Marine Propulsion
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Lecture - 34
Problems on Propeller Performance

Welcome to lecture 34 of the course Marine Propulsion. Today, we will discuss some Problems on Propeller Performance.

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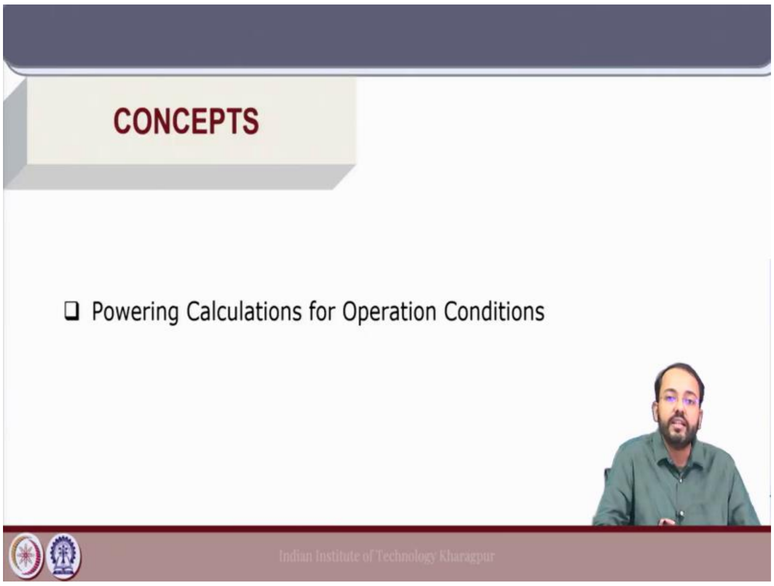

The key concepts regarding these problems will be powering calculations for different operation conditions and some calculations of gear ratio and propulsion factors for propellers.

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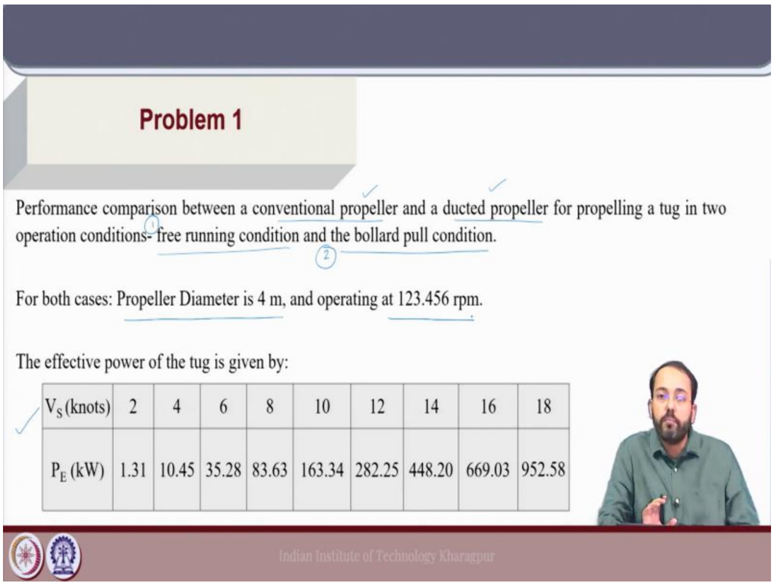

For the first problem, we are given a tug for which we have to do a performance comparison between a conventional propeller and a ducted propeller for two different operation conditions. 1 is the free running condition and number 2 is the bollard pull condition. So, we have a tug with given effective power versus speed curve and using this data, we have to apply the details of the propeller diagrams.

Once for an open propeller a conventional propeller, and another case for a ducted propeller and we have to do the powering calculations and obtain the performance comparison between the two cases. Now, the propeller diameter is 4 meter for each of these cases and the rpm is given as 123.456 for both the cases.

