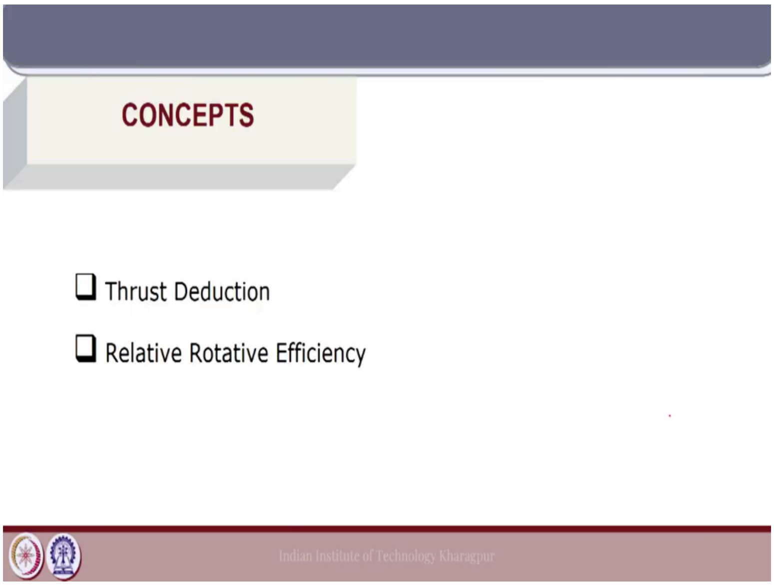
Marine Propulsion
Prof. Anirban Bhattacharyya
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Lecture - 17
Hull - Propeller Interaction (continued)

Welcome to lecture 17 of the course Marine Propulsion. Today we will continue with Hull-Propeller Interaction.

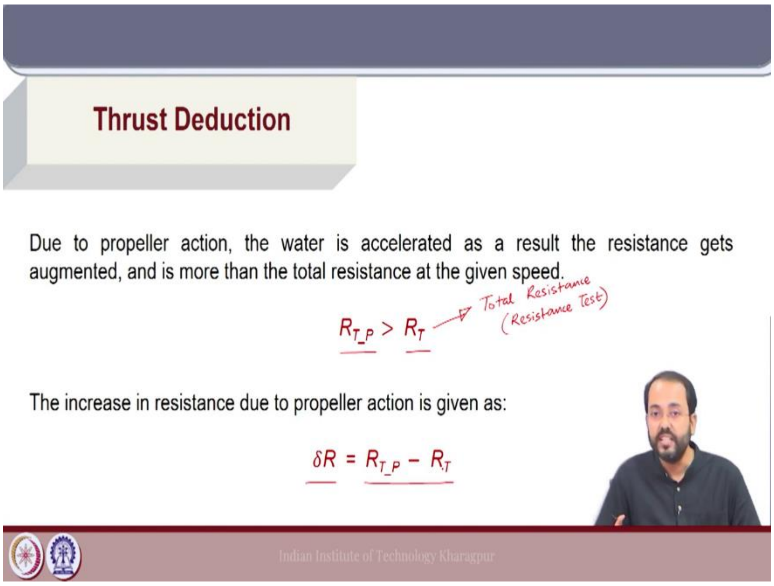
(Refer Slide Time: 00:33)



So, the key concepts covered in today’s lecture will be thrust deduction and relative rotative efficiency in the context of hull propeller interaction. So, in the last lecture we have seen the main aspects of hull propeller interaction that includes the effect of the hull on the propeller performance and also the effect of the propeller on the ship hull.

So, the main aspects of these interactions are the wake behind the ship hull at which the propeller operates. And, then the propeller accelerating the flow in the half part of the ship and the relative performance of the propeller in the open water and behind hull which gives rise to all these factors that we are studying.

(Refer Slide Time: 01:25)



