Marine Propulsion
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Lecture - 11
Propeller in Open Water 1

Welcome to lecture 11 of the course Marine Propulsion, today we will start with Propeller in Open Water.

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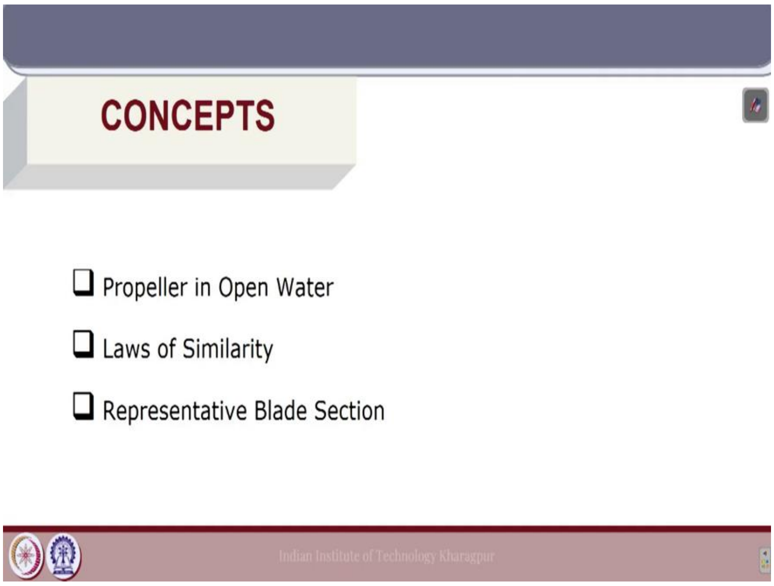

So, the key concepts covered in today's lecture will be propeller in open water condition which is basically the condition where there is no ship in front. Next some laws of similarity which are important in understanding the model shift correlation special in case of marine propellers and the concept of representative blade section which is used to define certain blade parameters.

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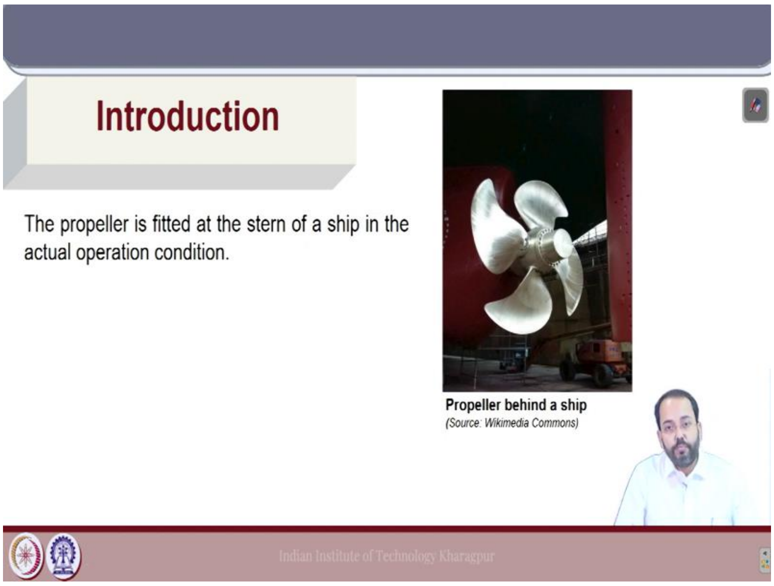

So, a propeller is typically fitted in the stern of a ship which is in the actual operation condition. This is the figure of a propeller behind a ship in front we have the ship hull here and behind the propeller we have the marine rudder ok. Now, this is the actual operation configuration of a propeller.

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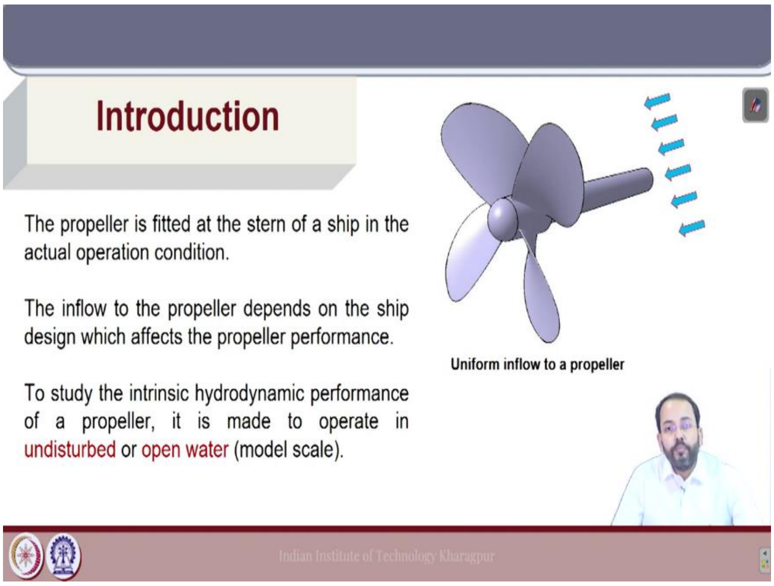

Now, in this particular case the inflow into the propeller will depend on the ship design which affects the propeller performance. Because we have the ship in front of the propeller the design of the ship specially the stern part of the ship will affect its performance. So, we also would like to understand the performance of the propeller separately; in order to do so, we have to test only the propeller.

When the propeller is acting behind a ship the inflow into the propeller is disturbed due to the presence of the ship hull. Now, the same propeller working behind different shift designs will have difference in their performance. So, it is also important to understand the intrinsic performance basically the hydrodynamic performance of a propeller in a condition where there is no ship in front.

