Marine Propulsion
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Lecture - 16
Hull-Propeller Interaction

Welcome to lecture 16 of the course Marine Propulsion. Today we will discuss Hull-Propeller Interaction.

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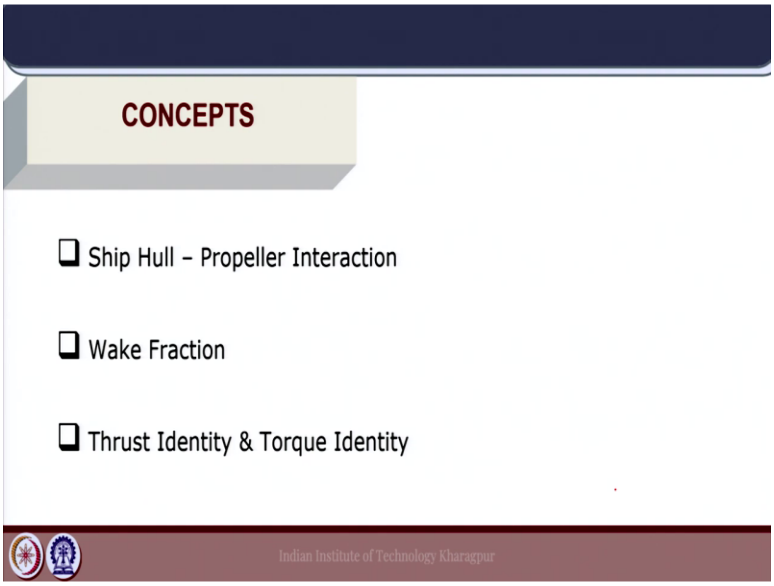

The key concepts covered in today’s lecture will be the basic aspects of hull propeller interaction, concepts of wake fraction, thrust identity and torque identity.

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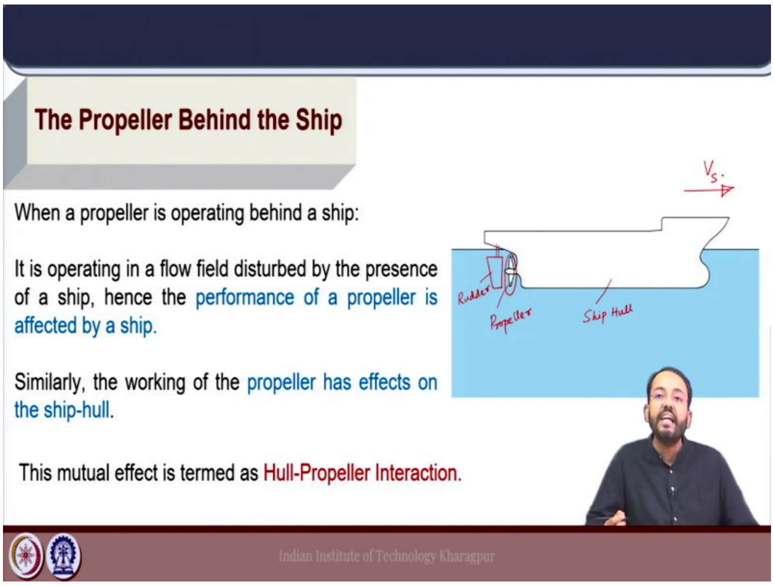

In the last week, we have covered different aspects of propeller performance in open water; that means, the propeller was working in uniform inflow condition without a ship in front of it. And, we have estimated the intrinsic characteristics of the propeller in terms of its thrust coefficient, torque coefficient and open water efficiency. Now, for a realistic condition the propeller should operate behind the ship for actual operations at sea.

And, this creates the concept of hull propeller interaction because, the propeller has an influence on the hull and also the hull has an influence on the propeller performance. So, the first thing here is the flow field into the propeller is disturbed by the presence of the ship hull. And, hence this modifies the propeller performance and also the working of the propeller will have some effects on the ship hull. This mutual effect taken together is called hull propeller interaction. So, in this simple diagram we have the propeller here and this is the ship hull.

In addition to that we will have the ship rudder here. This rudder is used for maneuvering the ship. So, the propeller slip stream will also have an influence on the rudder performance. Now, if we look at the different aspects of hull propeller interaction for example, we have the propeller and we have the ship hull. So, for the same ship hull if we change the propeller, the powering process will be different.

Because, different propeller designs will have different performance based on the geometric aspects of the design that we understand from the propeller theory and the open water performance discussion that we have done. Now, on the other hand if we change the ship hull for example, for the same propeller design if we change the design of the hull of the ship.

Typically, the design near the stern which impacts the flow into the propeller then what will happen? The flow field into the propeller will change and because the flow field will change the performance of the propeller will be changing. So, the aspects of hull propeller interaction in brief will cover the impacts of the propeller on the hull performance and also the impact of the hull on the propeller performance.