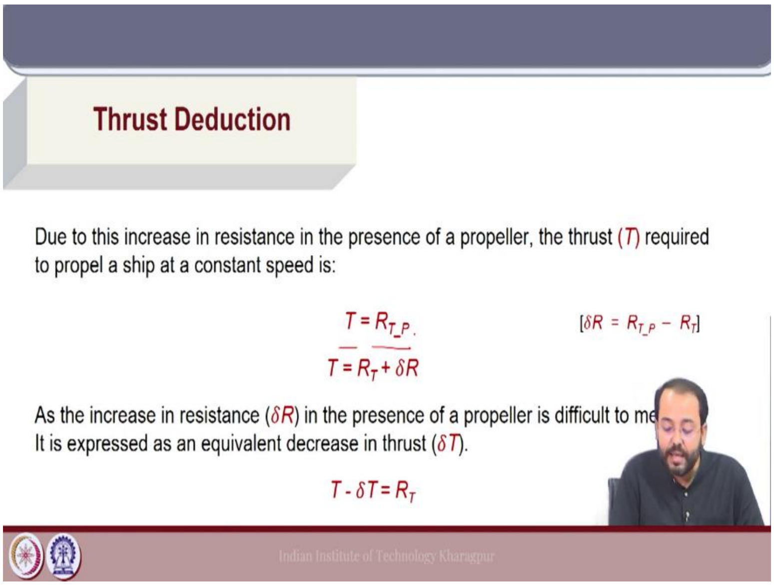
When the propeller operates behind the ship hull it accelerates the flow which is at the stern part of the ship. And, this results in the increase of the resistance of the hull. Now, this is shown here as the resistance of the ship which is the total resistance R_{T_P} in the presence of propeller will be higher than R_T. So, here R_T is the total resistance measured during resistance test.

So, if we do a resistance test where we do not have any propeller, then R_T is the total resistance. Now, during a self-propelled condition when the propeller is working behind the ship hull, the propeller accelerates the flow and that causes an augment of the resistance. So, R_{T_P} is the case which is the resistance when the propeller is working behind the ship and that also depends on the thrust loading of the propeller.

Now, how does it do it? When the propeller rotates, it accelerates the flow and also because of that there is a low-pressure region to in the turn of the ship. And, as a result we have a increase in the resistance which is higher finally, compared to the calm water resistance that we measure the total resistance in the resistance test of the ship without the propeller.

So, δR is the increase of resistance let us say for a specific speed. If that is so, δR will be given by R_{T_P} which is the resistance with the propeller working minus R_T which is the total resistance at the same speed of the ship.

(Refer Slide Time: 03:35)



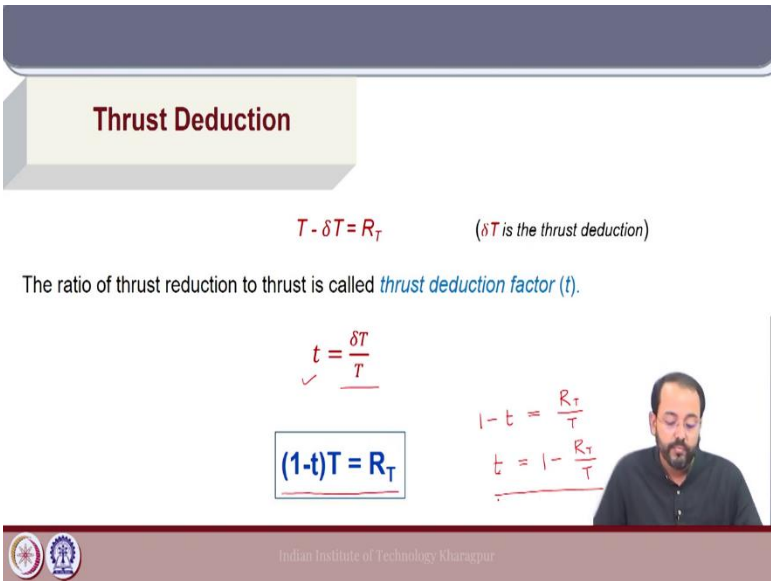
Because, of this increase in resistance due to the presence of propeller the thrust required by the propeller will be more. So, when the ship during the self-propulsion test or any practical case when a ship moves forward at the design speed, the thrust provided by the propeller should balance the total resistance in the self-propelled condition.

Now, that thrust T should be equal to R_{T_P} which is the total resistance of the ship with the propeller working behind. Now, because R_{T_P} is greater than R_T which is the resistance measured during the resistance test without the propeller, the thrust requirement should be higher as compared to the actual resistance without the propeller. So, in order to do this, we write $T = R_T + \delta R$. Now, it is very difficult to calculate or measure this added resistance due to the presence of propeller.

So, what we do for a practical purpose is we express it as an equivalent increase of thrust. So, if T is the thrust which is required to balance the resistance of the ship in the self-propelled condition, then the thrust that is required to balance R_T which is the total resistance of the ship that we measure from the resistance test should be lower than T by the amount δT, where δT is taken to be the same as δR which is the increase of resistance.

So, instead of increasing the resistance by δR what we do is we make an equivalent decrease of thrust. We see it as a loss of thrust, because our thrust has to now cater for the increased resistance in the condition where we have a working propeller behind that ship. So, in order to do that, we say that the thrust is reduced by the same amount by which the resistance was increased. So, T - δT = R_T which is the total resistance of the shift that we have measured during the resistance test ok.