So, that will give the performance of the propeller itself this concept is called the open water condition ok. Now, in an actual condition in the full scale it is not possible, it is only possible to evaluate the performance of a propeller in open water using model tests. So, in the open water condition what will we see the inflow into the propeller will be uniform, because the propeller is moving ahead at a uniform velocity without any ship in front.

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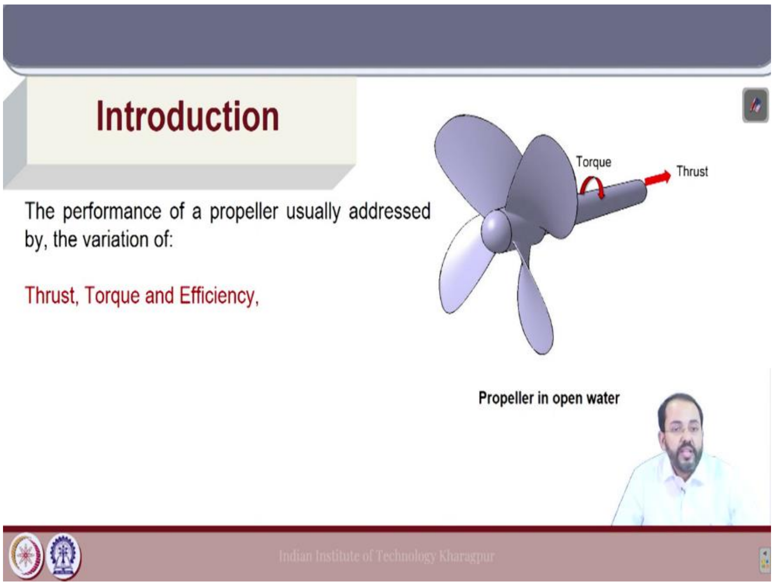

So, normally the performance of a propeller is usually addressed in the form of the variation of thrust and torque with certain parameters like advance ratio as well as the rotational speed. So, we have the thrust directed along the axis in the direction of the motion of the ship and the torque is supplied to the propeller from the engine ok.

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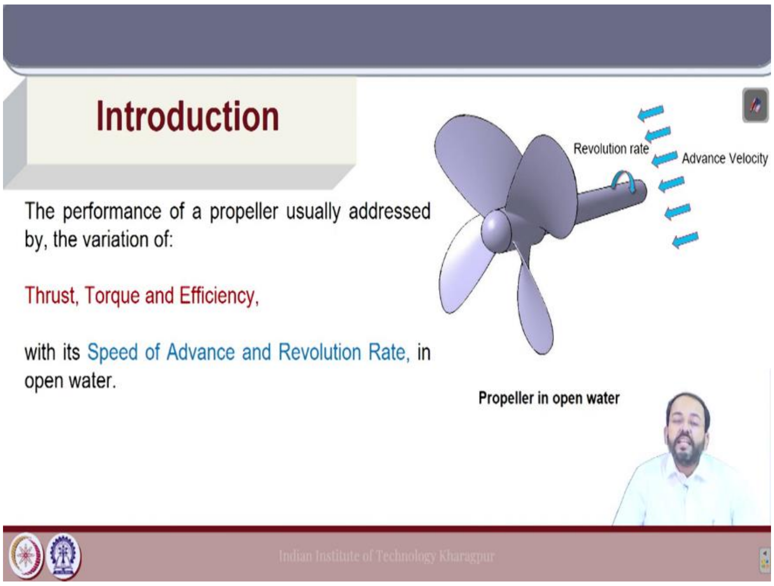

So, based on the speed of advance which is the uniform velocity V_A in the open water condition and the revolution rate the RPM of the propeller. We will try to compute the thrust torque and efficiency of the propeller in open water condition. So, here you see the arrow is given as a form of uniform advanced velocity at which the propeller is moving forward in that sense the fluid is directed in the opposite direction to the propeller motion as we have seen in the derivations for propeller theory.

Now, this is the figure of a propeller connected to a ship via the shaft propeller shaft. In an actual condition if we want to do an open water test the propeller has to move ahead; so, there should be a model or a body which is pushing the propeller in front.

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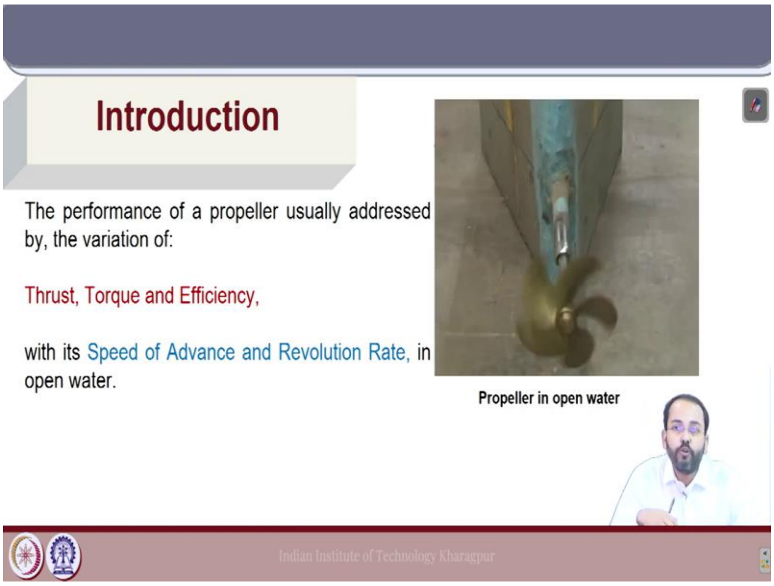

So, this is done in an open water test in this form as the diagram is shown here. So, we have a body behind a propeller which is connected by a shaft and the propeller is pushed. So, the propeller is put forward of the body in the open water test, we will go into details of this setup when we discuss propeller model testing and in the open water test the propeller is attached to the shaft in a reverse way. So, that because it is put forward of the model ok.

