Marine Propulsion

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Lecture - 02
Propeller Geometry

Welcome to the second lecture on Marine Propulsion. Today we will cover some basic aspects of Screw Propeller Geometry.

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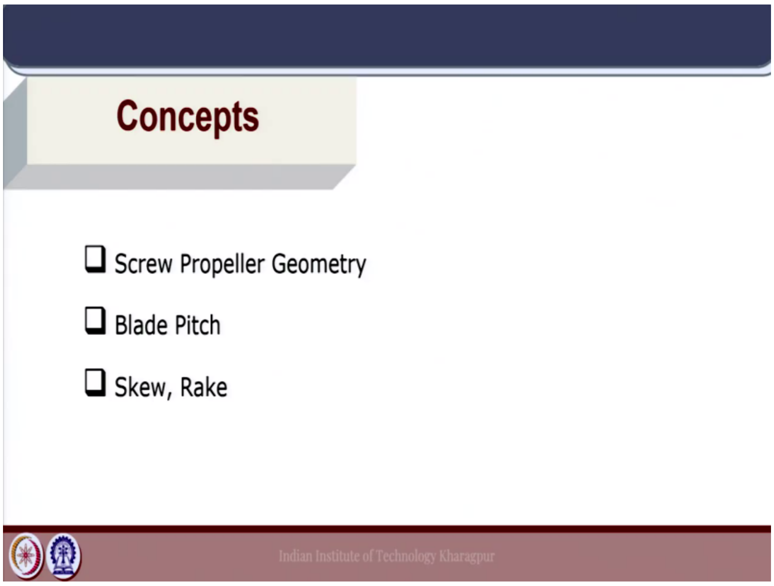

So, the concepts covered in brief in this particular class will be the Geometrical aspects of Screw Propeller, Blade Pitch, and concepts of Skew and Rake.

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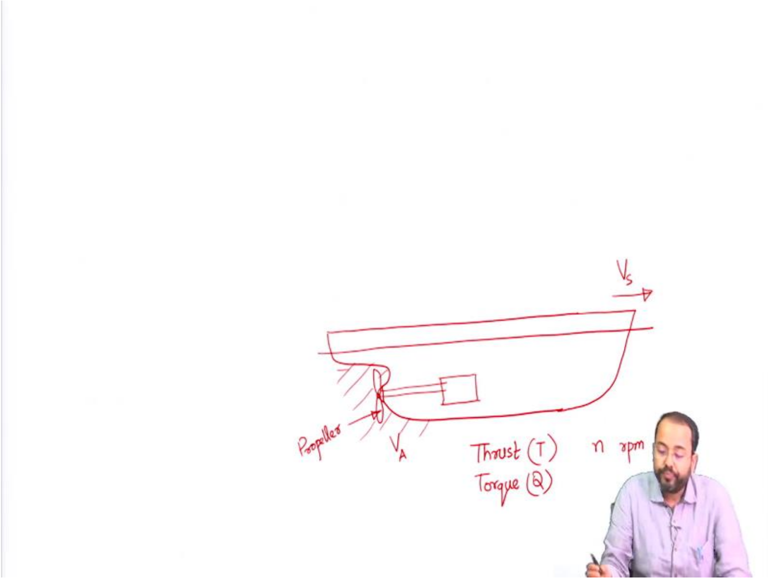

The basic thing which is very important to understand is the location of the propeller with respect to the ship. So, this is the ship let us say which is moving forward with the velocity V_s we have the propeller which is located in the stern of the ship. So, here we have the propeller. Now, the propeller is connected by a shaft to the marine engine which provides the power which is delivered to the propeller for its rotation.

Now the propeller is acting in a velocity field which is disturbed because of the presence of the ship. This is very important to understand here that the propeller being in the wake of the ship is facing a velocity which is V_a the details of these concepts we will understand when we study hull propeller interaction. But as of now let us assume that this V_a will definitely not be equal to the speed of the ship V_s.

So, it is facing it is acting in the fluid medium here the propeller is in the water acting in the fluid medium, and the inflow velocity into the propeller. So, let us say if we stand at the location of the propeller the velocity that we will face is a velocity V_a and it will definitely vary depending on the different planes in which we see. For example, along the vertical and transverse directions, the velocity field will vary.

But if we talk about a general average velocity we can say it is facing a velocity which is V_a at which the propeller is advancing in the flow. Now the propeller generates a thrust T and the ship because of the engine present within the ship the engine provides a delivered power P_d due to which a torque(Q) as a moment is being absorbed by the propeller and we have the 2 velocities V_s and V_n.

Another important thing to note is the rate of revolutions of the propeller let us say n rpm ok. So, these are the basic terminologies which will come in ship propulsion and which will be used time to time to define different propeller characteristics. And the location of the propeller the specific location which is behind the ship as of now let us take it as a basis for ship propulsion.

We will as again we cover the different aspects of the propeller characteristics as well as hull propeller interaction, we will understand why this is the optimal location for a propeller in the ship.

