Marine Propulsion
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Lecture - 37
Unconventional Propulsors

Welcome to lecture 37 of the course Marine Propulsion. The topic today is Unconventional Propulsors.

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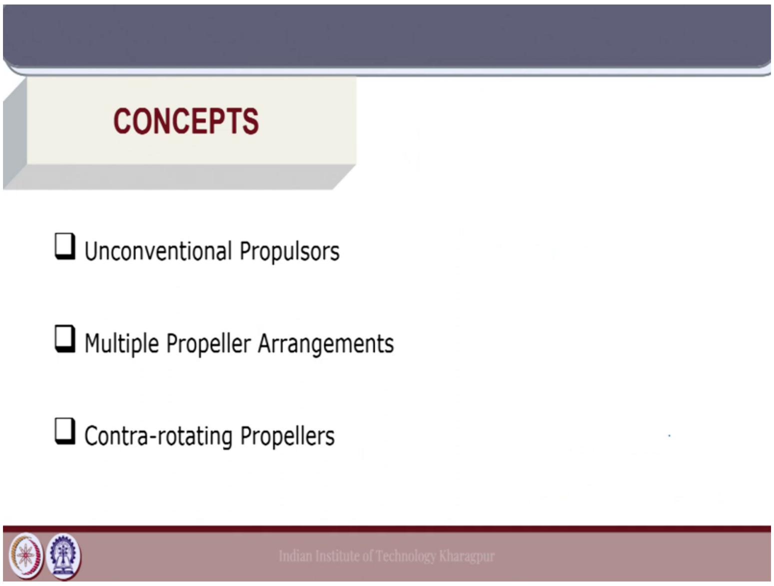

The key concepts to be covered in this lecture are general discussion on unconventional propulsors, their application, their advantages for specific operation conditions, some multiple propeller arrangements and contra rotating propellers.

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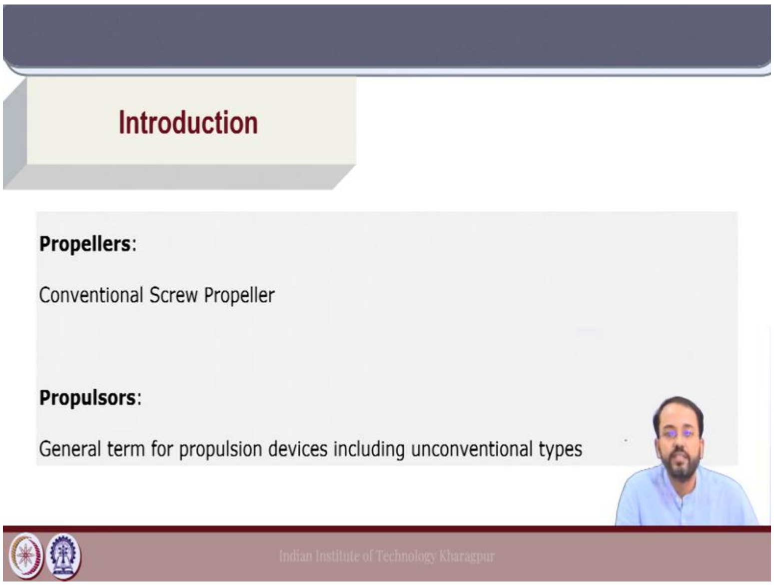

The term propeller in general refers to conventional screw propeller which forms the basis of this course. And, we have discussed different aspects of hydrodynamics for a conventional screw propeller. On the other hand, when we use the term propulsor, it is a more generic term. So, it can be used to define any propulsion device including unconventional propulsor types. In this course, we have discussed some other propulsor types like ducted propellers, podded propellers, surface piercing propellers and water jets.

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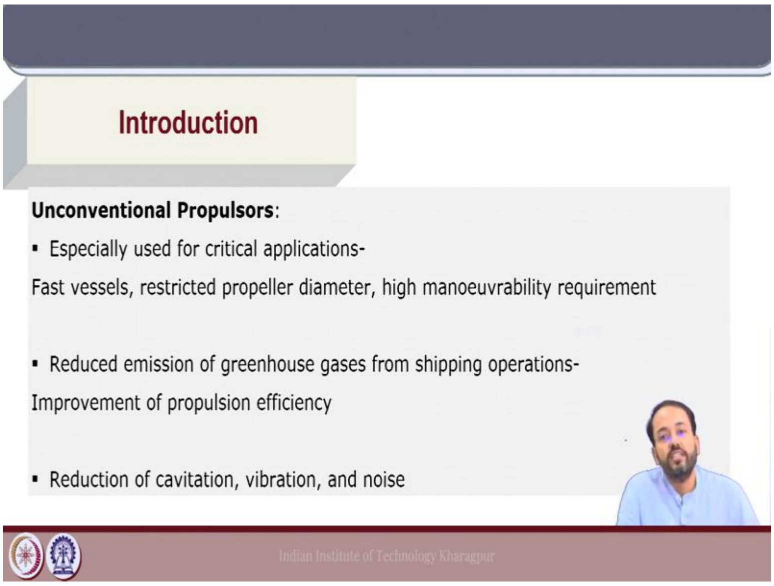

