**Marine Propulsion**
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**Lecture - 39**
**Miscellaneous Topics**

Welcome to lecture 39 of the course Marine Propulsion. Today we will discuss some Miscellaneous Topics related to marine propulsion.

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The key concepts to be covered in today's lecture are: unsteady propeller loading, propellers on the inclined shaft, propeller roughness, and propulsion in a seaway.

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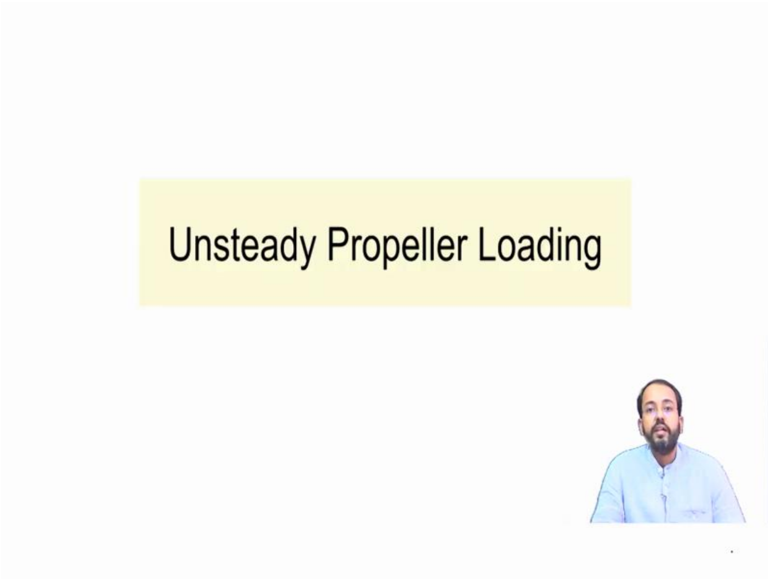


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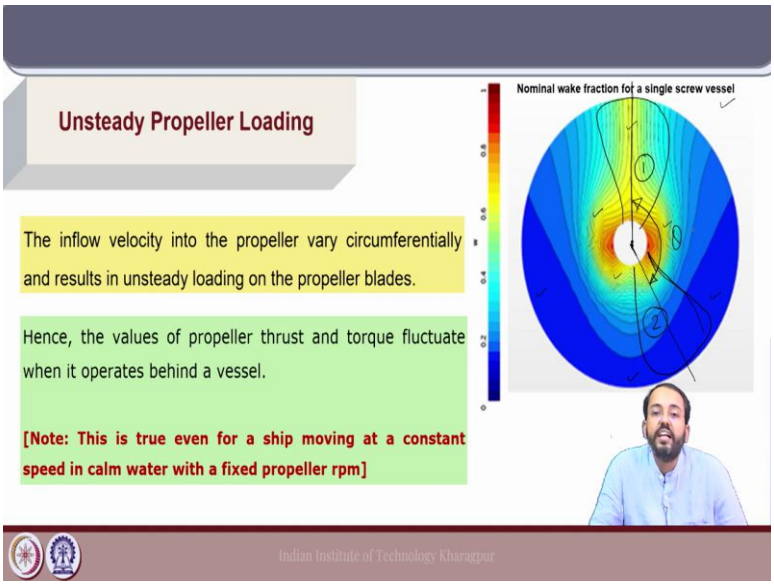


Let us start with the first topic which is unsteady propeller loading. The inflow velocity into the propeller varies circumferentially at each radial position on the propeller blade, and we have seen how the wake varies at the propeller position due to the presence of the ship hull.

Now, this diagram shows the distribution of nominal wake over the propeller plane; that means, the wake fraction without the presence of the propeller for a single screw vessel, and these ranges which are marked in yellow and red. These are the regions of high wake fraction where the blockage effect is very high due to the presence of the hull and the blue regions at the periphery are the regions where the wake fraction is close to 0.

Now, for each complete revolution the propeller blade passes through these different regions of wake fraction values and because of that the velocity which is the inflow velocity, if we consider the axial inflow into the propeller blade that varies circumferentially and it results in unsteady loading on the propeller blade. Now, this unsteady loading results in the fluctuation of thrust and torque when a propeller operates behind a vessel.

Now, this particular aspect is true even for a ship moving at constant speed in calm water for a fixed propeller rpm. So, these fluctuations of thrust and torque over a complete revolution of the propeller blade will happen even for a constant vessel speed and propeller rpm. Now, let us consider an initial position of the propeller blade here, which is the position for $\theta$ equal to 0, if we take $\theta$ as the angle taken from the vertical line as the reference.

Now, if we take a second position of the propeller blade here the wake velocities into the propeller at this particular position is very much different as compared to the position 1. So, this is the change in the angle $\theta$ between the two positions, and due to this there will be fluctuations in the thrust and torque as the inflow velocity changes into the propeller disc. And we will see later that these fluctuations are higher for propellers which are on inclined shafts, because the shaft inclination also results in additional changes in the velocity over the entire propeller disc.