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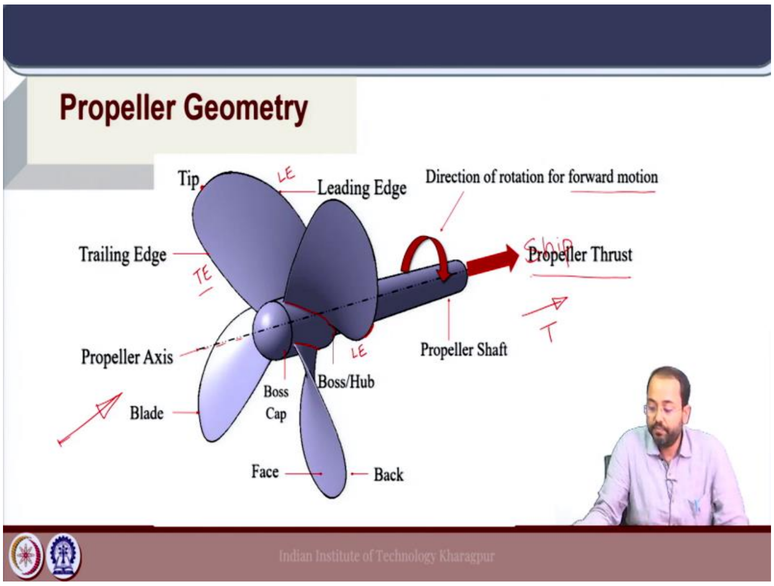

So, this is the geometry of a standard screw propeller where a set of blades are mounted on a central structure called the boss or hub which is connected by shaft to the marine engine. So, let us look at it one by one, we have the propeller shaft which is connected to the marine engine, and where through which the power is delivered to the propeller.

Next, the central line defines the propeller axis here about which the propeller is rotating in a particular direction to give the thrust force. The blades of the propeller which are mounted on the hub, now depending on the propeller design and the type of ship or marine vessel the number of blades can vary from around 3 to 7 and these blades have different sections based on the design and they provide the thrust force for the ship to move ahead. Again which depends on the flow characteristics and the rotation speed of the propeller.

The boss or the hub is the central structure on which the blades are placed. Now when the blade is rotating on the propeller shaft, the direction of rotation is very important in this particular case to define the edges of the blade. In this particular diagram you can see that the direction of rotation for forward motion is shown in the clockwise direction. So, that means if we look at the propeller from behind we have the ship here, where the propeller is connected to the engine in the forward direction.

So, if we stand in a location here and see from the aft of the ship standing behind the propeller and if the direction of rotation is in the clockwise direction, so it is called a right handed propeller ok. That means, if it is rotating in the clockwise direction to produce forward thrust for forward motion means the thrust is produced in the forward direction. So, this is called a right handed propeller.

Now, if it rotates in this particular direction what will happen we can define the propeller blade with a set of edges, we can have an edge which is in one direction which we call the leading edge and another one in the opposite direction which we call the Trailing edge. Now why is it named so? Because the edge of the propeller which leads the other edge; that means, when the propeller starts to rotate this edge. Now for this for the next blade this side will be the leading edge, so this is the edge which meets the water first.

As the propeller rotates the leading edge will hit the water first that is why it is called the leading edge and when we later study the sections of the propeller we will see that talking of airfoil sections which are typically used for propellers. The leading edge and trailing edge designs are completely different and that is how the flow around the propeller blade is defined which finally results in the thrust force.

Now, the tip is the location on the extreme end of the propeller which defines the diameter of the propeller ok and on the other side we have the root of the propeller which is attached to the hub. So, this location is called the root of the propeller blade on one side we have the tip which is the extreme end of the propeller and if we calculate the path of the traced by the propeller from tip to tip that will give us the diameter of the propeller and the part of the propeller which is attached to the base hub is called the root of the propeller blade.

So, this defines the basic geometrical aspects of a marine skew propeller and thrust. Again I have shown here as the propeller, this particular propeller if you see more carefully the propeller blades are not like flat surfaces they are curved towards the leading edge.

So, the blade has a pitch ok this is very important in defining the hydrodynamic characteristics of the propeller and we will see why it is called a screw propeller based on the pitch of the propeller blade, because the blade is a part of a helicoidal surface ok. And finally, the boss is closed by a cap which is called the boss cap at the aft end.