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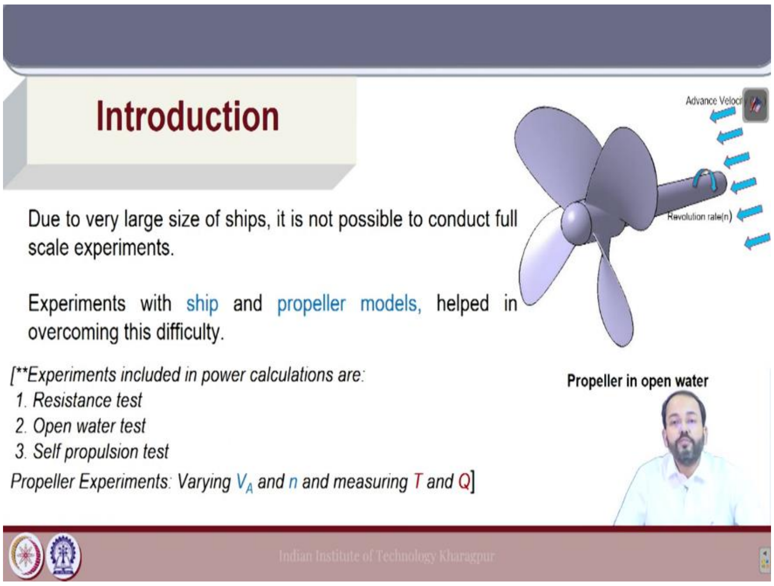

Now, for naval architecture we have the ships which are very large. So, it is not possible to have full scale testing for ships, only trials are conducted which is basically before handing over of the ship. So, one has to estimate the hydrodynamic performance of a ship using model tests. So, the standard model tests in naval architecture involve ship resistance test and for propellers there are open water test which is testing of only the propeller.

And then we have self-propulsion test where the ship and propeller together are tested in the towing tank. And in addition, sometimes cavitation tests are done for specific requirements. So, in these tests basically we estimate the hydrodynamic performance of the ship and propeller separately and also together as a single unit. For the propeller experiments what we do is, we vary the velocity of advance and the rotational speed to measure the thrust and torque of the propeller.

This is again the concept of advanced velocity and rotational speed for propellers which we use for during the open water test.

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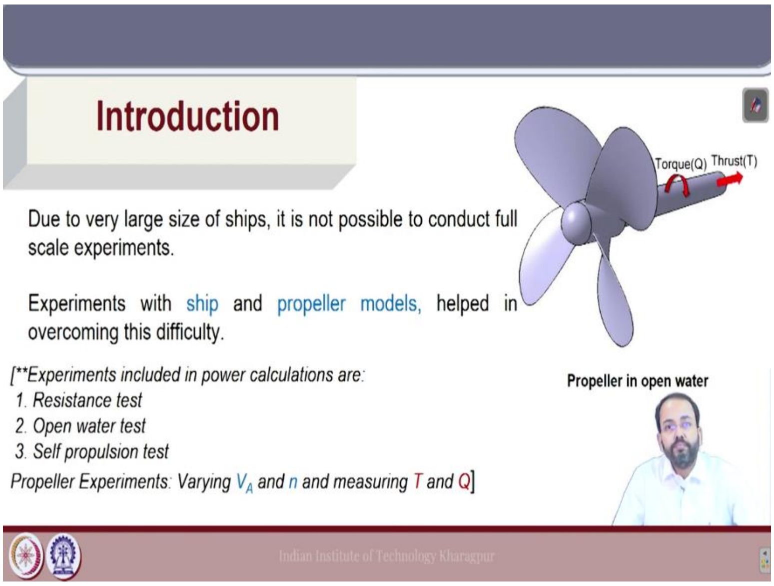

And the output we measure are the thrust and torque, we write it in the form of coefficients which we will define soon.

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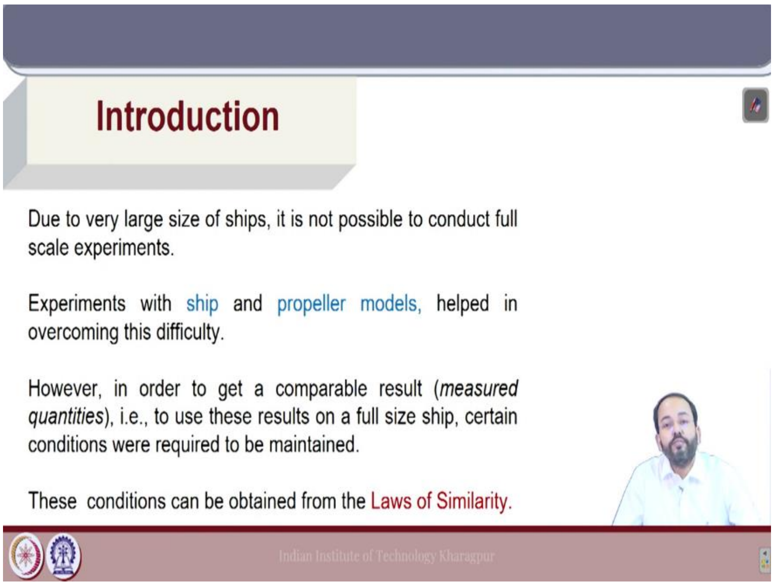

Now, the main issue we encounter in ship and propeller model testing is that the tests are done at a scale which are much smaller than the ship scale, because we are testing models where the forces are very low compared to the ship scale. Due to that reason we have to use certain similarities, certain concepts which can help us to relate the model scale forces and velocities to the full-scale values.