(Refer Slide Time: 05:57)

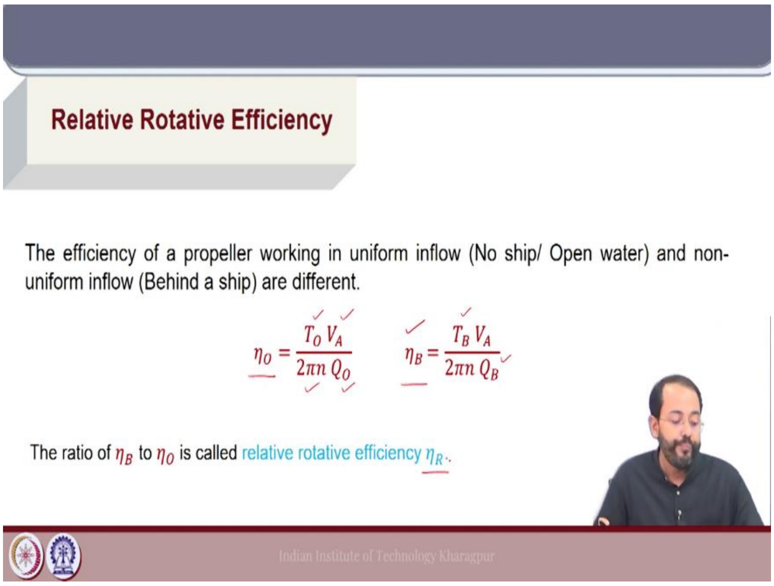


So, now this δT is; obviously, equal to δR which is the increase of resistance and the ratio of this δT to the thrust is called the thrust reduction factor. As we see in naval architecture, we express certain parameters as non-dimensional fractions. Here also we express this change in thrust or the thrust reduction as a fraction of the total thrust. And, mention it as t which is the thrust deduction factor or in some cases it is also mentioned as thrust deduction fraction.

Once we do it then we can express this thrust deduction fraction as a function of both the thrust and resistance in this form. So, the thrust that is measured in the self-propulsion test from the propeller is related to the total resistance of the ship, in the case where there was no propeller; the total resistance from the resistance test using the thrust reduction fraction in this way. So, we can write 1 - t = R_T / T, t = 1 - R_T/T.

Here t is the thrust of the propeller which is allowing the ship to move forward at a specific speed during the self-propelled condition. If there are more than one propellers in let us say, if there are two propellers then t is the total thrust from the two propellers. So, R_T is the total resistance from the resistance test for the ship without the propeller and t is the total thrust produced by a propeller or multiple propellers depending on the ship design. And, the thrust deduction factor t can be calculated using this expression.

(Refer Slide Time: 08:17)



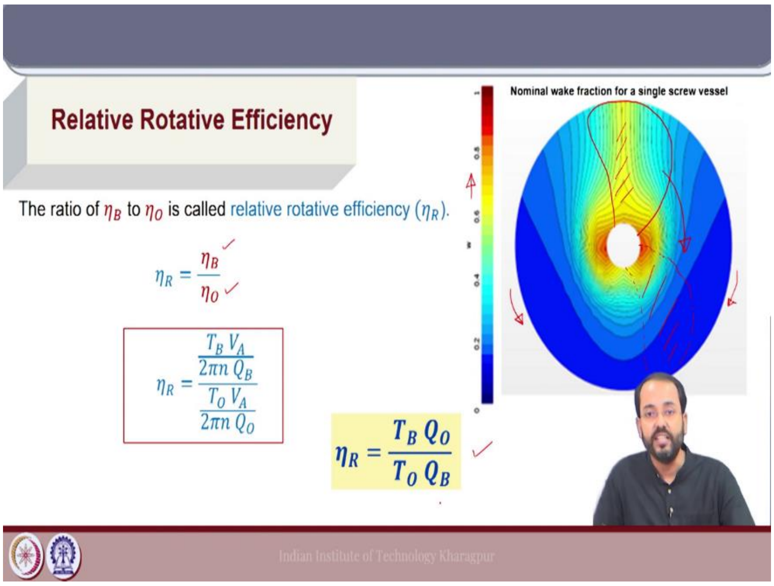
Next very important term is the relative rotative efficiency. So, when the propeller operates in uniform inflow then the flow into the propeller is totally uniform on the entire propeller disc. So, at each point on the propeller disc the inflow velocity is equal in the open water condition which is equal to the advance speed of the propeller.