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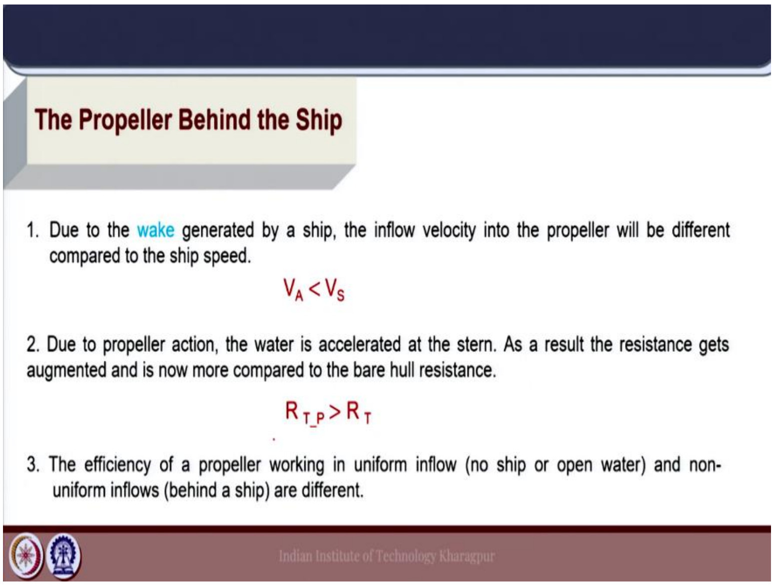

So, let us look into the basic aspects which are very important in defining certain parameters which will relate to the propulsion performance of the ship and propeller in unison. So, the first thing is the wake. When a body is moving in a fluid there is a wake generated due to the geometry of the body and the flow characteristics. And, this wake of the ship will define the inflow velocity into the propeller.

And, because the propeller is behind the ship that inflow velocity on the propeller plane will be different from the ship speed. And, that will again depend on the geometric design of the ship, typically the stern region which impacts the local velocities in a higher way. So, V_A which is the velocity of advance for the propeller which has been defined for example, in open water condition that V_A was the velocity at which the propeller was moving forward. So, there was no body in front of the propeller. Now, we have a ship.

So, the ship is moving forward with a speed V_S. The propeller is also attached to the ship. So, ideally it is also moving forward with a velocity V_S, because it is attached to the ship. But, because of the wake field created by the ship if we stand in the position of the propeller. So that means, if we stand in the position of the propeller here and the ship is moving forward with a velocity V_S. One will see that the average velocity at the propeller plane will be different from the speed V_S at which the ship is moving forward.

And, it will be seen that this particular velocity V_A which is the velocity of advance defined for the propeller will be lower than V_S. And, the reasons for this will be discussed in this lecture. Now, the second action is the propeller is working behind the ship and it is accelerating the water at the stern region of the ship. Because, of that the resistance of the ship gets augmented and this resistance becomes higher than the bear hull resistance.

That is why R_{T_P}, the resistance of the ship; the total resistance with a working propeller behind it is higher than R_T, where R_T is the total resistance measured from the resistance test, where there was no propeller ok. And, the third is the efficiency of the propeller working in uniform flow. For example, in the open water condition will be different to the case which is the actual condition of propeller operation behind the ship that is non-uniform flow field. So, the efficiencies of the propeller will be different in these two different conditions.

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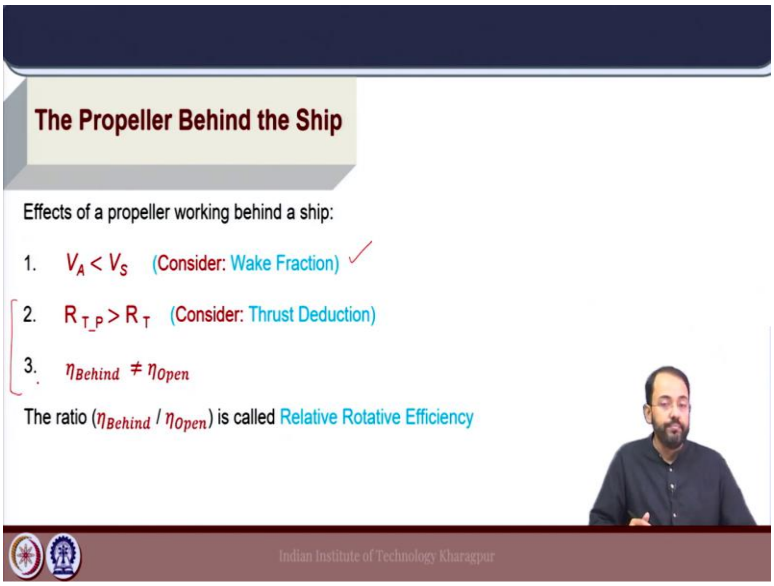

Now, if we look into these effects, the first one is the velocity of advance is lower than the ship speed and this leads to the consideration of wake fraction. The increase of resistance due to propeller action with respect to the total resistance measured during the resistance test is taken care of by a factor called thrust deduction. And, the difference in efficiency between the behind and open condition is taken care of by a factor called relative rotative efficiency.

