Performance of Marine Vehicles at Sea

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Lecture No. # 10

Propeller Geometry Part – I

Good morning, gentlemen. Today, we will start on screw propellers and we will start with geometry.

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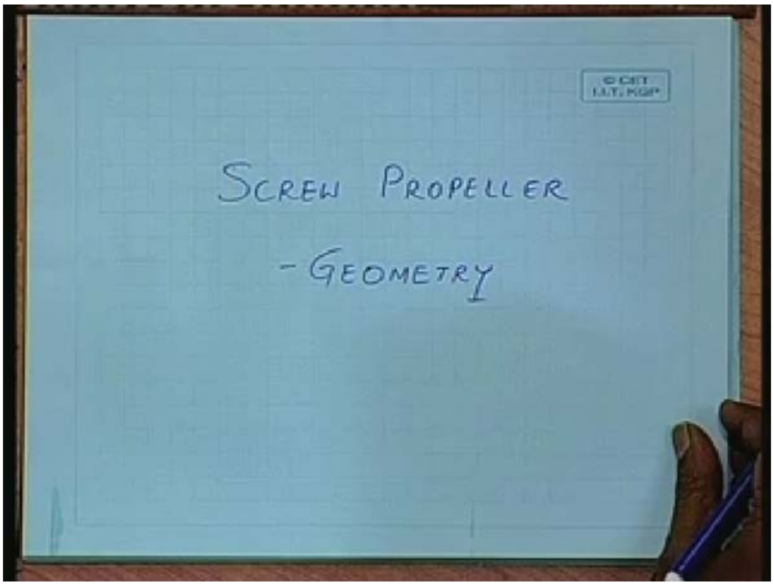

Every ship has an engine which is connected to a propeller shaft, a sort of shafting system consisting of a number of units ultimately as aft and the shaft is known as propeller shaft to which is attached the propeller; this propeller is rotated by means of the moment or torque supplied by the engine at a particular RPM, so once this propeller rotates it moves in a hydrodynamic medium and through interaction of water and the propeller blade an axial force is generated, which is known as thrust, in the direction in which the ship is moving. A ship when it moves forward it experiences resistance to its motion in the reverse direction, this force generated by the propeller known as thrust overcomes this resistance and allows the ship to move forward- this is the principle on which the propeller works.

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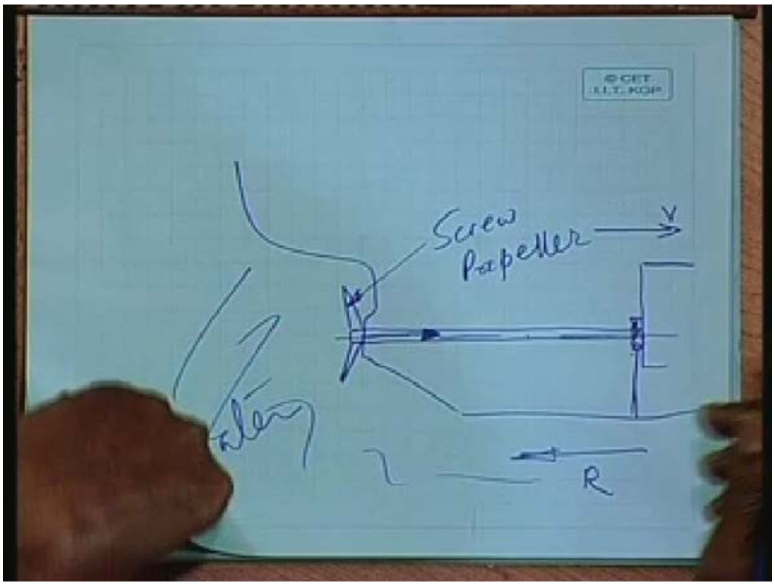

Simply said or diagrammatically said it is like this: you have the engine here somewhere, now, you have got a shaft coming here, and then this comes out of the ships, out of the ship on which is housed the propeller; now, the engine provides the moment to the propeller at a particular RPM, this propeller works in this fluid medium- this medium is fluid, water- and produces a thrust or an axial force in this direction, which is finally transmitted to the ship along the propeller shaft, and since the propeller shaft houses a baring here, thrust baring, through the thrust baring it is transmitted to the ship structure and the force is applied to the ship and the ship moves forward overcoming this force, R, resistance, which is experienced by the ship at a particular speed V .

The propeller geometry is such that when it rotates the one side of the propeller forms more or less a part of a screw- I suppose all of you have seen a screw, a nut and bolt, a bolt on which a screw is carved out and when you rotate a nut it travels in a particular fashion- a propeller blade surface, one of the surfaces is a part of this screw surface and that is why a propeller fitted behind a ship is called a screw propeller, so, this is, this is called a screw propeller. Before we go further it is necessary for us to understand the geometry of a propeller.

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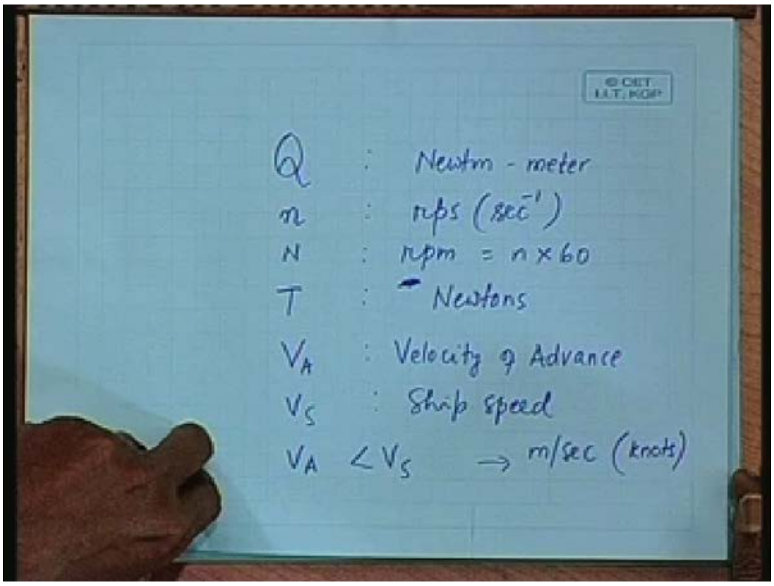

So, what have we got so far? The torque coming out from the engine being applied on the propeller is called torque Q represented as capital Q, and its unit is Newton meter- we are all talking about SI units; rotates the propeller blade, rotates at rpm at revolutions per second denoted as small n, rps, unit be second inverse, sometimes it is more convenient to say revolutions per minute in which case you write capital N, rpm, which is equal to n into 60; and then we have thrust generated, which is called thrust and the unit is that of force, Newtons.