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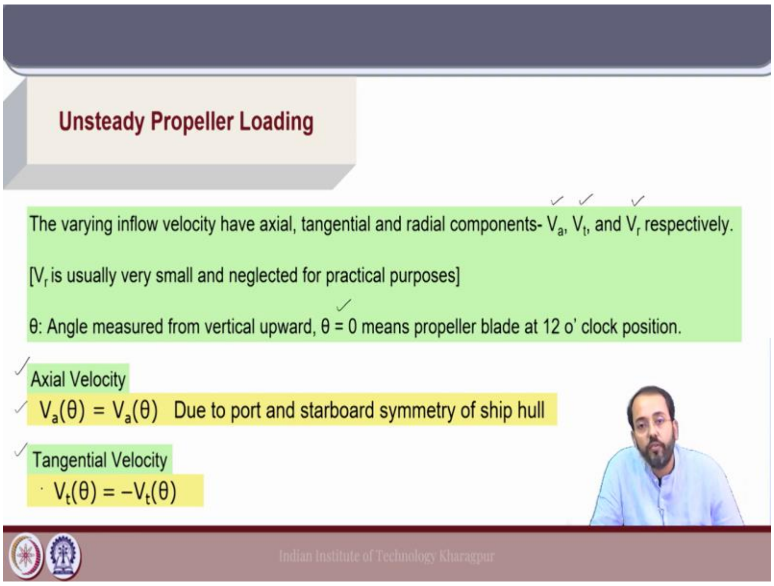


Now, the inflow velocity at different locations have axial, tangential and radial components as mentioned here $V_a$, $V_t$ and $V_r$. In general the radial component $V_r$ is very small and usually neglected for practical calculations. So, if we have the θ as the angle measured from the vertical upward as shown. So, θ equal to 0 will represent the 12 o' clock position of the propeller blade and both the axial as well as tangential velocities will be functions of the angle θ.

Now, because of the port starboard symmetry of the ship hull the axial velocity will be an even function of θ. So, it will be same on either sides due to the port and starboard symmetry whereas, due to the rotation of the propeller in a particular direction the tangential velocity will be an odd function of θ.

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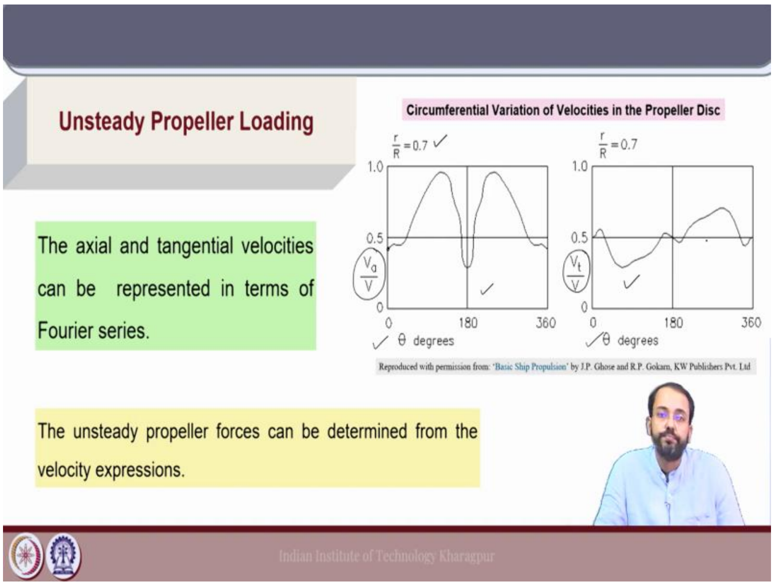


Now, the variation of axial and tangential velocities over the entire circumference location of the propeller disc based on the variation in theta is shown here. For the axial component it is non-dimensionalized by the inflow velocity V and similarly the same is done for the tangential component.

And, we see here that the axial component has a very low value at θ equal to 0 due to the high value of weight fraction and the value of $V_a/V$ changes drastically over different angular locations of the propeller blade, and as mentioned $V_a$ is an even function and that is how the curve of $V_a$ versus θ behaves between 0 and 360 degree which represents the entire position over different circumference locations at a particular radius.

So, these plots are done as the representative section r/R at 0.7 of the propeller blade and this variation is just a representative variation which will depend on the propeller geometry as well as the inflow characteristics. On the other hand for the tangential velocity it is an odd function and hence the changes in $V_t/V$ over the different circumferential positions are shown in this pattern.

Now, these axial and tangential velocities can be represented in the form of Fourier series and unsteady propeller forces can be determined from these velocity expressions from their changes over different locations on the propeller disc.

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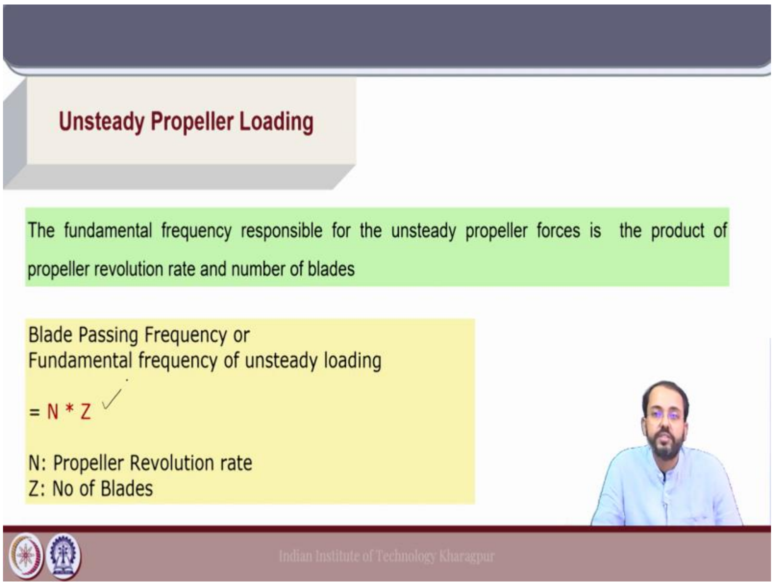