So, in this particular lecture, we will cover the first point which is the wake fraction and we will discuss two different identities; thrust and torque identities to calculate the effective wake fraction of a hull propeller system. Regarding, the points 2 and 3, thrust reduction and relative rotative efficiency; these will be discussed in the next lecture.

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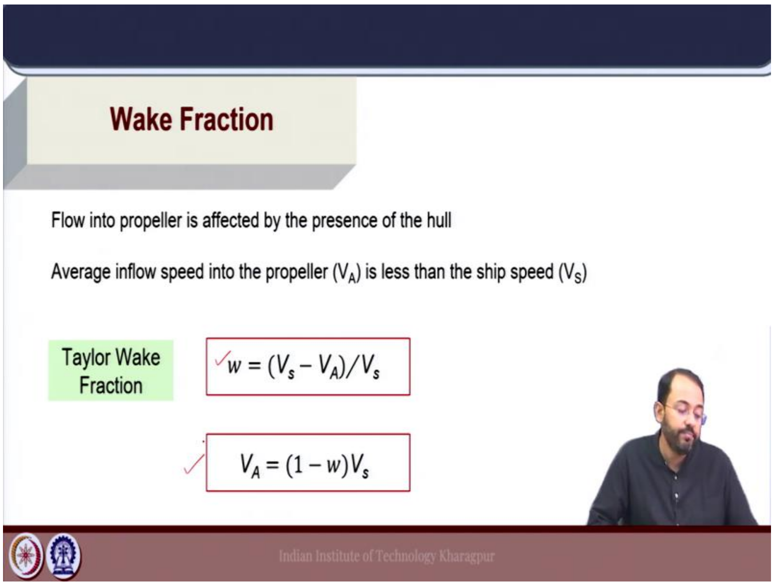

So, let us look into wake fraction. The flow into the propeller as we have just seen will be different from the flow condition in the open water condition, where there was no ship. That means; the average inflow field into the propeller V_A is less than the ship speed and that is how we define the wake fraction. The most standard way of definition is the Taylor wake fraction defined by Admiral Taylor, where the wake fraction denoted by w is defined by the difference in speed V_S - V_A divided by the ship speed which is taken as the reference.

Because, in the behind hull condition which is the actual operation condition for a ship; the ship speed. The speed at which the ship is moving ahead is the standard reference speed. And V_A is something we do not know, that we will see how we can compute the value of V_A for behind hull conditions using wake fractions. Now, in this way the wake fraction is defined with respect to the speed of the ship as well as the advance speed V_A.

Now, the same way V_A can be related to V_S using the value of wake fraction. So, next we will see the physics of this particular wake fraction; that means, why is the difference between V_S and V_A coming into the picture. What are the major causes of this particular differences?

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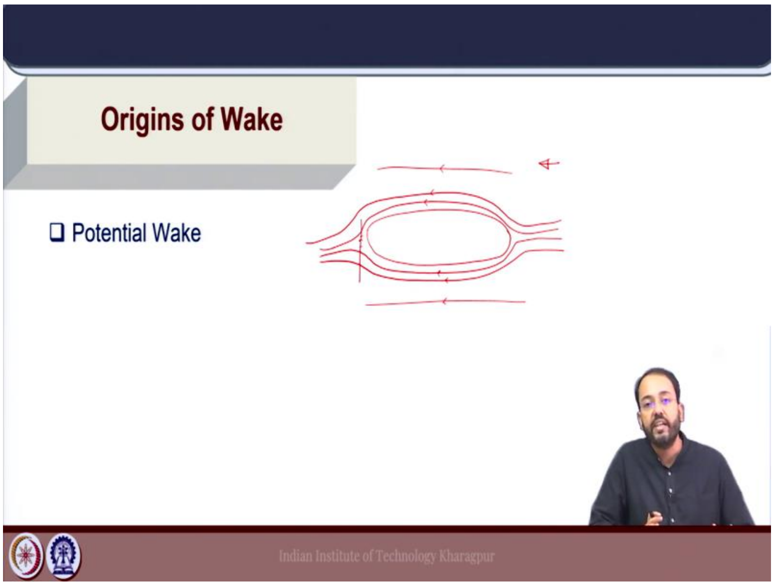

The first one as we call is the potential wake. If we have a body with an inflow here so, and consider potential flow condition, the stream lines will go around the body. We are neglecting viscosity here right and far away the stream lines will not be affected by the presence of the body. Now, because of this in this particular region, just in the wake of the body where we are concerned with because the propeller is present just behind the ship hull.

This particular diagram can be assumed to be a section taken at a water plane which is at any location on the propeller disc. Now, at this particular location behind the ship the stream lines will converge and because of that the pressure will be high, at that particular location. And, because of that due to Bernoulli's effect the velocity will be lower than the free stream velocity. And, that leads to a part of the wake fraction which is called the potential wake.