And this operates at a speed normally called velocity of advance VA. Now, this velocity of advance varies from, varies as where the propeller is working, if the propeller is working in open water, which will be seen, the VA will be equal to the speed of water whereas, if it is working behind the ship, it will also, the VA will be the mean velocity of water on to the propeller, which may be less than the ship's speed that is, if I write VS as ship speed, VA will be less than VS- units of all speeds will of course be meters per second, or more conventionally knots, which can be converted to meters per second by multiplying with 0.5144.

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I have got some propeller to show you here. I will show you this propeller, this is- can you see this?- this is a model propeller having three blades- can you see this?- this portion is called the boss of the propeller on which there are three blades. So, this is a three bladed propeller and this boss has a hole as you can see, which sits on the propeller shaft like this, so the shaft is on my right and the ship is also on my right that means, this side is the aft side, or this is, this portion is behind the ship, the ship is in front and it is moving that way. How is the propeller rotating? This is, if you are looking from behind the propeller, behind the ship let me say- still we have not said which is front and back of the propeller- suppose, I am looking at the propeller from the from behind the ship that is, from this side, then, if it rotates in the clockwise direction- is it the clockwise direction. this direction? Anticlockwise- so, how will be the clockwise, how will it be clockwise here, this way? Right. If it rotates.

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Looking from aft, looking from aft that is, this side, if I rotate it like this, then this is clockwise, this is called the right hand screw, right handed screw; if it rotates the other way, then it would be call the left handed screw. Normally, single screw propellers are all right handed propellers, right hand screws, but if I have a twins screw propeller that is, one on the fore side and one on the stable side to balance the uneven forces that may be generated, I would like to rotate the propellers, each propeller in the opposite direction, so, that means, one will be right handed propeller and the other will be left handed propeller.

So, right now let us look at this right handed propeller, what are its characteristics? The side that is facing you when you are standing behind the ship and propeller that is, this side, is called the face of the propeller- this is the face- actually, it is behind from the aft side, and this is the back of the propeller, and the edge that meets the water first, if it is rotating like this, this is the edge that is meeting the water first, so, that is called the leading edge of the propeller, and the other one is the trailing edge, this edge trails the propeller- am I clear? The furthest point of the propeller blade is called the propeller tip and the one that joins the propeller blade to the boss is called the root. So, I have got the root, the tip, the leading edge, the trailing edge, the face and the back. This would more or less define all the main features of a propeller and number of blades of course, and along with RPM and torque it is supposed to observe; what we have not defined yet is section shapes and the outline of the propeller blade now, we will see how they can be defined.

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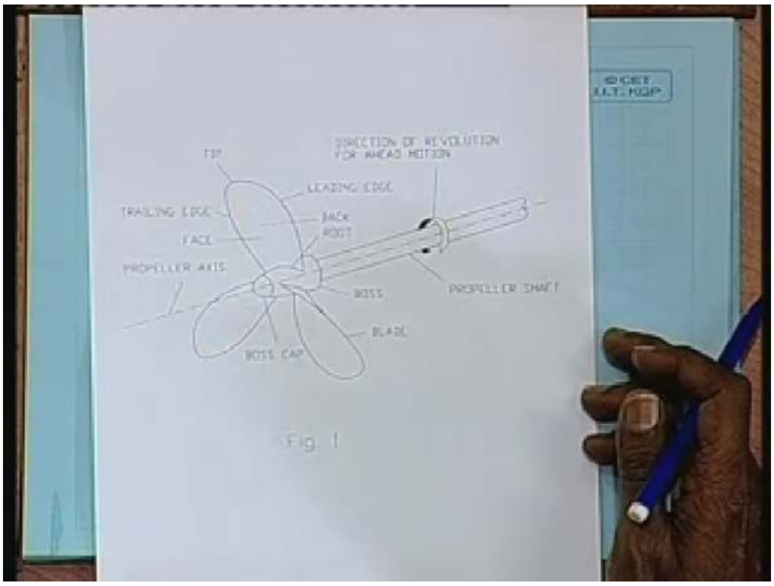

Showing it in the form of a diagram- can you see this, is it visible to you, yes, clearly visible? So, this is the shaft where this shaft is rotating in the clockwise direction looking from this side, and this is the face, this is the back, leading edge, trailing edge, this is the boss, this is the tip and this is the root where the propeller joins the boss- is that clear? Now, let us look at some other features of the propeller blade.

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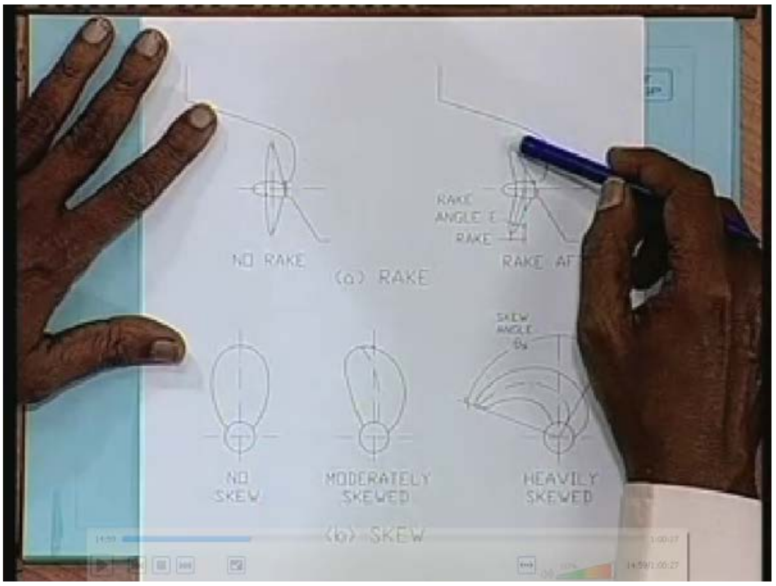

Now, you see here- is this visible, clear, or should I draw it? So, if the propeller axis is perpendicular to the shaft center line- this is the propeller center line, propeller axis as it is called, the shaft center line on which the propeller sits is called the propeller axis- if the propeller blade as in this case, as in this case, is the propeller blade is perpendicular to it in this plane, if it is perpendicular like this, then this is called a propeller with no rake. But sometimes it may be necessary to rake the propeller or tilt the propeller blade to one side of the plane perpendicular to the propeller axis like it is shown in the next diagram, this diagram- can you see it, is it understandable, can you understand?

