Marine Propulsion

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Lecture - 23
Ship Powering Performance Prediction

Welcome to lecture 23 of the course Marine Propulsion. Today, we will discuss Ship Powering Performance Prediction.

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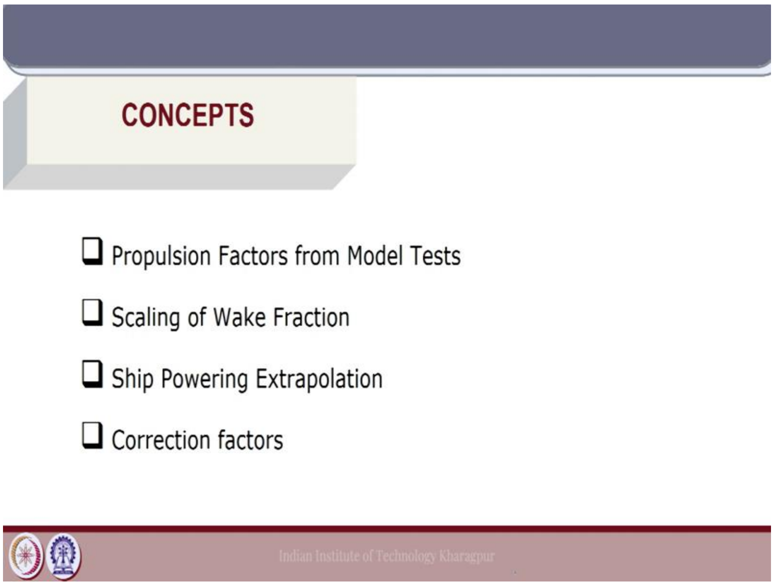

The key concepts covered in today's lecture will be propulsion factors from the model tests, scaling of the wake fraction, ship powering extrapolation from the results of model self propulsion tests using the data from resistance and open water tests. And finally, we will use some correction factors to relate the full scale powering to the values that we get from full scale trials.

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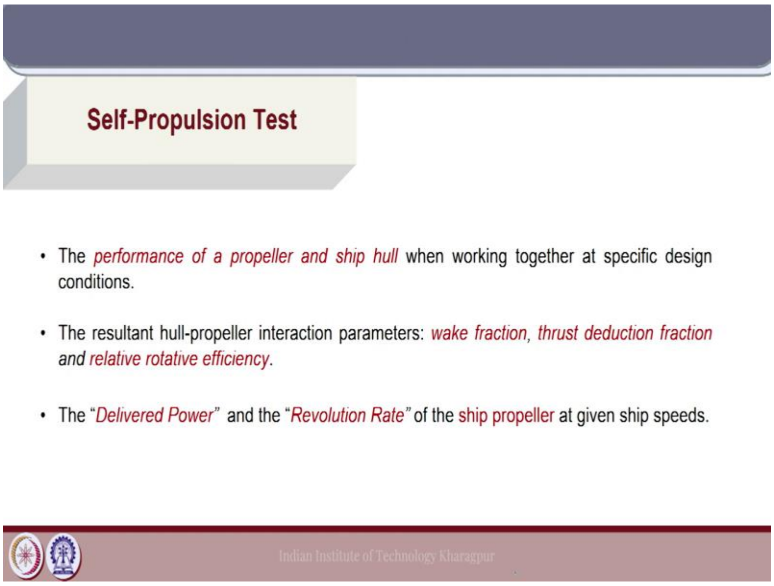

Just a brief background that we have discussed in the last class; the self propulsion test includes the performance of a propeller and a ship hull together where the propeller is acting behind the ship hull. And, in different forward speeds we estimate the propulsion performance of the ship in the model scale.

And, from that we have to estimate the hull propeller interaction parameters that is the wake fraction, thrust deduction fraction and relative rotative efficiency in the model scale. And, from these propulsion factors we will estimate the full scale powering performance based on standard ITTC recommended methods. And finally, the delivered power and revolution rate of the ship propeller at given ship speeds required to be calculated to estimate the powering performance of the ship in the full scale.