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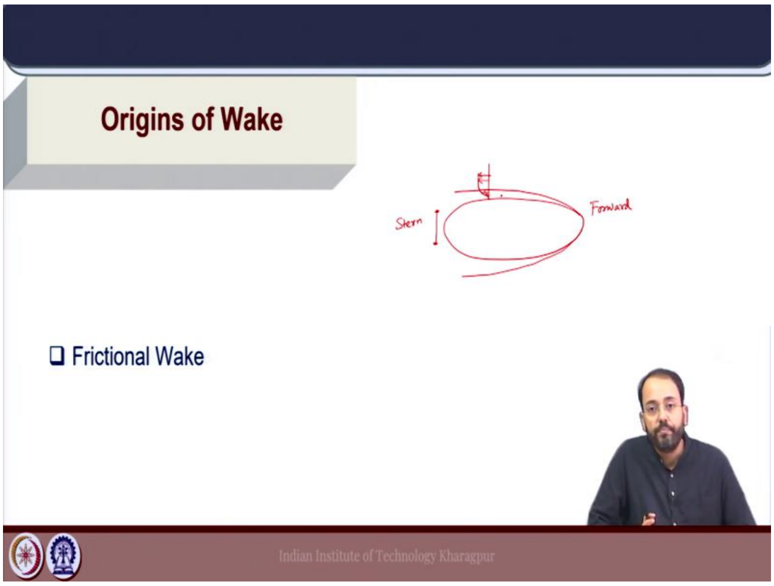

The next factor which has a major impact on the ship weight is the frictional wake. Now, if we try to look into the development of boundary layer on a ship, it will grow as we move from the forward of a ship to the stern. And, at the location of the propeller here the boundary layer effects will be strong because the propeller is located very close to the hull and there can also be local separation effects.

So, if we try to look at the velocity in the boundary layer, approximately the profile will be somewhat like this where the free stream velocity is outside. And, the local velocity will be much lower depending on the Reynolds number. And, due to that there will be a velocity deficit at the propeller plane where the boundary layer effects are strong.

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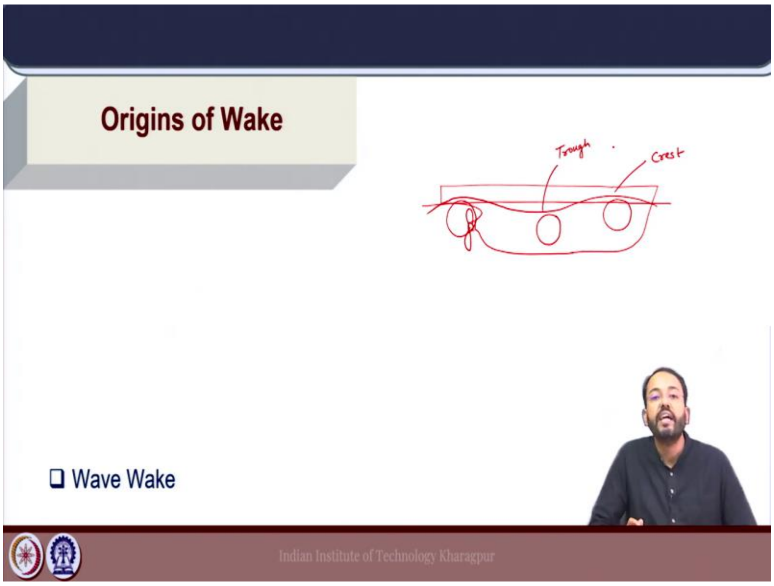

The third factor here is the wave wake. So, if we look into the location of the propeller behind the ship. The ship due to its motion forward at a particular speed creates a wave and this particular wave generated by a ship, this wave pattern depends on the Froude number of the ship. Due to this wave making pattern of the ship which is Froude number dependent or; that means, it is forward speed dependent, the wave pattern will impact the particle velocities just below the wave.

That means; we can take the crest of the wave or we can take a point at the trough of the wave and below the crest and trough the particle velocities, the directions as well as depending on the waves that are generated, the velocities will be different. Now, these create a small portion of the wake velocity and leads to the formation of wake fraction at the propeller plane. If sufficient depth of immersion is there, the portion of the wake influenced by wave is small as compared to the frictional wake and potential wake.

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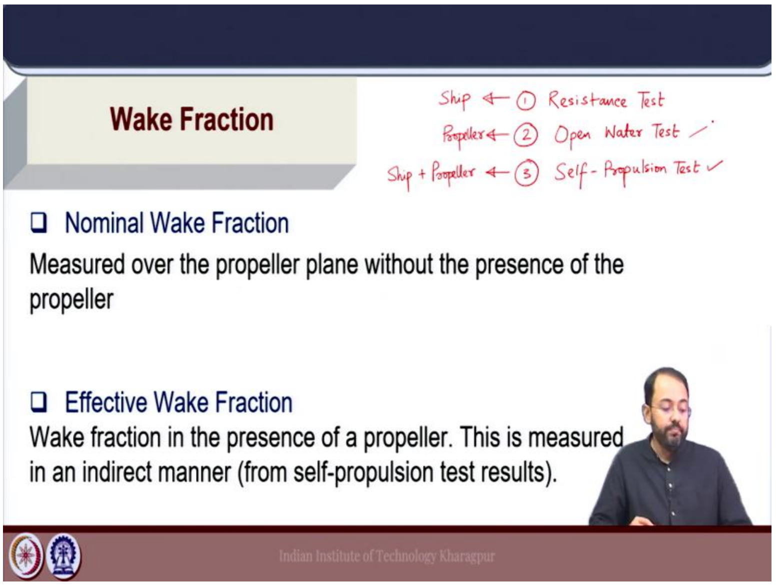

