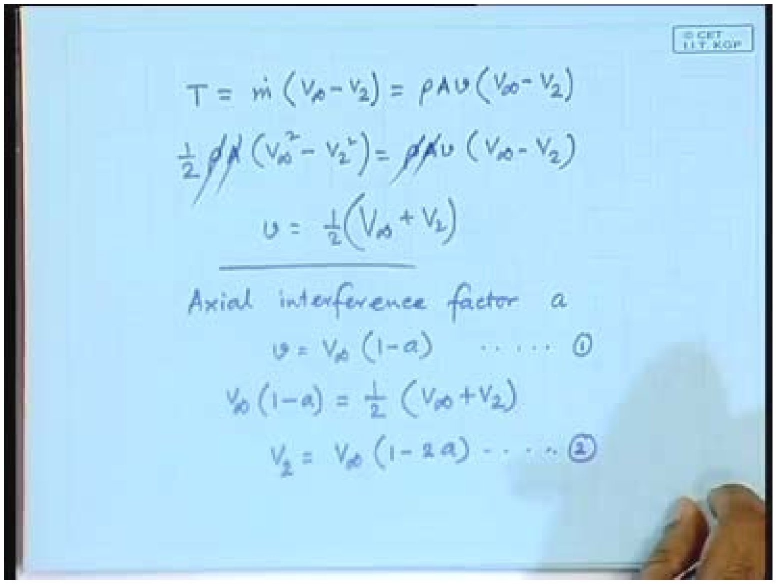


It is called the axial, so that, this is given the notation a, so that when a is zero, it offers no interference. If a is 1 it offers complete blockade, in between there should be some value of a at which it should maximize, right. So, how is a defined then? a would be defined as in terms of v is equal to V infinity 1 minus a, right, so that if a is zero small v is infinity, if a is 1 small v is zero, clear. So, we have defined a and we have obtained the expression for V in terms of that. Now, we can also obtain the expression for V 2 in terms of that. Can you just do that here, using this? So, you know V infinity into 1 minus a is this, equal to half V infinity plus V 2. We are trying to find out what is V 2, so you just find out how much it is. Yes, so you get V 2 is equal to V infinity into 1 minus 2 a. So, we have expressed small v in terms of a, we have expressed V 2 in terms of a and V infinity, of course. V infinity something that is not in your hand and we are expressing in terms of this, fine.

Now, we come to the issue of how much will be the power. How much will be the power extracted? It is the drop in kinetic energy of air, simple. This much was the kinetic energy and that much has been extracted. So, we get the rest of the kinetic energy.

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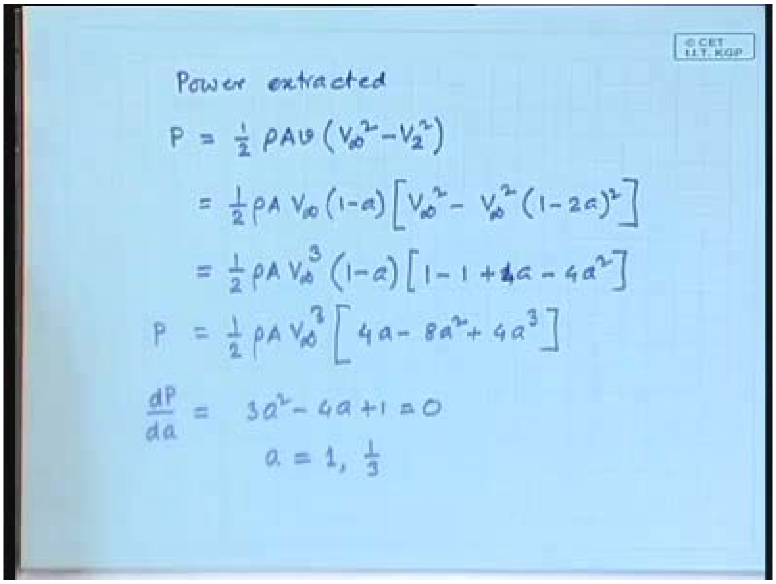


So, the power extracted is the drop in kinetic energy half m dot rho Av times V infinity square minus …, right. Notice what we are driving at. We are trying to express this P in terms of a, so that we can differentiate with respect to a. So, what we will do is we will substitute here v and V 2. Do that; substitute what we already know as the expressions for v and V 2 into that expression. So, you have half rho A, V is V infinity into 1 minus a and this is V infinity square minus V 2 is V infinity square into 1 minus twice a square, right. So, just simplify this tell me what you get. This will come out, V infinity cube 1 minus a times, what remains? 1 minus 1 plus twice a minus 4a square.