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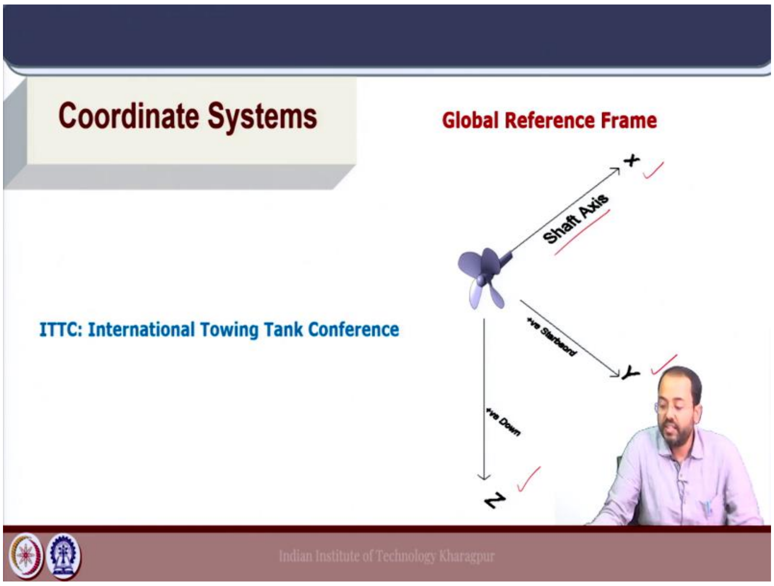

Now, the International Towing Tank Conference which is basically an association of organizations which deal with ship hydrodynamic testing. They have defined a global reference frame for ship propeller system and these ITTC norms are heavily used for experimental testing of model ships and propellers and also for numerical analysis of ship hydrodynamic problems.

Now, this shaft axis of the propeller which goes towards the ship engine along the length of the ship is defined as the X in the global reference frame as per the standard norms and the Y axis is defined as positive star board and the Z axis is defined as positive down. This is the standard norm practiced in naval architecture terminology.

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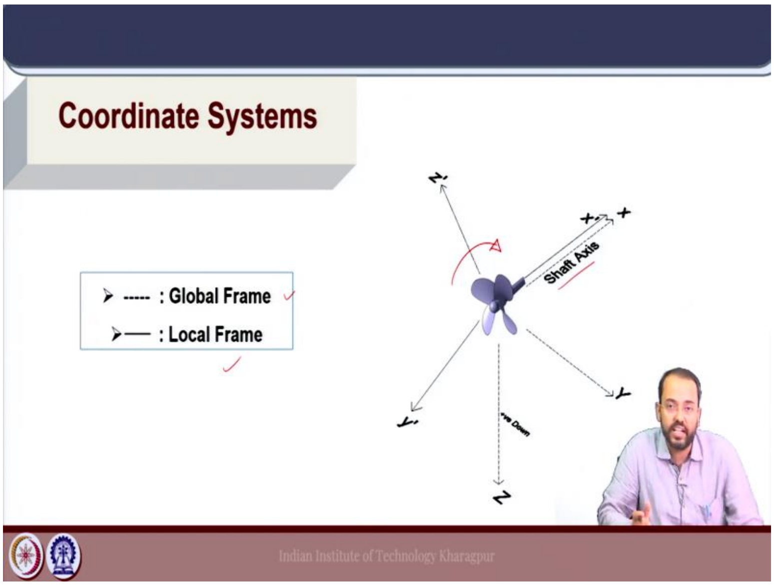

Now, if we look into the local axis system in the now the propeller is rotating the propeller blades are rotating about the central shaft axis. So, if I consider one particular blade its position is continuously changing depending on the angle of rotation of the particular blade at any instant about let us say vertical line. So, depending on that there is a local frame which is defined which is fixed with respect to a propeller blade.

Now, both the local and the global frame has the same X axis; that means, which is coincident with the shaft axis ok. Now the local frame is having a in this case, let u say Y’ and Z’ fixed with respect to a propeller blade and it is rotating about the X axis depending again on the propeller action. So, this set of coordinate systems can be used to define a ship propeller system.

On top of that, because the propeller blade sections are cylindrical sections, we will also use the concept of cylindrical coordinate systems to define the propeller blade sections. So, basically we will intersect the propeller blade with a cylinder and define the sections in that way. So, a cylindrical coordinate system will also be used from time to time to de define certain blade characteristics.

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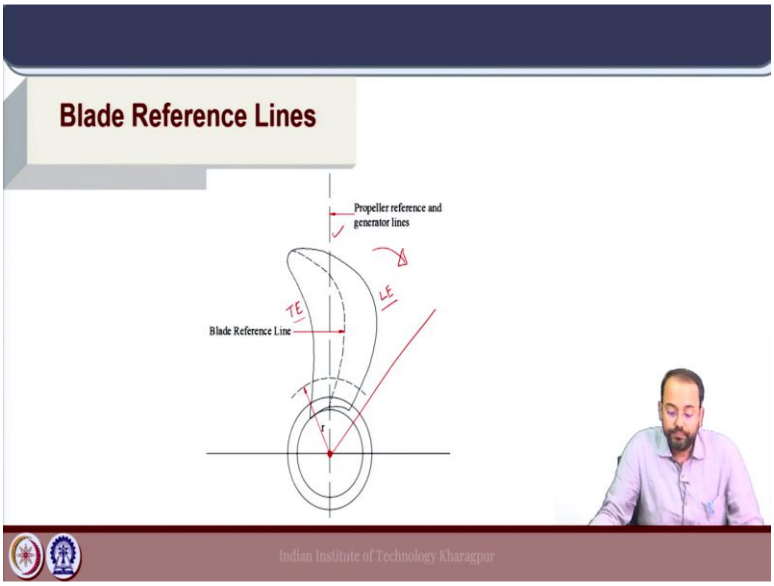