Now, these three effects create a difference between the forward speed of the ship V_S and the speed of advance of the propeller V_A. The difference is called the wake fraction which is expressed as a non-dimensional fraction divided by the forward speed of the ship. So, there are two ways of defining wake fraction.

The first one is the nominal wake fraction; that means, if we measure the velocities at the propeller plane behind the ship without the propeller being present that can be done using flow measurement devices placed at that specific location on the propeller plane at different points.

So, both radially and circumferentially we can measure the velocities at the propeller plane. So, that the effect of the ship hull in modifying the flow at that particular location is calculated by measuring the velocities without the propeller itself being present; that means, it is only the effect of the ship, that is called the nominal wake fraction. So, it can be measured using simple flow measurement experiments. For example, using Πtot tube or other flow measuring devices.

The other type is called the effective wake fraction; that means, when the propeller is working behind the ship, due to the action of the propeller itself the flow field into the propeller is modified. We have seen that the propeller induces velocities. So, both axial as well as tangential induced velocities have been calculated under propeller theory.

So, the propeller action itself will modify the wake velocity at that particular plane and this is called the effective wake fraction. When the wake fraction is computed with the working propeller and this is done in an indirect manner with the results from self-propulsion tests. Now, in this connection I should mention the three basic tests which are used in naval architecture for ship powering. The first one is the resistance test, second one open water test, third one is a self-propulsion test.

These are done in the model scale and these experiments are required to get the powering of the ship in the full scale. In the resistance test, we have only the ship in the model scale. In the open water test, we have only the propeller. In the self-propulsion test, we have the ship plus propeller. So, a detailed discussion of these different tests with actual videos of tests will be shown in the lectures under the model tests.

So, as of now this particular information is required that in the self-propulsion test, we have the ship and propeller working together. And, we can use thrust and torque identities as we will discuss later in this lecture to calculate wake fraction from the results of self-propulsion test and using the open water diagram that we have already discussed in the last week.

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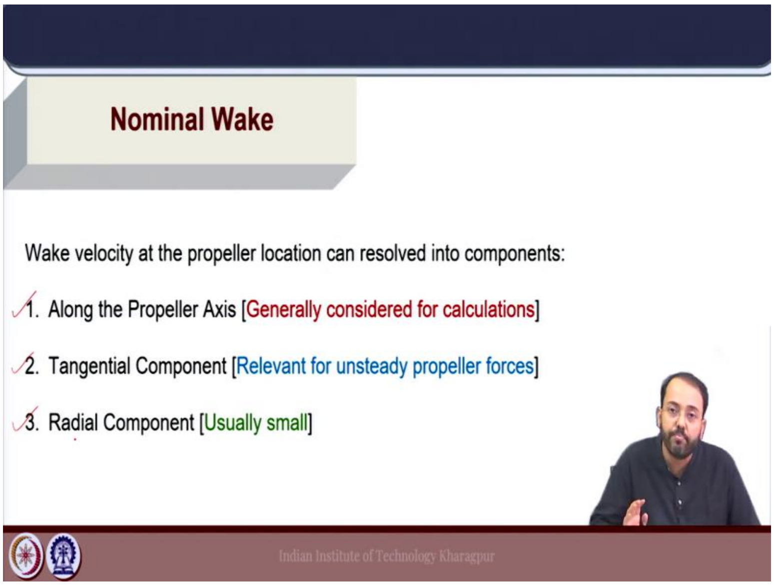

So, the different components of nominal wake are the three components. One in the axial direction which is the most important component and that is used for the propeller calculations. Because, the axial component of the wake fraction is what impacts the V_A

velocity of advance of the propeller. The other two components are tangential and radial components. The tangential component is only required for calculation of unsteady propeller forces and some specific calculations.

And, the radial component is usually small. So, here we will look into the axial component of the nominal wake which is along the x axis; that means, along the direction of the ship motion.