Student: …

Yeah, 4a minus 4a square, so you have half rho A V infinity cube. So, you have 4a minus 4a square here. I do not want to take common, I want to just express it as a polynomial, so that differentiation is easy. So, what is it polynomial like?

Student: 4a minus 8a square.

4a minus 8a square plus 4a cube. Can you just check, it is all right? Good. So, we have expressed P and what we want to do? We want to differentiate P with respect to …. What do you drive at? That should be equal to zero, so what you get?

Student: …

No.

Student: …

3a square minus 4a plus 1 equal to zero. Now, here is a polynomial and that polynomial you have two results. So, its, it would be …

Student: …

1 and one third, these are two possibilities. Is 1 possible? No. So, one third is possible. So, a very counter intuitive decision that the maximum power can be extracted only when a is one third, when a is one third, good.

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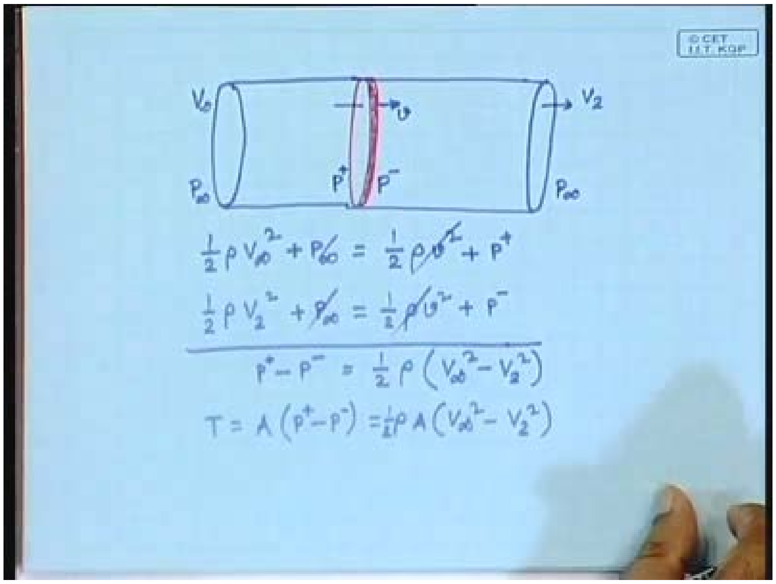

So, where was the picture? Here, which means that the maximum power can be extracted only when the speed when it goes through is two third of V infinity, because it is, it is defined as 1 minus a, fine. So, now we can, we can substitute this here, one third here. So, see what you get?

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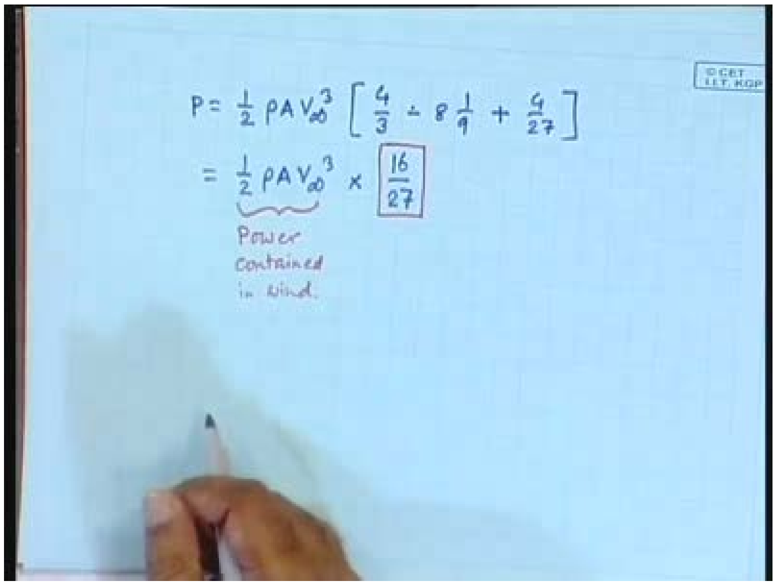


P is equal to half rho AV infinity cube times, you have 4 by 3 minus 8 into 1 by 9 plus 4 by 27

Student: …

What do you get ultimately?