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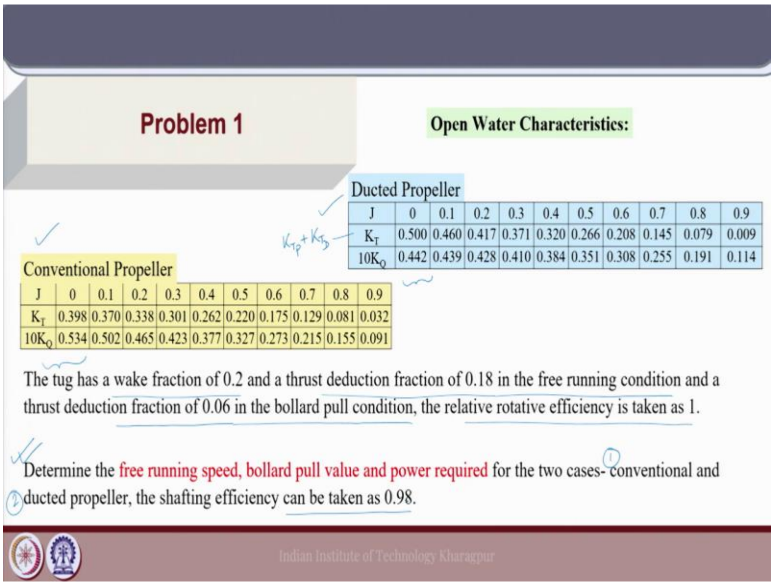

Next, the open water diagram for both the propellers are provided. Now, for the ducted propeller as we have seen the open water diagram consists of the total thrust coefficient and the torque coefficient of the ducted propeller unit. So, here K_T for the ducted propeller is $K_{TP} + K_{TD}$. So, it includes the contributions of thrust from both the propeller as well as the duct. And for the conventional open propeller we have the open water diagram with K_T and 10 K_Q as a function of J.

And briefly we can see here that at the bollard pull condition where J is equal to 0, the thrust provided by the ducted propeller given by this total thrust coefficient K_T is very high, 0.5, as compared to a conventional open propeller where the value of K_T is lower than that of the ducted propeller. So, this is where ducted propeller provides improvement in terms of higher thrust at high propeller loadings which means at very low J values.

Now, we are given a wake fraction of 0.2 for the tug and a thrust deduction fraction of 0.18. Now, these factors for a practical case will be slightly different between the choice of propellers. For example, if we use an open propeller or a ducted propeller, these values will be slightly different. But for the sake of simplicity in this particular problem these values are given and we can use these values for computations of both the cases.

Another thrust deduction fraction for the bollard pull condition is given here which is lower than the thrust deduction in the free running condition, the first one. So, we have to do the calculations for two operation conditions. One is the free running condition and another is the bollard pull condition; and the relative rotative efficiency is given as 1.

So, finally, here we have to determine the free running speed, bollard pull value and power required for the two cases. Once using the conventional propeller and for the second case using the ducted propeller, ok. The shafting efficiency is given here.

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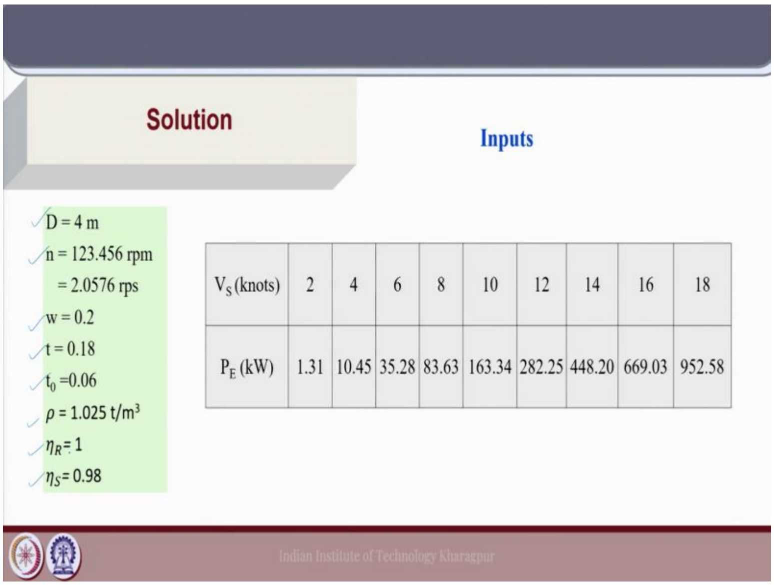

Now, let us look into the solution one by one. First the inputs of the problem which include the propeller diameter which is same for both the designs that open and the ducted cases. The rpm is given which is converted to rps, wake fraction, thrust deduction fraction, thrust deduction fraction in the bollard pull condition where J is equal to 0 is given and other factors like density, relative rotative efficiency and shafting efficiency are mentioned.