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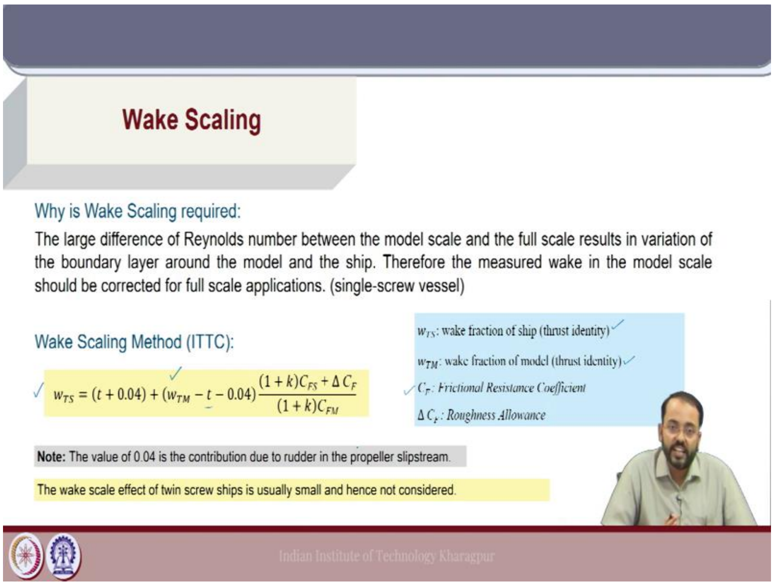

Now, the scaling of the wake fraction is very much required to get the effective performance characteristics in the full scale. Why? Because, the Reynolds number is very much different between the model scale and the full scale; as we have discussed multiple times that we maintain Froude number similarity in ship model testing. And, hence the Reynolds number is very large in the full scale and very small comparatively in the model scale,

Which leads to a huge difference in the frictional forces and the boundary layer flow pattern between the model and full scale.

Because, of that the wake in the model scale is different from the wake pattern in the full scale. Because, the propeller works in a region which is disturbed by the presence of the ship, the wake fraction that is computed at the propeller plane in the model scale has to be corrected to get the wake fraction in the full scale.

Because, the velocity patterns close to the boundary layer in the stern region of the ship will be different in the model and full screen. Here we will look into the wake scaling method recommended by ITTC for single screw vessels. The full scale wake fraction w T_S is represented as a function of the model scale wake fraction which is calculated using thrust identity. Here, in both cases w with a suffix T is used, S again for the full scale ship and M for the model scale and T represents that we are using thrust identity here for the calculation as a recommended case.

So, the full scale wake fraction is related to the model scale wake fraction with the value of thrust deduction t and a constant 0.04 here is used which value is basically due to the contribution of the rudder in the self propulsion test. As the rudder is in the slip stream of the propeller, it also impacts the wake fraction. Because, of that a value of 0.04 based on certain correlation this value is estimated and this is used as a constant in this particular relation.

And, again it is related to the frictional resistance coefficient C_F in both the model and full scales along with the roughness allowance, because that is the major impact due to the change of Reynolds number between the model and full scale. So, once we estimate the wake fraction in the model scale, this simple equation can be used to calculate the full scale effective wake fraction for single screw vessels.

Now, for twin screw ships it has been observed that the scale effect on the wake fraction is very small. One of the reasons being that the two propellers are not in the central line of the ship so; the blockage effect is less on the propeller plane. And, hence for twins two ships normally there is no correction used for scaling of the wake fraction. And, the model scale wake fraction itself is used to estimate the full scale performance.

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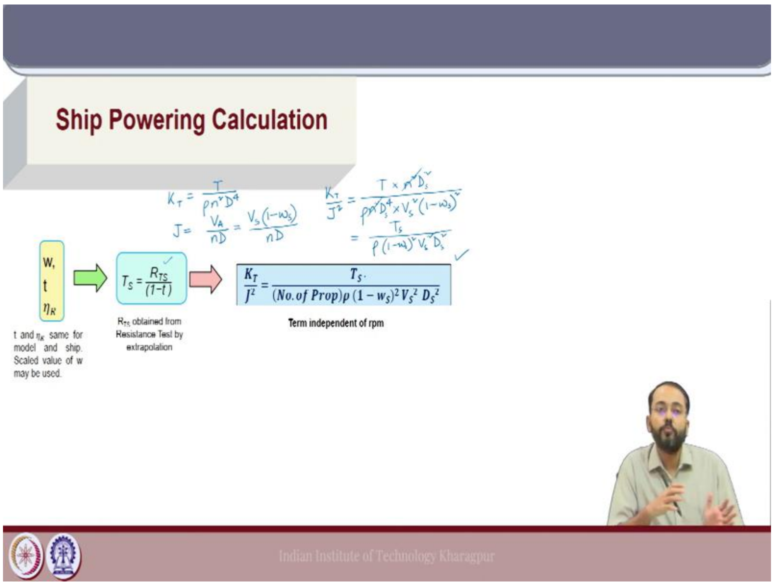