What benefit do we give, do we get if I rake the propeller? You can see this distance between the propeller trip and the hull here is less than the distance between the propeller trip and the hull here. We know that propeller works in a velocity field, which is varying and therefore, it is possible the propeller may transmit pulsating pressure forces on to the ship hull, which may cause vibration in this overhang portion of the hull that is, the stern, which may be transmitted to accommodation and the other areas. One way to reduce the effects of this vibration is to increase the clearance between the propeller tip and the hull- this minimum distance as I have discussed earlier is given by classification societies. So, if you do not get adequate clearance here, rake propeller is one way so that we can get increased clearance between the hull and the propeller.

Next, we have what is called skew of a propeller.

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Normally, propellers do not have forward rake normally, they do not have forward rake, but can always have a forward rake, it is not denied, but it is generally not there, because if you here forward rake the clearances reduce, the way the propeller is fitted behind the ship.

Skew is, if I take the propeller axis like this and if it is perpendicular to this, it is called no skew. So, there is another way to define this.

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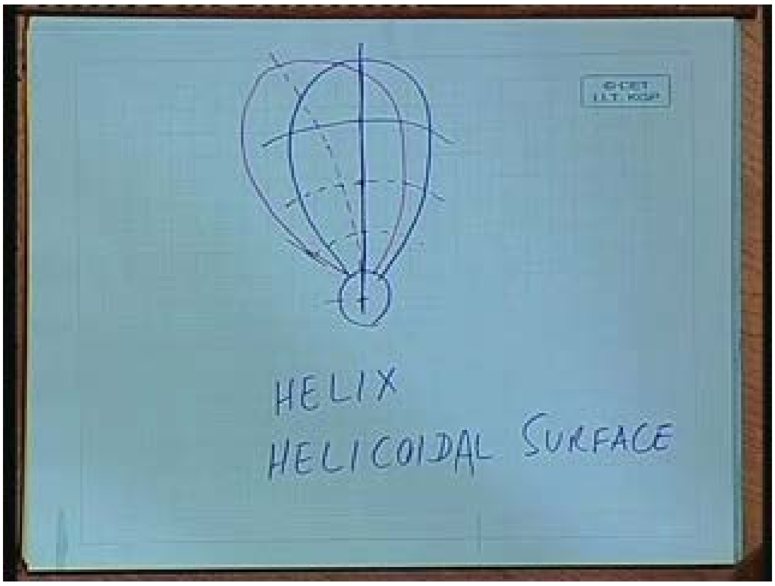

This is the propeller boss, I have got a blade here; now, at each section if I draw a radial section, radius here, and this is my section, I draw the mid line here, midpoint, if I join the mid points of all sections like this, all radial sections with this as center and I find they lie in one line, which is perpendicular to the center like this, then this is called a propeller with no skew, but if I have this blade shifted like this where the center point gets shifted to this, then this axis, the propeller's vertical axis is tilted to one side, then it is called skew.

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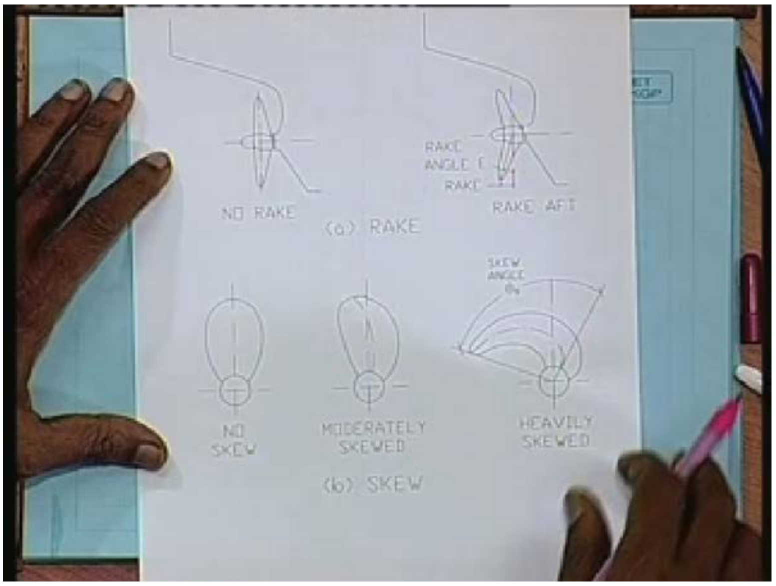

Now, some of these diagrams, this diagram shows you various types of skew that exist; this is a propeller blade with no skew, this is a propeller blade with slight skew and this is a propeller blade which is called heavily skewed that is, the skew is very high. And you can see the center line of each blade plotted here, and the measure of the skew is generally the angle between the propeller non-skewed axis to the line joining the propeller center with the tip, that line, this is the skew line and the measure is up to the tip, the skew at the tip, that angle- is that clear?

So, this is normally how propeller rake and skew are designed. Why is propeller blade skewed, there should be some reason why we do these heavily skewed propellers, particularly, one can appreciate that moderately skewed propellers can be designed to suit the geometry and other constants, but why heavily skewed propellers? It has been found that heavily skewed propellers can adopt themselves to varied weight field or varied velocity field much better than normal propellers so therefore, these propellers have been advocated and have been fitted to a number of ships who, where the velocity field is very uneven, which might have caused vibration.

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((Sir it been right handed skew also increase the gap in both the ways))

Skew may increase gap, but may not because skew is actually in this plane, so when the propeller blade rotates at someplace the gap may reduce, someplace it may increase, but of course, a well designed, a well skewed propeller may actually improve the gap.

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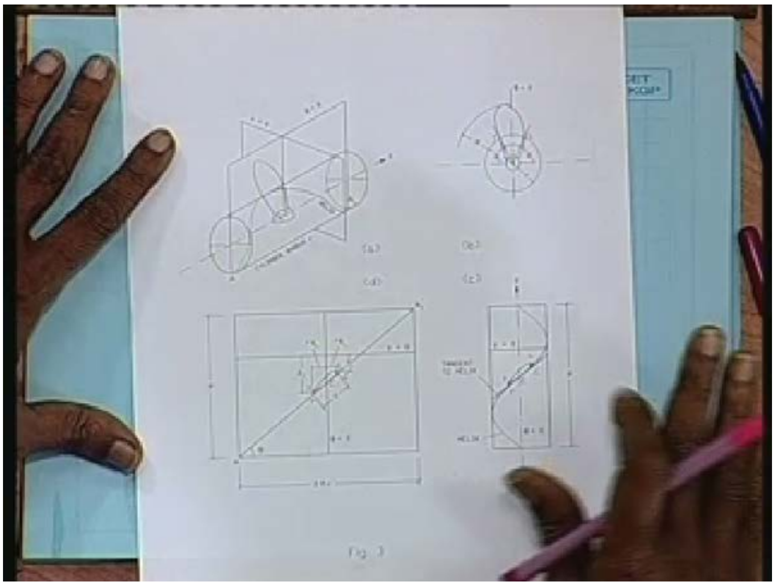

Now, let us look at this. Propeller geometry is actually very interesting, it is a highly three dimensional geometry, the face and, the propeller face forms a part of what is called a helicoidal surface. Now, what is a helicoidal surface? We have already mentioned that it forms a part of the screw surface, if I have an axis here like this and I have a line here perpendicular to the axis and I rotate this line here, then the tip of this line will form a circle. But along with rotating I also give a forward speed to this line that is, I not only rotate at a constant speed, but I also move this along this axis, so, how will it form? It will go like this.