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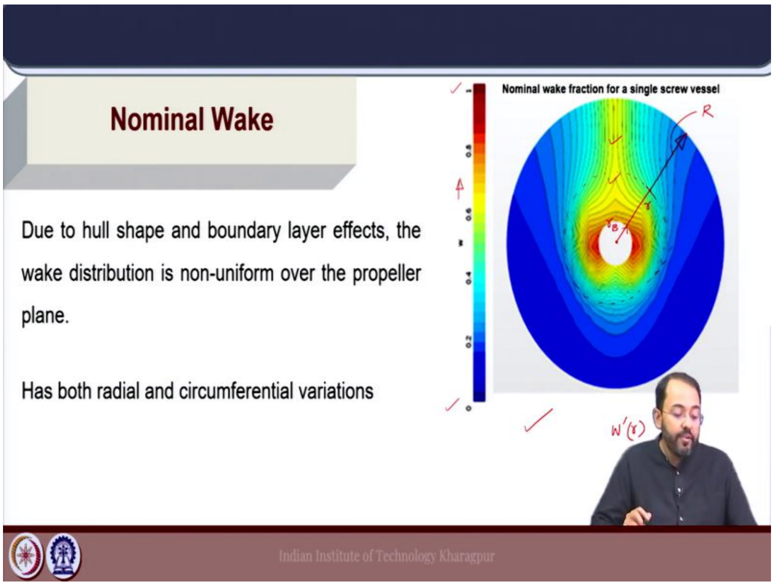

This diagram gives a plot of the axial component of the nominal wake fraction; that means, the wake fraction without the presence of the propeller and how it varies over the entire propeller disk. The value close to 1 is at the location, where the velocity deficit is maximum; that means; the blockage effect of the hull is maximum. And, the value which is close to 0; that means, V_A will be equal to V_S, where wake fraction is 0; where the flow is equal to the free stream velocity.

Now, we see that in the vertical position around this zone, the blockage effect is maximum and the value of wake fraction is in the higher range. And, the wake varies in both the radial as well as in the circumferential direction across the propeller plane. Now, due to the hull shape and the boundary layer effects, that we have discussed combination of both the potential and the frictional wake.

The wake distribution is highly non-uniform as we can see from this diagram. Now, appreciating the non-uniformity of wake is very essential here to understand how the propeller faces differential velocity field across the different positions on the propeller disc as the blade moves.

And, this leads to both radial as well as circumferential variations. So, very simply if we take a radial line here. This entire radius is the total propeller radius and this particular length is the radius of the boss. So, the wake is plotted only in the region where the propeller blades are operating. Now, at any radius small r, let us say here this radius r as we have taken before which is a variable radius.

One can average the circumferentially varying wake at that particular radius. And, we can write it as w'(r) which is the circumferentially averaged wake fraction at that particular radius. So, it will be a function of radius, I can take another radius and that value will be different.

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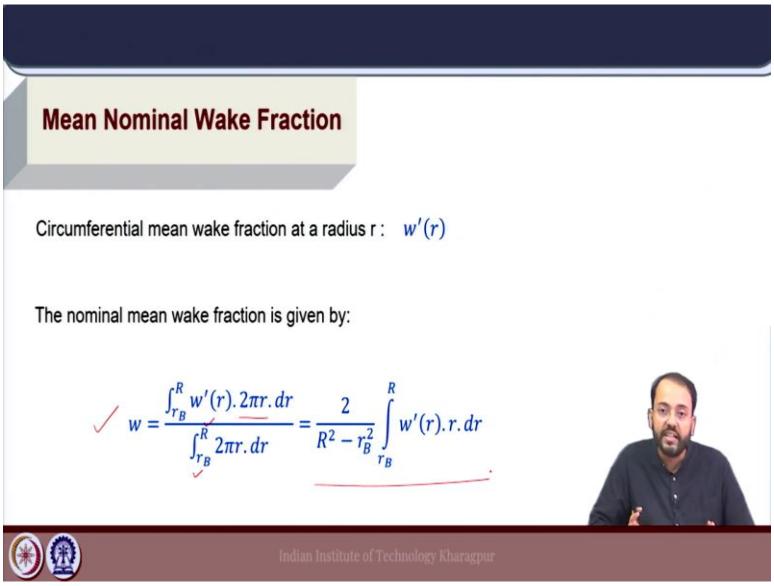

And, we can use this particular value to calculate the mean nominal wake fraction because, ultimately we want one particular value to do the estimation of ship powering. So, if we calculate the wake fraction by one particular value, it should be the averaged value of the wake fraction over the entire propeller disc, where the blades are located; that means, between the radii r_B and R.

So, if we take this mean wake fraction at a radius r, the nominal mean wake fraction will be given by this expression which is the averaged value calculated over the entire propeller disc, that is why it is integrated over 2 π r. Because, these strips are taken at radial locations and the total circumference at any radius small r is 2 π r. And, it is integrated over the entire range from the boss to the total radius of the propeller.

And finally, we have this particular value as the mean nominal wake fraction; that means, if we use an experimental apparatus. For example, pitot tubes or other flow measurement device to measure the nominal wake at different locations on the propeller disc, one can do this averaging to obtain the mean nominal wake fraction over the entire propeller blade.