Now, what is the fundamental frequency which is responsible for these unsteady propeller forces. It is the product of the propeller revolution rate and the number of blades this is also called the blade passing frequency. So if, N is the propeller rpm and Z is the number of blades. The blade passing frequency = N × Z and this frequency governs the unsteady propeller forces in a major way for the propellers. Also, there are higher harmonics of these frequencies for the propeller unsteady forces.

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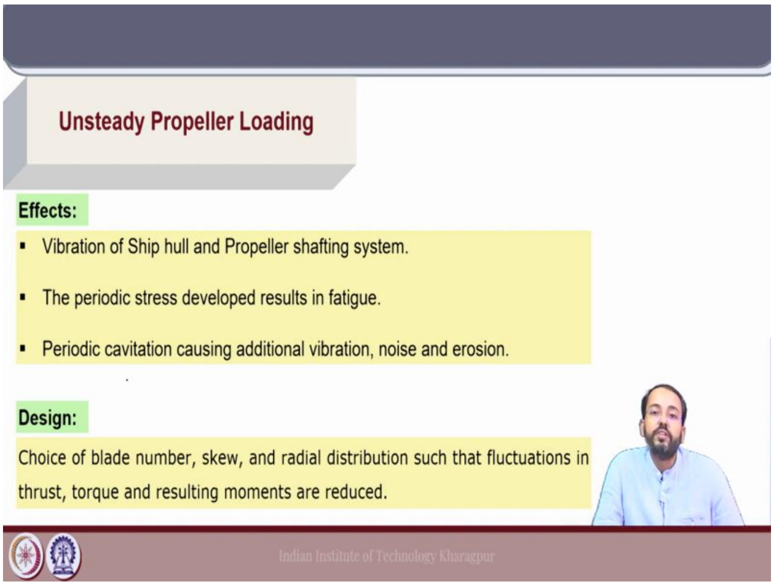

Now, what are the effects of unsteady propeller loading we have vibration of the ship hull and propeller shafting system. The periodic stress which is developed on the propeller blade that results in fatigue during the life cycle of a propeller as it is operating in the sea conditions, and periodic cavitation, which causes additional vibration noise and erosion.

Now, because this unsteady propeller loading changes the velocity patterns over the propeller blade and also the stresses, these periodic stress and cavitation results in different adverse effects for the operation of marine propellers. Now, from the design point of view the choice of blade number, skew, and radial distribution should be made. So, that a suitable design is adopted such that the fluctuations in thrust, torque and moments can be minimized. Now, these points have been discussed for the relevant sections under propeller design.

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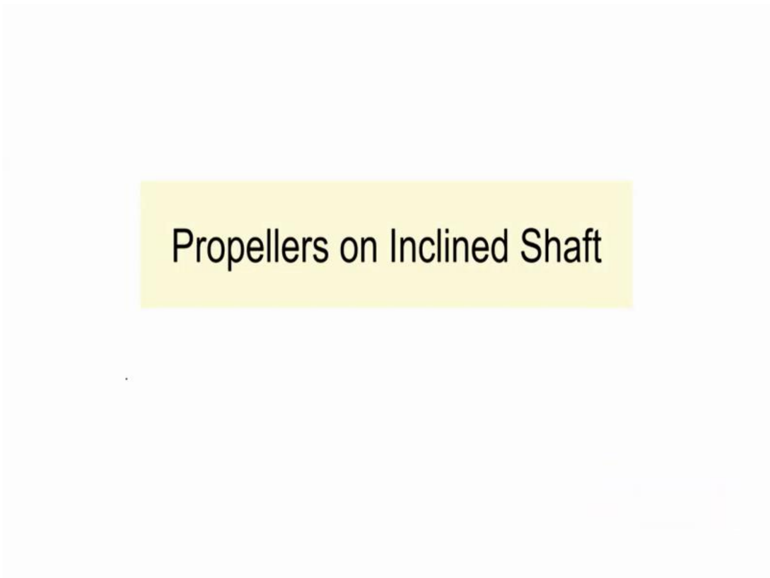