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Now, the line that is formed by the tip is a three dimensional curve known as a helix, the three dimensional curve is known as a helix, now, if this entire line I trace, it will form a three dimensional surface, which is called a helicoidal surface- is that ok?

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So, here what we have shown is this diagram, if you look at this diagram- can you see, is that clear?- this is a cylinder of a constant radius R and on top of this I have tried to move this R at a constant speed along the cylinder, it will move on the cylinder surface- is it not?- because R is constant, so this is the, line A will trace a line like this, a three dimensional line up to A1- it is shown, it is shown in a plane, but it is actually a three dimensional curve, this line actually goes like this.

Now, there are two planes I have, we have, defined here: one is the perpendicular plane to the, in one, one perpendicular plane to the propeller axis, which is called the theta equal to 0 axis; and another one normal to the both this propeller axis as well as this plane, which we have called as z axis. Why I have done this?

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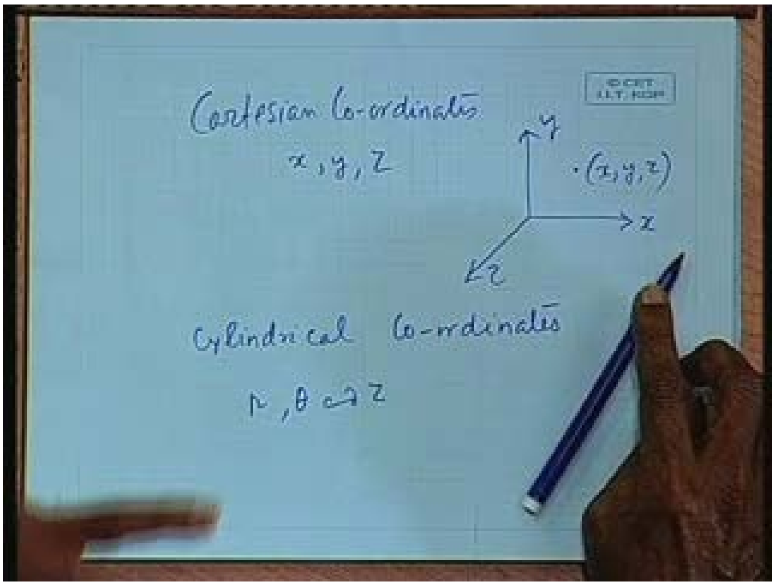

Normally, we know Cartesian co-ordinate system; in Cartesian co-ordinate system we defined the position of a point by x, y, z co-ordinates in three dimensions- is that right?- in space if I define an axis system x, y and z, then any point here will be defined by x, y, z; x is the distance this way, y is the distance this way, z is the height, from this plane, how far it is. Now, in propellers since, it is connected with a cylindrical movement it is easier for us to define the propeller, a point on the propeller blade in what is called cylindrical cylinder co-ordinates- this is Cartesian co-ordinates- that is R, theta and z- this z remains same as the Cartesian co-ordinates, but r and theta that is, if I have got this propeller, this propeller let us, let us compare this with this diagram that we have seen.

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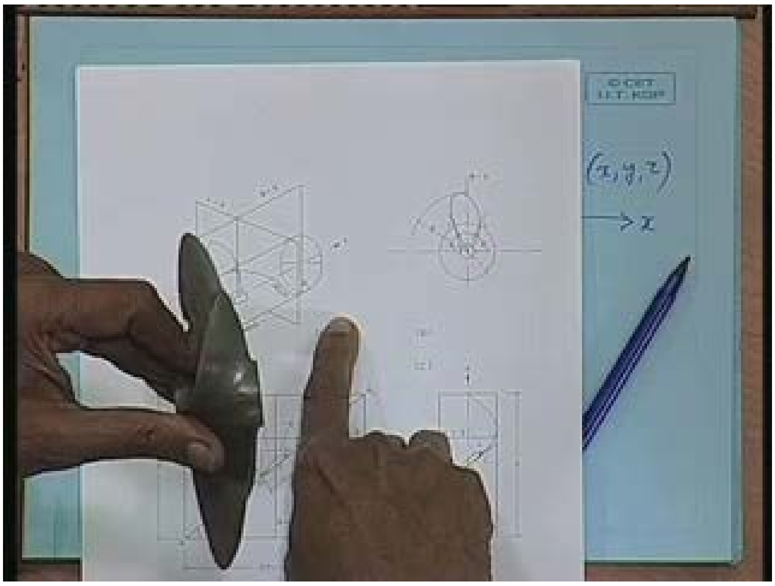

This is the propeller blade, this is the propeller blade, and a point here if I move, it will form a helix, this line, this plane is the theta equal to 0 plane, this plane that means, if I take a radius r, I take a radius r here, if this plane is defining theta equal to 0, then the point passing through that circle that I have drawn would be theta equal to 0, but any other point here we will have to move through an angle theta- am I clear, Mr. Mukharji? So, this point can be defined by R and theta, but it has also a co-ordinate in this direction, that I am calling z, if I pass a plane here, a z equal to 0, then the point from that plane to this point will be the z point; so, this point we will have a R co-ordinate, will have a theta co-ordinate, which is how much it has moved angularly from this axis and the z co-ordinate that from standard plane how far it has gone, how far deep it is, how deep it is- is that clear?

So, any point in space can be defined by three co-ordinates; in Cartesian co-ordinates we had x, y, z, where all the three co-ordinates are measured linearly from the three defined axis; in the cylindrical co-ordinate system we are defining by a point, by R theta and z. So, R and theta define a point in a plane perpendicular to the propeller axis- R is this distance and theta is the angle, and z is the distance from that plane- so, that defines the co-ordinates of a propeller.