And this chart provides the effective power requirement for the tug at different speeds. Here as we see the effective power increases drastically with the increase of speed of the tug. So, this forms the requirement of the power for the tug based on which we have to use the open water diagrams for the two propellers individually, and match the output from these propellers with the power requirement that is provided for the tug. And we have to calculate the free running speed in that way.

And apart from that each propeller will have a different open water diagram and they will have different thrust coefficients in the bollard pull condition, which we will use to do the bollard pull calculations.

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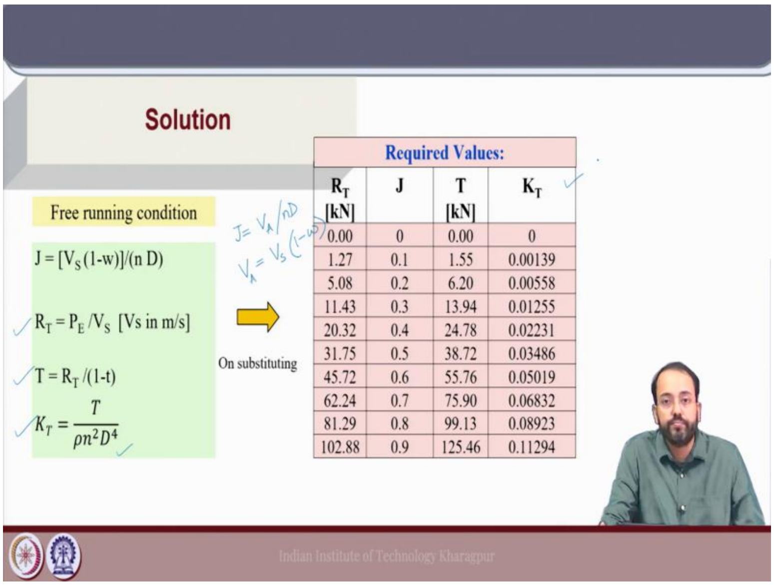

So, let us look into the free running condition. Here we can calculate the advance coefficient J based on the shift speed V_S, the wake fraction, and the propeller rpm in diameter. So, J = V_A/nD, and V_A can be written in this manner. Next the resistance can be written as the effective power divided by the speed of the tug and the thrust which is required from the propeller is resistance / (1 - thrust deduction). That is how thrust deduction factor is defined.

And finally, the thrust coefficient will be thrust divided by $\rho\ n^2\ D^4$ to make it non-dimensional. Now, this is the requirement of the tug from the point of view of its operation. And now we have to use this requirement to create a table for different values of J, so that we can get a curve of the required thrust coefficient for different values of advance coefficient J.

Now, if we use the resistance values for the different P_E or the effective power is given, and for each case if we calculate the J, based on the given values which includes the speed of the ship n and D which are mentioned in the problem. We can calculate the range of J and for each J we can calculate the value of K_T using these expressions.

Now, this particular table is calculated based on the requirement of thrust for the tug at different speeds. And we have to match this K_T requirement with the K_T that is obtained from the open water diagram for the two propellers. Once for the open propeller and once for the ducted propeller.

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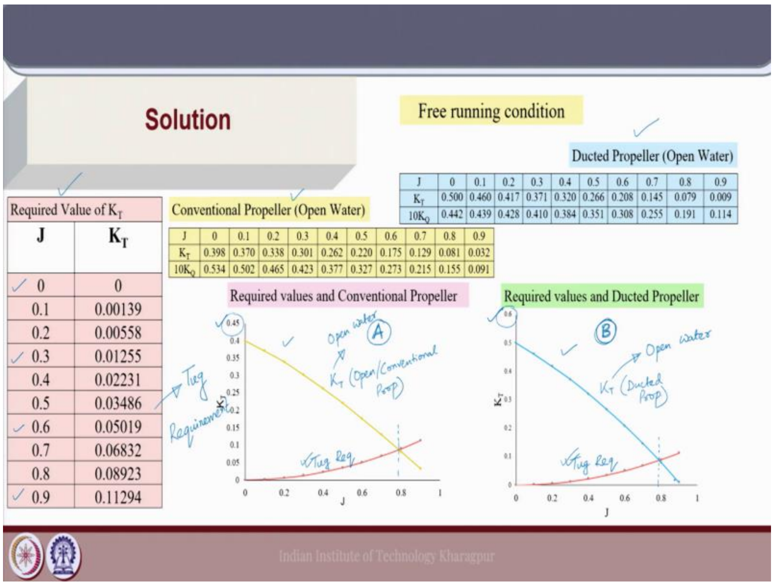