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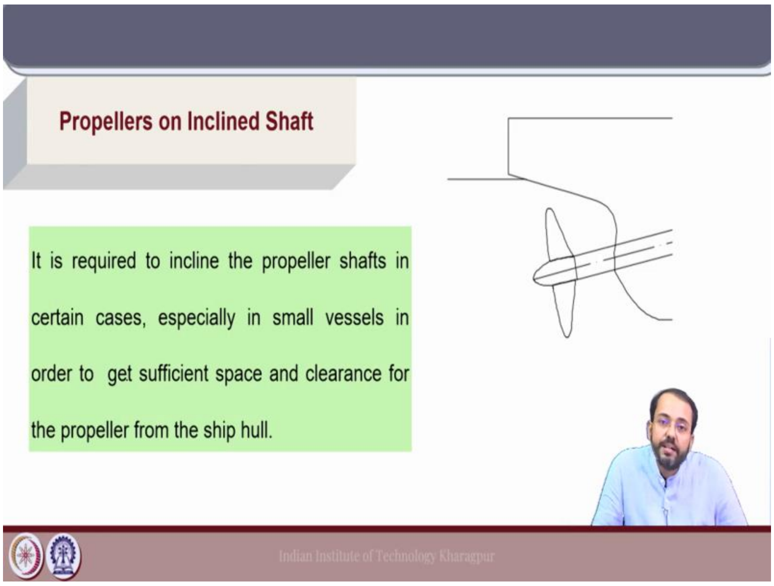


Next, we will look into propellers on inclined shaft. For certain ship designs it is required to incline the propeller shaft, especially in small vessels where sufficient diameter is not available. So, in order to maintain the clearance from the ship hull the shaft of the propeller is inclined, and because of that a greater space can be obtained for the propeller in the stern of the ship.

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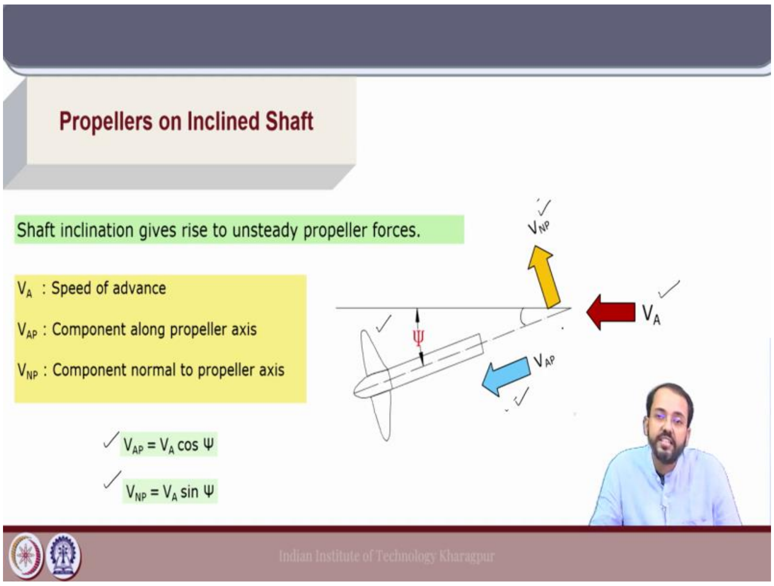


Now, for inclined shaft propellers there are additional unsteady forces that will be encountered because of the velocity components that comes due to the shaft inclination.

Let us take a propeller here which is inclined at an angle ψ with respect to the horizontal. Now, as the shaft of this propeller is inclined, we have $V_A$ as the velocity of advance based on the ship speed and the wake fraction. Now, due to this shaft inclination this $V_A$ will have a normal component $V_{NP}$ perpendicular to the propeller shaft axis and a component $V_{AP}$ along the propeller shaft axis.

And we have to analyze the propeller performance with respect to these components for propellers on inclined shaft, and we will see that this $V_{NP}$ the normal component will lead to changes in the tangential forces on the propeller blade at different locations and lead to unsteady propeller forces.

Now, we already have unsteady propeller forces due to the propeller acting in different regions of circumferentially varying weight. Now, for these propellers on inclined shafts this extra velocity components will lead to further unsteady propeller forces and moments. So, $V_{AP}$ can be written as $V_A \cos(\phi)$ and $V_{NP}$ as $V_A \times$ sin of the angle of inclination ψ.

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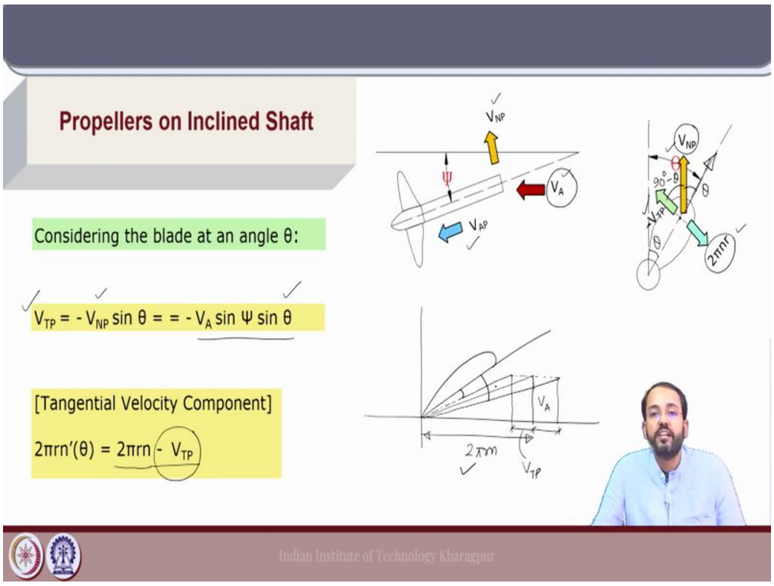


Now, let us consider the case of a propeller which is on an inclined shaft and the instantaneous position of one of the propeller blades is at an angle θ with respect to the vertical 12 o' clock position. So, we have this $V_{AP}$ which is the axial component due to the velocity $V_A$ and $V_{NP}$ which is the normal component for the case of an inclined shaft propeller.