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So, that is what is shown here, the axis theta equal to 0 and z equal to 0 are shown, so any point on this can be...Now, you see this is the face of the propeller blade, this is propeller blade- this is the face corresponding to the diagram we had seen earlier- this helix forms a part of that face, or rather the face forms a part of this helix that has been shown here, this part of the curve. Now, if I open this cylinder up, I have drawn this line on the cylinder now, I open it up, what do I get? You see here, this is the cylinder of radius R, so if I open it up, it will open up to 2piR and the distance here along this axis if it has moved, it has moved through a distance called pitch- I have not defined pitch earlier that is, when this, when this line moves through one revolution, the distance it has travelled longitudinally or axially is called the pitch of the helix, or helicoidal surface if the entire surface is moving the same distance.

So, when I open this cylinder up, what do I get? This side will be p and this side will be 2piR, this is what is shown here P is, one side will be distance P the other side will be distance 2piR, and this helix will convert itself to a diagonal, it started from one end and ended at the other end- do you understand? So, this A, A1 that we had here is converting itself when I, when I open up the cylinder into a diagonal of the rectangle the two sides of which are P and 2piR ; now, this section that was here, this helix that was here on this face, face section that was here that will now appear here on this diagonal.

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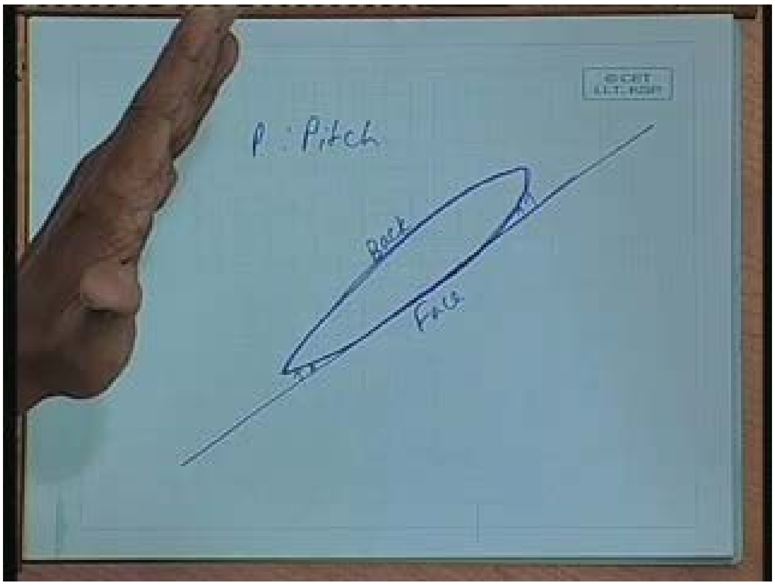

Now, this section that you have seen this side is the face and this side is the back; now, I said that the face is a part of a helicoidal surface, or at a particular radius it is a part of a helix, what is shown here is the helix, but you will notice that if I expand this, this is the diagonal going and my section shown here is something like this, is not actually, the face is not actually on this line there is little bits of deviations from here, and this is the back, this is the face – is it not?

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So, this is what is shown here, I have just expanded this, you see here, the face is more or less falling on this helicoidal line just slightly adjusted, slightly offset at the leading edge and the trailing edge, this is the leading edge L and this is the trailing edge T, the projections of L and T on the exact line is shown here as Ldash and Tdash. So, this is the actual section shape of the blade at that radius R- am I clear? Now, if this, it is projector, in other views they will look like this, I think we can skip it for the time being and proceed further- any doubt so far regarding how wave propeller should behave?

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((Sir this ensures (( )) it will be flat face))

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No, it will not be a flat face. Of course, it is a curved face, this is what I have shown here, this is curved, this is curved; this is, this is face, this is supposed to be on the helicoidal surface and this you can see is not strictly on the helicoidal surface, but it is slightly offset from the helix at the ends that is, at the leading edge and the trailing edge; back is not on a helicoidal surface, we are not saying that same thing for the back, we are more concerned about the face, but it is more or less on a helicoidal surface, this is what we are trying to say.

So, if the propeller actually moved as a helicoidal surface in a solid medium, please understand, if it moves in a solid medium, then there will be no slip, when you move the propeller forcible like a nut moves on a screw of a bolt, it does not have any facility to slip away unless the screw has broken. The nut will move when you move it, one revolution- sorry- one rotation, it will move a certain fixed distance, if you move it ten times, it will move ten times of that distance, that distance, which it moves in one rotation is called the pitch- and this is what we defined pitch here. But since the propeller is moving in a fluid medium it may not move, behave, as if it is moving in a solid medium therefore, there may be slip, its actual movement may not be equal to P, if I defined P as pitch that is, the distance moved in one revolution of this helicoidal surface, the propeller actually need not move P, it may move less because it is in a fluid medium, it may slip- this part we will see later.

Right now, let us just understand that though we are defining the propeller blade as a helicoidal surface and defining P as a distance moved in one revolution, in an actual case, propeller may not move distance P in one revolution because the medium is not solid, there may be many other reasons, but one of the main reasons is it is not solid, to overcome the resistance in a solid medium, we are actually applying manual force to move it; in a fluid medium what happens as we go along the course we will see- have I been clear ?

So, most difficult part of propeller geometry is representing it diagrammatically, showing its various features.

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So, if I bring back this diagram again, this section that is shown here, this section is what is called an expanded section that is, if I expand the helix this is how the section would look. Remember, what I have actually drawn is, what I have actually done is I have taken this propeller a at a constant radius, a constant radius, it is not a flat line, it is a constant radius, the section shape what I have shown here, it is not a straight line it is at a constant R; what I have shown here is if that radial arc was made into a straight line, how this section would look- do you understand- we expanded this to a straight line, is it not the helix?

This is a diagonal, it is a straight line. So, this is as if we have expanded it along this line and the angle of this line is phi of pitch angle, you see this angle here, phi- can see?- this angle is called the pitch angle defined by the P and 2piR.

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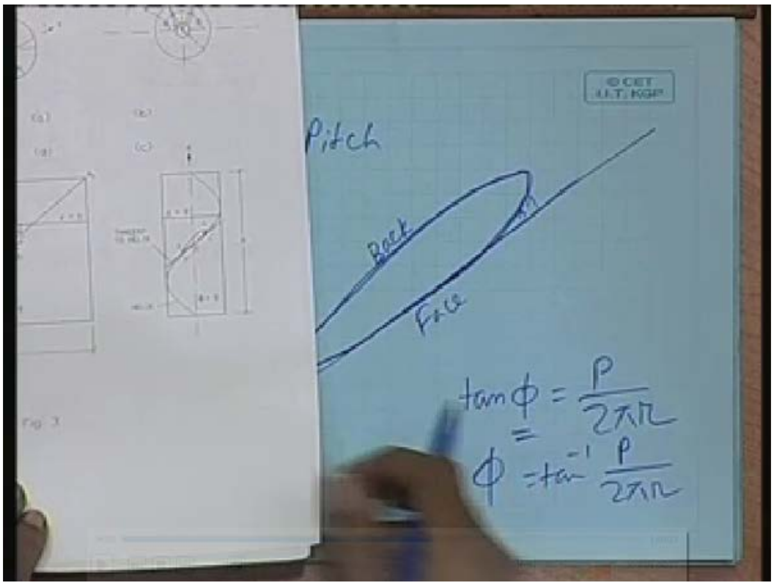

And what is pitch angle? You can tell me, tan phi is equal to, tan phi equal to P by 2piR,P divided by 2piR is the tan phi. So, pitch angle phi is tan inverse of P by 2piR .