So, based on this we will use the model scale results to extrapolate the full-scale values and use it for actual ship powering calculations. These conditions which needs to be maintained for testing of ship and propeller models are called laws of similarity, these are extensively used in naval architecture which forms the basis of model testing.

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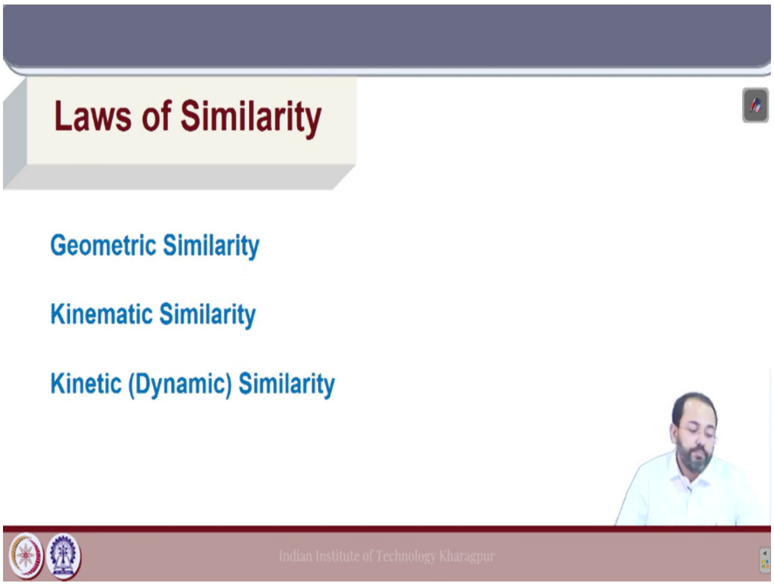

So, what are the different similarities that we use, the first one is the geometric similarity which says that the model and the full scale or the prototype should be geometrically similar. The second one is the kinematic similarity which relates to the ratio of the velocities in the model and full scale which have to be kept similar. And the third one is the kinetic or dynamic similarity which mentions that the ratios of forces in the model and full scale should be similar depending on the forces which are important for the typical investigation that we are doing.

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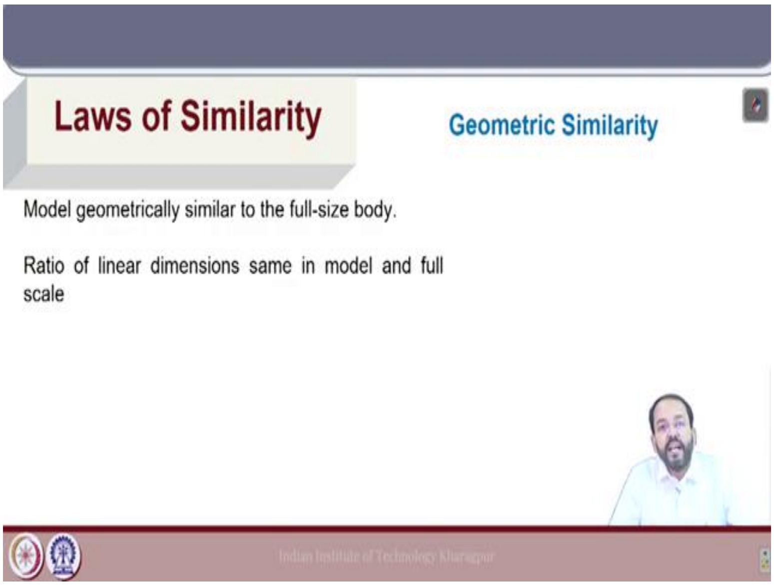

So, we start with the geometric similarity which is basically the similarity of the model geometrically to the full size body.

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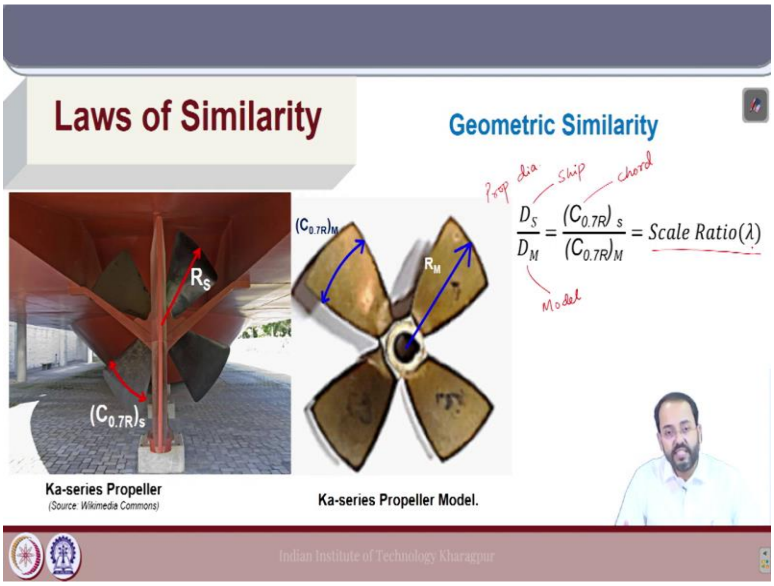

So, suppose we have a propeller here we have a full size Ka-series propeller which is of a particular design depending on the series parameters shown in the left fitted behind a ship and we have a model of the same propeller which is shown on the right. So, what does geometrical similarity mean that we have to maintain similarity of the geometry between the full scale and the model.

