

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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CONCEPTS

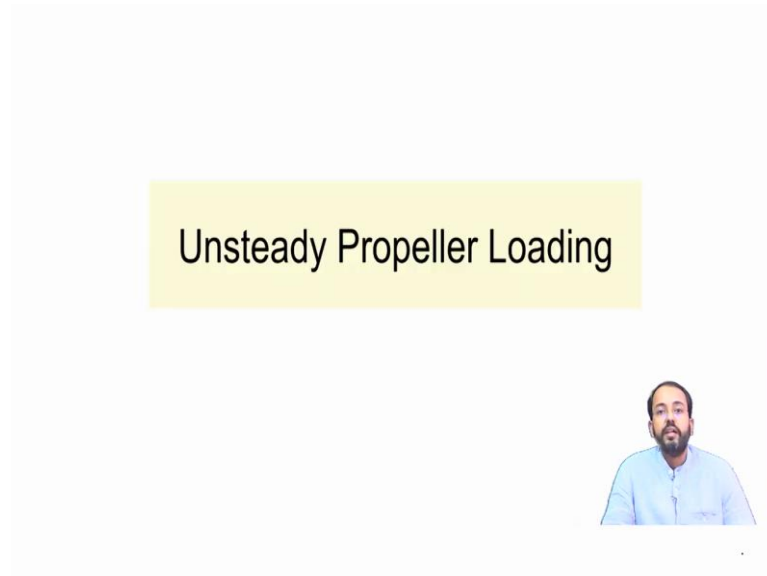
- Unsteady Propeller loading
- Propellers on Inclined Shaft
- Propeller Roughness
- Propulsion in a Seaway



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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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The slide features a title box "Unsteady Propeller Loading" on the left. Below it, a yellow text box states: "The inflow velocity into the propeller vary circumferentially and results in unsteady loading on the propeller blades." A green text box below that says: "Hence, the values of propeller thrust and torque fluctuate when it operates behind a vessel." A red text box at the bottom left contains a note: "[Note: This is true even for a ship moving at a constant speed in calm water with a fixed propeller rpm]". On the right side, there is a circular diagram titled "Nominal wake fraction for a single screw vessel" with a color scale from blue (low) to red (high). The diagram shows a propeller with two blades and a wake field. Two regions of high wake are marked with circled numbers 1 and 2. A speaker video inset is in the bottom right corner. At the bottom of the slide, there are logos for IIT Kharagpur and the text "Indian Institute of Technology Kharagpur".

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 θ equal to 0, if we take θ 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 θ 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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Unsteady Propeller Loading

The varying inflow velocity have axial, tangential and radial components- V_a , V_t , and V_r respectively.
[V_r is usually very small and neglected for practical purposes]

θ : Angle measured from vertical upward, $\theta = 0$ means propeller blade at 12 o' clock position.

✓ Axial Velocity
✓ $V_a(\theta) = V_a(\theta)$ Due to port and starboard symmetry of ship hull

✓ Tangential Velocity
✓ $V_t(\theta) = -V_t(\theta)$



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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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Unsteady Propeller Loading

The axial and tangential velocities can be represented in terms of Fourier series.

The unsteady propeller forces can be determined from the velocity expressions.

Circumferential Variation of Velocities in the Propeller Disc

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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.

(Refer Slide Time: 07:24)


Unsteady Propeller Loading

The fundamental frequency responsible for the unsteady propeller forces is the product of propeller revolution rate and number of blades

Blade Passing Frequency or
Fundamental frequency of unsteady loading

$$= N * Z$$

N: Propeller Revolution rate
Z: No of Blades



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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 = $N \times Z$ 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.

(Refer Slide Time: 08:10)


Unsteady Propeller Loading

Effects:

- Vibration of Ship hull and Propeller shafting system.
- The periodic stress developed results in fatigue.
- Periodic cavitation causing additional vibration, noise and erosion.

Design:

Choice of blade number, skew, and radial distribution such that fluctuations in thrust, torque and resulting moments are reduced.