In this lecture, we will continue with multiple propeller arrangements and contra rotating propellers which are some other forms of unconventional propulsors designs. Now, if we talk about unconventional propulsors in general, they are specially used for some critical applications; for fast vessels, restricted propeller diameters and high manoeuvrability requirement which generally cannot be met by a conventional propeller.

So, for certain application conditions which are very general, conventional screw propellers are the most widely used propulsion devices in the marine industry. But, for certain specific applications, specially, where the diameter is restricted in shallow draft conditions or for requirements of high thrust or manoeuvrability necessity, these unconventional propulsors of different designs find their application.

Now, in the marine industry, there is also a huge requirement for reduced emission of greenhouse gases from the shipping operations. And, that can be obtained by improvement of propulsion efficiency among other conditions which will also help in reducing greenhouse gas emissions. Now, if we want to reduce the propulsion efficiency for specific vessels and operation conditions, one has to look into the aspects of the propeller design with respect to the ship design for the condition in which the ship is operating.

And, here these unconventional propellers sometimes play a big role in improvement of the propulsion efficiency. And, reduction of cavitation, vibration and noise, these are also concerns which are important for the propulsor design.

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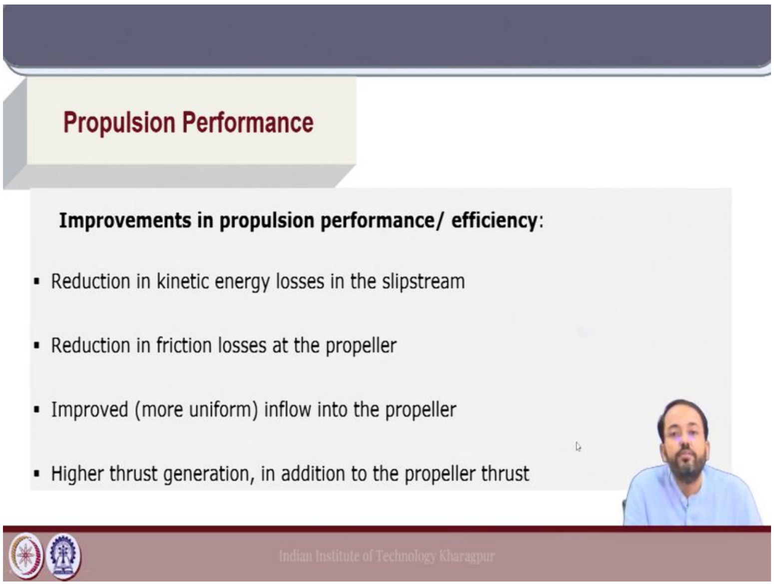

Now, it is very important to understand how improvements can be made in the propulsion performance or the propulsive efficiency for a vessel. There are certain ways in which energy losses occur in the propulsion system. And, if they can be reduced, then that is one way of improvement of the propulsion performance. The first point here is the reduction in kinetic energy losses in the slip stream.

Now, when a propeller operates, it generates a thrust and there is a slip stream of the propeller where certain kinetic energy losses occur in the form of axial kinetic energy rotational and also the losses due to the vortex shape from the propeller blades. If some of that losses is reduced, then the efficiency can be improved. Next, reduction in friction losses at the propeller for example, the geometry of the propeller blade will govern the friction losses at the propeller.

And, there are ways to reduce the friction losses by which efficiency can be improved. A more uniform inflow into the propeller, this is a very important point by improving the flow which the propeller faces. That means, a more uniform flow into the propeller in terms of both radial as well as circumferential distribution the propeller performance can be improved.

And, the vibration and noise characteristics of the propeller can be improved. Now, this can be achieved by a set of devices which are called energy saving devices which we will separately study at the end of this course. Also, improvement can be done by increasing the total thrust generation; that means, by having a device in addition to the propeller which also generates thrust.