Now, this $V_{NP}$ is the velocity component in the vertical direction for the propeller blade and let us take a section of the propeller blade here where, due to the rotation at n rpm we have the tangential velocity $2 \pi n r$, which is standard for the propeller blade at a radius r.

Now, due to this extra velocity component $V_{NP}$ at an angle $\theta$, this $V_{NP}$ will have a component in the direction which is outwards to the propeller radius and in the tangential direction which is $V_{TP}$. In this particular diagram we are only considering the tangential forces because that is how the tangential velocity components will be altered. So, this angle is $\theta$ because this is $\theta$ and hence the angle between these two forces the tangential component of $V_{NP}$ and $V_{NP}$ itself will be $90^0 - \theta$.

So, we can say the tangential component $V_{TP} = - V_{NP} \sin(\theta)$. The minus sign because it is directed opposite to $2 \pi n r$ for this particular location of the propeller blade. Now, $V_{NP} = V_A \times \sin \psi$ as we have seen earlier where $V_A$ is the velocity of inflow the axial velocity, hence this tangential component is given by $-V_A \times \sin \psi \times \sin \theta$.

Now, over one complete revolution of the propeller blade, the angle $\theta$ will change, but the angle $\psi$ is constant which is for a specific inclination angle of the propeller shaft. So, the tangential velocity at any radial location on the propeller blade will be $(2 \pi r n) - V_{TP}$, where $V_{TP}$ is given by this expression. Now, depending on the instantaneous location of the propeller blade the value of $\theta$ will vary from 0 to 360 degree and hence the value of $\sin(\theta)$ will be varying between -1 and 1 and also become 0 at some points.

And hence this added part to the already existing tangential velocity will vary in sin. So, if we try to look into the propeller blade element diagram, we have $V_A$ here and if this is $2 \pi r n$ then there will be a continuous fluctuation of that value by the value of $V_{TP}$ which is the additional tangential velocity component, sometimes increasing this original value $2 \pi r n$ and sometimes decreasing.

And hence if we draw the resultant velocity between these two points, the resultant angle of attack will vary between two extreme angles for a propeller blade at different angular locations in one complete revolution. Hence, propeller shaft inclination leads to additional fluctuations in thrust and torque forces for the propeller blade sections, which is on top of the fluctuations due to the varying wake at different circumferential regions.

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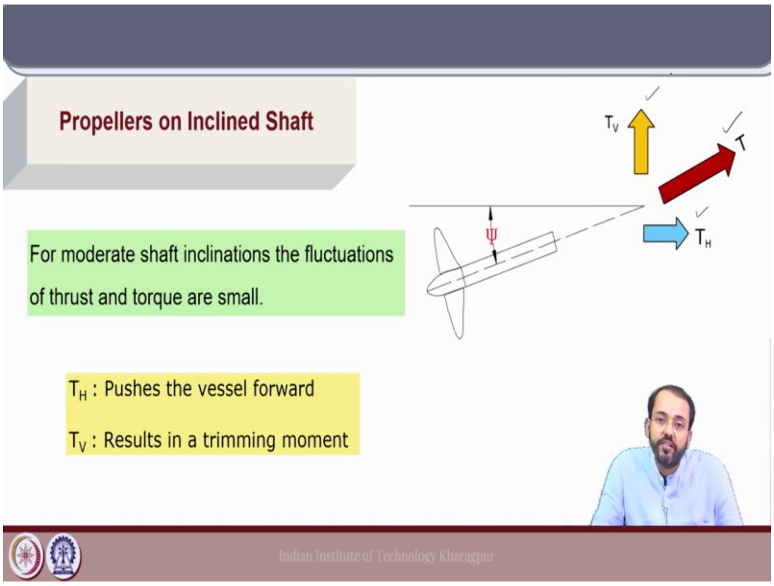


For moderate shaft inclinations the fluctuations of thrust and torque are small, and here the thrust that is provided by the propeller blade is directed at an angle because of the shaft inclination and hence we can think of a horizontal and a vertical component of the thrust. Now, this horizontal component of the thrust for propellers on inclined shaft, push the vessel forward. On the other hand the vertical component results in a trimming moment that depends on the operational condition of the ship and the value of thrust generated by the propeller.