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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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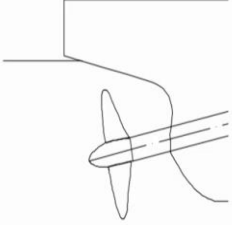


Propellers on Inclined Shaft


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Propellers on Inclined Shaft

It is required to incline the propeller shafts in certain cases, especially in small vessels in order to get sufficient space and clearance for the propeller from the ship hull.



The diagram shows a propeller mounted on a shaft that is inclined downwards relative to the horizontal. The propeller blades are shown in a cross-section view.



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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.

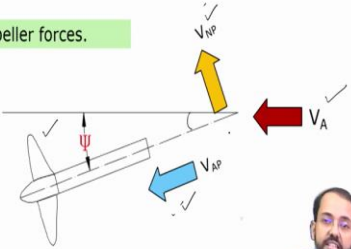
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Propellers on Inclined Shaft


Shaft inclination gives rise to unsteady propeller forces.

V_A : Speed of advance
 V_{AP} : Component along propeller axis
 V_{NP} : Component normal to propeller axis

$V_{AP} = V_A \cos \psi$
 $V_{NP} = V_A \sin \psi$



The diagram shows a propeller on an inclined shaft. A red arrow labeled V_A points to the right, representing the speed of advance. A blue arrow labeled V_{AP} points along the shaft, representing the component along the propeller axis. A yellow arrow labeled V_{NP} points upwards, perpendicular to the shaft, representing the component normal to the propeller axis. The angle between the shaft and the horizontal is labeled ψ .



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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 $V_A \cos(\psi)$ and V_{NP} as $V_A \times \sin$ of the angle of inclination ψ .

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Propellers on Inclined Shaft

Considering the blade at an angle θ :

$$V_{TP} = -V_{NP} \sin \theta = -V_A \sin \psi \sin \theta$$

[Tangential Velocity Component]

$$2\pi r n'(\theta) = 2\pi r n - V_{TP}$$

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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 θ , 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 θ because this is θ and hence the angle between these two forces the tangential component of V_{NP} and V_{NP} itself will be $90^\circ - \theta$.

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 θ will change, but the angle ψ 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 θ 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.

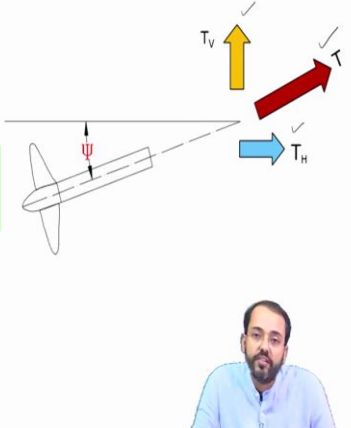
And hence if we draw the resultant velocity between these two points, the resultant angle of attack will vary between two extreme angles for a propeller blade at different angular locations in one complete revolution. Hence, propeller shaft inclination leads to additional fluctuations in thrust and torque 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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Propellers on Inclined Shaft

For moderate shaft inclinations the fluctuations of thrust and torque are small.

T_H : Pushes the vessel forward
 T_V : Results in a trimming moment



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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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Propeller Roughness

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Propeller Roughness

$$\eta_o = \frac{K_T \downarrow \times J}{K_Q \uparrow \times 2\pi}$$

When a ship is in service, the hull and the propeller surface gets progressively rougher.

This increase in hull roughness results in increase in effective power of the vessel

The increase in roughness alters the lift and drag coefficients of the propeller blade sections which results in the change of thrust and torque

The increase in roughness of propeller blades results in increase of K_Q and decrease of K_T which results in decrease of propeller efficiency.