For example: multiple propeller configurations where we have more than one propeller generating the thrust. And, also for ducted propellers where we have seen that the duct in addition to the propeller generates thrust and it leads to higher efficiency for specific propeller loading conditions.

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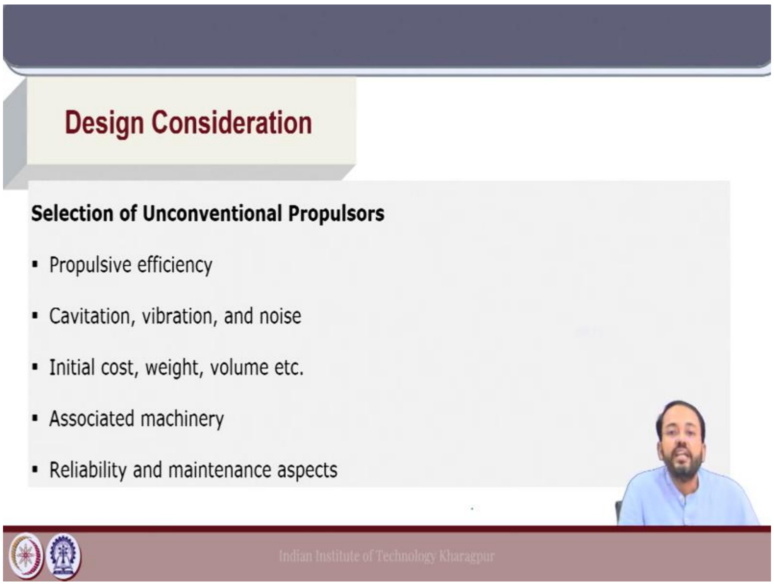

Next, we will look into some design considerations which are important in the selection of unconventional propulsors. One of the most important considerations is the propulsive efficiency because, when an unconventional propulsor is selected for a specific vessel type depending on its operation conditions and performance requirement, the propulsive efficiency is directly linked to the power requirement and the economics of the vessel operation.

Next, cavitation, vibration and noise; different propeller types and also these unconventional propulsors depending on the operation condition have cavitation noise and vibration characteristics based on the flow properties. And, these needs to be checked before these configurations can be applied for specific vessel types. Initial cost, weight and volume: Now, these unconventional propulsors have different geometrical configurations and because of that the cost, weight and volume varies widely between different choices of propulsors.

And, these factors needs to be considered for the application of unconventional propulsors. And, the machinery which is associated for these propulsors also needs to be understood. Finally, the reliability and maintenance aspects when using an unconventional propulsor needs to be considered for practical applications. So, when we choose a particular propulsor type for a specific vessel, all these factors will play important roles in governing the choice and the design of the propulsor.

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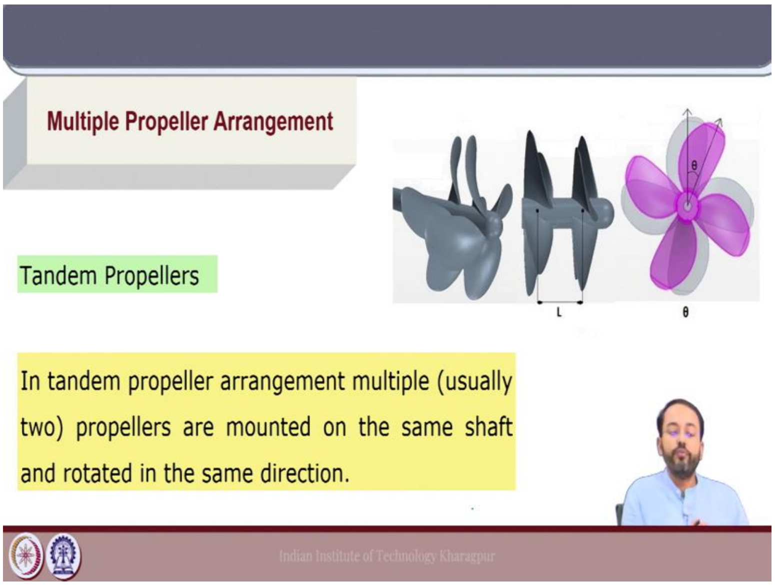

Now, let us look into some multiple propeller arrangements which are used for chips. The first one is a tandem propellers; that means, we have multiple propellers usually two which are mounted on the same shaft and they are rotating in the same direction. So, in a tandem propeller configuration, we have a forward propeller and an aft propeller, if we have two propellers then they are co axially mounted and they rotate in the same direction.