So, this particular table shown here is the same table which was calculated in the last slide and this forms the required thrust coefficient for different operation conditions. And here we have the two open water diagrams, one for the conventional propeller and another for the ducted propeller. And from each open water diagram we can have a thrust coefficient versus J curve and we can match that with the required value of thrust for the tug. So, this table gives the tug requirement.

And next, we have the open water diagrams for the conventional and ducted propellers shown in the two tables. So, let us look into the matching of these different curves. First one here let us say plot A, here we have this red line which is the tug requirement and the yellow line which is the K_T of the open propeller or conventional propeller we can write. And in the plot B, we have again the tug requirement given by the red line and the K_T for the ducted propeller.

Now, it is important to note here that as J increases the open water thrust and torque coefficients will decrease. So, this K_T for open and ducted propellers are the open water values, ok. And typically, for these problems thrust identity is assumed. So, this thrust coefficient will be directly used for comparison with the requirement of thrust for the tug in the behind condition.

Now, the red curve which shows the thrust requirement for the tug is same for the two plots, here and here. But the values seems slightly different because the two open water diagrams for the conventional and ducted propellers have a slightly different range. It is also important to note that the thrust requirement in the form of K_T for the tug, increases with the increase of J as we have computed earlier.

So, this is just reverse to the thrust curve pattern in the open water diagram for the conventional as well as the ducted propeller, ok. So, we have to find the intersection points for the thrust requirement as compared to the open water K_T for each case. So, for case A, this is the intersection point and for case B, this is the intersection point, where the K_T requirement from the tug and the K_T provided by the propeller intersect and that will be the free running point for the tug.

Now, at that free running point the calculation of powering should be done for each of these individual propeller cases.

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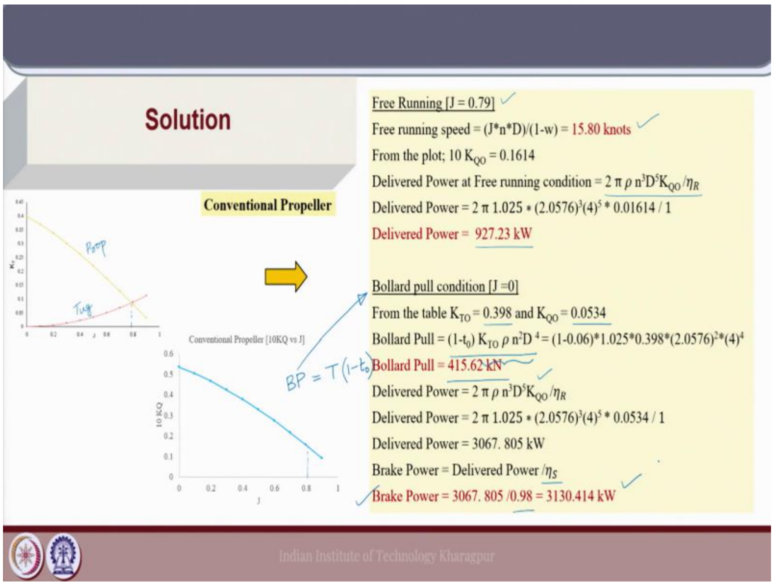

Let us go into the next step the solution for the conventional propeller. We have the two curves here the K_T from the propeller and the K_T from the tug requirement. And for that intersection point the calculated value of J is 0.79. And if we know the value of J, the free running speed can be calculated using this expression where we know the propeller rpm, diameter, and the weight fraction.

And for that particular value of J, one can calculate the open water torque coefficient. Now, the open water torque coefficient can be used to calculate the delivered power in the free running condition using this expression, where the relative efficiency value is used. And finally, the delivered power is calculated in the free running condition.