Student: 8 by 27

8 by 27 or should normally get 8 by 20, okay, okay, here is half, so this term is different. So you have, you have already multiplied it here.

Student: Yes.

No, no, I do not want that. I want only this. Yes, half rho AV infinity cube; there was a reason for which I kept it aloof, because this is the power contained in the wind times …

Student: 16 by 27.

So, this fellow is the maximum possible efficiency. This is the power contained in the wind. So, 16 by 27, it is, it is not like 1 minus T 2 by T 1, where there was something, T 2 and T 1, you needed to know. Here it is hard number 16 by 27 that is the ultimate maximum efficiency that you can get.

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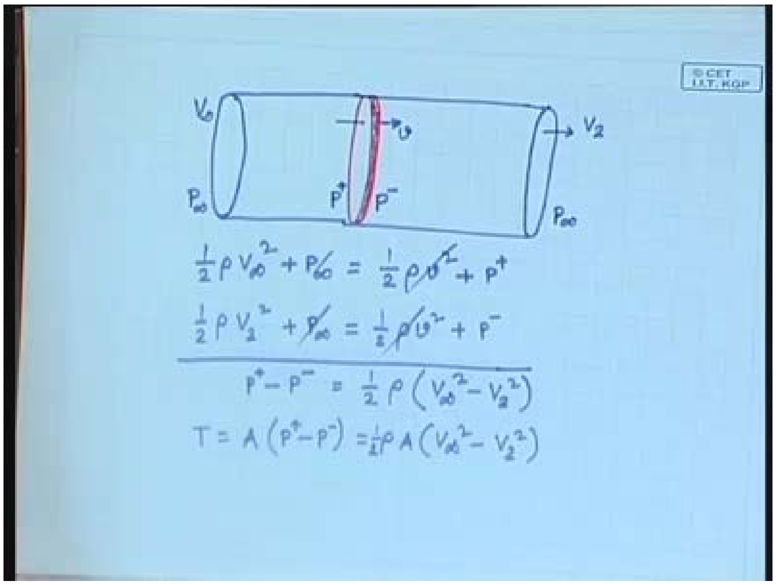


But, you will notice that here we considered some kind of a disc that remains there and extracts energy. Obviously, it does not work on the thrust principle. If it works on thrust principle it would recede, right.

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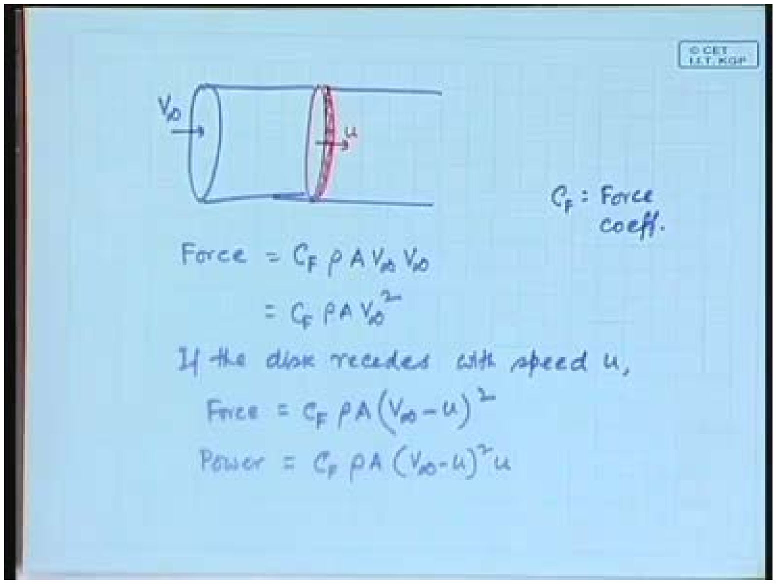