Now, because we have two propellers, there will be a small axial distance between the two propellers which is mentioned here and as they are connected to the same shaft and which is having a specific rpm, they are being rotated in the same direction. So, a small angular difference also is kept between the propeller blades of the forward propeller and the aft propeller, such that the vortices generated by the forward propeller do not have a large impact on the performance of the aft propeller.

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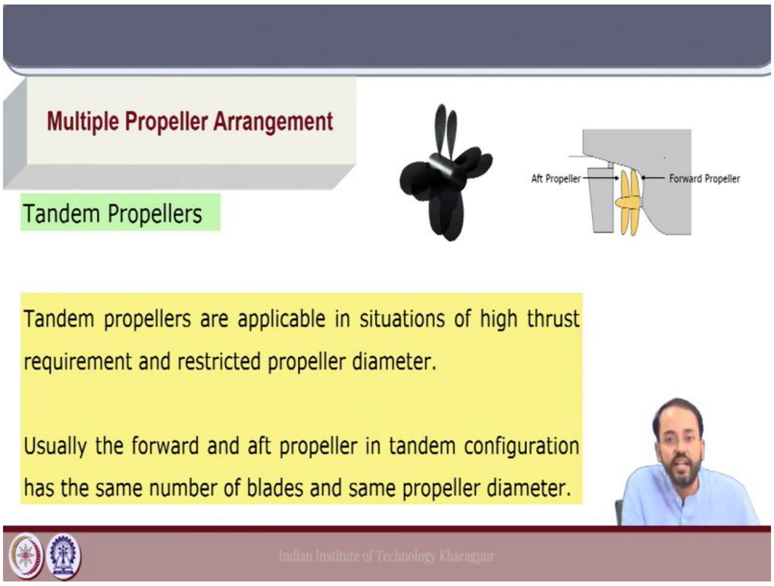

Tandem propellers are applicable for vessels which have typically a combination of high thrust requirement and also restricted diameter; that means, for inland vessels where the draft is restricted and also we do not have a large available diameter. Tandem propellers can help in distributing the thrust between the forward and the aft propeller. So, that both of them can operate in optimum thrust loading conditions.

So, because we have two propellers and typically these propellers have the same number of blades and the same diameter in standard tandem propeller design. Also, the pitch of the aft propeller should be higher than the pitch of the forward propeller. The reason is that the aft propeller is working in the slip stream of the forward propeller, where the inflow velocity is very much accelerated due to the action of the forward propeller.

And, hence a larger pitch ratio is required to design the blades of the aft propeller to maintain the flow angles, typically the angle of attack depending on the inflow velocities. Here, we have a ship with a tandem propeller fitted at the stern and the forward and the aft propeller are mounted on the same shaft and being rotated in the same direction.

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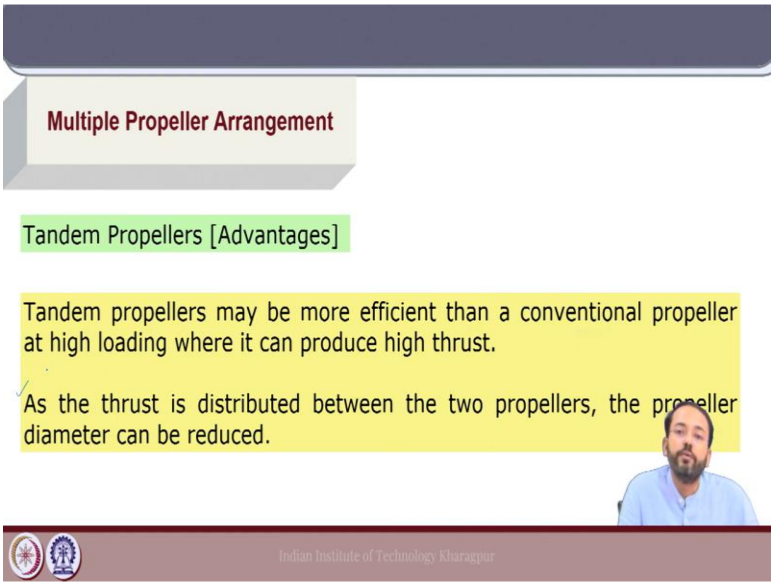

What are the advantages of tandem propellers? In very high thrust loading conditions which correspond to very low values of advance coefficients, a tandem propeller where we have a forward propeller and an aft propeller rotating in the same direction can provide higher total thrust as compared to a single conventional propeller.