So, the concept here is we use the intersection point of the K_T requirement from the tug and the K_T provided in the open water diagram which is K_{TO} for the conventional propeller. The same process will be repeated also for the ducted propeller. And for that intersection point we find the advance coefficient J and at that advance coefficient we calculate the free running speed. Next, we move on to the bollard pull condition where the advance coefficient J is equal to 0.

Now, from the open water diagram the thrust and torque coefficients at the bollard pull condition for the conventional propeller are mentioned here. And the bollard pull can be written using this expression where this K_{TO} multiplied by $\rho\ n^2\ D^4$ is the thrust. And multiplied by 1 - thrust deduction at the bollard pull condition which was given in the problem gives the value of bollard pull. So, this is bollard pull.

Why is thrust deduction used in this equation? Because even at 0 forward speed in the bollard pull condition there is a small value of thrust deduction which is given in this problem. And that will cause a difference between the thrust provided by the propeller and the bollard pull that it can exert. So, we can calculate the bollard pull of the tug, and at that condition the delivered power can be calculated using the value of the torque coefficient.

And because we are using thrust identity again for the torque coefficient η_R is used and the delivered power can be calculated finally, which gives the brake power which is required by the engine, where we divide the delivered power by the shafted efficiency which is given as 0.98. So, the brake power in the bollard pull condition is calculated here.

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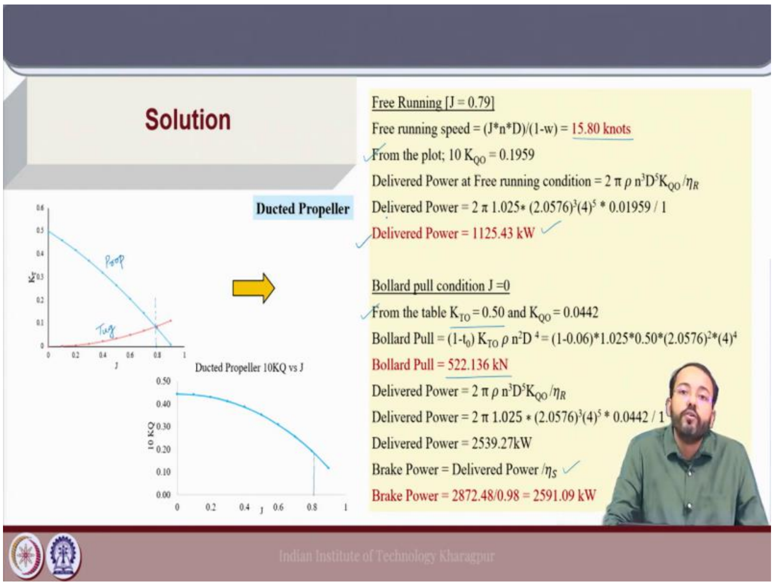

Next, we do the same calculations for the ducted propeller. Here also we find the point of intersection between the K_T curves from the tug requirement, the red line, and the K_T curve for the propeller. And we see that for this particular problem the data is given in such a way that they intersect at the similar value of J which is 0.79 and that gives a free running speed of 15.8 knots which is same as for the other case.

And at the same condition we again take the value of the torque coefficient from the open water diagram. Now, for the ducted propeller the torque coefficient is very much different at the same value of J as compared to the conventional propeller. So, if we calculate the delivered power in the same fashion from the torque coefficient, the value will be higher as compared to the conventional propeller.

Now, because in the free running condition the value of J is quite high, which means the propeller loading is low. So, the ducted propeller will be less efficient as compared to the open propeller and that is why the power requirement is high. Now, if we go to the bollard pull condition in the similar way for the ducted propeller, the bollard pull condition has a much higher propeller thrust and we use that thrust to calculate the bollard pull which is much higher as compared to the open propeller.

Now, using the same expressions we can calculate the delivered power in the bollard pull condition and from the delivered power we can finally, calculate the brake power in the bollard pull condition. So, this problem gives a comparative analysis of two different propeller types for a tug with a given power requirement and which gives the performance analysis of the two propellers in terms of thrust torque and powering demand for two different operation conditions.

