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

Lecture - 21
Propeller Model Tests (Part - I)

Welcome to lecture 21 of the course Marine Propulsion. Today we will start with Propeller Model Tests.

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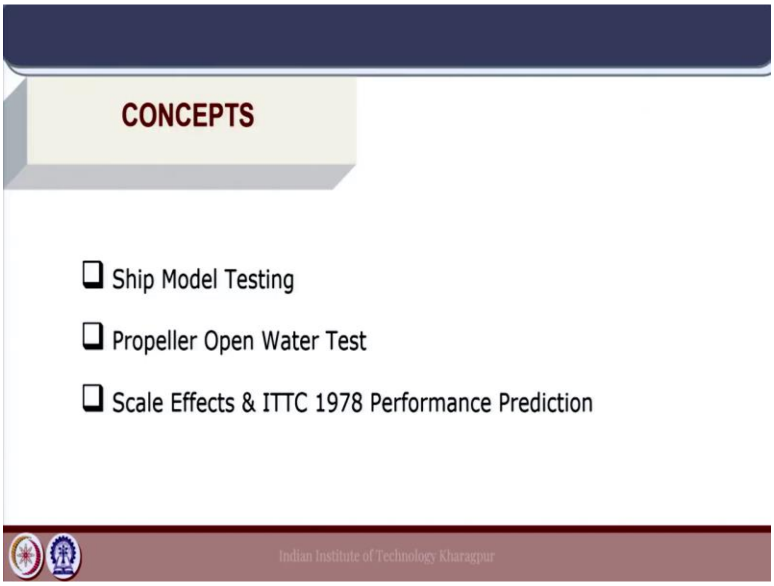

The concepts of Ship Model Testing will be discussed in general. And then we will discuss Propeller Open Water Tests, and the performance prediction for propeller thrust and torque in the full scale based on ITTC 1978 method, which takes care of the Reynolds scale effects between the model and full scale.

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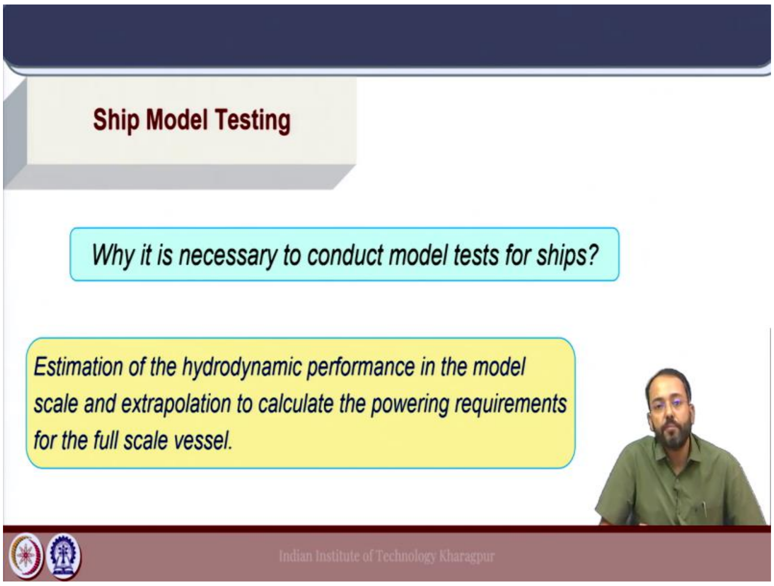

So, the first question that arises is, why do we do model testing for ships? As we have earlier discussed in similarity, we cannot directly test a full scale ship or a propeller, because the ship will only be built once.

So, in order to estimate its performance in the full scale, we do certain model tests to estimate the hydrodynamic performance of the ship and also the propeller separately and then together. So, we have different tests involved and based on these tests we extrapolate the characteristics in the full scale to get the powering performance of the full scale vessel.

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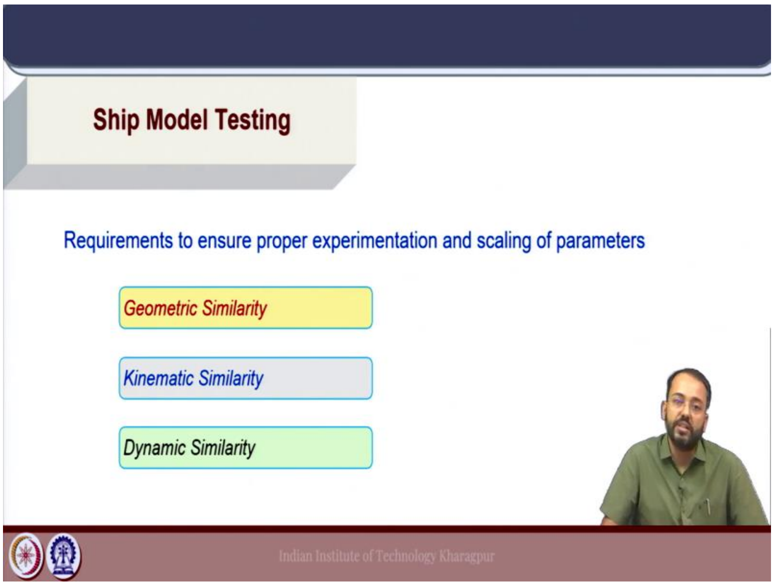

So, the requirements that are important for experimentation and scaling of the parameters between the full scale and model scale are the similarity conditions that we have already discussed.

The geometric similarity, which ensures that the model ship or the propeller is of a similar geometry; so, that all the dimensions are scaled in a similar way. The kinematic similarity ensures the similarity of the different velocities, and the dynamic similarity ensures the similarity of the force ratios. So, certain similarities we maintain and we have seen that for ship model testing, we maintain the Froude number, similar in the ship scale and the model scale.