Now, after estimation of the propulsion factors in the model scale, we will do the ship powering extrapolation in the full scale. So, we have the wake fraction, thrust deduction and the relative rotative efficiency. And, we can apply the standard ITTC method to get the full scale wake fraction from the effective wake fraction using the equation that was shown in the last slide.

For the thrust deduction and relative rotative efficiency, it is assumed that they are free from scale effects. The first step here is to calculate the thrust of the ship, the total thrust in the full scale. So, we have the resistance of the ship that we get from the resistance test. What do we do in the resistance test? We measure the total resistance in the model scale and use standard ITTC extrapolation procedures to get the full scale resistance of the ship R_{TS} in the full scale.

So, that R_{TS} divided by (1 - thrust deduction) will give us the thrust of the full scale ship ($T_S = R_{TS} / (1-t)$). Now, one thing is very important here because this is for the full scale ship, there is no F_D term here. In the relation between resistance and thrust for the model scale, because it was done at the ship self propulsion point the tow force term F_D was there which was the skin friction correction force. In the full scale, we will have the resistance and thrust directly linked with the thrust reduction factor as seen earlier.

So, once we have the full scale resistance of the ship, we can divide by 1 - t to get the total thrust in the full scale. Now, the next step is to estimate this factor K_T/J^2 in the full scale which is a very important step for the powering performance estimation. Why? Because, we do not yet know the rpm of the propeller in the full scale; so, in order to enter into the open water diagram, we have to use a factor on an expression, which is devoid of rpm.

Now, K_T = thrust (T) / (ρ n^2 D^4) and J is V_A/nD, where V_A = velocity of the ship (V_S) × (1 - wake fraction). We can write wake fraction with a suffix S for the full scale by nD right. So, $K_T/J^2 = (T/ \rho n^2 D^4) \times (n^2 D^2) /(V_S^2 (1 – (\text{wake fraction}))^2)$ right and we see that the n square terms cancel each other.

And, we can get from this $T/(\rho \times(1 – (\text{wake fraction}))^2 V_S^2 \times D_S^2$. Now because we are doing it in the full scale, I can write D_S for the D^2, T_S for the thrust. So, this is matching with the expression shown here. One additional term here is the number of propeller. If this is a single screw vessel; so, this will be 1, but for twin screw vessel this number of propeller term will be 2.

Now, why we are using number of propellers here? Because, the open water diagram is for one single propeller and from R_{TS} / (1 – t), we get the total thrust of the ship. Now, we have to convert that total thrust into thrust per propeller to enter the open water diagram for a property ok that is why it is divided by this term multiplied by number of properties ok. So, finally, we get a term which is independent of rpm and we will see that rpm will be an output from this calculation.

So, we are using this K_T/J^2 term here. Now, in this term the total thrust in the full scale is known, number of propellers is known and wake fraction, speed of the ship, diameter everything is known. So, we should be able to calculate K_T/J^2 for different speeds. Now, for each model speed, corresponding to that we have a full scale ship speed and we can calculate K_T/J^2 based on our model test results and the results from the resistance test.