Once in the free running condition and another in the bollard pull condition. And we see that in the bollard pull condition the ducted propeller is more effective in providing a much higher bollard pull at a lowering power requirement. Also, in the free running condition the tug can achieve the same free running speed of 15.8 knots with the open propeller at a lower power requirement as compared to the ducted propeller.

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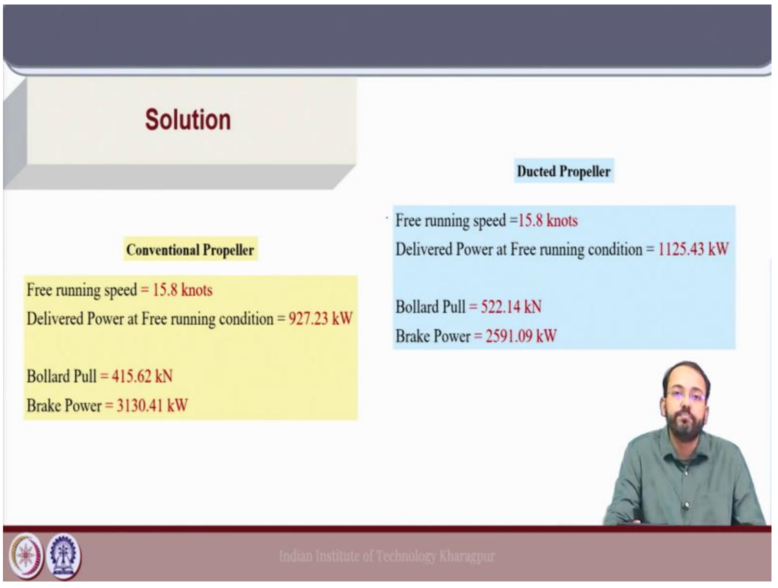

This table gives a comparative overview of the powering requirements using the conventional and the ducted propellers for the given tug and also the bollard pull comparison for the two propellers.

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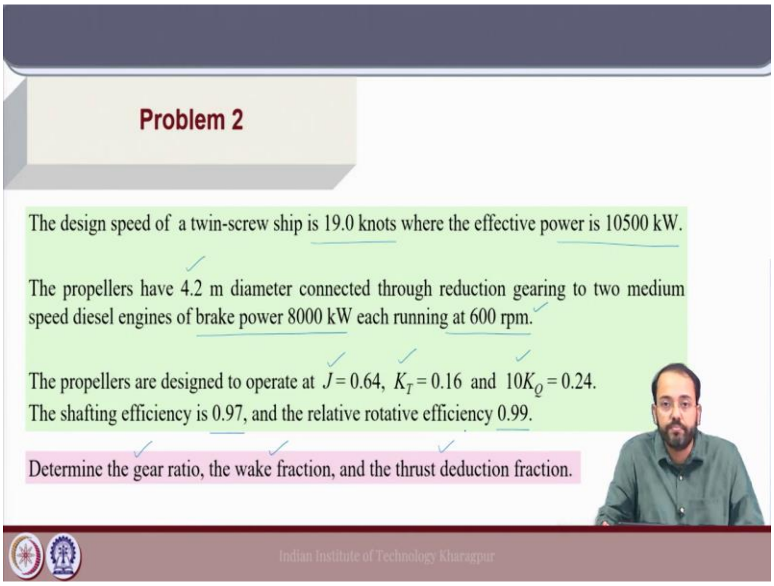

Let us look into another problem where we have a twin-screw ship of design speed 19 knots where the effective power requirement is provided. And it has propellers of 4.2 meter diameter and because it has medium speed diesel engines, reduction gears will be required as the propeller rpm will be different from the engine rpm. And the brake power of these engines two of them is provided and the engine rpm is also provided.

The propeller operation point is mentioned in the form of advance coefficient and the value of thrust and torque coefficient at the operation points are given. The shafting efficiencies provided as well as the relative rotative efficiency. So, for the given engine speed the propeller performance characteristics at the operation point are provided and we have to calculate the gear ratio.

That means, the propeller rpm needs to be calculated and since we already have the engine rpm given here, the gear ratio can be computed as a ratio of these two rpms. The wake fraction and thrust deduction fraction which are the propulsion factors will be also calculated in this problem.