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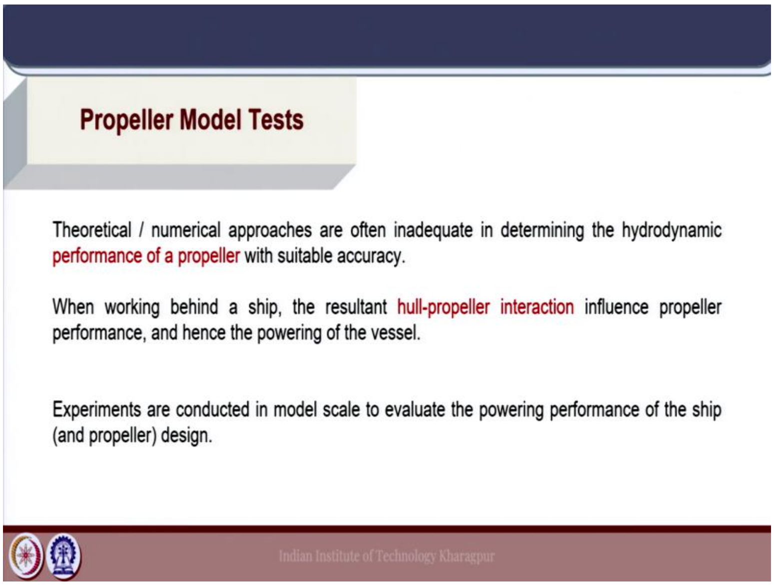

So, regarding the propeller model tests the theoretical and numerical approach that we have discussed, that can predict the performance of a propeller.

But to evaluate its performance depending on the characteristics of the exact propeller that we have the geometry of the propeller, which is considered for a specific design. It is essential to perform a model test to investigate its performance with a proper accuracy. And also for the propeller we have its performance in open water, where there is uniform inflow condition and when the propeller is working behind the ship hull its performance changes because of the effects of the wake. So, the hull-propeller interaction is also important in the behind hull performance of a propeller.

So, we have propeller model tests both in open water condition and the self propulsion test to evaluate the performance of propellers, and these experiments are conducted in the model scale and we use suitable extrapolation methods to evaluate the performance of the propeller and also the ship and propeller together to assess the powering performance of the ship.

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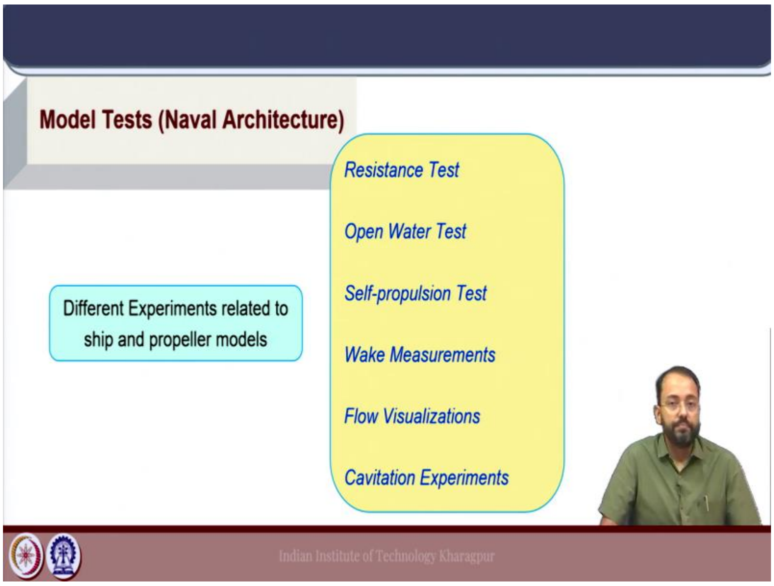

So, what are the standard tests that are involved in naval architecture? We have seen that the three basic tests we have discussed earlier. In addition to that we will also have some other test to evaluate both the performance as well as flow characteristics of the ship and propeller models.

So, the first one we have the standard Resistance Test where, we measure the resistance of the model ship. Next, for the Open Water Test we assess the open water performance of the propeller that is we measure the thrust and torque characteristics of the propeller for uniform inflow condition, where we do not have the ship hull. Next, in the Self-propulsion test - we have the model propeller fitted behind the ship and the propeller performance is assessed for different conditions of the ship forward speed as well as propeller rotation depending on the self propulsion point.

And there we will estimate the ship powering in the full scale, based on the model scale measured values. In the powering process, we use the resistance test, open water test, and the self propulsion test data together to do the extrapolation procedure.

Next there are some additional tests involved, which are required to assess the design of the ship and or propellers for wake measurements tests these are performed to estimate the nominal wake behind the ship hull; where the velocities in the wake region of the ship are determined especially, in the propeller plane to assess the design. Specially, the hydrodynamic design of the stern part of the ship and that is used as an input sometimes to propeller designs.

Flow Visualization tests are done to assess the local flow characteristics over the ship hull at different positions. And also on the propellers these are mainly paint tests or some other methods of flow visualization, which can be done to have an estimation of the flow characteristics over the model ship, or the propeller blades. And finally, Cavitation Experiments are done. In specialized facilities called cavitation tunnel for propellers to evaluate the performance of the propeller at different cavitation numbers, which we will understand when we study the section on cavitation.

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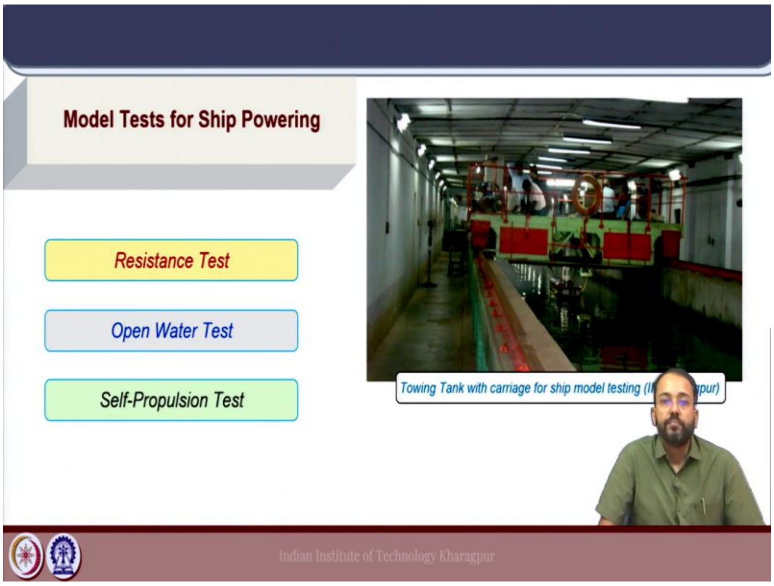