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So, here you have got this line, which would come on the helix if it was drawn in your straight line at an angle to the 2piR line phi, and this would be as if the section has been straightened.

That is not the section of that part where it is cutting

Yes, it is exactly that, it is exactly that. If I take R here and cut it here, if I take this R and cut it here, this is actually a section in three dimensions, but if I have expanded it, pulled it out along the helix, then it becomes a straight line, the section elongates in length along that line- do you understand?- so, that is that section, it would look like this and this is the actual section with which we will be dealing, this is called an expanded section- you got it? Expanded section- am I clear, has it been understood?- actually, it is on a three dimensional plane, the section is in three dimensions, it is as if I have pulled it out to a straight line and that straight line is at an angle to horizontal, then that section will look like this.

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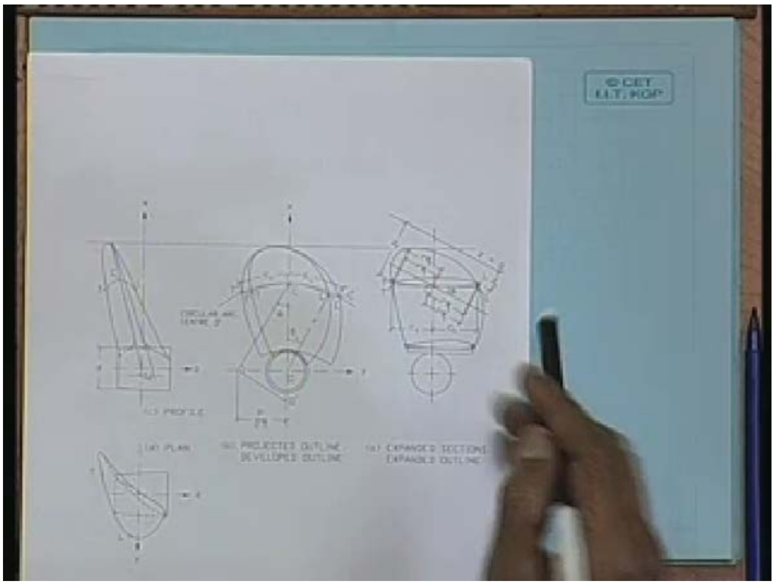

Now, what I do is I now move it at that same distance r, I make that line horizontal instead of diagonal like this, I make this line like this, horizontal, I made this line horizontal, just physically moved it then, I get a line- you see here, can you see this diagram clearly, all of you can see it? This is that angle phi, this is the angle phi, here is what I have R theta L and R theta T- I do not know whether I have explained this to you or not.

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This distance, this distance here is called r theta L, you see, this is, this distance is actually how I would have seen it on the arc- that is, that is the projection, this distance is the projection into this plane, in theta equal to 0 plane, projection is from here to here- tell me if you are not understanding, this is very important for us to define the three areas, that are important to proceed with later on.

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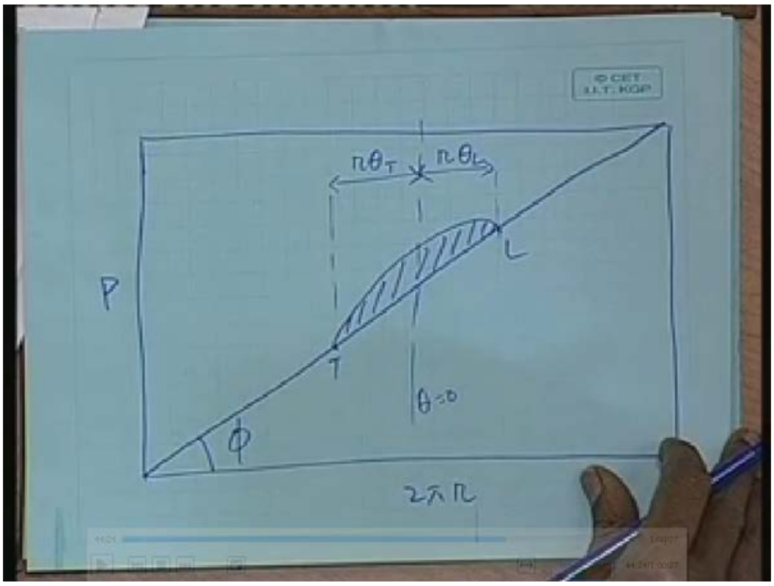

What have we done? We have expanded the cylinder; this is P, this is 2piR , the cylinder was like this, in this it was like this, I have expanded it, this is the helix that I had- so far so good?- now, when I expanded the helix since, at a particular radius of the propeller blade the face I am saying is a part of the helix that would come has a straight line here actually, it is not straight will it come as a straight line? So, let us say the pitch was coming here, face was coming here now, I am not giving any offset to face- let us understand the geometry first- and it has a back like this let us say, this is my blade section, but if I look at the propeller blade straight away like this, then this would be my point, this is my projected length, my projected length if I do a projection of the propeller blade, it is here, but if I expand that line, then the propeller blade comes like this, elongated- this can be understood.

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Sir Yeah.That part will be (( )) and that propeller is a three dimensional. So, there is a difference there also you are telling that (( ))

We have taken the pitch. We have taken the pitch here, this is the length of the propeller blade section, actual length.

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(( )) that is the (( )) Yeah.(( )) Um.That the arc will be a two dimensional curve (( )).

This arc is a three dimensional curve, this is a helix, the part of a helix, this arc, this arc is also moving, it is part of a helix- do you understand?- so, this is, now, as if I have straightened the helix, so this is a longer length, which I am actually not seeing, what I am seeing is the projection here, this much. So, this is actually the projected length of that section, but this is the actual length, if I measure the length, it would be this, what is this, what is this? At constant R if I measure, I take a thread put it from here to here at constant (( )) and expand it this is the length I will get.

That is a actual actual length.