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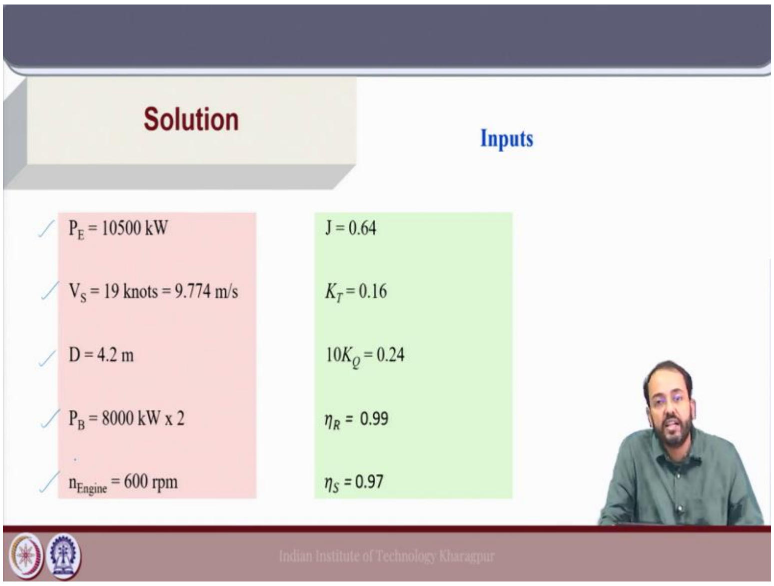

So, let us look into the inputs, the effective power, the design speed, the diameter of each propeller for the twin-screw ship, the brake power of each engine and the engine rpm. And on the propeller side for the given advance coefficient, the thrust and torque coefficients are provided and the relative rotative efficiency and shafting efficiency are given.

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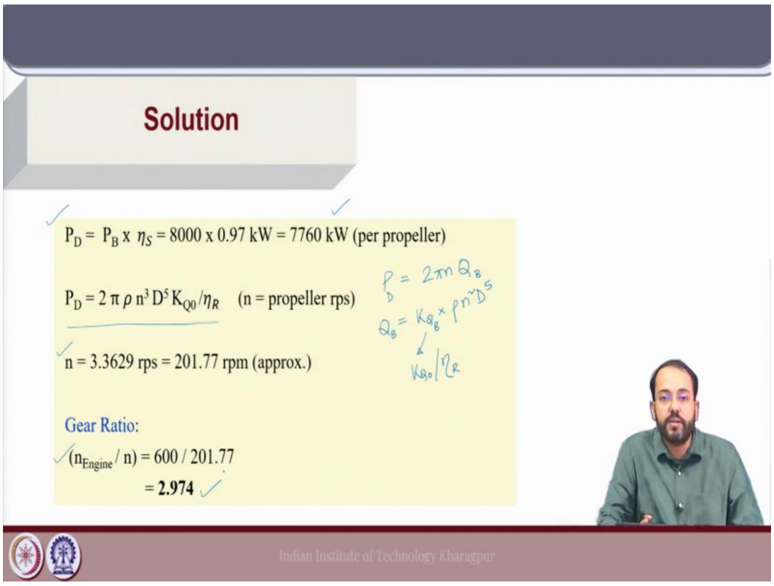

So, the first step will be to calculate the delivered power because we have to compute the propeller rpm. So, the delivered power can be easily calculated from the brake power of the engine using the shafting efficiency. And this value is the delivered power P_D for each propeller because we have two propellers. So, if we have the P_D for each propeller we can use that to calculate the propeller rpm using the value of torque.

So, P_D can be written in this form, where $P_D = 2 \pi n Q_B$, where Q_B is the propeller torque in the behind condition, and $Q_B = K_{QB} \times \rho n^2 D^5$, and K_{QB} can be written as K_{QO}/η_R, the relative rotative efficiency. And the value of K_{QO} is given in the problem for the corresponding value of J at which the propeller is operating. So, we can use this equation to calculate the value of propeller rpm as all the other terms are known.

Now, if the propeller rpm is calculated, the gear ratio can be simply calculated by the ratio of the engine rpm and the propeller rpm. Now, because we are using medium speed diesel engines the value of the engine rpm is much higher than the value of propeller rpm which gives us a gear ratio of 2.97. So, this solves the first part of the problem.