So, the 3 tests, which are core to ship powering extrapolation are the resistance test, propeller open water test and the self propulsion test. And the combination of these 3 tests will lead to the powering process of the ship, where the full scale extrapolation of the powering demand of a ship is calculated based on the model scale results. These tests are done in the towing tank, which is a standardized facility for ship model testing. Here a picture of the towing tank facility at IIT Kharagpur, in the department of ocean engineering and naval architecture is shown.

Where we have a tank with rails fitted along the 2 walls of the tank on which a carriage moves, along the length of the tank. And the ship model is attached to the carriage and it is towed at a specific speed as per the model requirements, and we measure the ship speed as well as the ship resistance, and for propulsion test we measure the propeller thrust and torque for the designated conditions.

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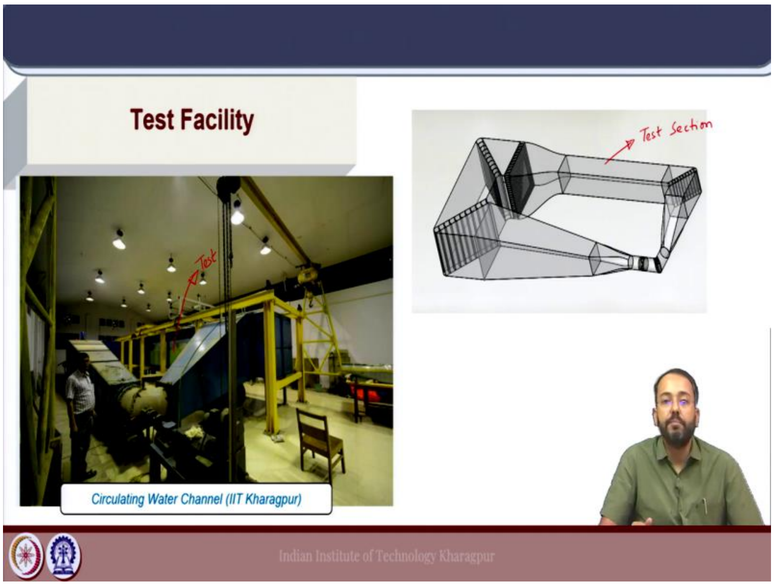

There is a different type of facility, which is called the circulating water channel, which is used for certain experiments for measurement of forces or flow visualization over certain bodies like foils, propellers, or small objects.

So, in the circulating water channel, we have a water channel in which the water is being circulated and we have a test section here; which is this region, where we keep our body of interest and the characteristics in terms of either force measurements or flow visualizations are done.

The difference in working principle between the towing tank and circulating water channel is that. In the towing tank, we have the model which is being towed along the length of the tank, and the water is still. But in the circulating water channel, the water is being circulated in the channel with the use with the help of an impeller, which is driven by a motor; but the model or the body of interest is kept still at the test section.

So, the desired velocity here is obtained by moving the fluid in the circulating water channel at a specific velocity depending on the motor, which is driving the fluid in the tank. So, these 2 facilities form the main setups for experimentation purpose for underwater bodies or ships or propellers, which are typically used in the marine technology domain. In addition to this for cavitation experiments there are cavitation tunnels, which are larger versions of these circulating water channel where, in addition to the velocity the pressure can also be regulated. So, that cavitation phenomena can be observed.

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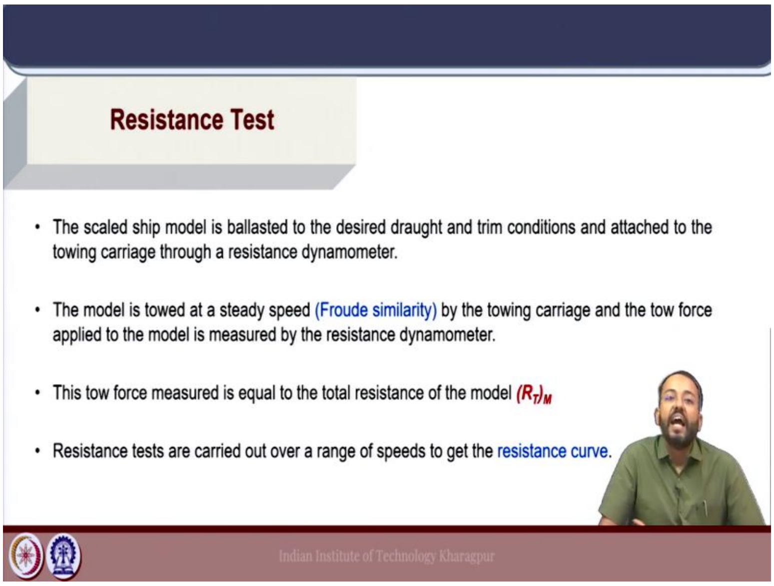

So, for the propulsion tests the background is the resistance test, which is typically covered in a shift resistance course. I will just very briefly mention the basic aspects of a resistance test for the sake of completeness. In the resistance test, we use a scaled model of the ship and that follows the standard food scaling procedures to get the speed in the model scale and the ship is ballasted to the desired draught and trim conditions as per requirement.

Next, we tow the model at a specified speed in the towing tank, and there the tow force is applied using the resistance dynamometer, which we will measure and get the value of the total resistance of the ship in the model scale.

And these resistance tests are done over a range of speeds again which are obtained by Froude scaling from the full scale ship speed. And there we get the resistance curve, which is the total resistance variation with the speed.