And, the efficiency for high thrust loading conditions can also be slightly higher than a single propellant. So, specially, for conditions of restricted diameter, a tandem propeller can be beneficial as compared to a single propeller. And, because the thrust is distributed between two propellers, the diameter of the propeller can be reduced specially, for inland vessels, if there is a restriction of operation draft these tandem propellers can be useful.

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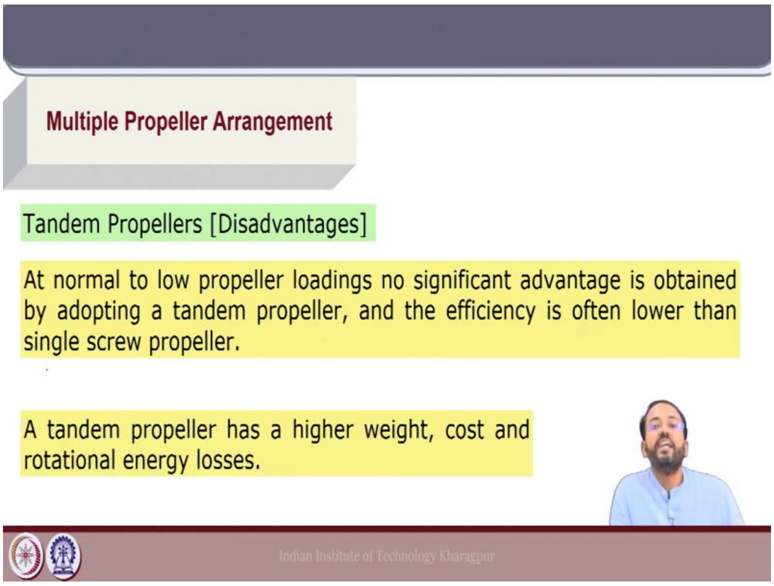

On the other hand, tandem propellers have certain disadvantages for which they are not widely applied for different vessel types. One of the main disadvantages is its performance at normal to low propeller loading conditions. Because, in these conditions the tandem propeller efficiency is much lower as compared to the conventional single propeller. And, also a tandem propeller has a much higher weight, cost and rotational energy loss.

Now, in this tandem propeller configuration both the forward and aft propellers are rotating in the same direction. And, because of that the induced velocity in the slip stream due to the propeller rotation by the forward propeller as well as the aft propeller are in the same direction. And, hence that leads to higher losses of rotational energy in the propeller slip system. And, that reduces the efficiency of a tandem propeller as compared to a single conventional propeller.

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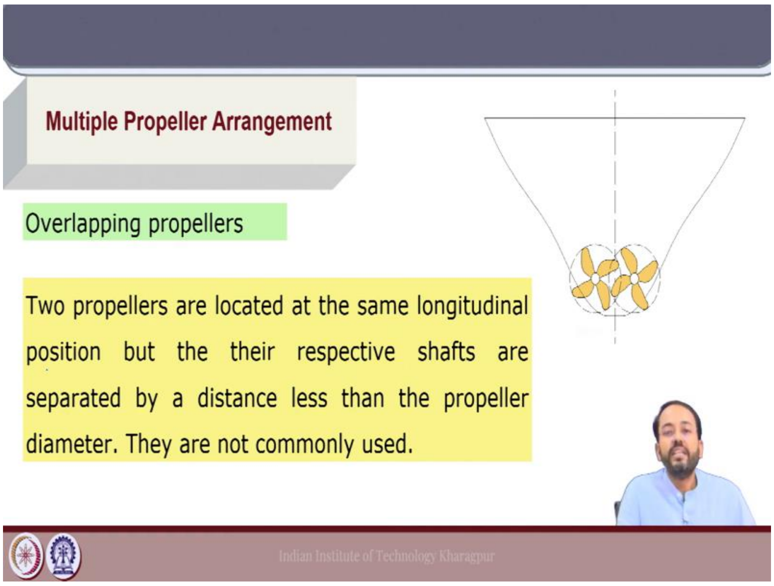

Another example of multiple propeller arrangement which has very limited application is the overlapping propellers. Here, two propellers are located at the same longitudinal position behind the ship at the stern, but their shafts are separated by a distance which is typically less than the propeller diameter. That means, when the blades rotate, the area swept by these blades will have some overlap.