It means that suppose at a particular radius here it is shown at a radius of 0.7R which again I will explain when I discuss representative sections. Let us say it is C in the full scale with a suffix S and the radius of the full-scale propeller is R_S. Then in the model scale we will have; obviously, a different chord length C and a different radius. Now, geometric similarity means that the ratios of these dimensions should be equal.

So, the model is geometrically similar in all dimensions in all the different axis with respect to the full-scale ship. So, in this case D_S is the diameter of the propeller in the full scale which is the ship scale and D_M is the diameter of the propeller in the model scale ok. So, propellant diameter and C is the chord length at the radius r/R equal to 0.7 again in the ship and model scale; so, this ratio should be same.

So, the ratio of the chord length between the ship and model scale should be same as the ratio of diameters and that is equal to the scale ratio (λ) which we maintain same for the propeller as well as the shape. So, this is the basis of geometric similarity; so, all the dimensions are uniformly scaled between the ship and model scales.

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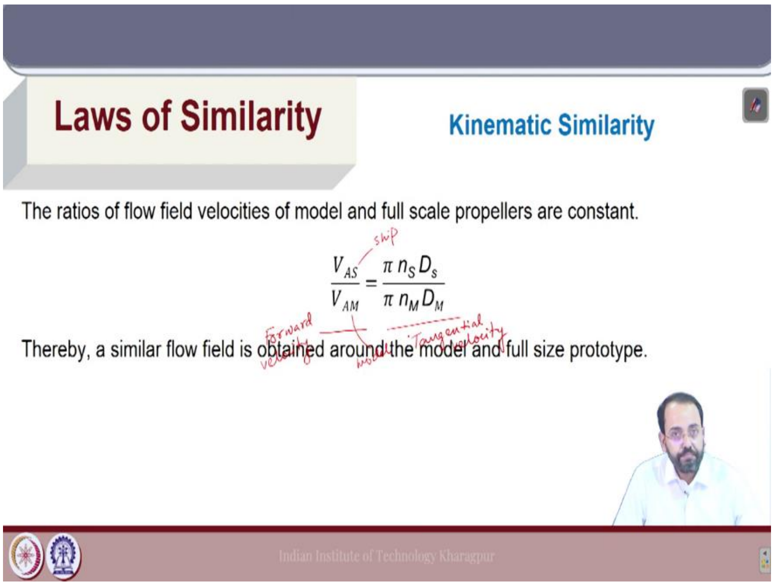

Next is the kinematic similarity which says that the ratio of flow field velocities of the model and full-scale propellers are constant. Again, which means that lets say we have the V_A which is the forward velocity and this is the tangential velocity due to the rotation right. Now, this ratio of the forward velocities between or the advance speed between the full scale again S is the ship scale and M is the model scale.

So, the velocity of advance between or the forward velocity between the ship scale and model scale should be equal to the velocity which is the tangential component due to the rotation of the propeller blade, here the velocity is taken at the using the diameter. So, what is the outcome of this kinematic similarity? The outcome is that if we maintain a similar ratio of the velocities a similar flow field can be maintained between the model and the full scale propeller.

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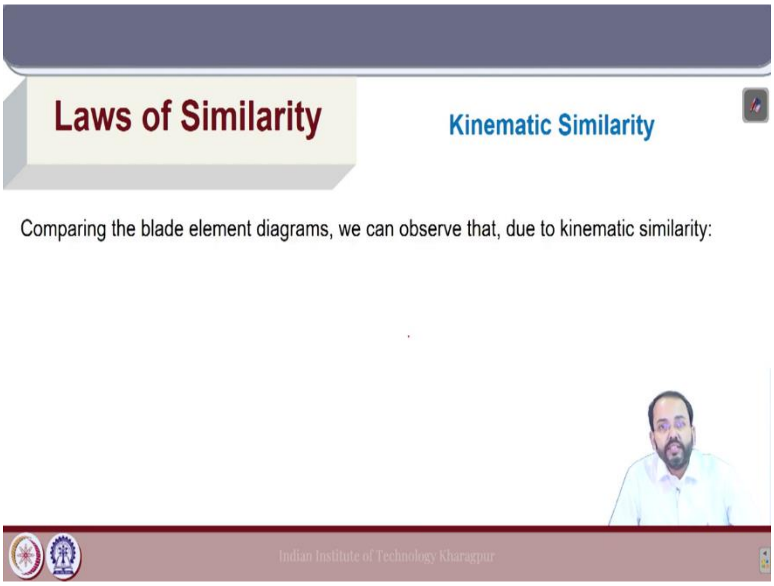