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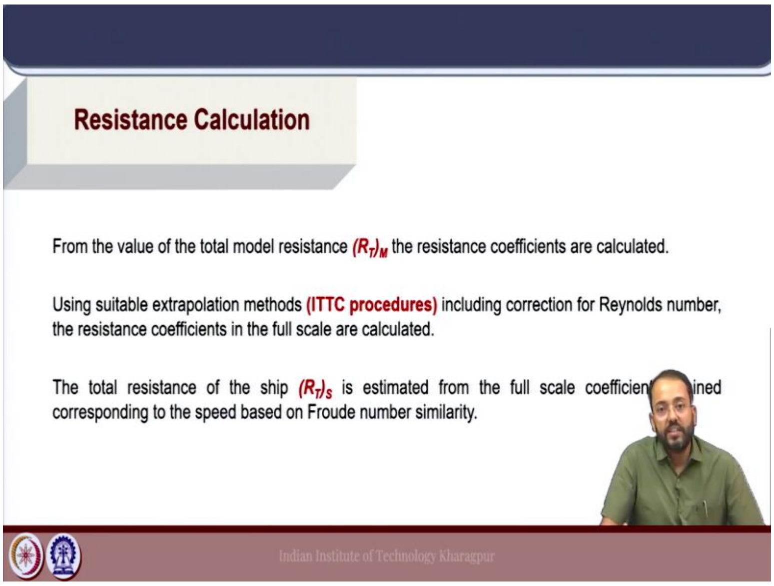

From the value of total resistance, we compute the resistance coefficients and using standard ITTC procedures, which are laid down by the international towing tank conference. We do the extrapolation from the model scale resistance correcting for the Reynolds scale effect to the full scale resistance coefficient and get the finally, full scale resistance of the ship.

So, I have just mentioned it very briefly. Again this is shown just for the sake of completeness; the purpose of this particular lecture is to start with the model tests involved for ship propulsion. So, today we will be discussing the open water test for model propellers.

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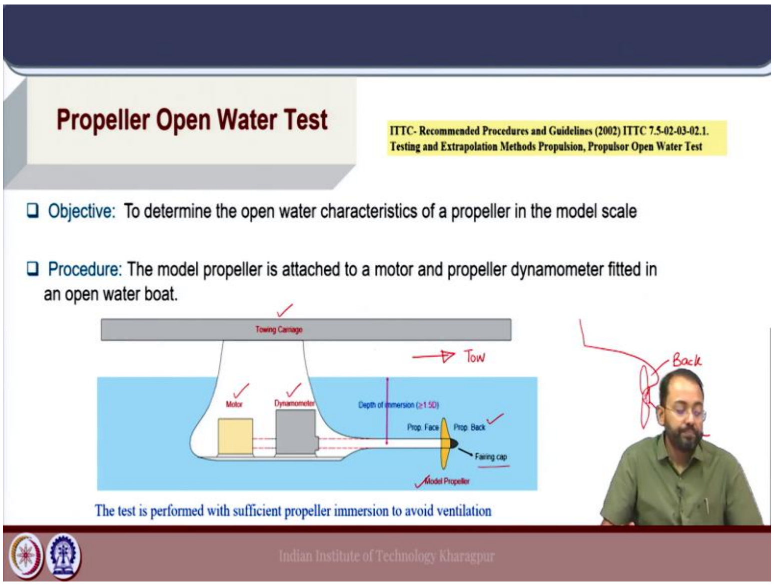

So, we will follow the recommended guidelines by the international towing tank conference for the propeller open water test where, we will estimate the hydrodynamic performance of the propeller the thrust and torque in the model test for uniform inflow condition.

So, there is no ship in front of the propeller, we have only the model propeller. This is a standard setup for propeller open water experiment, I will show a video of the propeller open water test from our facility after this where we will be able to visualize the different components of the experiments in a better way.

So, we have the open water boat, which is the arrangement containing the propeller, which is to be towed in the open water condition connected to the towing carriage here. This carriage is moving on rails on the towing tank.

And because we are towing the propeller, which should meet the water first in the open water condition the propeller has to be pushed by the boat. So, we have the model propeller here for a standard configuration for a propeller behind the ship. We have the face of the propeller which can be seen if we stand behind the propeller, but here we have to put the back of the propeller which is in the forward direction, because the back of the propeller is the one which is actually facing the ship, when the propeller is behind the ship hull.

So, the back of the propeller is facing the inflow, which is the V_A into the propeller blade. So, if I draw a ship propeller; this side is the back, which faces the inflow into the propeller based on the wake velocity of the ship. So, here we will have the propeller back, in the same way facing the uniform inflow which is the V_A. And a fairing cap is put on the propeller blade to have a properly faired velocity profile on the propeller. And another important part here is the depth of immersion of the propeller that is kept as a minimum of 1.5 the diameter of the propeller as per ITTC requirements.

This is to avoid ventilation of the propeller; that means, if the propeller is operating very close to the free surface, because of its rotation it will draw in air and then its performance will change. That is why it is to be avoided, this process is called ventilation and in order to avoid this we maintain a depth of immersion of at least 1.5 propeller diameters. Now, the propeller is driven by a motor, which gives the required rpm for the propeller to estimate the thrust and torque performance; and a dynamometer is used to measure the propeller thrust and torque in the open water condition.

So, this is a standard setup where we have only the propeller, which is being towed in this direction. This is the towing direction to obtain the open water characteristics, which is the thrust and torque of the propeller, which can be converted into the coefficients.