Now, this is slightly different from a standard twin screw propulsion system, where we have a port propeller and a starboard propeller rotating in opposite directions. Here, for overlapping propellers, the port and starboard propellers are very close to each other and they have a certain overlap in their rotational path. And, the blades are positioned in such a way that they can operate together. Now, for an overlapping propeller set, the blades rotate in opposite directions, but they have certain disadvantages for which they are not commonly used.

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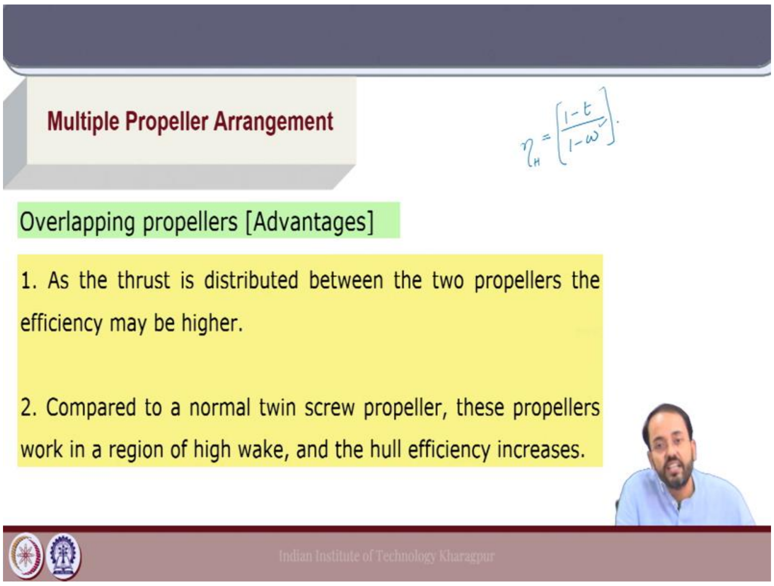

First, we will look into some simple advantages of overlapping propellers. Now, like any multiple propeller arrangement, overlapping propellers have more than one propeller. Now, for these cases the thrust can be distributed between two propellers and hence the thrust loading on one propeller will decrease as compared to a single propeller. So, that leads to a higher efficiency of propulsion.

And secondly, if we compare this overlapping propeller concept to a normal twin screw propeller, that we have seen earlier with a port propeller and a starboard propeller separated by a proper distance depending on the ship design. These overlapping propellers operate at a region of high wake. Why? Because, the overlapping propellers are very close to the centre line of the ship where the wake is high.

The wake fraction because of the blockage effect due to the presence of the hull and because of that the hull efficiency will be higher for overlapping propellers as compared to the twin screw propulsion systems. Now, hull efficiency η_H is given by (1 - thrust deduction) / (1 - wake fraction). And, we have seen that hull efficiency is a parameter in the calculation of the total efficiency of the propulsion system; though it is not strictly an efficiency term, it is just a ratio of these two factors (1 - thrust deduction) / (1 - wake fraction).

And, if the value of wake fraction is high because of the blockage effect of the hull for overlapping propellers, the hull efficiency will be higher as compared to standard twin screw propellers.

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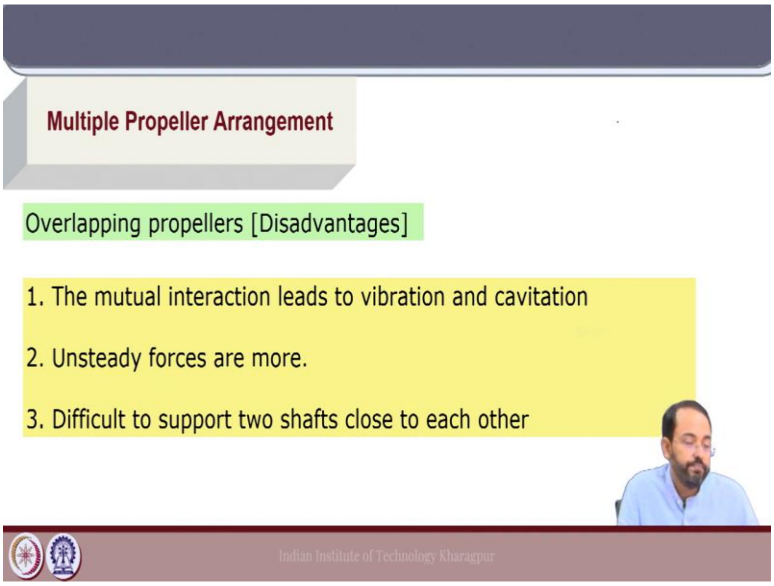

However, there are critical disadvantages of overlapping propellers for which they are not widely used for marine vessels. The first disadvantage is the strong mutual interaction between the two propellers. For overlapping propellers, the two sets of blades for the two propellers are operating very close to each other. And, the flow fields have a strong mutual interaction due to the induced velocities from each propeller.