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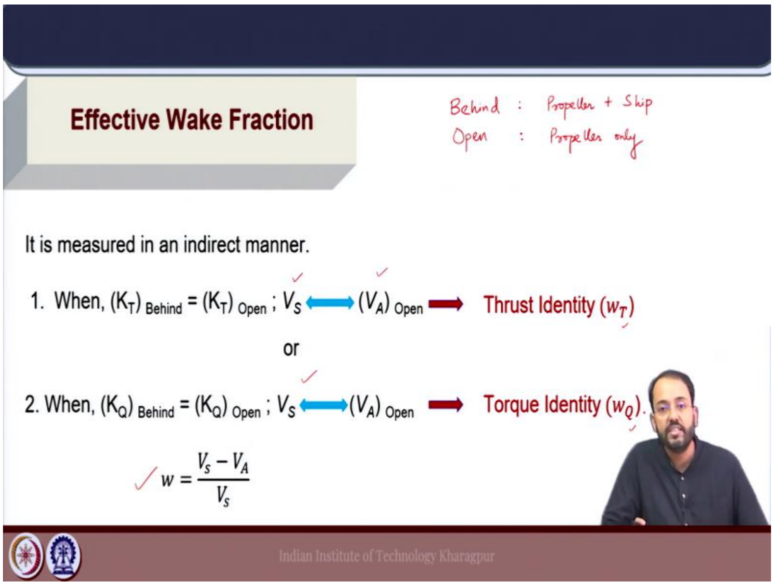

Now, we will move on to the effective wake fraction; that means, the wake fraction when the propeller is working behind the ship. In this particular case, we do not measure it directly. It is estimated in an indirect way; that means, we use the different identities, the thrust and torque identities using the results of the self-propulsion test and the open water test.

Now, as mentioned we will discuss this model test separately under a different lecture for model test experiments. As of now, let us try to understand that the behind condition refers to the propeller plus ship, when the propeller is working behind the ship. And, the open condition refers to propeller only which is the open water test condition. And, behind condition means the self-propulsion test condition which is the actual ship operation condition the propeller is operating behind the ship.

Now, there are two identities which we normally use for estimation of effective wake. First the thrust identity, we assume that the thrust coefficient of the propeller in behind condition is equal to the open condition. And, assuming that we relate the ship speed to the V_A from the open water diagram, we will see how it is done and we calculate the wake fraction. Similarly, using the torque identity, we assume the torque coefficient in the behind condition is equal to the open water torque coefficient.

And, we relate the ship speed to the V_A in open water and calculate the wake fraction as per this particular equation that we have already seen. Now, the thrust identity and torque identity gives us slightly different values of wake fraction. And, we mention it using a suffix T and Q, just to relate them to the exact identity by which it is calculated ok. And, for normal self-propulsion test calculations, we use thrust identity to do ship powering calculations.

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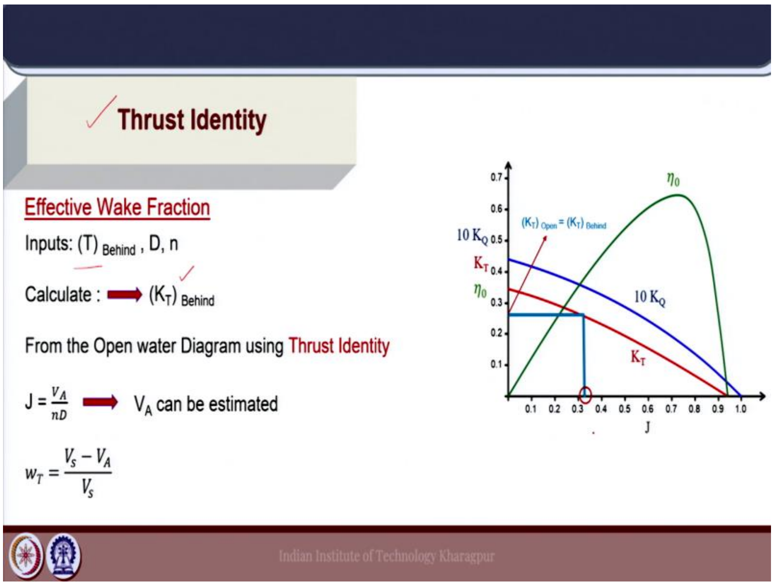

Let us look into each of these identities. First the thrust identity. Here the inputs are the thrust in the behind condition will be known. For the propeller working in behind condition the thrust is measured. And, we know the propeller diameter and rpm. Using that we can calculate K_T behind. We know the equation of the thrust coefficient. Now, using this K_T we enter the open water diagram of the propeller. This diagram is basically a plot of K_T,

$10K_Q$ and η_O versus J that we have already seen. So, to enter into the open water diagram we use K_T behind in the thrust identity.

So, we have the value of K_T by the measured value of thrust in the behind condition and using the diameter and rpm and we enter the open water diagram. Assumption is K_T open is K_T behind and for that particular case we calculate what is the J for the particular propeller. Now, what is J? J is V_A/ nD. Now, we can use this value of J to calculate V_A, because propeller n and D are known.