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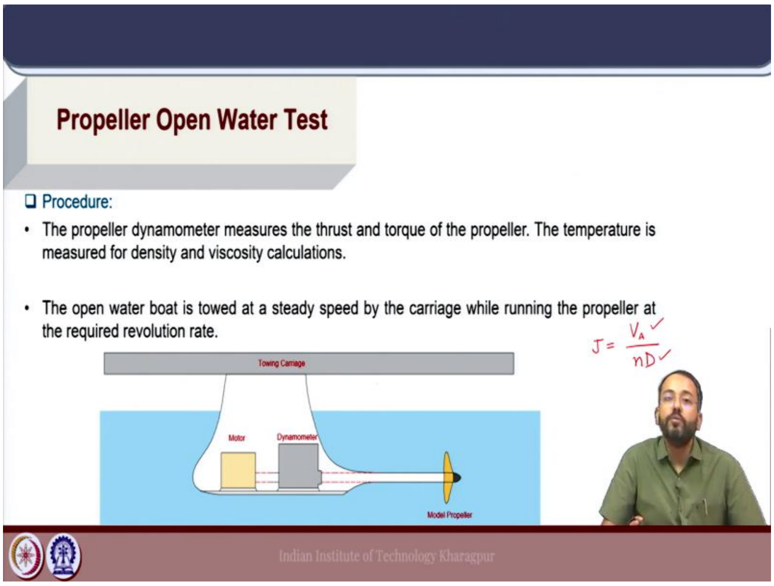

The temperature is measured in the open water test and this is required to calculate the density and viscosity of the water during the open water test, which is required to calculate the coefficients and the Reynolds number. Now, the open water boat is towed at a steady speed while running the propeller at the required revolution rate.

So, in the open water characteristics curve, we have seen that the advance coefficient J which is given by V_A the velocity of advance by nD, where D is the diameter of the propeller and n is the rotational speed.

So, we have to get the thrust and torque for different advance coefficients. So, which is a combination of the forward speed and the rotational speed multiplied by diameter. So, in a standard open water test, we have the towing carriage, which is towing the model propeller at a specific forward speed and the rpm of the propeller is kept at a suitable value as per the requirement of the range of advanced ratios.

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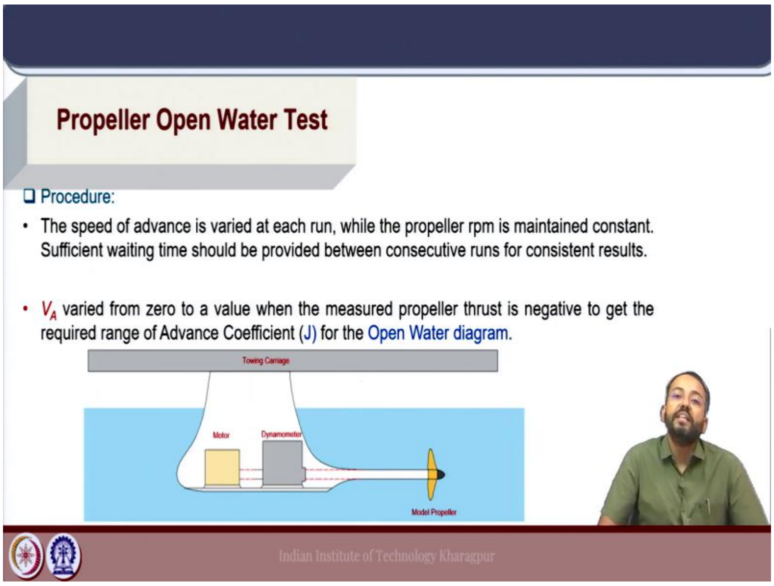

Now, over each run the speed of advance is changed; while the propeller rpm is maintained constant this is a standard norm for propeller open water testing. So, we change the advance coefficient value by changing the forward speed at which the carriage is towing the propeller by and keeping the rpm constant. So, in this way we change the J value and we calculate the coefficients finally, from the measured thrust and torque from the dynamometer for each condition.

And we for each particular condition, time has to be taken. So, that the data is acquired over a specific time as per the requirement and between 2 tests sufficient waiting time should be given for the water to be calm. So, that the results are consistent and there should not be any disturbance in the water, which will can impact the results of the thrust and torque, which are obtained. In the open water tests as a standard the value of V_A the forward speed is changed from 0, which is corresponding to the bollard condition to a high value, which is corresponding to a negative value of thrust.

So, that we obtain the entire open water diagram.

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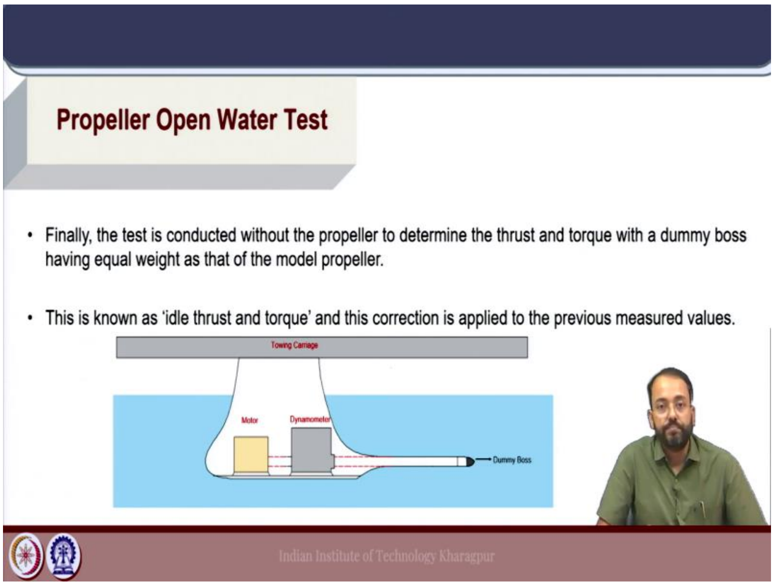

And finally, the test is conducted without the propeller. This part is important, because the we want to evaluate the thrust and torque of the propeller blades. Now, after estimating the propeller thrust and torque for different conditions a correction needs to be applied. Because, there will also be a thrust and torque generated from the propeller boss, and this is done by putting a dummy boss which is of the same weight as that of the model propeller and again the thrust and torque for different rpm is measured for this configuration.

So, here we do not have the propeller blade. The propeller is just replaced by a dummy boss. And these measurements are called ‘idle thrust and torque’ measurements and this correction is to be applied to the values measured previously for the propeller thrust and torque to get the thrust and torque contribution only from the propeller blades.