Actual length at radius R- is that clear? So, this is phi and I can say this is theta equal to 0 line, what is the, see this is theta equal to 0 line let say, and this is R, so what is the length of this arc, projected length? Now, let us say projection means I will have a circle and a cylinder at a constant section and I draw a line, what is that arc length? R into theta, whatever is a theta, so this distance is therefore, R into theta L and this distance is R into theta T, trailing edge this is L, this is T, the projections, mind you- is it too difficult?

See here, let us make this surface flat for the time being, what is the section you will see? You will see this length, if I take a photograph, what length I will see? This length and that will be on this arc, so the length of this will be R into theta, length of an arc is R into theta, all I am saying from standard co-ordinates the leading edge will be R theta L and trailing will be R theta T- that is the projection.

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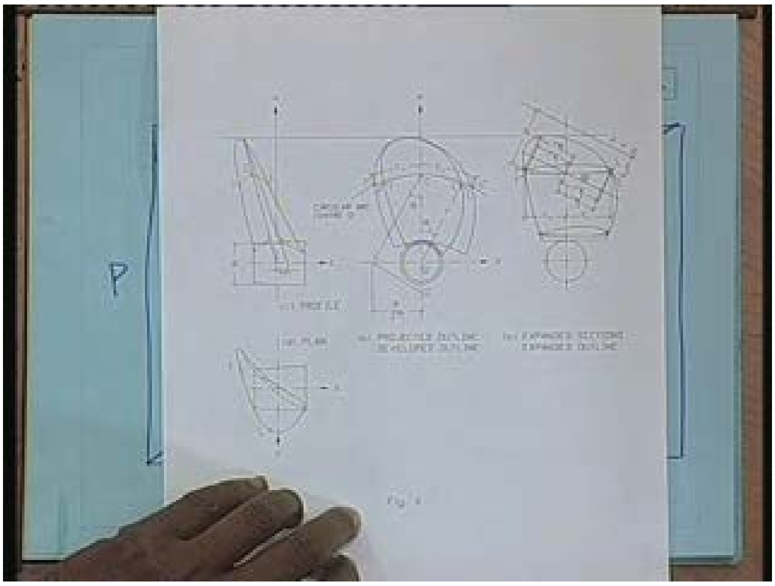

So, now when I draw the propeller outline and come back to this diagram, when I draw the propeller outline, if I draw an angle phi here, my section would have come here, that I am drawing on a horizontal plane. So, this is R theta T and this is R theta L along that diagonal line at angle phi and that when I bring it to the horizontal plane it becomes a longer line- do you understand? So, this section is now known as the expanded section drawn horizontally- have you understood, I am asking you, you have understood? Good

But if I have, if I want to draw a projected line, then it is only on that arc I put, if I draw at an R, draw theta L and theta T this side I get this L and theta lines and join them I will get the projected line- projection is very simple once I know the pitch and I once I know the angles, theta L and theta T, I can easily draw the projected outline. The expanded outline I have to draw by drawing this phi line, the pitch, and then projecting it into a horizontal line, that would give me an outline which is called the expanded outline. So, you have got an expanded outline, you have got the projected outline.

Now, there is a an outline called the developed outline that is- see what we are getting- the projected outline is if I had R here and I drew it, if I took the photograph here, how that line would look that is, this circle T C and L – is it not- that is why I am doing the projected line. Now, suppose I do not actually make it into a straight line, but bring this circle to a single plane, this circle is in three dimensions if I bring this out to two dimensions, then I will again get a line which is more than the projected line- can you understand?- that line is called the developed line, where that will be horizontally projected from L and T to give, here in this case we have done Ldash and Tdash, which is the along with the offset of the leading edge. It is the horizontal line and it would come on another circle, which will be geometrically defined as, if you take P by 2pi this side and angle phi here, you will get this center and from there you draw a circle, which will automatically give this Ldash and Tdash projected horizontally on this circle to Ldoubledash and Tdoubledash if you join them they are called developed outline- have you understood?

Basically, what I have done if I take a radius R a section if I draw it projected, same section I get projected outline, if I that section I bring to a single plane by expanding it, not by making horizontal, but in that same circle, then I get developed outline, that circular line if I pull it and make it straight, then I get expanded outline.

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(( )).

Actual expanded outline is not opening the second curvature, well, yes, that is true, in two different planes. We will stop now, have a small gap and start again. Thank you.

Preview of Next Lecture

Lecture No. # 11

Propeller Geometry Part – II

We will continue with propeller geometry. We have seen there are three outlines that can define a propeller: the expanded outline, the developed outline and the projected outline.

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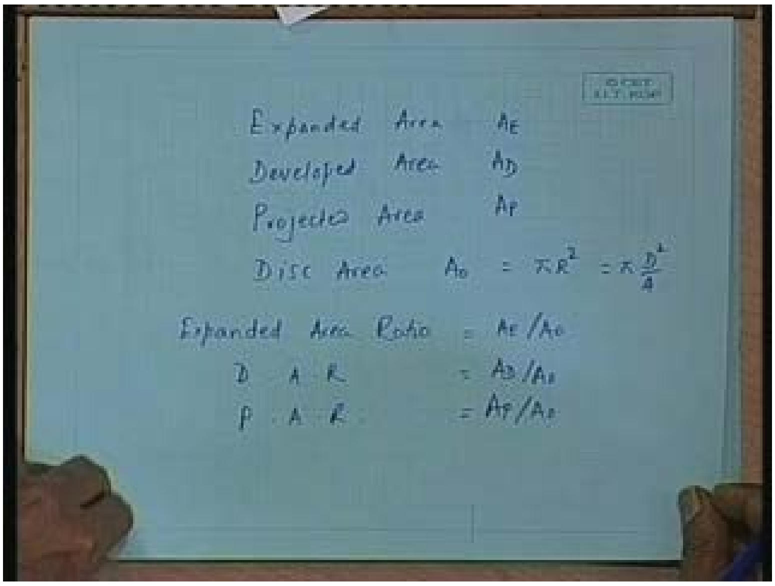

Correspondingly, there are three areas that we can define that is: expanded area, developed area and projected area. Now, the area that is covered by the circle with radius R that is, propeller radius, R is the radius up to the propeller tip, that is called the disc area, A0, which is equal to pi R square or pi D square by 4, if D is the propeller diameter. Expanded area normally is represented by AE; developed area AD; and projected area AP. So, non dimensionalising this we have three area ratios that is, expanded area ratio, which is equal to AE by A0; similarly, developed area ratio is equal to AD by A0; and projected area ratio, which is equal to AP by A0. So, this is the definition of area.

Propeller diameter is given by D, and propeller pitch as we have seen is given by p. Now, this pitch will be constant at all radii if the propeller face formed a single helicoidal surface.