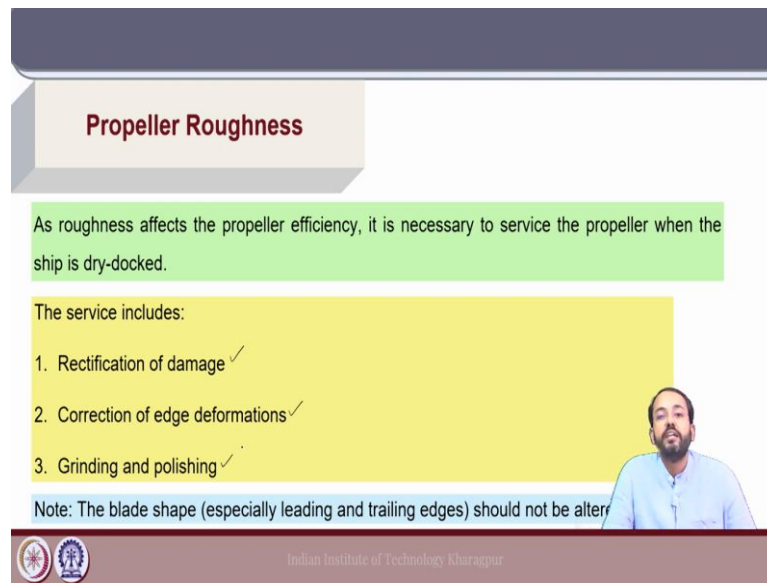
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Next, we will discuss propeller roughness. When a ship is in service, both the hull as well as the propeller surface will get progressively rougher due to its operation in the marine environment, and corrosion will also occur. And, this increase in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

As roughness affects the propeller efficiency, it is necessary to service the propeller when the ship is dry-docked.

The service includes:

1. Rectification of damage ✓
2. Correction of edge deformations ✓
3. Grinding and polishing ✓

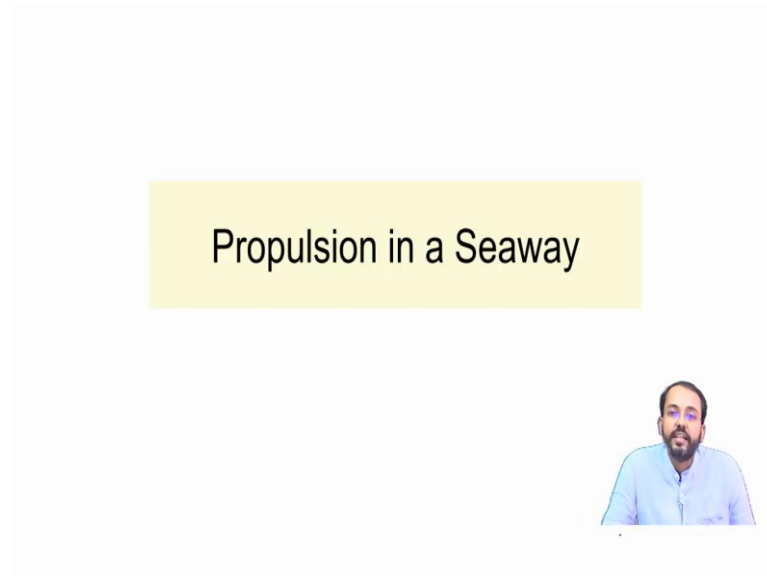
Note: The blade shape (especially leading and trailing edges) should not be altered.

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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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A presentation slide titled "Propulsion in a seaway" in a dark blue header. The main content is on a white background. At the top, a green box states: "The power requirement of a ship at a given speed varies with the wind and wave conditions at sea." Below this, two scenarios are described. On the left, a yellow box says: "At a given power, as the sea state increases the speed of the ship decreases." A green arrow points down to a pink box: "This decrease in speed at a constant power due to increase in sea state is termed as **'Involuntary Speed Loss'**". On the right, a blue box says: "For severe sea conditions it is required to reduce the power to minimize ship motions in order to prevent damage." A red arrow points down to a grey box: "This decrease in speed due to voluntary reduction in power is termed **'Voluntary Speed Loss'**". A small video feed of the same speaker is visible in the bottom right corner. At the bottom of the slide, there are logos of Indian Institutes of Technology and the text "Indian Institute of Technology Kharagpur".

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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Propulsion in a seaway

The effect of sea conditions on a vessel are estimated by:

- ✓ Model test (Self propulsion test) in waves to estimate propulsion factors and powering.
- ✓ Numerical Calculations of added resistance and speed loss of a ship in waves

The type of propulsion plant installed also governs the vessel performance in waves during fluctuations in the propeller loading.