Instead, if you consider something working on the thrust principle that means where you have the wind coming and here is a disc that actually recedes. So, wind is giving a thrust and pushes it back and it can extract energy out of it. Let us try to find out how much would then be the maximum possible efficiency? Well, in that case, what is the force experienced by this fellow, force given by the wind? The force is, the change of momentum would be rho A V infinity into V infinity. Suppose this is stopped, this is not moving, then wind was coming at velocity V infinity here and at that point it is stopped. So, how much is the change in momentum? This; well, normally not the full change in momentum is transferred into this. So, there has to be something called force coefficient. So, CF is force coefficient, but in general it is …., so CF rho AV infinity square.

Now, if now this fellow moves, then how much will be the force experienced by it? Suppose it moves with a velocity u, then how much will be the force experienced by it? It will see, it will see a wind velocity that is V infinity minus u and the same expression will be there, only V infinity will be replaced by V infinity minus u. So, if the disk recedes with speed u, then force CF rho A V infinity minus u square, right. How much will be the power extracted? Force time the motion. So then, power … Done?

Well, now again in this case you will notice that if u is zero, then the power extraction is zero. Force is there, but u is zero, so power extraction is zero. If u moves with a same velocity V infinity then, again power zero, because force is zero. In between, there must be some maximum. In order to find that what would you have to do? Again differentiate. So, differentiate, go ahead and differentiate this with respect to u.

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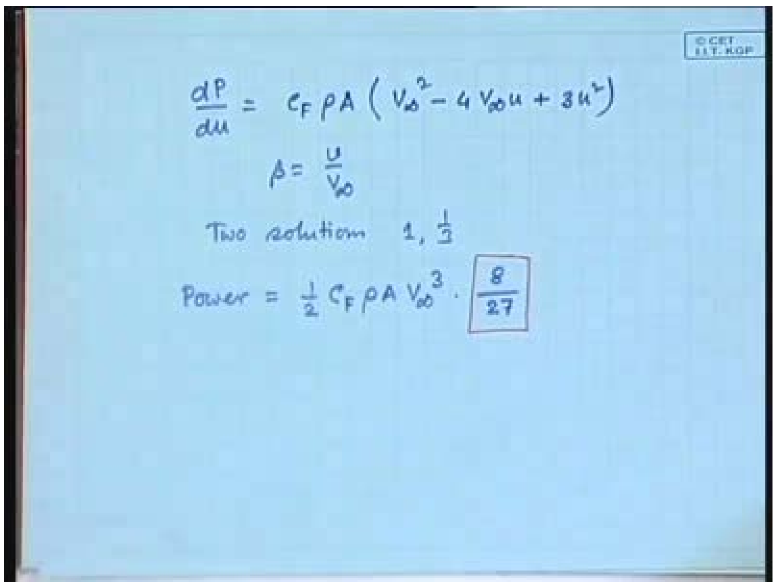


So, in this case dp du, you will get …, these things remain C F rho A, then you have to differentiate V infinity minus u squares time u. So, you will get V. First express it as a polynomial and then differentiate; that is easier. You get V infinity square minus 4 V infinity u plus 3 u square. In order to do the calculation easily, just …

Student: …

Yes, it will be, it will be the same, wait. But nevertheless, just let me do this here. In order to do this calculation, it is, you just define beta is v by V infinity, so that you express this in terms of beta and beta is the maximum value that you obtain. So, as you said, if you, if you do this, if you express this and solve this polynomial equal to zero, you get again two solutions, 1 and one third. So, two solutions, 1, one third. Out of that is beta is equal to 1, feasible?

Students: No.

No, one third is the only possible solution. Now, what does this imply? What will be the total power output? Substitute it that here. You get power is equal to C F rho A …
Student: …

No, I want half rho AV infinity to be out and things expressed as a coefficient of that. I want half rho AV infinity cube to be out and then something to be multiplied with it.