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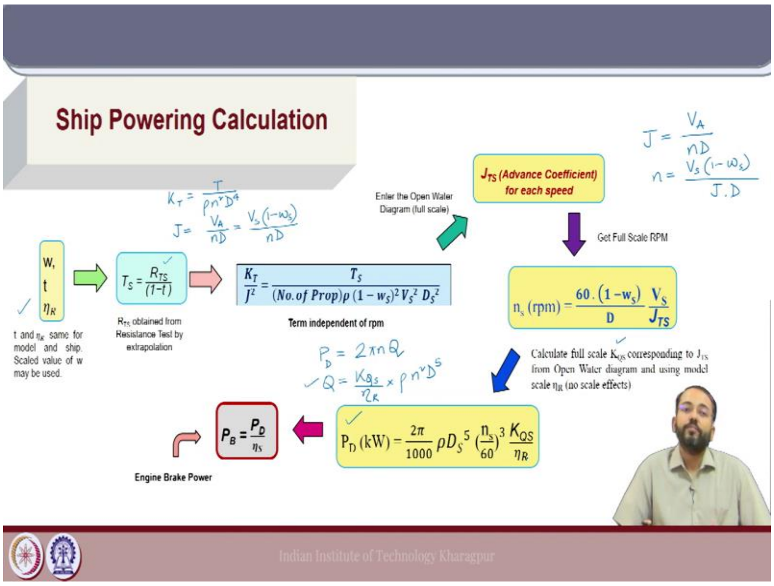

In the next step, we will use this value of K_T/J^2 to enter the open water diagram in the full scale. Now, we have also discussed how to get the full scale open water diagram from the model scale, if we are correcting for the Reynolds scale effects; that we can do using ITTC standard procedures or some towing tanks have their own way to get the full scale open water diagram from the model scale.

Now, we enter using K_T/J^2 and for that K_T/J^2 from the open water diagram, we can get the corresponding value of J for a specific speed of the ship, that we name it as J_{TS}, because we are using thrust identity in that sense K_T/J^2 squared identity. So, we name it J

T_S which is the advanced coefficient in the full scale that is why S is used for the full scale ship for a particular speed.

Now, for that advanced coefficient we can calculate the rpm. So, for any speed once we enter the open water diagram with K_T/J^2, we can calculate the corresponding J and from J we can calculate the rpm. Why? Because, J is V_A/nD and V_A is nothing but $V_S \times$ (1-wake fraction). So, n will be (V_S (1 - wake fraction))/(J × D), J × D, J here is J_{TS}. Now, we have multiplied it by 60, because in the full scale ship the propeller speed of revolutions is typically mentioned in rpm.

So, we have converted the R_{TS} value to rpm by multiplying with 60. So, once we have the rpm in the full scale, the same J can be used to calculate the corresponding K_Q from the open water diagram for the ship in the full scale. And, this K_Q can be used along with η_R which we had already calculated did in the beginning. So, this K_Q from the open water diagram divided by η_R will be the behind condition K_Q in the full scale.

And, η_R is considered to be divide of scale effects for standard calculation purpose. So, we can use these values to calculate the delivered power of the ship in the full scale. So, the delivered power P_D is given by $2 \pi n_Q$, where Q is K_Q; now K_Q is K_Q in the behind condition. So, it will be K_{QS} / η_R, because we have calculated this K_{QS} using this J_{TS} from the full scale open water diagram multiplied by $\rho n^2 D^5$.

So, if we multiply this Q with $2 \pi n$, we will get this particular equation for P_D. So, now, instead of n_S we have $n_S / 60$ as n_S is mentioned in rpm. And, for P_D because full scale power is typically expressed in kilowatt, it is divided by 1000 to get the power in kilowatt. So, in this particular expression all the values of this parameters are now known. So, we are in a position to calculate the delivered power in the full scale.

Now, the brake power of each engine can be calculated from this delivered power divided by η_S which is the shafting efficiency. The mechanical efficiency involved in the shafting components which is typically having a value of around 0.97. So, we have the engine brake power in the full scale ship.

This is how we get the propulsion factors from the model tests using the results of the self propulsion test, the open water test, in addition to the resistance test. And, we use standard extrapolation procedures for ship powering prediction from the model test results using K_T/J^2 similarity to enter into the open water diagram in the full scale and calculate the rpm and delivered power for the full scale ship.

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Now, this powering calculation that we have just done is based on the model test results. But, a correlation factor also is often applied to match this powering prediction from the model test with the measurements that are obtained from full scale trials. Trials means, the estimation that is done during the trialing of a new built ship. So, when a ship is built it has to undergo sea trials for estimation of different parameters for a ship, one of it is the powering performance.