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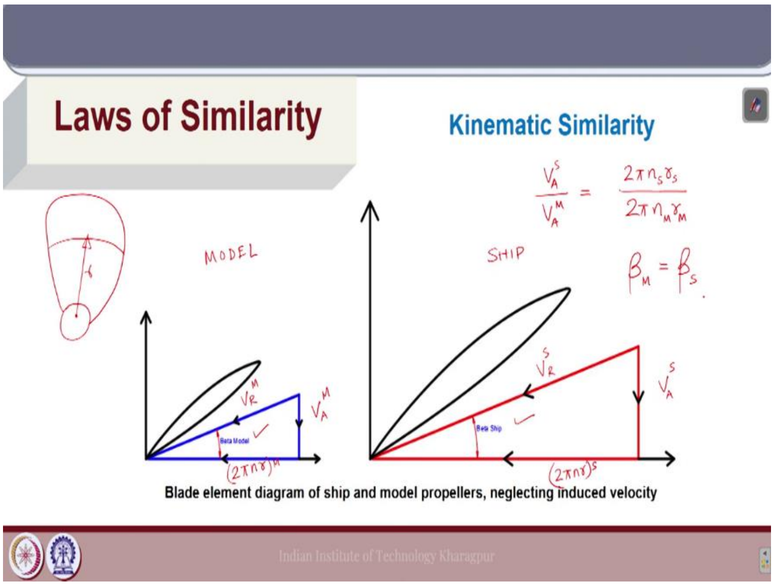

So, if we look into the blade element diagrams between the model and full scale what do we have? We have V_A which is the advance velocity plotted here. And here we had 2πnr, this is basically at a radius r we are showing the blade element diagram; so, the resultant is V_R right. So, in the full scale this is V_A^M, let us say V_A model scale and 2 π n r in the model scale V_R^M, full scale is V_A^S, $(2 \pi n r)^S$ and V_R^S.

So, this kinematic similarity basically means that if $V_A^S/V_A^M = 2 \pi n_S r_S / 2 \pi n_M r_M$, what will happen then if we can maintain the same ratio of these velocities in the model and full scale? This is ship and this is model scale. Then the V_R will be aligned at the same angle with respect to the base which means that the beta (β_M) in the model and beta ship (β_S) will be same; so, beta model equal to beta ship ($\beta_M = \beta_S$).

Now, why is this very important? Because, this hydrodynamic inflow angle (β) basically is the main factor which governs the angle of attack and the development of the sectional forces which basically will give the thrust and torque of the blade section. So, if we can maintain kinematic similarity, the same thrust and torque coefficient can be maintained between the model and full scale up to a certain level.

We will see into other effects of viscosity later, but the basic angle which comes from the blade element theory can be maintained similar if we can maintain kinematic similarity.

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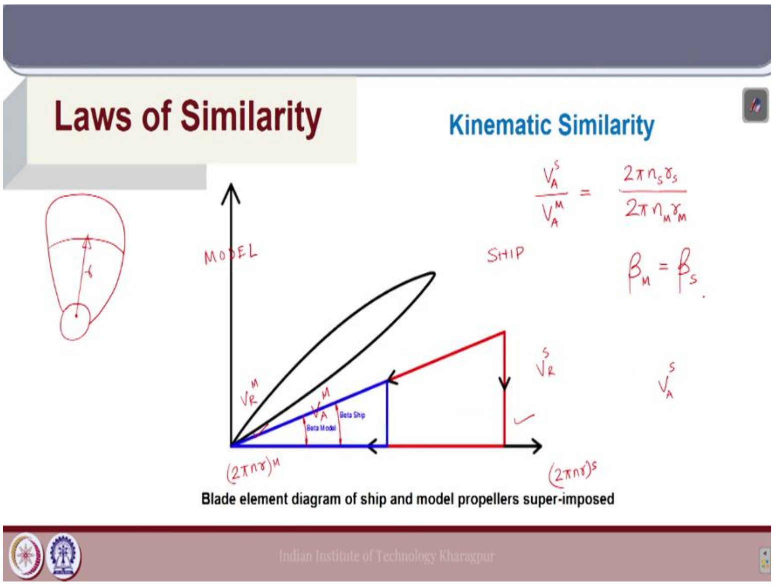

So, these two diagrams are juxtaposed in the model and full scale. The depending on the actual scale factor the values of these vectors will be much higher for the full scale compared to the model scale.

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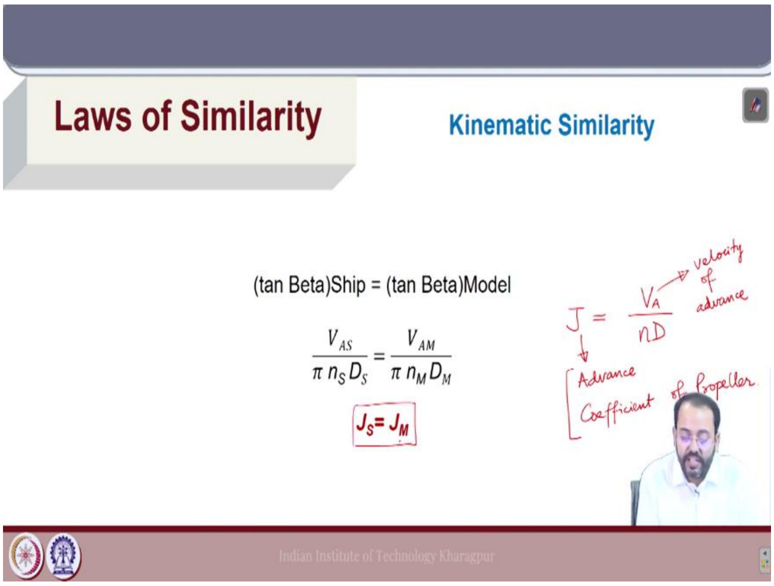

If we compare the two diagrams what we have obtained is that the β also the tanβ in the ship and model scales are equal which is the ratio of the advance and the tangential velocity components. This entails that we will have the same advance coefficient in the model and full scale where the advance coefficient J is given by V/nD ok.

So, if V is the let it is V_A is the velocity of advance and n is the rotational speed D is the propeller diameter then the ratio of V_A/nD is called the advance coefficient of the propeller. So, the kinematic similarity gives that the advance coefficient of the propeller in the model scale and full scale should be equal.