Student: …

Yes, if you substitute this in here, you get …

Student: …

8 by 27; C F is an additional thing, ideally you can assume it to be 1. Assume that the whole of the momentum lost by the wind is transferred into the, into the disc ideally. Even that is so, even if that is so what is the ideal efficiency? 8 by 27, half of the ideal efficiency we have obtained earlier. Why? Because in this case, it is working on the thrust principle. So, for a thrust operated wind turbine, even the ideal efficiency is half than what you should be able to achieve, clear. So, that essentially tells you that we should not, if you want to, if you want to obtain high efficiency we should not operate the turbine on the basis of the thrust principle. Something else has to be done, clear; something else has to be done. Are you convinced?

So, what did we do? Notice the line of argument. First, we said that let there be a slit through which the wind is passing and we are, we have some kind of a converter that is extracting that energy output and we proved that the maximum possible efficiency is 16 by 27. Then we said that, no, let us now think in terms of existing wind turbines which operate on thrust, not today existing, but existing at that time which operate on thrust and there we obtained that it must be less efficient. So, there has to be some other principle of operation completely different from the thrust principle and yes, all the modern wind turbines operate on the basis of the aerodynamic principles, not thrust, the same principle on which the aeroplane wings are operating. So, aeroplane wings, the helicopter wings, they all operate on aerodynamic principles. All modern wind turbines operate on aerodynamic principles, so let us understand that.

How does an aeroplane wing work?

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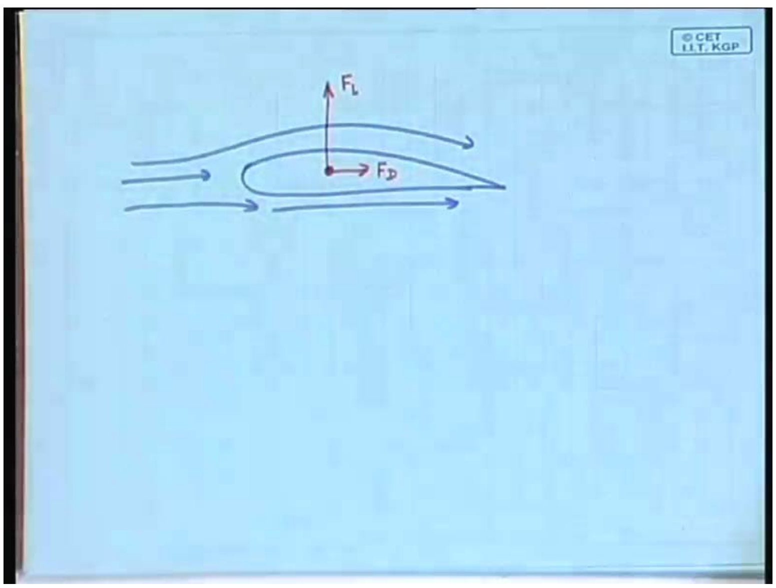


You have the wing shape like this and you have the air coming and it flows like that. Because of the specific shape, air is forced to flow like that. As a result, the air that is going up, above and the air that is going below have to traverse different routes, this route being smaller and this route being larger. Again by the Bernoulli's principle you will see that there will be a pressure difference and that pressure difference will result in an upward lift. Now, for us, when you are in school that much understanding sufficed. But now for us, things have to be quantified, things need to be understood in terms of quantities, numbers. So, in this case, what has happened? You have created some kind of a lift, upward push.

So, in this case, suppose this is the point at which it is working; there would be a point where you can assume that the forces are working. There will be a lift force that goes upwards and also because the wind is trying to push this airfoil back, there will be another force like this which you cannot avoid. So, there will be two forces really. This force is called the drag force and this force is called the lift force. They are two forces actually and in case of the aeroplane, the drag force is overcome by the jet engine and that is how it goes forward and the lift force is what it makes it float. But, in general, here we have drawn it as if the airfoil is directed, oriented exactly in the direction of the air, but that may not be so always.