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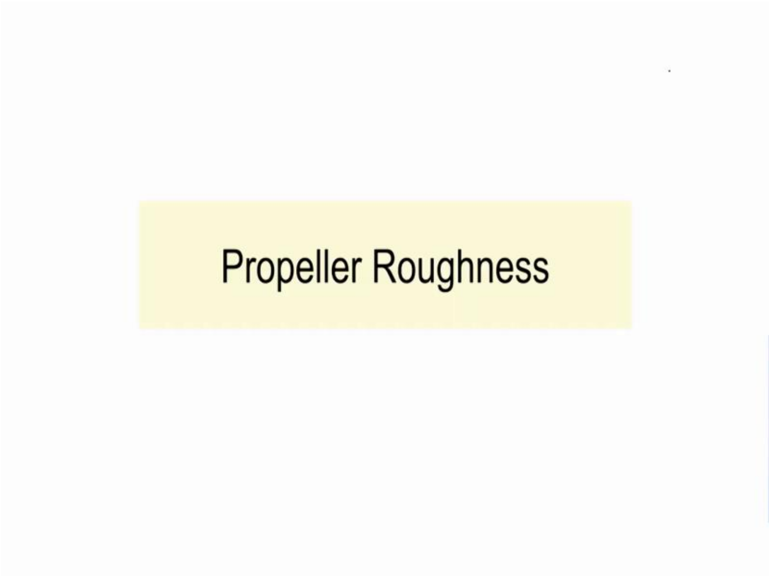

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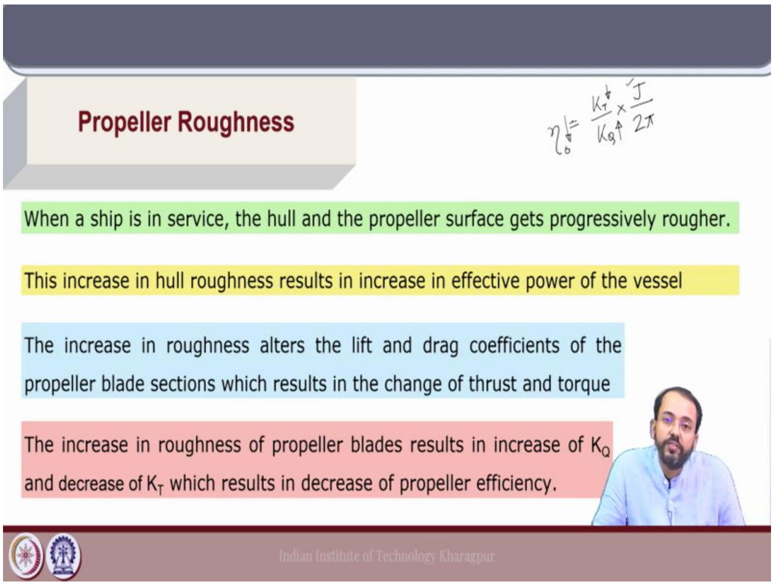


Next, we will discuss propeller roughness. When a ship is in service, both the hull as well as the propeller surface will get progressively rougher due to its operation in the marine environment, and corrosion will also occur. And, this increase in roughness will result in the increase of effective power of the vessel.

Now, the increase in roughness for a propeller blade will alter the lift and drag coefficients for the propeller blade section and this will result in the change of thrust and torque. So, typically what is observed that the thrust coefficient of the propeller blade will decrease because roughness will increase the drag of the propeller blade with time and the torque coefficient will increase.

So, if the torque coefficient increases and the thrust coefficient decreases we have seen that very simply the propeller open water efficiency is given by $K_T/K_Q \times J/2\pi$. So, even if we disregard the effects of the hull propeller interaction at the same loading condition if the thrust coefficient decreases $K_T$ and if $K_Q$ increases that will lead to a decrease of the propeller efficiency. So, this needs to be addressed by proper servicing of the ship and the propeller.

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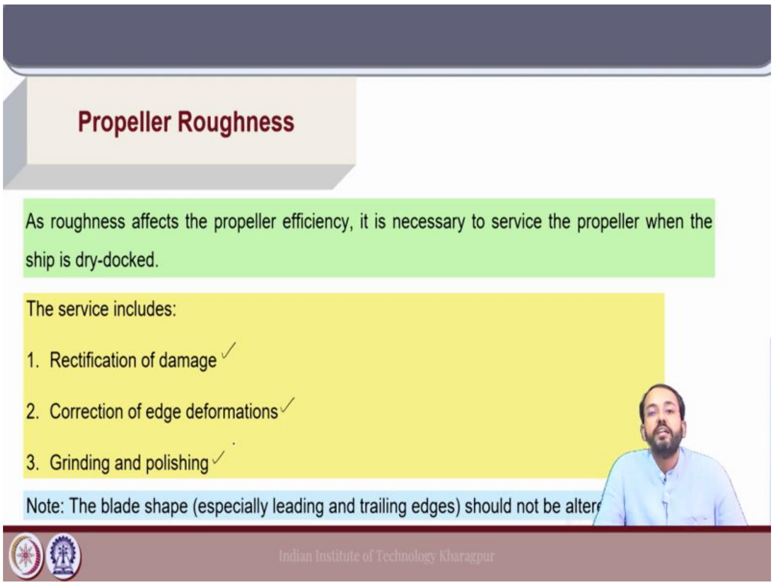


When the ship is dry docked periodic servicing of the ship as well as the propeller can be done. Now, servicing includes rectification of the damage to the propeller blade correction to any edge deformations that have occurred on the propeller blade and grinding and polishing to make the surface of the propeller blade smoother.

So that to reduce the drag and improve the efficiency. Now, another factor that needs to be checked here that the propeller blade shape specially at the tips and the leading and trailing edges should not be altered during these service procedures, because these are very critical, which defines the cavitation performance and the resultant thrust and torque performance of the propeller for different pitch conditions.