Now, when it works in the behind hull condition then we have seen that the wake velocity of the ship is actually the inflow into the propeller. So, what the propeller faces is basically the nominal wake that we have already discussed. So, in this case the propeller works in a flow field where the velocities vary in both radial and circumference directions. Hence, the efficiency of the propeller when working behind the ship will be different from the efficiency in the open water condition.

This is mentioned in the condition of behind hull η_B. So, for the open water condition η_O, the efficiency is defined in this way T_O which is the thrust of the propeller in the open water condition multiplied by advanced velocity by 2 π n, the rotational speed into torque. So, in the behind condition in a very similar way instead of T_O and Q_O we will be having T_B and Q_B which are the thrust and torque in the behind condition.

So, η behind here is the efficiency of the propeller working behind the ship hull in the wake of the ship. So, the relative rotative efficiency is defined as the ratio of η_B to η_O. So, η_R is the relative rotative efficiency given by η_B divided by η_O.

(Refer Slide Time: 10:19)



So, one must understand here that the relative rotative efficiency is just a ratio of two efficiencies; that means, the efficiency of the propeller behind hull and the efficiency of the propeller in open water. So, strictly speaking the relative rotative efficiency is not an efficiency term. It is defined as a ratio of two efficiency terms. So, it is not defined as output by input power just like for example, how propeller efficiency is defined in the open water or behind condition.

So, each of these terms η_B and η_O are actual efficiency terms which define the ratio of output power by input power. So, these are practical efficiency terms for propellers, η_B and η_O, but η_R is just a ratio of two efficiencies. So, it is strictly not an efficiency term. Hence, the value of η_R can even be higher than 1.

So, if we see typically the value of η_R varies from anything between 0.95 to around 1.05 in that range. So, it depends both on the propeller design as well as the hull form design the stern part of the hull, how the flow into the propeller is happening and how the propeller is performing hull with respect to the open water ok.

So, now if we look at typically how the wake field is for a propeller. This is a nominal wake fraction plotted over the propeller disc for a single screw ship. So, it has only one propeller in the center line of the ship and the wake fraction is plotted on the entire propeller disc. The central part here, the white region is the hub region where we do not have the blades. So, the wake fraction is plotted only in the range between R_B to R where we have the propeller blades.

So, here we can see that the wake fractions are very high at the central locations, where the blockage effect is highest. So, the wake velocities will be low which will give rise to high wake fraction. And along the periphery, specially along this region and these regions the wake fraction value is very low because the velocities are very close to the free stream velocity or the ship velocity here.

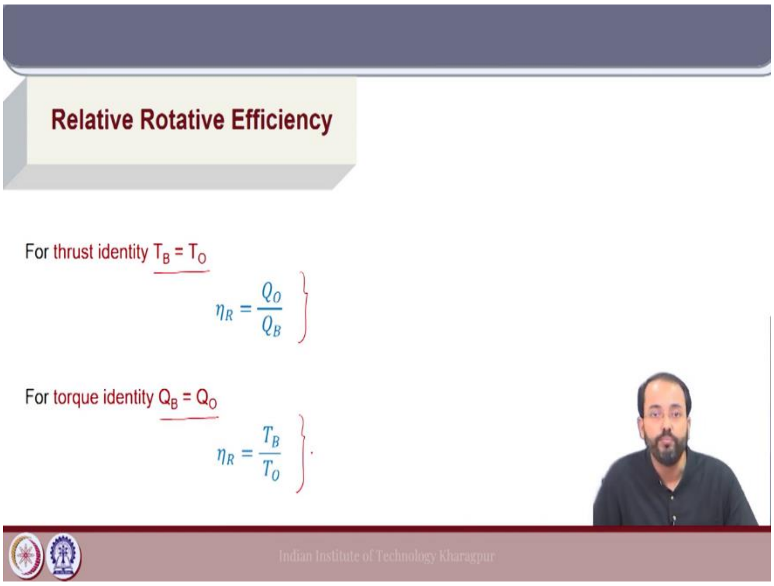
So, the wake fraction is high in the central region and in the vertical domain, here in this region the wake fraction value is high where the blockage effect due to the hull is maximum. So, this gives an idea of the velocity field which the propeller faces when it works behind a ship. So, if we try to draw a propeller blade here very simply. So, in this particular position, it will face the velocity field as depicted by this wake fraction.

Now, when the propeller moves, let us say if we if you rotate the propeller. If it rotates in the right-handed way, in the clockwise direction. So, when it comes to a position here, the velocity field it faces will be totally different because the nominal wake fraction will be different in this domain. So, nominal wake fraction is what? It is the wake fraction which is encountered without the propeller.