So, we can do the calculation of effective wake fraction in this particular case by using the ship speed. And the V_A here, the velocity of advance of the propeller which is calculated using thrust identity; that means, I entered the open water diagram by assuming K_T in the behind condition as K_T in the open. So, here we assume the thrust generated by the propeller in the open water and behind condition, its characteristics are same. So, accordingly we calculate the wake fraction using thrust identity.

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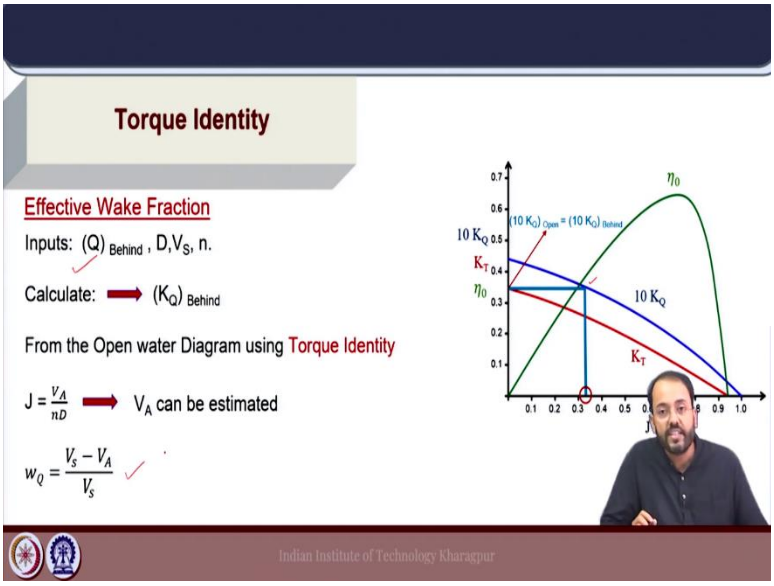

In the other way, which is the torque identity we calculate the torque coefficient based on the torque of the propeller in the behind condition, the measured torque here. And, we can calculate K_Q behind using the standard equation for torque coefficient. And, we enter the open water diagram using torque identity; that means, the value of $10K_Q$ is now known, because we assume that the propeller torque coefficient is same in the behind and open water condition.

So, we multiply it by 10, get the 10 K_Q and for that particular case in a similar way, we calculate the value of J at that specific point here. And, that J is again given by V_A (the advance speed) / nD and we can use it to calculate V_A, if n and D are known for that specific condition. And, again the wake fraction can be calculated using the same equation with this new V_A. Now, this particular V_A is the V_A coming from torque identity and we can calculate the wake fraction using torque identity.

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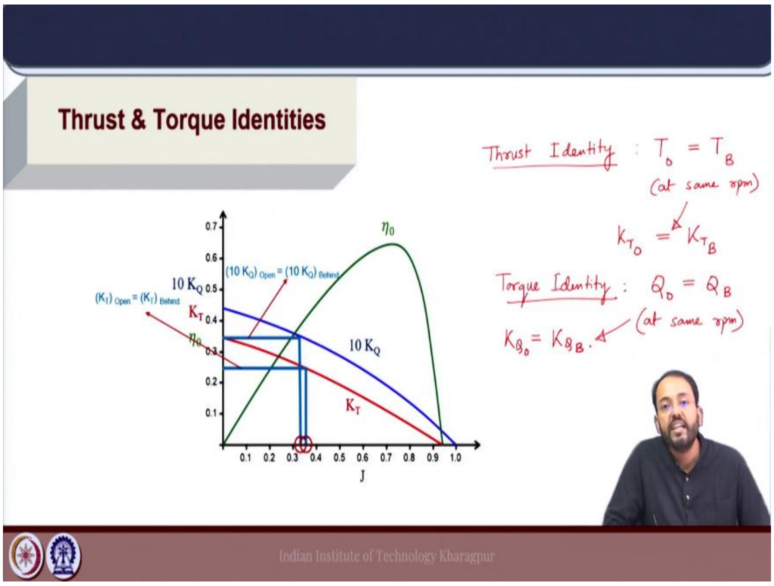

So, if we sum up the concepts of thrust identity and torque identity in a very simple way, the idea for thrust identity is that the thrust generated by the propeller in the open water and behind condition is same when it is operating at the similar rpm. That means, thrust in open water equal to thrust in behind at same rpm which gives the condition of K_{TO} equals K_{TB}.

In a similar way, the concept for torque identity can be written as torque in the open water condition is equal to the torque in the behind condition at same rpm which implies K_{QO} equals K_{QB}. Because the propeller is producing same torque at the same rpm, if we assume torque identity. Now, either thrust identity or torque identity is required to enter into the open water diagram, when we have the results of the propeller thrust and torque in the behind hull condition.

So, this is how we use these two identities to compute the wake fraction and other aspects of hull propeller interaction. In the next lecture, we will discuss the other aspects of hull propeller interaction like thrust deduction and relative rotative efficiency. This will be all for today’s lecture.

Thank you.