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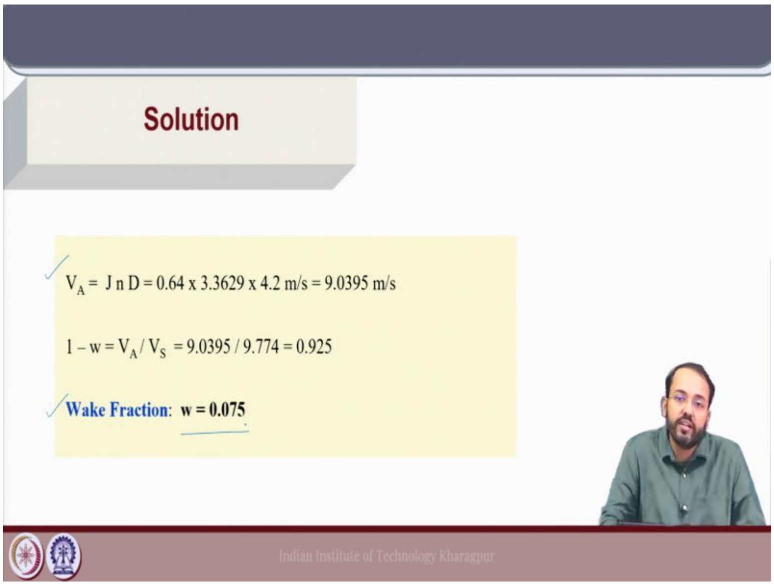

Next, we have to calculate the propulsion factors. Now, for the given value of J we can calculate the advance speed V_A, and because the shift speed is known we can simply calculate the wake fraction by comparing the advanced speed with the ship speed. Here, we should note that the wake fraction is very low because this is a twin-screw ship. And it is expected here that the value of wake fraction will be less than 0.1.

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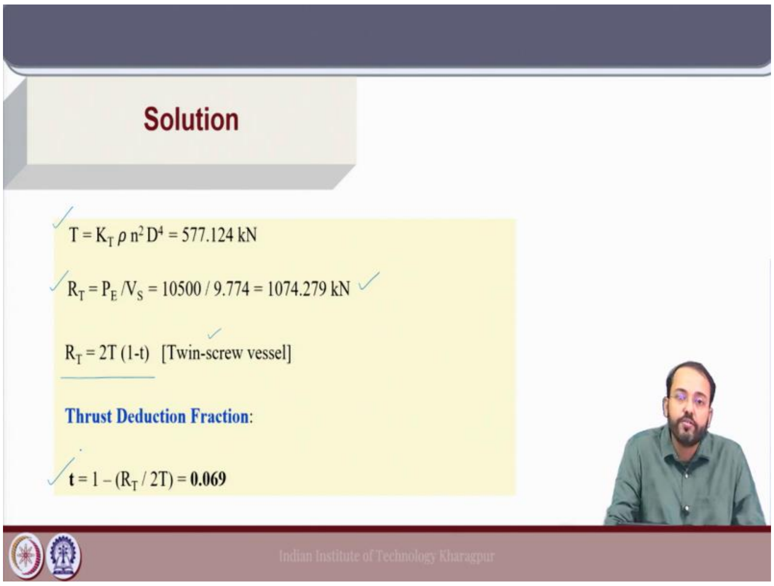

The next step will be to calculate the thrust deduction fraction. Now, for that we need to compute the thrust which can be calculated using the value of K_T which is provided for the particular advance coefficient and we are using thrust identity again here. So, from the value of thrust, we can use the value of resistance of the ship to calculate the thrust deduction factor. And resistance can be calculated by the effective power divided by the speed of the ship for the particular design speed.

And now comparing the resistance value and the total thrust from the two propellers, we can calculate the value of thrust deduction. Because this is a twin-screw vessel and hence the thrust from each propeller needs to be multiplied by 2, to get the total thrust and that needs to be used to compute the thrust deduction fraction, which is given by this expression.

So, this problem provides an example of the calculation of gear ratio and propulsion factors for a twin-screw propulsion system. This will be all for today’s lecture.

Thank you.