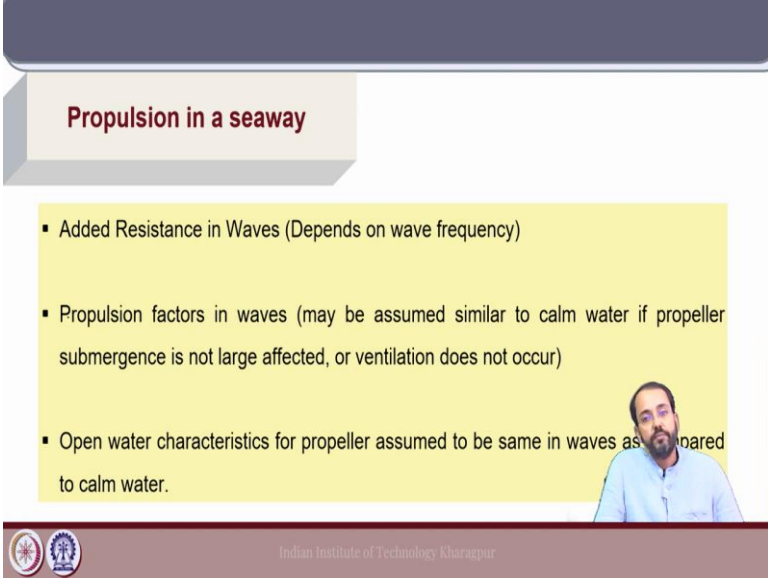
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So, the effect of sea conditions on a vessel can be estimated by model tests. So, we have seen model self propulsion tests as a part of this course. Now, in a towing tank there is a possibility of generating waves using a wave maker fitted in the tank. 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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Propulsion in a seaway

- Added Resistance in Waves (Depends on wave frequency)
- Propulsion factors in waves (may be assumed similar to calm water if propeller submergence is not large affected, or ventilation does not occur)
- Open water characteristics for propeller assumed to be same in waves as compared to calm water.

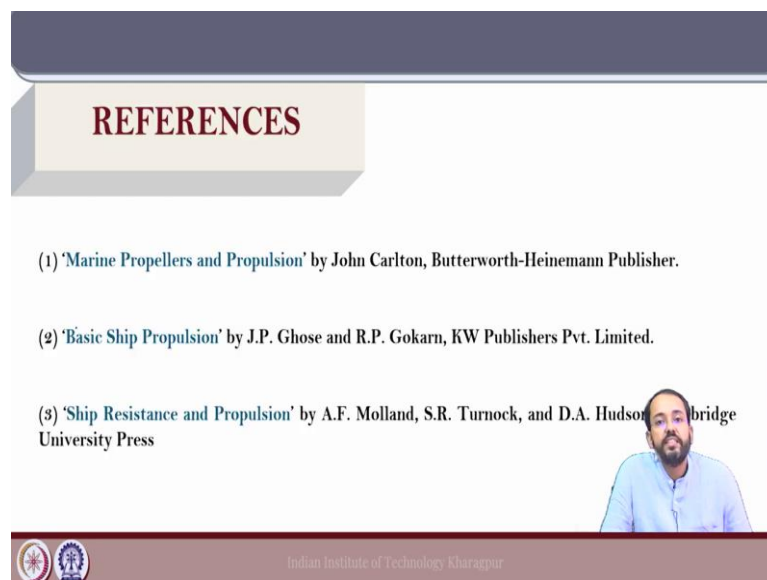
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So, what are the effects of a ship in waves? We have the added resistance. So, because of the wave condition depending on the wave frequency the ship will have a higher resistance in waves due to the motions specially the heave and pitch motions are 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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REFERENCES

- (1) 'Marine Propellers and Propulsion' by John Carlton, Butterworth-Heinemann Publisher.
- (2) 'Basic Ship Propulsion' by J.P. Ghose and R.P. Gokarn, KW Publishers Pvt. Limited.
- (3) 'Ship Resistance and Propulsion' by A.F. Molland, S.R. Turnock, and D.A. Hudson, Cambridge University Press

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Some references are mentioned here.

Thank you.