So, this is only due to the effect of the hull. So, if we put a propeller blade in this particular location, it will experience this change of velocity over an entire rotation; because of the change in wake fraction in both radial as well as circumferential direction. Hence, this gives a picture of the changes in the inflow velocity that a propeller blade encounters over one whole rotation behind the ship hull. Hence, the efficiency of a propeller blade working behind the ship hull will be different.

So, when we discuss about propeller design, the concepts of wake adapted design will be discussed. So, basically it is possible to design blades in such a way that they will perform quite good behind the ship hull. And, they will be adapted to the wake of the ship hull depending on the design of the stern. So, the equation for relative rotative efficiency can be finally, written in this form. The ratio of the thrust in behind to open water multiplied by the ratio of the torque in open water to behind condition ok.

(Refer Slide Time: 15:20)

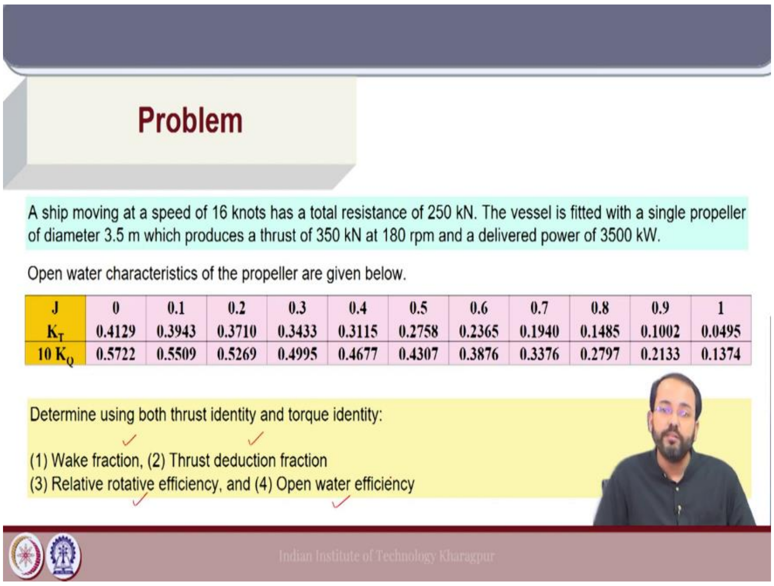


Now, if we go back to our discussions on thrust identity and torque identity, we get two different conditions. For thrust identity, it was assumed that from the self propulsion test and in the open water condition the thrust was same. So, T_B is equal to T_O. If we assume thrust identity then from the η_R equation, we will get that it can be expressed as the ratio of torques. So, η_R will be the open water torque value by the behind hull torque for the propeller.

In the same way, if we assume torque identity; that means, if we take the torque value equal between the behind hull and the open water condition then η_R can be expressed as a ratio of the thrust values. In this case, it will just be the reverse; that means, η_R will be the behind hull thrust divided by the open water thrust.

So, when we do an evaluation of the powering of a ship using the self-propulsion test results and open water data, we will use these identities. And, in this way we can compute the η_R with the ratio of the behind hull torque or the thrust to the open water valves. Now, this will be better explained using a simple problem that we will do now.

(Refer Slide Time: 16:51)



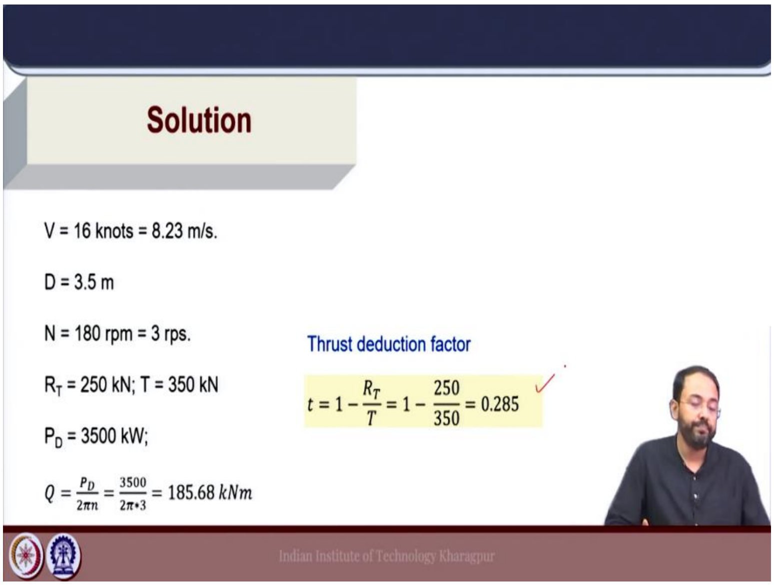
So, in this problem what we want to do is for a given set of conditions we have to calculate the coefficients. So, we have a ship here which is moving ahead with a velocity or speed 16 knots and a total resistance of 250 kN is given ok. Now, the vessel is fitted with a single propeller, the diameter is given.