Now, there are set of reference lines which are sometimes used to define propeller blade characteristics. So for example, we have the propeller reference line, which is perpendicular if I draw the shaft axis will be perpendicular at this point to the plane of this paper. So, the shaft will be somewhere perpendicular to this plane. So, the propeller reference line, in this case, is perpendicular to the shaft axis and for the blade of the propeller, another blade reference line is defined when we define certain angles like a skew.

The blade reference line is basically the locus of the midpoints between the leading and trailing edge of the propeller. So, if we consider this particular propeller blade the leading edge will be this one. So, we are seeing the face of the propeller blade sitting from the back. So, this will be the leading edge and the other one which will trail the other leading edge will be defined as the trailing edge and the propeller rotation direction is clockwise ok.

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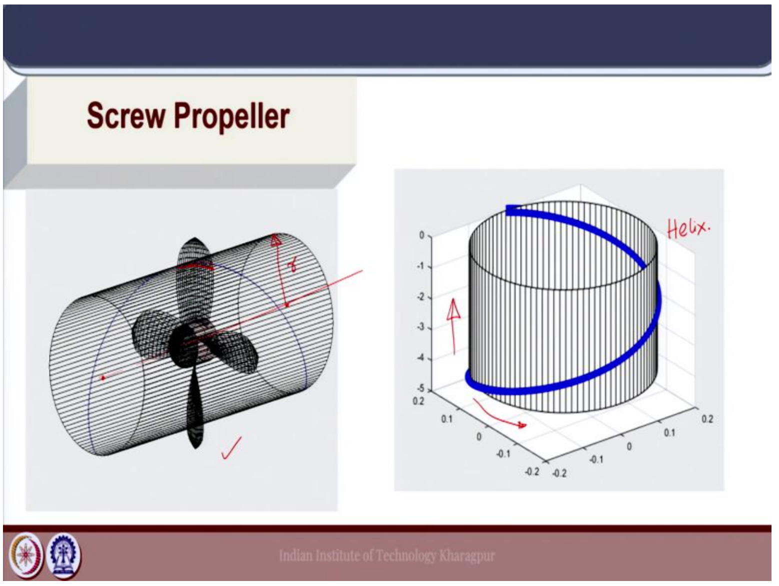

Now, why is a propeller called a screw propeller? As we have seen in the introduction class that the basis of a screw propeller comes from the concepts of Archimedean screw; that is screw having a certain pitch as it rotates along. Now when we have a screw it rotates along a central axis and it also moves forward.

So, if we have the propeller blade here in the first diagram, if we have the propeller blade and we intersect the blade with a coaxial cylinder which has the cylinder having the axis same as the propeller axis ok. Now each blade section that we have let us say we intersect the propeller at a radius r, if it intersects the propeller blade at a radius r then the section that we have the propeller blade section at the radius r will be defined as on a part of the helix.

Now, as the blade rotates and moves forward the surface it generates is a helicoidal surface. Now very simply how do we define it? If I take a point on the right hand side of you can see if I take a point on a cylinder ok and if it just moves around the cylinder on the base what will it trace the locus will be a simple circle. But if we take a point on the cylinder and we rotate around the cylinder and also move it around along the axis of the cylinder. So, we give it a rotation about the axis of the cylinder and also move it vertically along the axis.

So, the path traced by this point or the locus will be a helix, so this is a helix. So, a point on the propeller surface as it moves as it rotates and move forward will trace a helical path and if we see multiple turns.

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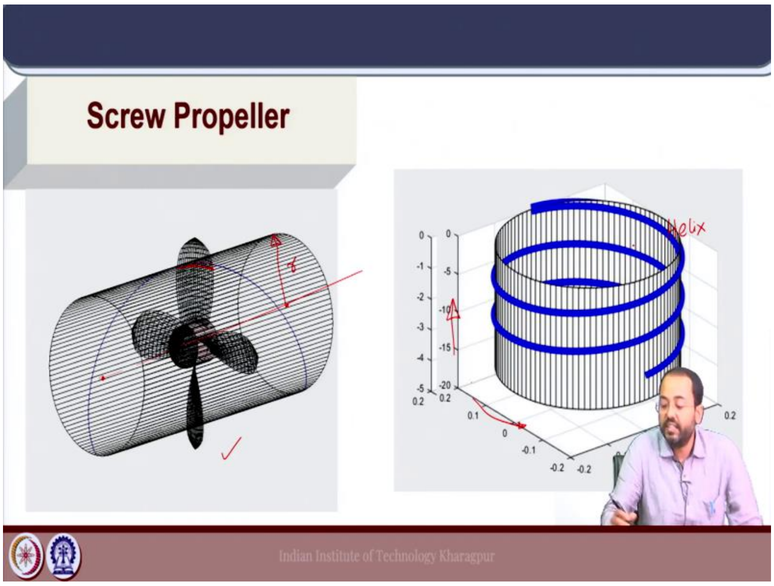

Now for the same diagram if we see multiple turns now you can visualize the helical surface in a better way ok, as it moves along the cylinder.