And, due to that there is very high vibration as compared to twin screw propellers which are separated by a larger distance and also cavitation concerns are present. Unsteady forces are more as compared to twin screw propulsion, because of these mutual interactions of overlapping propellers. And, also because the two shafts are very close to each other, it is difficult for the structural arrangement and support system of the two shafts and the other structures that are related in the propulsion system. So, these disadvantages are critical for overlapping propellers.

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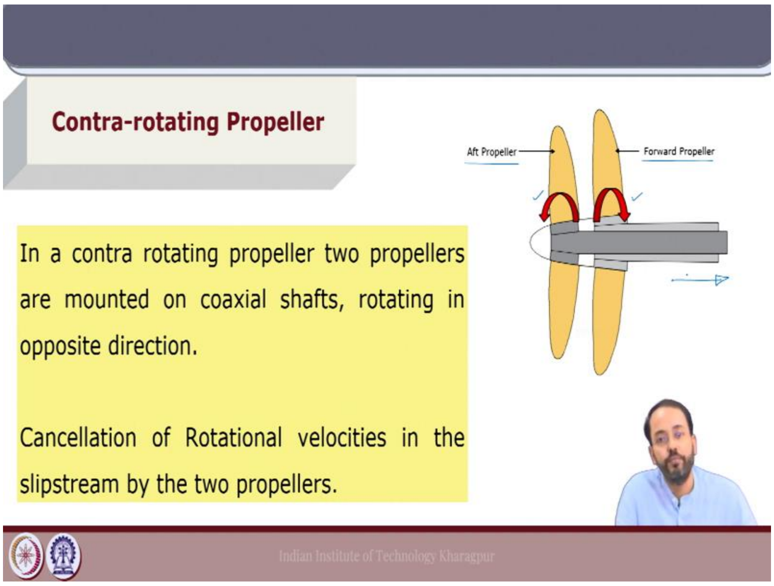

Next, we will discuss a very special propulsor type which is a contra rotating propeller; that means, we have two propellers which are rotating in opposite directions. Here, also we have a forward propeller and an aft propeller and together they are termed as contra rotating propellers. And, these two propellers have opposite rotation directions and the two propellers are mounted on coaxial shafts which are rotating in opposite directions.

Now, the characteristic feature of contra rotating propellers is the cancellation of rotational velocities in the slip stream due to the two propellers. Now, because the two propellers rotate in opposite direction, the induced velocities due to rotation, the tangential induced velocity in the slip stream due to the forward propeller is in a direction opposite to that of the aft propeller, as the vortices due to the two propeller have different directions of rotation.

Now, these trailing vortices induce tangential velocities in the slip stream due to the propeller rotation. And, using a contra rotating propeller can lead to a large reduction of the losses due to these rotational velocities in the slip stream and that is how the efficiency of the total propulsion system can be improved.

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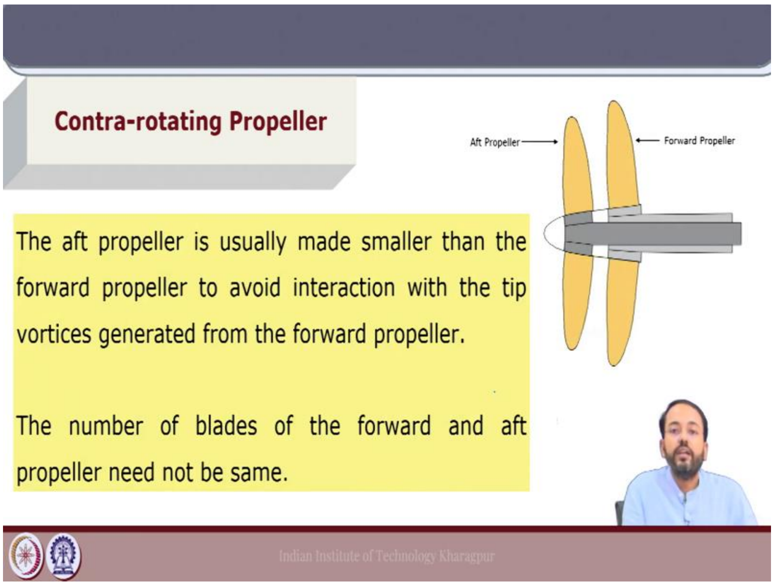

For a contra rotating propeller, the aft propeller is usually having a smaller diameter as compared to the forward propeller. The reason is to avoid the interaction of the aft propeller with the tip vortices generated from the forward propeller. Because, if the tip vortices interact strongly with the aft propeller, that will reduce the performance of the aft propeller.