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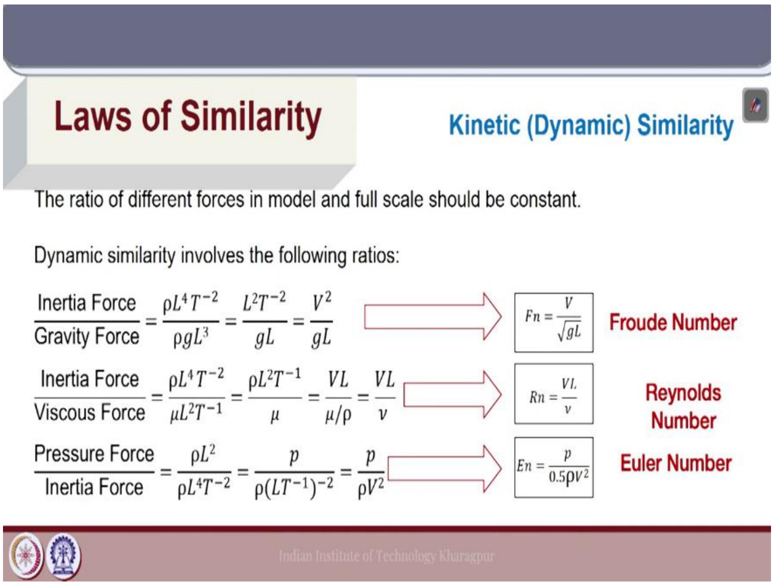

The next similarity is the kinetic or dynamic similarity; here, the ratios of the different forces in model and full scale should be constant. So, what are the different forces that we encounter in the model and full scales? We have the inertia force, the gravity force, viscous force and the pressure force. We can look into combinations of these forces and how they can be expressed as a ratio of the other forces.

For example, the first one inertia force by gravity force; if we express in terms of dimensions finally, we get the value V^2/gL where V is the velocity and L is the length which is the characteristic length for any problem for which we are trying to solve; so, this gives the concept of Froude number.

So, if this ratio is taken and we take a square root of this inertia force by gravity force, we get what is called the Froude number. The next one, inertia force by viscous force again if we get the dimensions finally, the ratio is VL/ν which is the Reynolds number. And the third one pressure force by inertia force is $p/\rho V^2$ which is given by Euler number.

So, in the context of model testing dynamic similarity means that these ratios needs to be kept similar, if we want to maintain all the similarities between the model and full scales.

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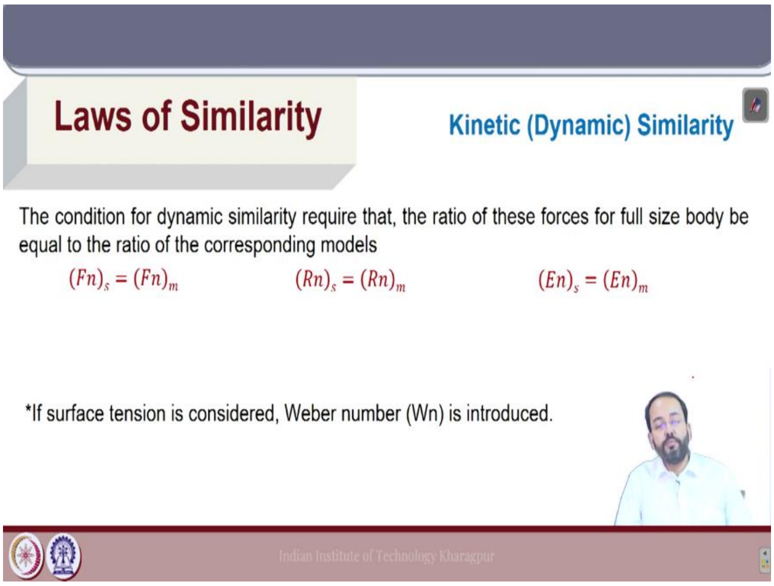

So, in order to maintain dynamic similarity, the ratios of these forces in the model scale and the full scale should be similar which means that the Froude number, Reynolds number, Euler number in the model and full scales needs to be kept similar. We will see that it is impossible to keep all these ratios same in the model and full scales for practical model testing.

So, we have to look into the feasibility based on the requirement and the problem that we are trying to solve when we are doing hydrodynamic model testing. If for example, surface tension is considered another non-dimensional quantity Weber number will be introduced. For example, if we have surface piercing propellers where surface tension is an issue then the concept of Weber number will come in.

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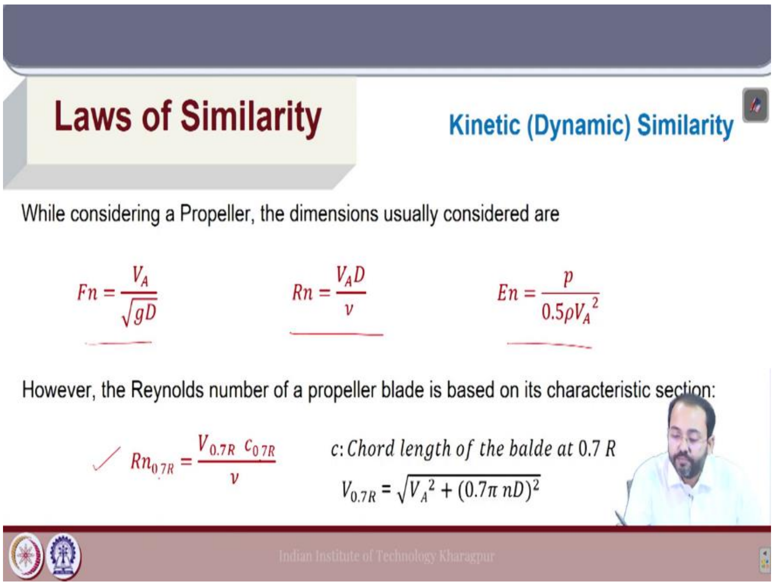