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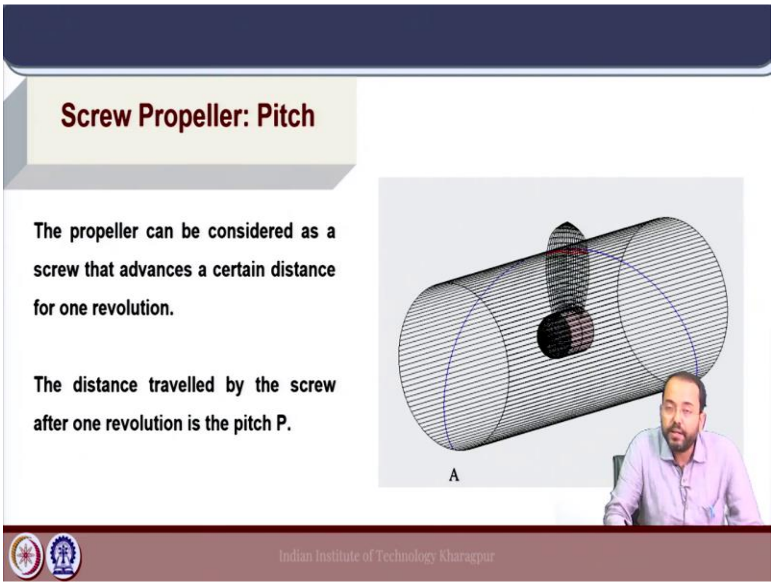

Now a screw propeller can be considered as a screw that advances a certain distance for 1 revolution ok. Now, the distance travelled by the screw after 1 revolution is called the pitch which is also used for helix. Now each propeller blade here in instead of the entire propeller we are showing only 1 blade of the propeller. So, each propeller blade if it is intersected here on the surface of a cylinder the path traced by a point on the blade will be a helical path ok.

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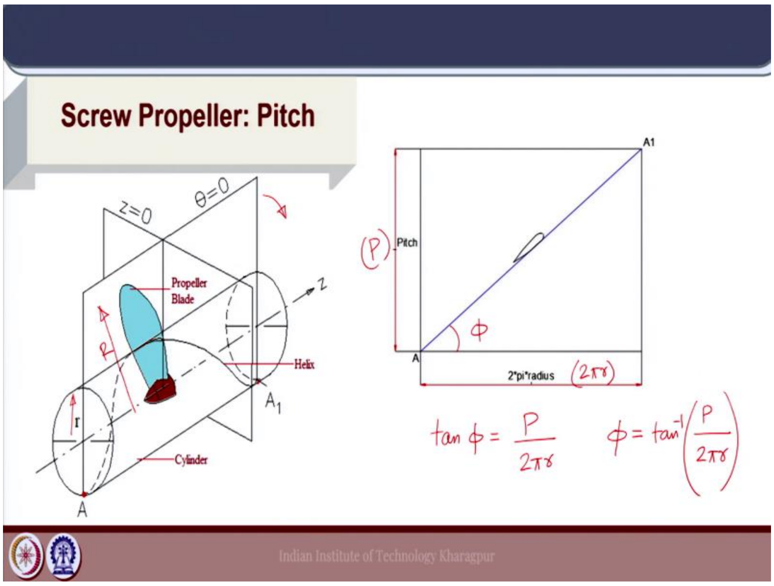

Now, if we try to visualize putting a set of axis on this entire diagram, we have the cylinder and we try to develop a very simple coordinate system which is basically the cylindrical coordinate system defined by r, θ, and z. Now, z is along the axis of the propeller here r is simply along the radius of the cylinder, and θ is defined with respect to the vertical.

That means θ is 0 in the vertical plane as the propeller blade rotates in the clockwise direction we will have θ gradually increase from its initial value of 0. So, z equal to 0 plane is defined at the central axis of the propeller blade, z is positive in the forward direction r is in the radial direction and θ is the angular coordinate of the cylindrical coordinate system.

So, θ is the rotational angle of the propeller blade. Now, if the propeller blade rotates and moves forward on this cylinder what will happen? At a particular point initially let us say the blade was here and as it has gradually rotated the propeller; this section on the propeller blade is both advancing along the cylinder and also changing its position on the surface of the cylinder that is where the helical path comes in.

So, let us say it started at a point A and after some advancement, we have the present location of the propeller blade here. Now after one whole revolution on the cylinder it will come back to this point A again, but it has already advanced along the cylinder because the propeller is rotating and also moving ahead ok.