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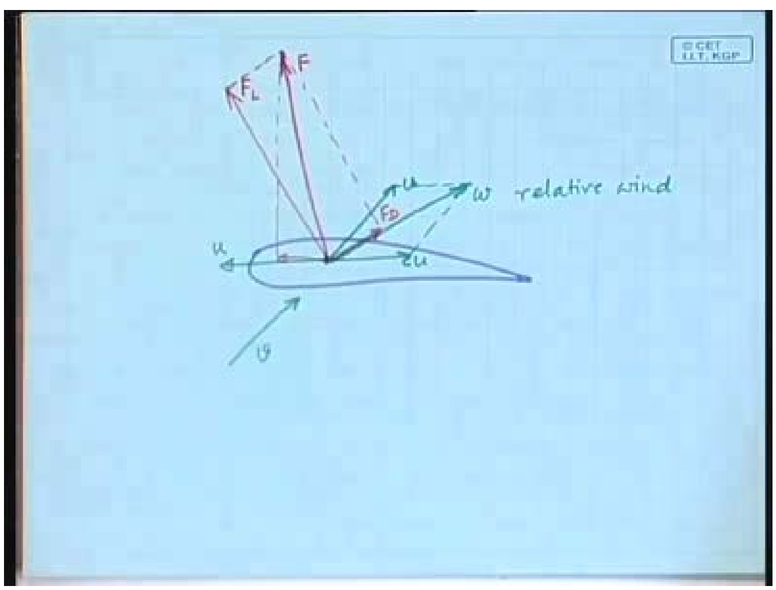


So, in general, you might visualize a situation something like this that you have got the airfoil and the wind is coming from say this direction. So, you have its own motion this way and the winds motion this way. In that case how will you visualize the different forces? Simple really, because in that case you have to consider what is the speed of wind as seen by the airfoil. What is the speed of the wind as seen by the airfoil? You will have to take this, you will have to take this, v and you have to take the negative of u; you will have to obtain the parallelogram and this is the speed seen by the airfoil. So, what you did? You obtained a vector summation of v, the wind speed and minus u the negative of the airfoil speed. This is called the relative wind noted as w, called relative wind, so that is denoted as w.

So, if you have the relative wind flowing like this seen by the airfoil like that, then what will be direction of the forces? Again, we represent it in terms of the same two forces, obviously. If the airfoil sees this as the relative wind, where will be the drag force work? Along the direction of the relative wind; so, the drag force will work along the same direction F D and where will be the lift force work? Orthogonal to that. Now, the lift force happens to be much larger than the drag force in a properly designed airfoil. So, I have drawn it larger. As a, as a result, what will be the total force? Summation of these two; the summation of these two would be … This is the total force F. So, this is what happens in an aeroplane wing, helicopter wing and also a wind turbine.

Now, notice that this F, it will have, it can be resolved into two components - one in the direction of motion like this and another in the direction perpendicular to it. So, in the direction of motion there is a component. Can you see that? Here is a component that is in the direction of motion. What will it do? It will aid its motion. That means it is this force that will make it move in the direction it was moving already. Can you see that? So, because of this, actually the wind turbine rotates; modern wind turbine rotates because of this force. All modern wind turbines, I just said that that India is producing something like 6000 megawatts of power out of wind. All these are working on these principles, not the thrust principle, not the push, the lift force.

So, essentially what I have tried to show today is that if you want to talk about a modern wind turbine, high efficiency wind turbine, you will have to understand aerodynamics and the essential of aerodynamics can be contained in this kind of a, you know, vector diagram that I have just drawn here. After having understood this, the natural question is how exactly this airfoil is oriented in the wind turbine? Where is the airfoil? Airfoil is something like this. See, the wind turbine is, a modern wind turbine looks something like this.