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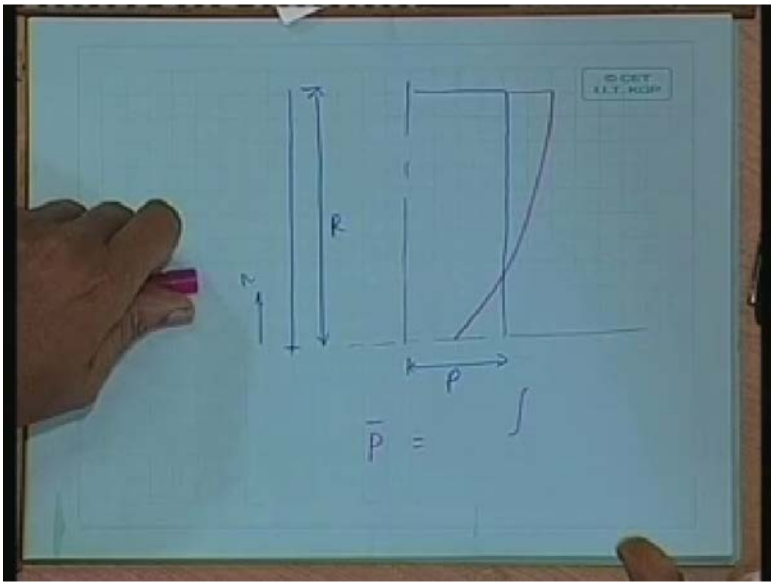

But sometimes we may not give a constant pitch across the radius that is, the pitch may vary like, if this is the radius R- this is full radius- then your pitch distribution may be constant; if it is a constant pitch, then the pitch distribution will be like this to the R, this is the pitch, at all radii the pitch is constant. On the other hand, I may decide that this pitch distribution is not ok, I can reduce pitch at the root and increase pitch at the tip, so in that case I can also give a pitch distribution, which may look like this; I can give a variable pitch distribution to the propeller blade. In that case, what will be the resultant pitch?

If I give a variable pitch distribution, the resultant pitch of the propeller, if I want to designate it by a single quantity, then in the variable pitch case, resultant pitch, you will, you can see, can be given as mind you, the pitch is starting only after the root, the boss, the blade is starting from the root till the tip.

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shape is known as aerofoil section where you can see the leading edge is not really sharp, it is rounded and the trailing edge is sharp- that is how propeller blades are made- the leading edge has a curvature, but the trailing edge is sharp. There is another way of knowing for which is the leading edge- the one that is sharp is the trailing edge, the one that is blunt is the leading edge and that is the one that will be meeting a water first, so you can also decide which way the propeller rotates by just looking at the propeller if it has the aerofoil section.

Now, as we have seen later, earlier, you can also give some offset to the face from the straight line and still it would be an aerofoil section. This is the most commonly used section for majority of propellers available in the world. This on the another hand is called a segmental section where the back of the propeller section is a part of a circle- unlike an aerofoil section you can see it is not part of a circle, it is blunt forward and sharp towards the trailing edge- here in the segmental section the back is part of a circle, this is many times used where there is a requirement of a, typically these sections are used in propellers for trollers where you require not only free running speed, but also some amount of pull that one must exert such as, hauling a troll net or something like that. In many propellers there is a combination of both aerofoil section and segmental section that is, aerofoil sections up to a certain radius and then the section slowly change to segmental section- we will see some of these propellers later on.

Then, what we have is called a lenticular section where the section is symmetrical about its central line.

There will be a drag in the same direction, but lift in the opposite perpendicular direction. So, if you look at this lift, which is going like this, most of its component is in the axial direction; if I now compute it, one is this direction, one is in this direction, most of it is this way because perpendicular to, perpendicular is very, making very small angle to the axis of the propeller. (( ))

Thrust and lift are not same, are not different, the axial component of lift is the thrust; otherwise, what is thrust, how do you get this axial force? This lift that I am getting, the component of that in the axial direction is what I call an element of thrust by any point here, that thrust integrated over the whole blades, all blades, gives me the total thrust on the propeller- is that clear? I am also loosing something in the form of drag, so, ultimately, the propeller efficiency will be, is a ratio between lift and drag- but have you understood how lift is being generated?

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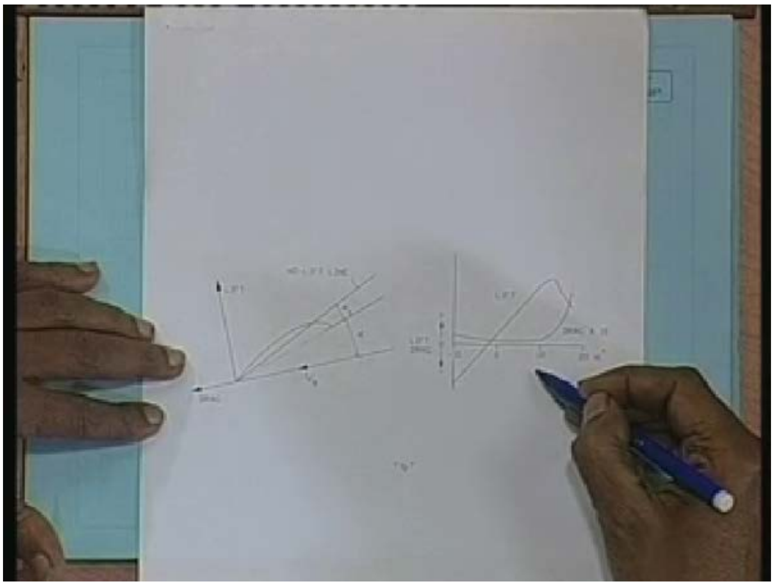

So, let us look at this diagram a little bit. We also know from aerofoil theory that if you go on increasing this angle- this angle alpha called the angle of attack- if I go on increasing this angle of attack, lift increases more or less linearly like this- as I have shown here- that is, I get small lift if the angle is small, and if my velocity angle of attack is more and more, I get more and more lift. But very strangely beyond a certain lift angle, certain angle of attack- this is angle of attack axis- lift suddenly drops that means, you do not get any more lift- this is called the stall angle, it is called the stall angle. So, we have to design your propeller that the lift is, the angle of attack is within this. Now, when you go reducing the angle, when it is at a particular angle to the propeller there will be no lift, so that angle is somewhat this- this is called the no lift angle; only when the angle is created with respect to that, start getting lift till stall angle; so, our aim should be to design the blade sections so that you stay between no lift line and stall angle- am I clear? We will stop here and next class we will continue with propeller theories. Thank you.