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Here is a short video of the propeller open water test. We have the KCS propeller model. KCS is kriso container ship and this propeller is fitted in front of the open water boat and this particular part is shown out of water.

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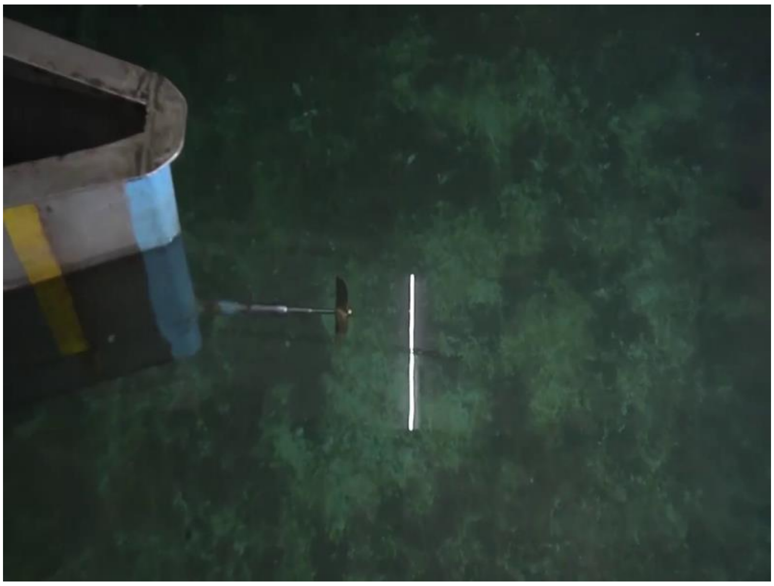

So, we are just testing the propeller and shaft connections, giving a propeller rpm and the motor and dynamometer is housed within the open water boat. So, here we have the dynamometer and the motor which are directly connected to the propeller shaft. Now, this open water boat is put into water and connected to the carriage here and this carriage is towing this open water boat in such a way that the propeller is in front. This is for open water conditions. So, we have uniform inflow. So, the propeller is in front of the boat as discussed.

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And the propeller is given a specific rpm, and the carriage is towing the boat along with the propeller along the length of the towing tank. And the 2 sides of the towing tank have rails on which the carriage is moving. Now, in the open water test for every propeller rpm, the forward speed of the carriage will be varied and to vary the J, which is the advance. Finally, for each case we will compute the thrust and torque coefficient from the measured value of thrust and torque from the dynamometer and then plot the open water diagram.

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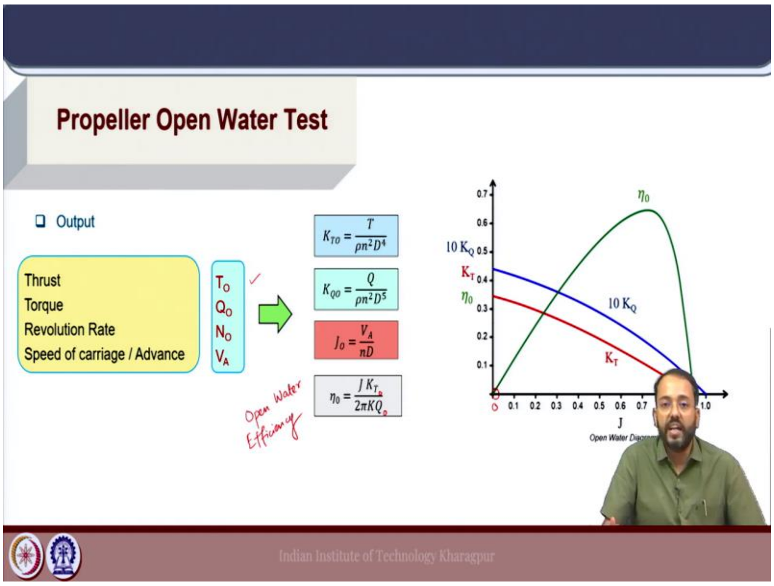

So, the output from the open water tests are the thrust and torque of the propeller as a function of the propeller revolution rate and the speed of the carriage, which is equal to the speed of advance here; because we do not have any ship. So, these values are mentioned with a suffix O, because these are open water values and from this we can calculate the thrust and torque coefficients of the propeller, which we have already seen earlier and the advance coefficient J can be calculated and from that finally, the open water efficiency can be calculated from the K_T and K_Q values in open water.

So, this will be K_{TO} and K_{QO} for the open water. Now, we have the standard open water diagram that we can draw after we have computed the values of thrust and torque coefficients, and that is why we need to run the test for a range of conditions where we change the forward speed right from 0, which gives the starting point of the open water diagram. This point the bollard pool condition to a point; where the thrust is negative. So, that we have the entire range of propeller performance, in the open water diagram.

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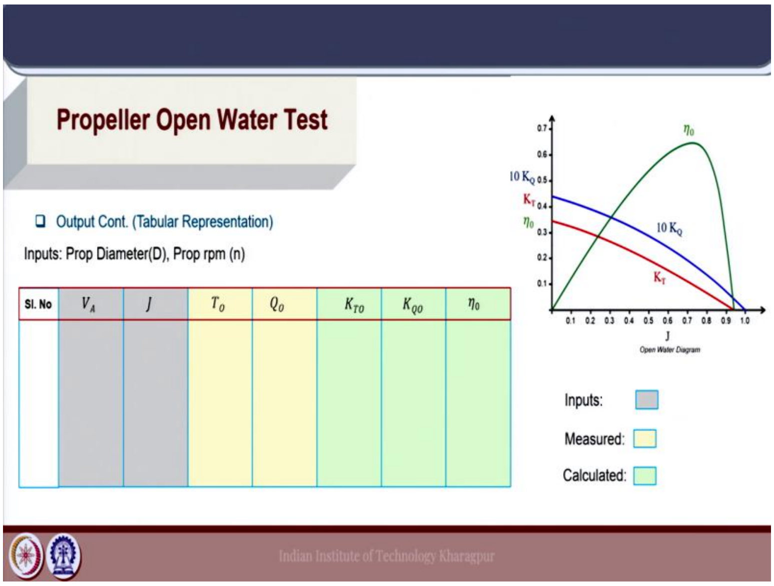

Now, another important part of the open water test is that, it is recommended to run open water tests at least at one higher rps. So, we use a different propeller speed, which is slightly higher and again run the open water tests and get the open water diagram, just to understand the influence of the Reynolds number. So, that if we keep the same values of the advance coefficient, but increase the propeller speed and also the model speed accordingly. What will be the impact of that on the open water diagram, and the idea is at least one of them should be conducted for the Reynolds number, which is according to the self propulsion test. This is required by standard ITTC guidelines.