Now, from the full scale trials the value of the powering performance parameters of a ship can be correlated with the powering predictions that are done from a model test facility. And, based on this comparison of results for previous model tests a correlation allowance is developed for different types of ships. Now, different model test basins have different types of facilities. For example, the length of the tank, the capacity of the tank in terms of the model size, the model speeds will be different from one towing tank to another.

Now, based on this there will be some bias errors in the estimation of ship powering performance from different towing tank facilities. So, what is done typically is based on the full scale estimations from trials, the powering calculation obtained after extrapolation from the model tests, that we have seen in the last slide are compared. And, a statistical analysis is done based on specific ship types over many years of experience for a particular facility.

And, they are computed into a correlation factor which is used in the powering performance extrapolation for future ships. So, each model tests that is being done is used in this statistical process and these correlation factors are defined over time. So, that a particular model test results when extrapolated to full scale can be effectively converted into a result, that can be used for a full scale ship in an actual trial condition. So, these systematic errors that can arise in different test facilities are basically included in this correlation factors.

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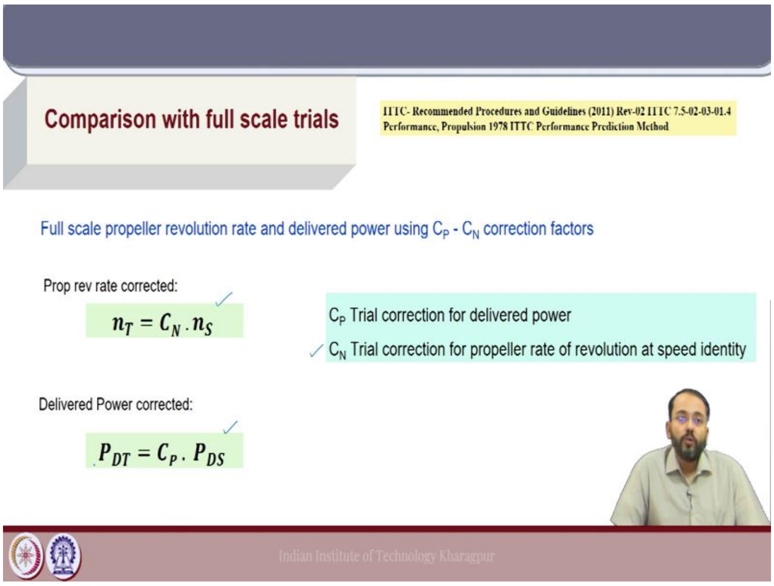

So, as per ITTC recommended guidelines, there are different kinds of correlation factors, which are used for model testing in naval architecture. For propulsion tests, the commonly used correlation factors are C_P, C_N correction factors which are the correction factors for propeller revolution rate and delivered power. Now, C_P is the trial correction for the delivered power and C_N is the trial correction for the propeller rate of revolution at speed identity.

So, if we have the n_S, we have seen that in the powering performance extrapolation we have calculated the revolution rate of the propeller in the full scale which was n_S which is the value that is obtained from the model test after extrapolation. Now, this n_S using this correction factor C_N for the propeller rate of revolution, we can convert it to n_T, which is the trial value of the propeller revolution.

Similarly, we can use another correction factor C_P to convert the calculated value of the delivered power of the ship in the full scale to the trial value P_{DT}. So, in this way we can convert the values, which are obtained in the full scale from the model test extrapolated results to the trial values using some correction factors, which are based on analysis of previous model test results as well as full scale trials for similar kinds of ships.

So, these correlation factors value will be different for different model test facilities and they are based on previous experimented values and experience. Now, this will be all for the part on propulsion tests and powering extrapolation to the full scale.