And, it produces a thrust of 350 kN and the rotational speed is given as 180 rpm and a delivered power, P_D of 3500 kW. So, basically the operation condition for a ship and its propeller is given and the open water diagram is also given for the propeller. Because, we have seen that when we want to calculate all these propulsion coefficients, we need to go to the open water diagram.

And, get the open water thrust and torque coefficients to mostly the first step will be to get the operation point, because that is where the propeller characteristics will be calculated from the open water.

Operation points means, the advance speed or the advance ratio J at which we are operating the propeller when the ship is moving at that speed. So, finally, we are asked to calculate the propulsion coefficients. Basically the wake fraction, thrust deduction fraction, relative rotative efficiency and open water efficiency ok. So, what we have learnt in the hull propeller interaction part, we will be using those expressions and those techniques to work out this problem and calculate the propulsion coefficients.

(Refer Slide Time: 18:42)



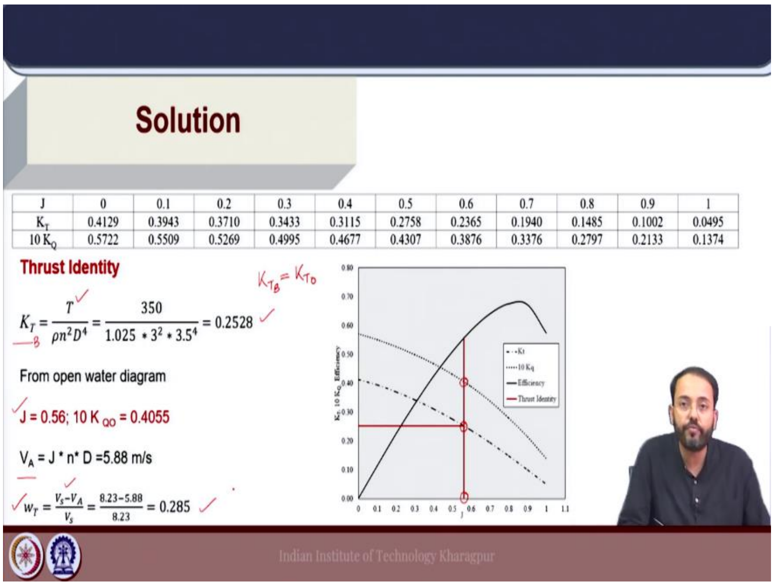
So, these are the input values which are given in this problem. The velocity is converted into meter per second for standard calculations. The N, the rotational speed is 3 rps, the total resistance R_T is given which is the resistance for the ship. This is actually the extrapolated resistance which we get from the model scale to the full scale. So, this is the resistance without the propeller.

So, R_T is basically the total resistance of the ship alone. So, it is the resistance of the ship without the acting propeller R_T, which in standard way we call the total resistance. P_D is the delivered power 3500 kW. Now, using that we can calculate the torque. So, the torque the propeller will absorb will be $P_D / 2 \pi n$, where n is the rotational speed.

And, we can first calculate the torque as the first step in this problem using the delivered power. The next thing we can compute is the thrust deduction factor, because the total resistance of the ship is given and the propeller is producing a thrust of 350 kN for the specific speed of 16 knots.

So, we can use the value of the total resistance and thrust to calculate the thrust deduction factor. Now, to calculate the other aspects of hull propeller interaction, we have to either use thrust identity or torque identity. And, in this problem both of them will be used to calculate the factors separately.

(Refer Slide Time: 20:28)



So, we have the table which is representing the open water diagram for the propeller and we start with the thrust identity. So, just a brief recap; what is thrust identity? Thrust identity assumes that the thrust produced by the propeller in the behind hull condition is same as in the open water condition for the same rpm.