So, if we want to tabulate the results of the open water diagram. So, we have the inputs here which are the forward speed or the speed of advance of the propeller and from that we can calculate the J, the advance coefficient based on propeller rpm. Now, the measured values are the propeller thrust and torque and from that we can calculate the thrust coefficient, torque coefficient, and the open water efficiency of the propeller.

So, we have the open water diagram as seen earlier. So, this is the primary output from the propeller open water test, which is required for ship powering extrapolation, when we do the self propulsion test we will require the open water diagram to evaluate the wake fraction and relative rotative efficiency. That we will discuss later.

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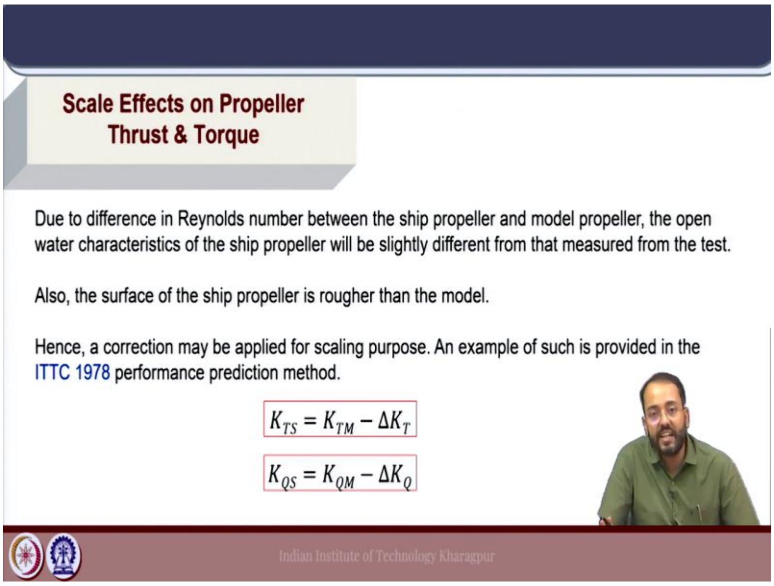

Now, the Reynolds number that we have in the model scale; the blade Reynolds number is much smaller as compared to the full scale propeller.

So, the open water performance that we see which is the performance of the propeller in uniform inflow. So, it is the actual performance of the propeller without any influence from the ship hull. So, this will be different in the model and full scale. Also another reason is that the ship propeller surface is much rough as compared to the model scale propeller. So, because of the change in Reynolds number and roughness effects; the model scale results may be corrected or the some extrapolation procedure may be applied to get the full scale propeller performance from the open water diagram.

So, ITTC has recommended a procedure, which is called the ITTC 1978 performance prediction method, which is used as a standard to get the full scale propeller characteristics from the open water diagram that we have just measured or calculated based on the open water test in the model scale. However, one should know that every towing tank in the world has their own way of extrapolating the propeller open water characteristics and this depend on experience.

And also there are different designs of propellers, for not only standards two propellers, but there are also different kinds of propellers in an unconventional designs. For example, ducted propeller contra rotating propellers where certain scaling procedures are applied based on those specific designs and experience. The idea is here we have measured the open water performance for a model propeller. And because of the effects of change in Reynolds numbers and also roughness the full scale performance of a propeller will be different. And some procedure may be applied to convert this model scale values to the full scale value.

And one example of that is this ITTC 1978 performance prediction method that we will discuss now. So, here what we do is we have the full scale K_{TS}. So, the suffix S is corresponding to the full scale and the suffix M corresponds to the model scale. So, we get the full scale thrust and torque coefficients as the model scale values minus some corrections in the thrust and torque coefficients which we name as ΔK_T and ΔK_Q.

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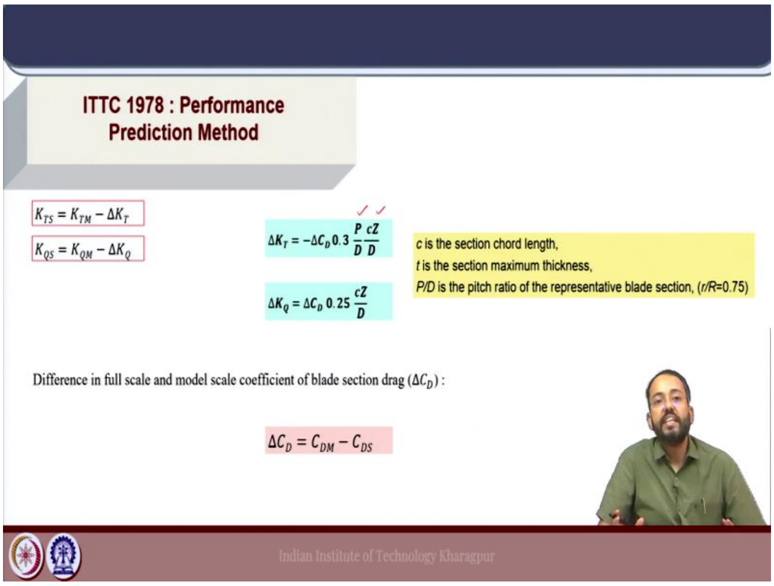

Here we have the corrections delta K_T and delta K_Q as functions of this change in the blade section drag and also the function of some geometrical aspects of the propeller blade; the pitch ratio P / D the section chord length, c Z the number of blades and D the diameter of the propeller blade. So, this ITTC method corrects for the difference in sectional drag between the model and full scale.