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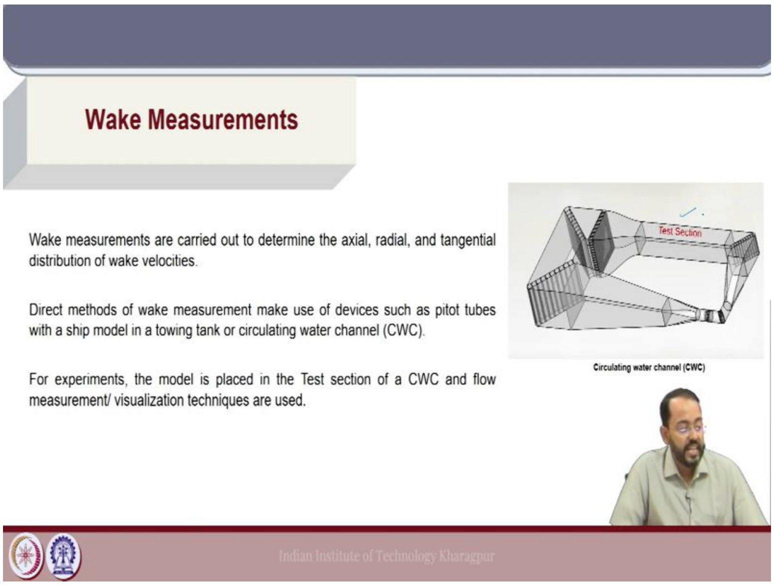

Now, some other measurements that are done related to propellers are wake measurements, which are typically done to assess the wake velocities behind the ship hull in the propeller plane without the presence of the propeller. So, it can be done using a circulating water channel as we have seen earlier.

And, these channels have a test section where we can keep the body of interest, in this case the model. And, behind that some flow measurement device like pitot tubes can be used to estimate the velocities which are measured in three different directions, basically in the axial, radial and tangential directions on the propeller plane to estimate the nominal wake field behind the ship.

And, this is used to have specific insights into propeller designs which are tailored for a specific ship type, based on the wake velocities and also the stern design of the ship. The effectiveness of the design in certain aspects can be checked in terms of the wake velocity, which are measured in these wake measurement devices in the circulating water channel. Wake measurements can be done in both towing tank as well as circulating water channel and they can be used effectively for certain design purposes.

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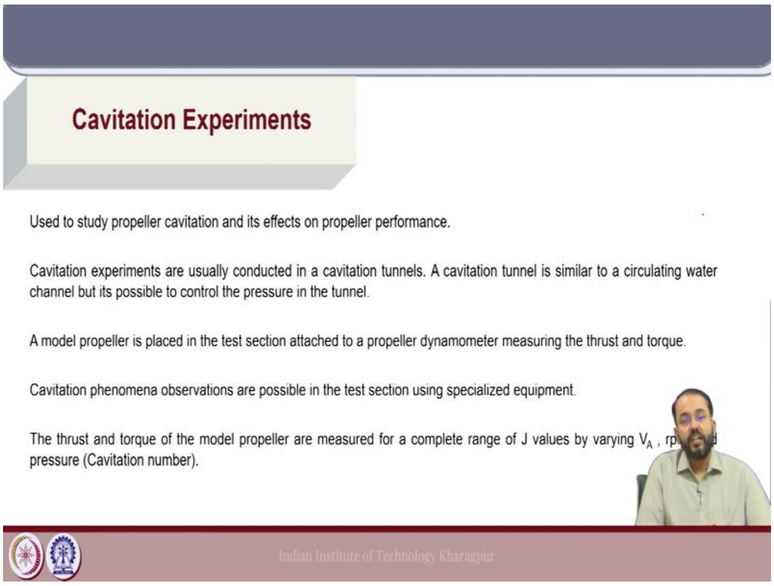

Another set of experiments which are popularly used for ship propellers are cavitation experiments. Cavitation will be covered in details in the next classes. I am just giving a brief overview of cavitation experiment, because this falls under the different types of model testing we do for marine propulsion. So, in a cavitation experiment what we do is the propeller performance is measured in cavitation tunnel.

So, the propeller thrust, torque and efficiency are measured for different flow conditions in a cavitation tunnel, where in addition to the propeller rpm and the velocity of advance we can also change the pressure. So, in a cavitation tunnel, the pressure can be controlled and that leads to cavitation phenomena or; that means, occurring of cavitation over different propeller blade sections depending again on the propeller design and the operational conditions.

And, it can be observed for different pressure conditions, which relates to the cavitation number. So, the idea of these cavitation experiments is to assess the performance of a propeller under different conditions of cavitation number and obtain the open water diagram for different pressure characteristics, which is related to the cavitation number on the propeller. We will continue with propeller cavitation in the next class.

Thank you.