Now, when we consider a propeller, what are the dimensions that we are taking into account? For Froude number we have a velocity and we have a characteristic length we can take it as the diameter of the propeller. For example, if we talk about Reynolds number, we can have a combination of velocity and the diameter of the propeller divided by ν. And when we talk about Euler number then the pressure $p/½\rho V^2$ where V can be taken as the velocity of advance.

Because Froude number is a ratio of inertia and gravity forces, the wave making becomes very much dependent on the Froude number. For propellers in open water the immersion depth is kept sufficient, so that it does not create waves on the surface. In that case, Froude number for propeller open water testing is not a very important criteria.

Now, if we talk about Reynolds number for propellers, typically for a propeller blade the Reynolds number is based on the resultant velocity over a particular blade section which is the representative section of the propeller blade. So, on the top what we have mentioned is a very simplistic idea, how we can relate these non-dimensional numbers with respect to the propeller advanced velocity and diameter.

But if we do practical studies we will see that the Reynolds number of a propeller blade is based on the chord length of a section which is taken at 0.7R and the resultant velocity. Now, here we will go into the concept of representative section.

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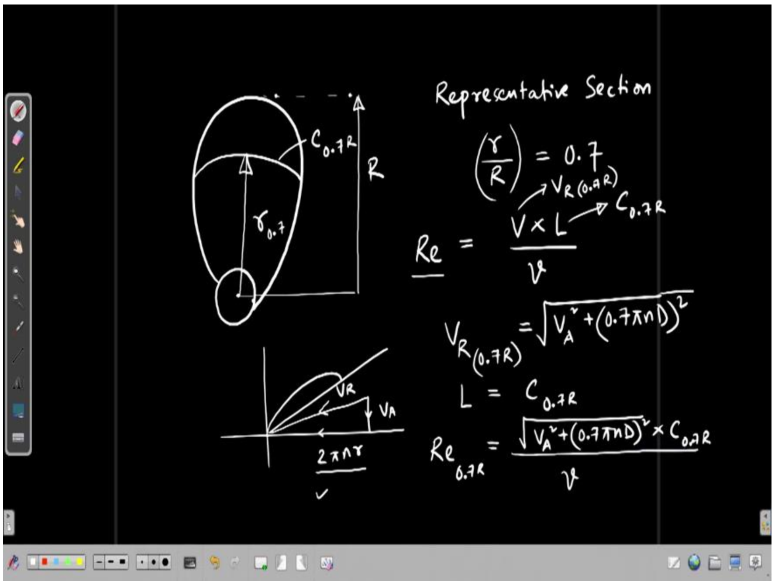

Let us consider a propeller blade of radius R. So, representative section of a propeller blade means, a particular section which can represent the properties of the entire blade. It is typically taken at 0.7R; so, here R 0.7; that means, this is taken at a radius R where r/R equal to 0.7 ok. So, the meaning of representative section is that at this particular section the sectional properties will mimic the properties of the propeller.

It is not always exact, but the concept of representative section is used to explain the certain parameters of a propeller blade which are otherwise difficult to estimate. One example is the Reynolds number; for example, we have the Reynolds number of a propeller blade will depend on a velocity, a characteristic length divided by ν.

Now, what will we take as the velocity? We see that we have a velocity V_A which is the advanced speed and we have a velocity due to the rotation of the propeller blade. Now, that rotational component depends on the radius, when we have the blade element diagram, we see that there are two components of velocity V_A and $2 \pi n r$.

Now, V_A is independent of the propeller radius; so, whatever section we take we have the same velocity of advance for open water condition. But, this tangential component $2 \pi n r$ is a function of radius; so, finally, the V_R that we have the resultant velocity over any propeller blade section is also a function of radius. So, this concept of representative section gives an idea of the calculation of certain parameters. For example, Reynolds number based on the values of the velocity as well as the length of that section.

So, we take this chord length of that section $C_{0.7R}$ as the length here characteristic length ok, $C_{0.7R}$ and for V we take the velocity $V_{R(0.7R)}$. So, how do we write? $V_{R(0.7R)}$ will be the resultant root over $V_A^2 + (0.7\ \pi\ n\ D)^2$, because we have a two here and our L in the Reynolds number equation is $C_{0.7\ R}$ chord length.

So, we have the Reynolds number at 0.7R for the propeller is given by or we can also say it is the Reynolds number of the propeller blade as root over of $V_A^2 + (0.7\ \pi\ n\ D)^2 \times C_{0.7R}$ divided by V ok.

$$Re_{0.7R} = \frac{\sqrt{V_A^2 + (2\pi nD)^2}\ \times C_{0.7R}}{V}$$

We can also write the Reynolds number with respect to the propeller diameter as the characteristic length or the V_A as the characteristic velocity, but this is the most commonly used value of Reynolds number.

In some texts you will also find the characteristic section taken at 0.8R instead of 0.7R. So, the idea is same that these sections are used to represent the property of the propeller blade with respect to certain parameters. For example, for Reynolds number and for cavitation calculations etcetera. This is how the laws of similarity apply to model testing, we will continue with other aspects of propeller in open water in the next class.