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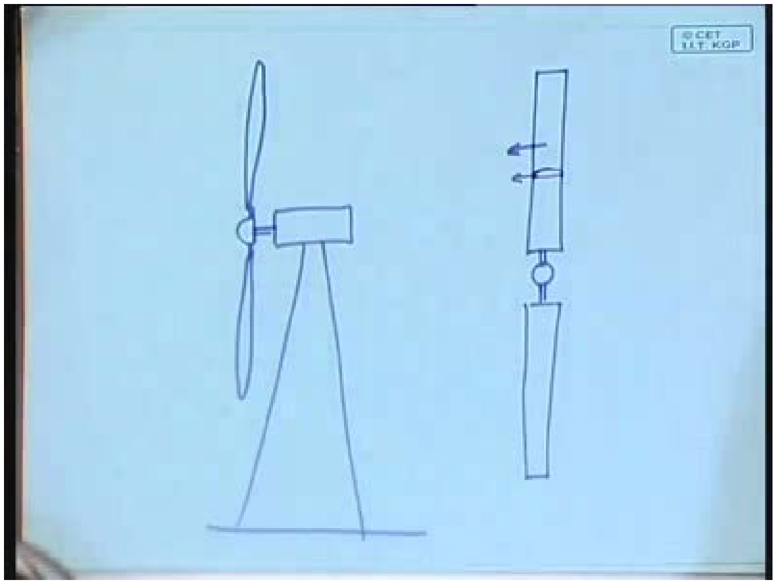

You have a shaft, it is a horizontal axis wind turbine and there is a blade here, there is another blade here and you have got … and it has to be on top of the tower. That is the structure and this fellow is rotating like this. If you see from the front it will be, to draw it in a simplistic manner, I will just draw two, now the blades. Now, this fellow is moving in that direction. Where is the airfoil? This section, if you cut the blade that section is the airfoil section. How is it oriented? If it is rotating that direction if it is …. rotating that direction, then it is like this. Its head, its head is here in this direction, its tail is here in the opposite direction, so that as it moves, as it moves, it actually moves into the air. So, as it moves, this becomes your u, clear. This fellow is rotating and wind is coming like this.

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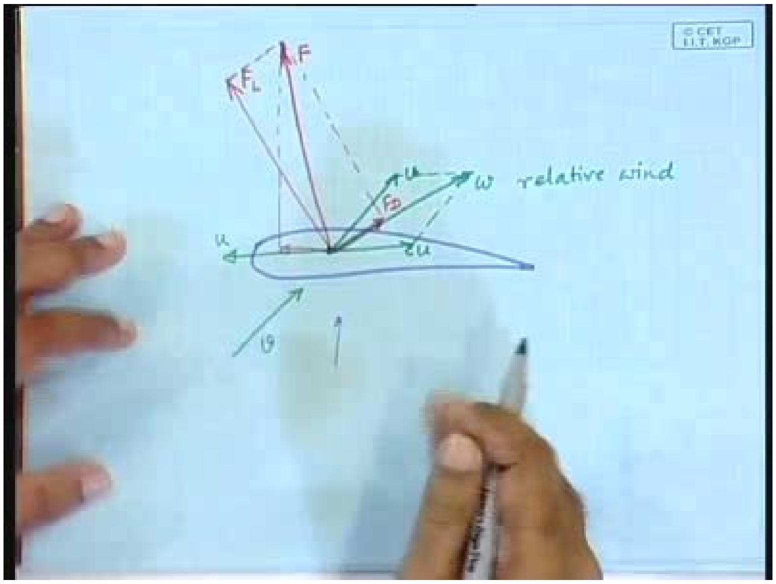


So, instead of drawing like this, in our case, in our specific case, wind will be coming like that. So, u is here, wind will be right here, which we will take up in the next class. But, try to understand the structure. So, wind is coming like this. This fellow is rotating like that and obviously, in this case wind will be coming like that. There will be again a parallelogram creating this relative wind, but in that case you will not need to draw a parallelogram, it will suffice to draw a rectangle, because they are orthogonal and normally, okay, it is, it will not be difficult for you to understand at this stage.

See, you would like to minimize the drag and maximize the lift, because drag is opposite, acting in the opposite direction, to the lift; the more the lift, the more this force. So, you want to reduce the drag and what was drag proportional to? How much area does the wind see, accordingly it tries to push back. So, you would like to make sure that it sees a least area and when does it see the least area? When this airfoil is oriented in the direction of the relative wind, clear? So, that is why, here this is not really flat in that direction, it actually is oriented like this and in this part it is oriented like that, clear. So, as it moves, wind comes it moves, but it sees whatever the direction of the relative wind sees, it also is oriented in that direction. This angle is normally variable called the pitch angle, clear. We will we will continue with this in the next class.