So, then the new point is A_1 on the cylinder. Now what we have done is from the point A to A_1 we unwrapped the helix what do we get this A-A_1 will be net on the diagonal and when we unwrap the surface of the cylinder what do we get? we get the circumference of the cylinder which is nothing but ($2\pi r$) and on the other side we will get the distance on along which the propeller blade has traversed along the axis of the cylinder.

So, basically when we are opening the whole diagram what do we get on one side we have the length by which the propeller blade has travelled after 1 whole revolution which is defined by the pitch of a helix. And on the other side because we have opened up the surface of the cylinder we have the perimeter or the circumference for a let us say of cylindrical body. So, it is ($2\pi r$). So, along the axis now or let us say along the diagonal we will have the location of the line A-A_1, so this angle which is defining the pitch of the propeller blade (ϕ).

Then we can write $\tan(\phi)$ is equal to this pitch(P) this is $2\pi r$; that means, $\tan(\phi) = P/2\pi r$. Now this r is a variable radius here shown because the actual propeller radius of the propeller blade will be somewhere here ok, we have just taken a cylinder of arbitrary radius r which is less than the actual propeller radius, and intersected it with the propeller to get a section of the propeller blade. And we are trying to get the locus of the section as it rotates one full revolution about the cylindrical axis ok.

So, for this particular section, the pitch angle(ϕ) can be given as $\phi = \tan^{-1}(P/2\pi r)$. Now, what if we take another section on the propeller blade? Now depending on the propeller blade design it can the propeller blades can have a consistent pitch; that means, pitch is constant with radius or it can be variable pitch. So, in that case we will have a different pitch angle if the pitch varies ok. Normally for a propeller blade the pitch is defined as a non-dimensional quantity.

As we see that in naval architecture most of the terms finally, because we need things to be expressed in both model and full scales we define with respect to certain non-dimensional quantities for ease of expression. So, propeller blade pitch is also non dimensionalized with respect to the diameter, because pitch is a dimension in linear unit in meter let us say we divide it by the diameter of the propeller blade and express it as a non-dimensional ratio we call it the pitch ratio ok.

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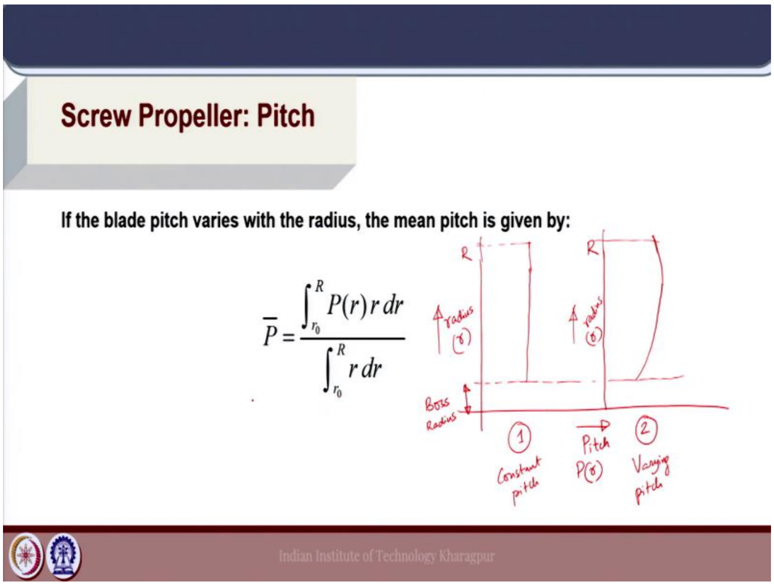

Now, let us try to understand this concept, if we plot the propeller radius in this direction we can plot it as radius or also non-dimensionalize it with respect to r and on the X axis if we plot the pitch. Now for a propeller where the pitch distribution is uniform we have to take out a certain part here which is basically the boss radius, where the blade is not present ok.

So, now if I have a pitch this pitch which is constant with radius. So, this will be the pitch of the propeller blade and let us say this is case1 for which the propeller is constant pitch. Now if we take a second case where, the pitch is varying with radius case2 where varying pitch. So, in this case the pitch will have a certain value; let us say I am again drawing a new axis here for ease of understanding radius.

So, the pitch here let us say is increasing and also normally towards the end the s short let us make the 2 diagrams of the same length for ease and this is equal to the radius of the propeller the actual radius of the propeller blade. Now in the second case the pitch is varying with radius ok. Now if pitch is varying with radius, so here we are talking of pitch. So, we write pitch as a function of radius in the X axis and the radius in the Y axis r right.

So, in the first case P(r) is constant. So P basically that means, P is not a function of r. So, the pitch does not vary with in the second case P is a function of r. So, we define the average pitch in this way we take the moment of the pitch about r and we define the average pitch of a propeller blade in using this particular equation integration of P(r) d r by integration of rdr. Now, see one important thing here the integration is not from 0 to r the integration is from r_0 to r.