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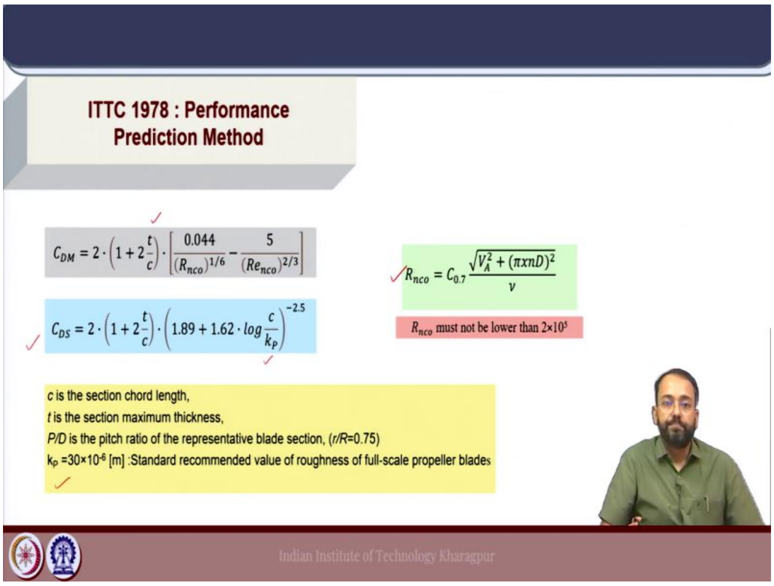

Now, how do we calculate C_{DM} and C_{DS} it is done using this formula, where we have the drag coefficients in the model and full scale as functions of the t/c; that means, the ratio of the maximum section thickness of the blade to the sectional chord length.

And we have Reynolds number defined on the propeller blade for the blade section at 0.75 r. So, that is the representative section, which is used for calculation of these blade parameters, which are used for the performance prediction method. As we have discussed earlier that the blade section at the radius r/ R= 0.7 or in this case 0.75 is called the characteristic section of the propeller blade, which is supposed to represent the properties of the entire propeller blade.

So, here if the pitch ratio is varying with the radius we take the P/ D as the pitch ratio of the representative blade section, at r/ R = 0.75 for this particular case. And R_{nco} here, which is the Reynolds number, which is again calculated for the representative blade section at 0.75 r and in the model scale this should be at least 2×10^5 for the requirements of model scale testing. So, these equations can be used to convert the model scale open water characteristics to the full scale values yeah.

Another important aspect is for the full scale drag coefficient. We see that the factor K_P is used K_P is the standard recommended value of roughness, for full scale propeller blades. So, K_P is not there in the model equation. So, it is used to account for roughness for the full scale propeller blades and it influences taken care of in the drag coefficient for the full scale blade ok.

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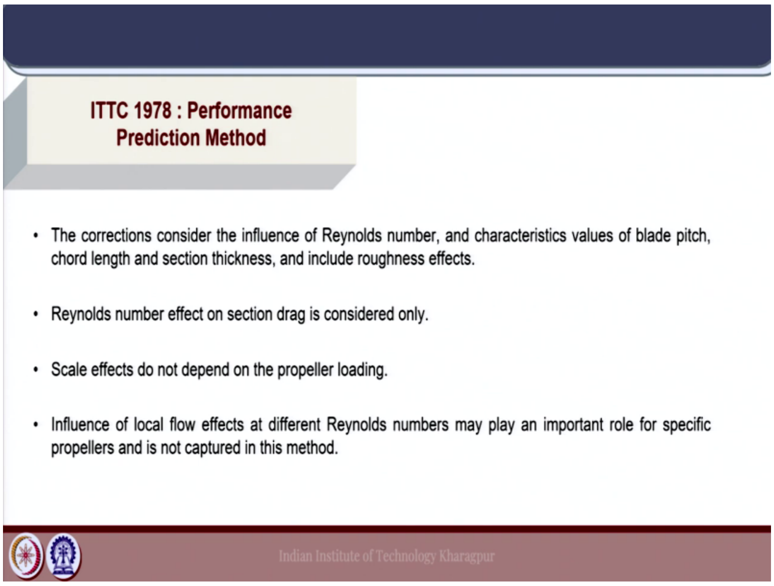

So, what are the characteristics of this ITTC performance prediction method? The corrections are applied for the change in Reynolds number and they are functions of blade pitch, chord length, and section thickness and roughness effects are also included using a particular value of standard roughness in the full scale.

Now, the Reynolds number effect is considered only on the section drag. We do not have any Reynolds number effect on the section lift in this particular method, but for actual cases, it is observed that when we go from the model to the full scale, there are changes in the pressure over the propeller blade.

So, the pressure distribution over the propeller blade also changes and for that there are changes in the lift coefficients also for the propeller blade between the model and full scale. And that is not taken care of in this particular method. And also the influence of propeller loading; loading means the represented by the J value, which is the advance coefficient.

So, the influence of propeller loading is not taken care of in this extrapolation method. So, the scale effects that we calculate here or the corrections are independent of the propeller loading, but it is observed that for a realistic case. There is an influence of propeller loading, because it impacts the flow characteristics over the propeller blade. And that also is influenced by the difference in Reynolds number. And other local flow effects, which are important for different types of propeller designs, whether it is for normal screw propellers or unconventional propellers are not also taken care of in this particular method.

So, this ITTC method can be used as a representative method to have an idea of the difference between the model scale and the full scale open water diagram. However, for rigorous analysis or depending on experience, also for different propeller types and other unconventional devices; specific extrapolation method using advanced computational methods one can also try to get the full scale results and those can be correlated with the model scale and the Reynolds number effect can be understood.

So, this gives an idea of the propeller performance in the open water condition and its testing for the open water test. And the extrapolation of the propeller open water diagram using a standard procedure from the model scale to the full scale. In the next class, we will continue with self propulsion test.

Thank you.