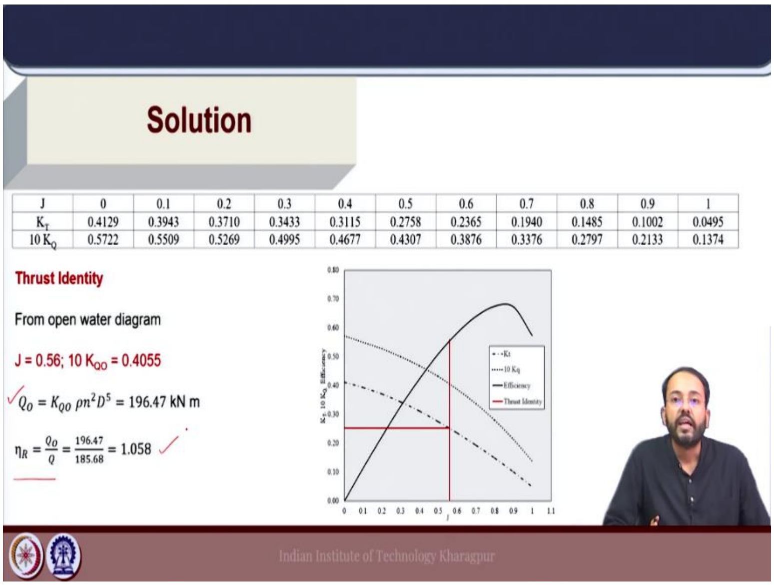
And, that leads to the condition where K_T or the thrust coefficient for the propeller is same in the behind hull condition and open water condition. So, if we apply thrust identity, the first step will be to calculate the thrust coefficient.

So, from the given value of thrust for the propeller, we can calculate the thrust coefficient based on the diameter and rpm and we get the value of K_T. As we have seen in the calculation for effective wake fraction, we have to use this value of thrust coefficient to enter the open water diagram. Because, here K_{TB} which is calculated here, this value is K_{TB} and we will assume that K_{TB} is equal to K_T open water for thrust identity.

So, we enter the open water diagram with the calculated value of K_T and with the input K_T we need to calculate the J which is the advance ratio and the value of K_Q and open water efficiency. So, next we can calculate J for the given K_T. We entered the open water diagram here at the point which is encircled. And, we can calculate the corresponding J and the corresponding K_Q. And, from the calculation of J, we can get the velocity of advance V_A as J n D, where the propeller rpm and diameter are already known.

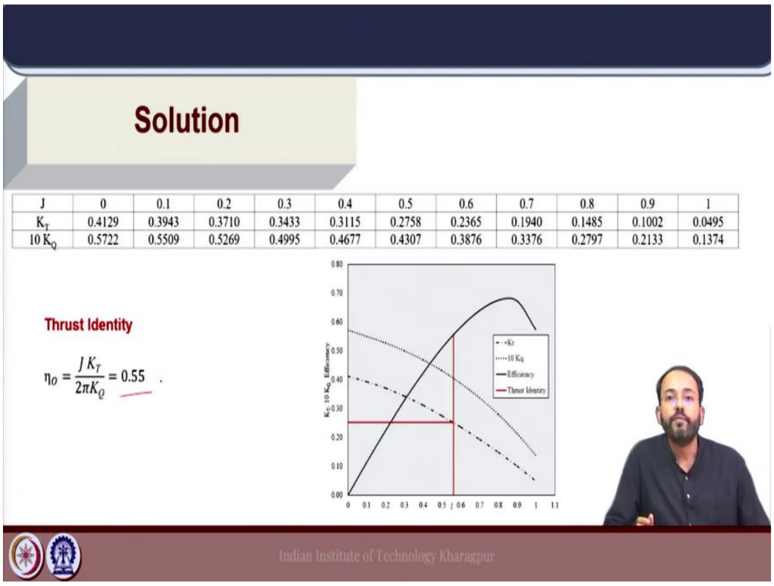
So, based on thrust identity, it is the same rpm here and we can calculate the velocity of advance. Now, once we have that we can calculate the wake fraction, the effective wake fraction based on thrust identity because that is the premise of this particular calculation. So, it is given with respect to the speed of the ship and the speed of advance here and we get the value of wake fraction.

(Refer Slide Time: 23:17)



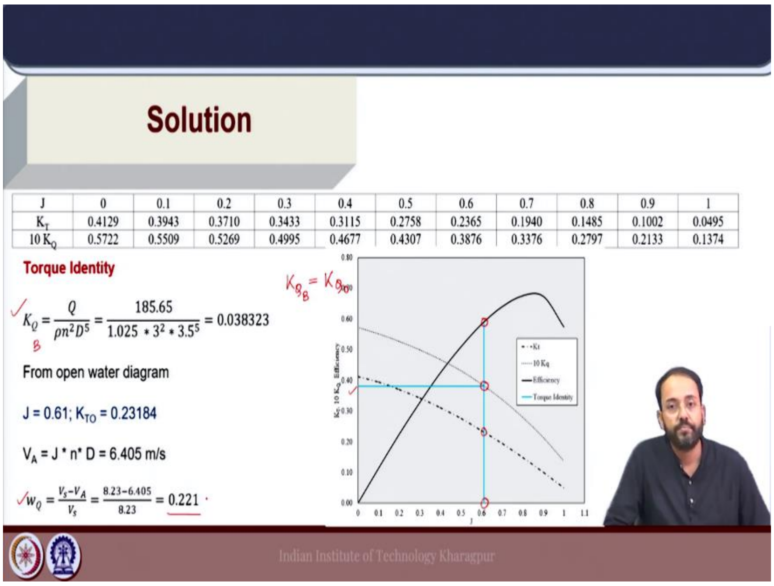
Similarly, we can use thrust identity to calculate the K_{QO} which is the open water torque. Now because thrust identity is assumed, the open water torque coefficient is not equal to the behind hull torque coefficient. So, from the open water torque coefficient K_{QO}, we will calculate the torque in the open water condition. And, the relative rotative efficiency using thrust identity as we have already seen is given by this particular expression. And, it gives us a value of 1.058 in this condition.