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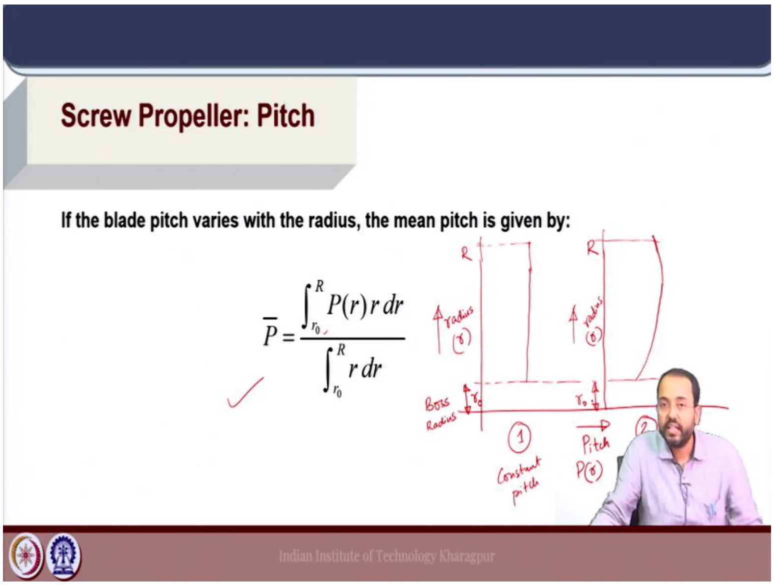

This is basically r_0 that is why we are starting the curves from r_0 right.

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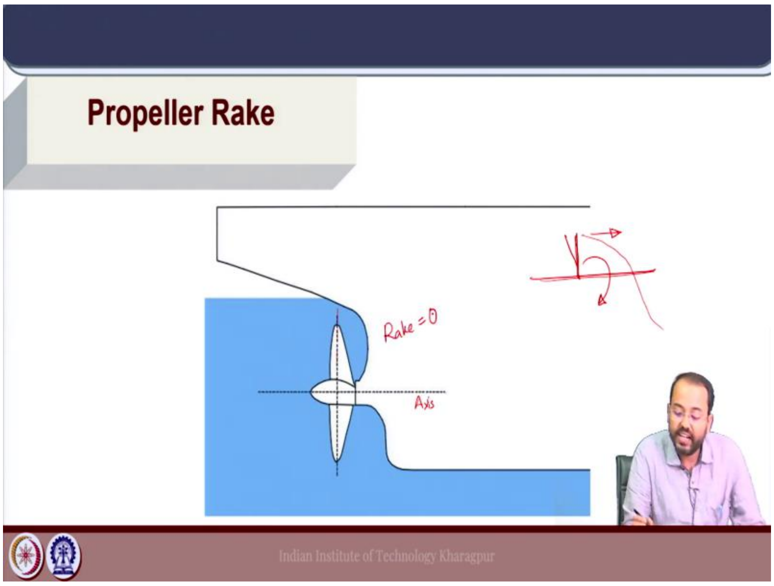

Next propeller rake is a very important angle to be considered in the geometry of the propeller, if the propeller is placed in such a way that the propeller axis is vertical ok. That means, the blade axis here the reference line is vertical with respect to the propeller axis. So, this is the axis of the propeller and if the blade is placed such that the blade references axis or the reference line of the blade; that means, now let us say we can define it with a very simple way the blade paths a traces a helicoidal path as it rotates that we have seen.

Now if we rotate a straight line with respect to this particular axis and if we rotate this straight line about this axis and also move forward. So, the path this straight line will trace this particular straight line will trace is a helicoidal path right. But now if we give a give a small angle to this straight line and again rotate about this and also move it forward.

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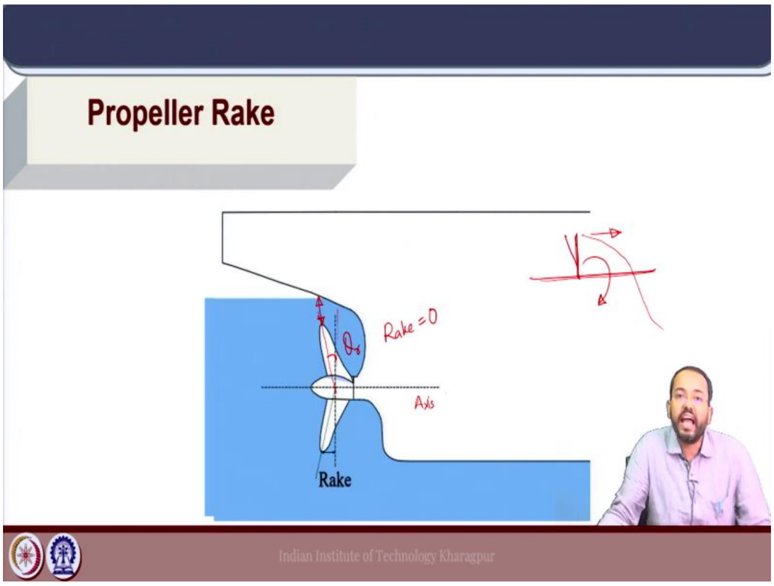

What we get is the path will be a helicoidal, but with an angle. So, this will be the generated path the screw propeller generated from such a line will have a rake. Now why is rake given to a propeller? The first one the propeller had in the earlier picture had no rake in this particular case. So, rake is 0 rake angle is 0.