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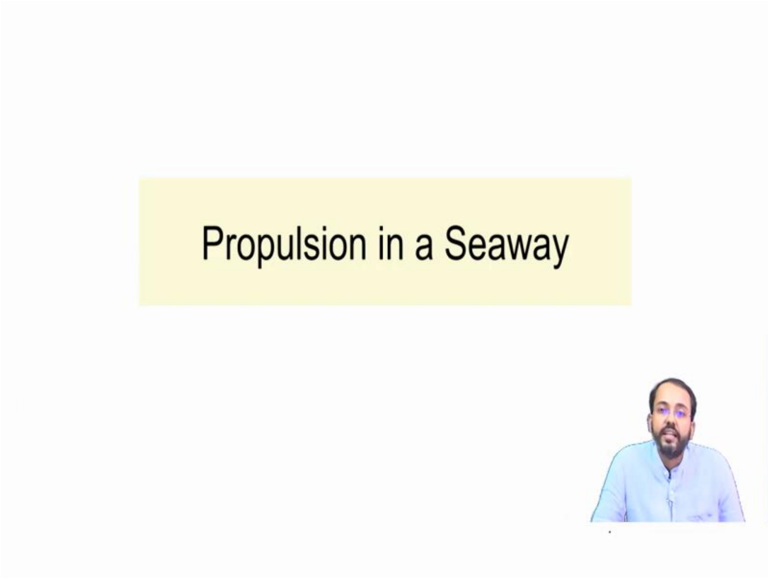


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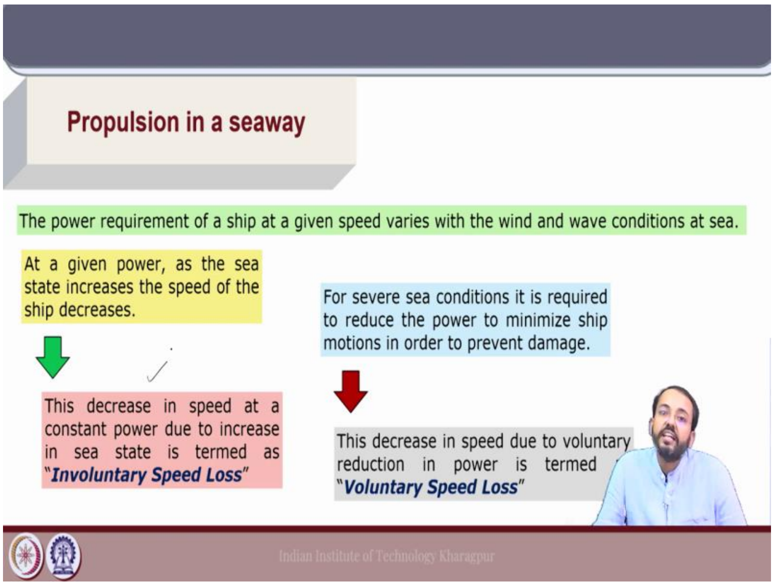


Next, we will discuss propulsion in a seaway. The powering performance of a ship for a specific speed will vary with the wind and wave conditions at sea. And, hence the sea condition which is typically given by sea state will decide the powering performance of a vessel in an actual operation condition.

So, at a given power if the sea state increase that means, the wave height increases, the significant wave height then the speed of the ship will decrease because it will lead to higher ship motions. This decrease in the speed of the ship at a constant power due to the increase in the sea state is termed as involuntary speed loss, because this is occurring due to the condition of the sea.

On the other hand for severe sea conditions it is required to reduce the power by reducing the propeller rpm, because for very severe sea conditions for high wave heights the ship motions will be very critical and due to very large ship motions that can lead to the damage of the ship, and this decrease in speed due to voluntary reduction in power is termed as voluntary speed loss.

So, the performance of a ship at sea the propulsion performance typically includes these two types of speed loss in the waves. One the involuntary speed loss which is at a constant power due to the motions of the ship in waves, and the second one is the voluntary speed loss due to the reduction in power at severe sea conditions which is done voluntarily.

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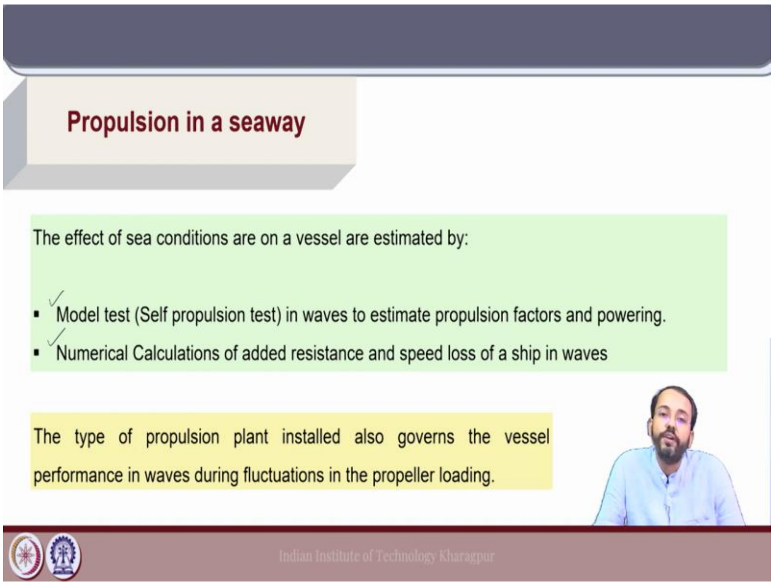


So, the effect of sea conditions on a vessel can be estimated by model tests. So, we have seen model self propulsion tests as a part of this course. Now, in a towing tank there is a possibility of generating waves using a wave maker fitted in the tank. Now, the same self propulsion test can be done in different wave conditions and the propulsion factors and powering can be estimated just like the same procedure that has been followed in calm water.