(Refer Slide Time: 24:00)



And finally, we calculate the open water efficiency from the given value of thrust coefficient. It comes out to be 0.55 using thrust identity. So, in thrust identity we enter the open water diagram with the calculated thrust coefficient and get the hull propeller interaction coefficients which is the effective wake fraction, relative rotative efficiency and also the efficiency of the propeller in open water η_O.

(Refer Slide Time: 24:39)



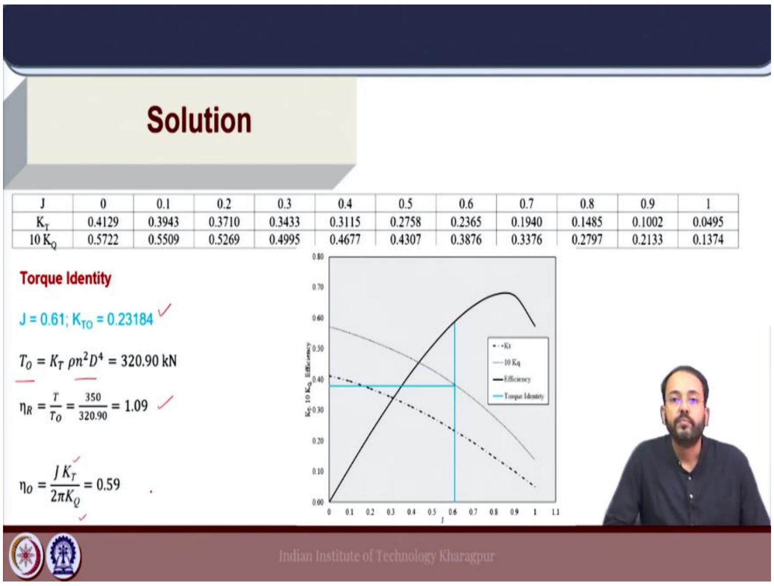
Next, we will use torque identity; again what is the assumption in torque identity? That the propeller has the same torque in behind hull and open water condition when having the same rpm. So, just the inverse way here, instead of thrust we will enter the open water diagram with the torque coefficient. So, the first step will be to calculate the torque coefficient K_Q and this is K_{QB} and we will assume that K_B is equal to K_{QO} as per torque identity.

And, we entered the open water diagram with the torque coefficient in the torque identity. So, the calculated value of $10K_Q$ is taken here on the curve for the $10K_Q$ and corresponding to that point we get the value of J and also get the value of K_T and η_O. So, in a similar way we get the value of the advance coefficient and K_{TO} and from the value of J, we calculate the advance speed.

And finally, from the advance speed we use the value of ship speed to calculate the wake fraction, the effective wake fraction by torque identity written as w with a suffix Q. And, we see that the value is slightly different from the value obtained using thrust identity. Now, this is based on the problem values which are given for the thrust and torque of this particular ship propeller combination.

For an actual case the differences may be slightly lower between the values obtained by thrust and torque identity. Now, in general when we do self propulsion tests, the thrust identity is used to calculate the propulsion coefficients.

(Refer Slide Time: 26:42)



So, moving ahead we use the same way to calculate the value of the open water thrust coefficient from the open water diagram. And, from that we calculate the open water thrust T_O, the rpm and propeller diameter are known. This is under the torque identity. And, we see that now the relative rotative efficiency because we have assumed torque identity η_R, will be expressed as a function of the behind hull thrust divided by the open water thrust.

And, we have a slightly different value of relative rotative efficiency here and finally, the open water efficiency once we know K_T and K_Q can be computed. So, this is the result from torque identity. So, this problem gives a basic idea of calculation of the hull propeller interaction coefficients and efficiencies using thrust identity and torque identity. This will be all for today's class.

Thank you.