In the next case the propeller has a rake angle which is given by θ_r. Now rake is given to increase the clearance with the hull. So, in some cases what it is observed that the propeller during design you will be able to appreciate it in a better way, that the clearance minimum clearance is to be required to maintain between the propeller blade and the hull.

Now, to maintain that minimum clearance sometimes the propeller diameter becomes restricted. Now, if we give a rake to the propeller blade; that means, if we incline it slightly towards the aft we can maintain a bigger clearance with the hull compared to the case if we did not have a rake. Now why is that clearance required? The clearance is required, so that the because the propeller is continuously rotating in the fluid medium what happens that it gives a periodic pulsation force.

So, that leads to hull vibration and discomfort of passengers and crew and also may lead to structural damage. So, that is why a minimum clearance between the propeller blade tip and the hull has to be maintained and for cases where sufficient diameter is not available the option of raking a propeller blade slightly towards the aft is used. Normally a rake angle of up to 15 degrees can be used for depending on the propeller design.

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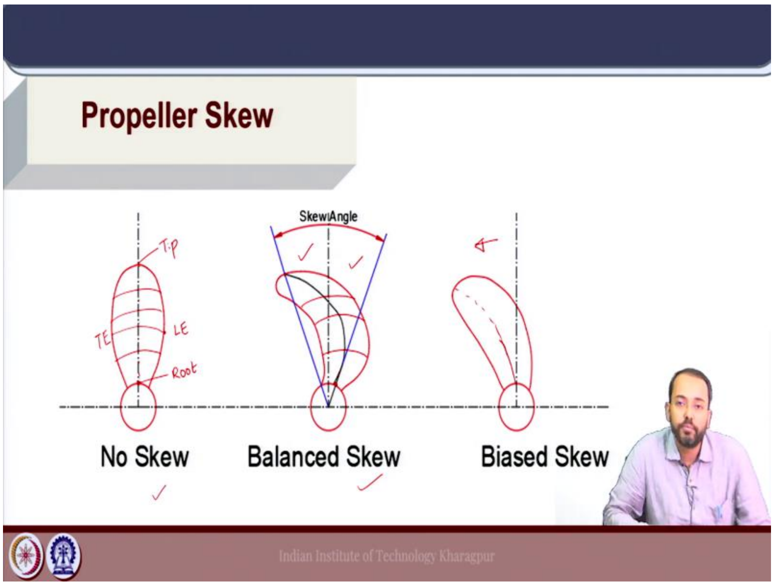

And another angle which is very important to define a propeller is the propeller skew angle. Now, if we see the propeller blade from the face. So, if you stand behind the propeller blade a propeller can have no skew; that means, the blade axis this is the blade reference line that we have seen which is connecting the central of the leading as well as the trailing edge. That means, if you have the leading and trailing edge if we join the midpoints of the leading and trailing edge right from the root this is the root section of the propeller blade and this is the tip.

So, if we join the midpoints of all the propeller blade sections right from the root to the tip ok. If that is purely vertical with respect to the horizontal line; that means, the propeller has no skew. In most cases in propeller designs the blades are skewed back. That means, if I join the central line between the leading and trailing edge for each section. Now remember here also the section that we are talking about are the cylindrical sections at taken at certain radii.

Now, if they make an angle with between the midpoint at the base and the midpoint at the tip that angle is called the skew angle. So, depending on the skew it can be balanced skew; that means, part of the skew is towards the forward part of the central line the vertical line here which is the reference line. So, a part is here and another part of the skew is here.

So, the skew is distributed on 2 sides of the reference line or in the second case of biased skew. What is happening? The entire skew here the central line is somewhere here, so the entire skew is defined on only one side of the reference line that is called Biased skew. So, why is skew given for propeller blades, because the propeller is working in a field in a velocity field in a flow field which is disturbed by the presence of the ship and that we call as the wake-field the concepts of which we will cover later.

But as of now let us try to understand that the flow characteristics on the propeller blade are not constant all over the blade. So, because of the velocity distribution which varies it is observed that providing a skew to the propeller blade makes the flow more uniform on the propeller blade and it improves the performance of the propeller blade and leads to better efficiency.

And it makes the flow more uniform over different chord-wise locations on the propeller blade , that is why most propellers skew is provided. So, this will be all for the basic concepts covered in this class we will continue with propeller geometry again in the next class.

Thank you.