So, the propeller loading will change and the powering characteristics will change depending on the wave frequency and the amplitude of the wave with respect to the ship, because the wavelength with respect to the length of the ship will decide the motion characteristics of the ship and finally, the added resistance and powering in waves. Also, numerical calculations of added resistance and speed loss can be done to assess the performance in wave conditions.

Here it is important to mention that the propulsion plant that is installed in a ship governs the vessel performance during fluctuations of the propeller loading in wave conditions, because the engine propeller matching is very important to assess the performance of the ship in an integral manner. So, the nature of the propulsion plant the main engine of the ship will also govern the vessel performance in wave conditions, which will lead to fluctuations of the propeller loading.

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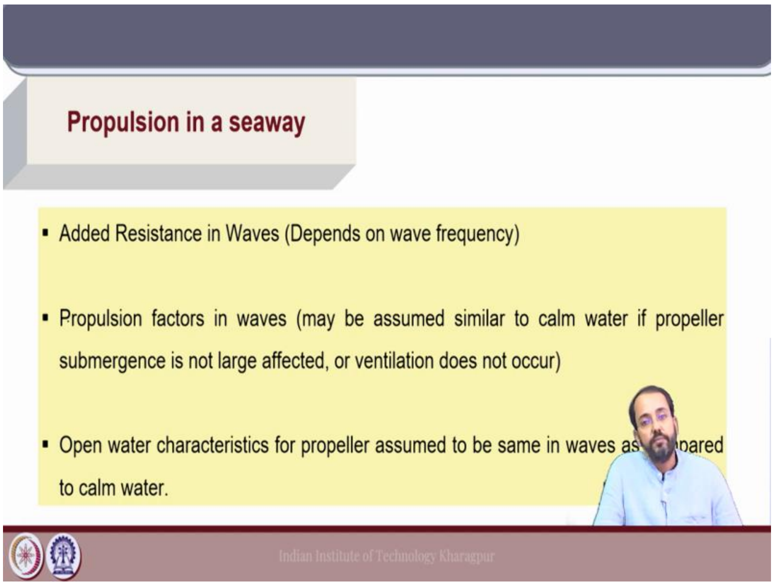


So, what are the effects of a ship in waves? We have the added resistance. So, because of the wave condition depending on the wave frequency the ship will have a higher resistance in waves due to the motions specially the heave and pitch motions are very critical and that leads to added resistance if we consider head waves. Propulsion factors in waves may be assumed to be similar to calm water, but if the wave scenario is such that the submergence is affected or ventilation occurs then that will also change the propulsion factors.

So, if there is no change in submergence or there is no ventilation then for calculations it may be assumed that the propulsion factors are similar for ease of computations. Also, it is assumed that the intrinsic characteristics of a propeller which are the open water characteristics. The thrust, torque and efficiency in open water they are same in waves as compared to calm water.

This is generally assumed for computations of the propulsion performance of a ship in waves. So, the added resistance of a ship the propulsion factors and the open water diagram can be used from model tests values also numerical computations may be used to assess the performance of a ship in waves. This will be all for the discussions on miscellaneous topics.

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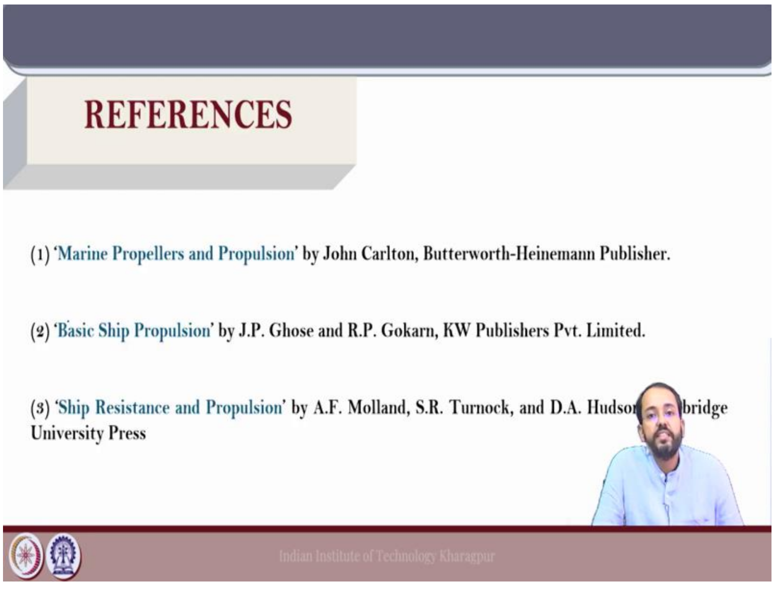


Some references are mentioned here.

Thank you.