And, the pitch of the forward and aft propellers must be selected in such a way that the rotational energy losses can be minimized by a combination of a clockwise rotating propeller and then anticlockwise rotating propeller. Now, the number of blades for the forward and aft propeller in this contra rotating propeller configuration need not be same.

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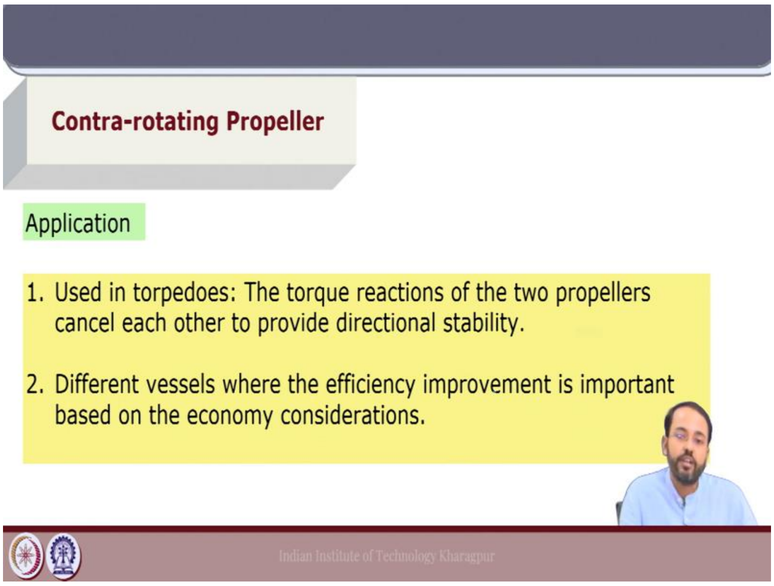

Regarding applications for contra rotating propellers, they are used in torpedoes because these torpedoes are in the shape of a body of revolution. And, if contra rotating propellers are used then the torque reactions of the two propellers as they are rotating in opposite directions will cancel each other and that will provide directional stability. Also, these contra rotating propellers can be used for different vessel types where efficiency improvement is important based on the economy considerations for vessel operations.

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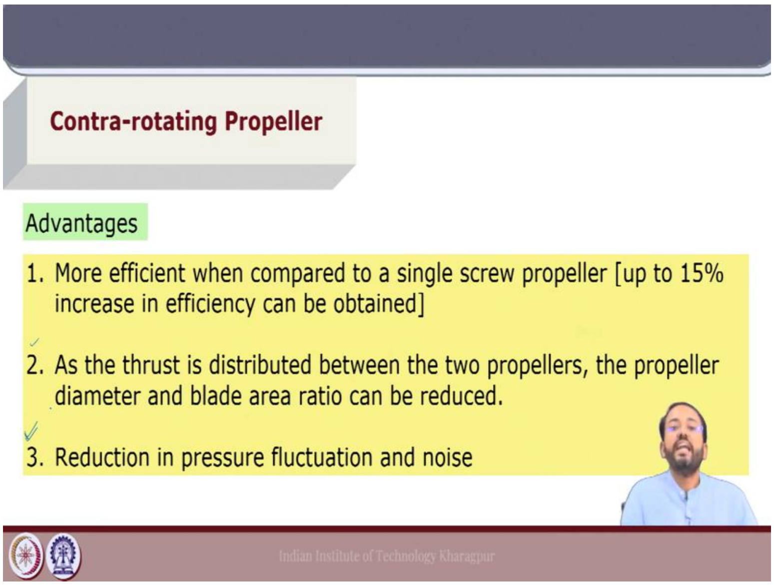

What are the advantages of contra rotating propellers? These are more efficient as compared to a single screw propeller because of the reduction in rotation energy, losses in the slip stream. And, it is observed that up to 15 percent improvement in propulsion efficiency can be obtained by use of a contra rotating propeller. Next, as the thrust is distributed between the two propellers, the propeller diameter and blade area ratio can be reduced.

Again, this particular point holds true for any multiple propeller arrangement. The 3rd point here is a possible reduction in pressure fluctuations and noise, because the two vortex systems from the two propellers in contra rotating mode can cancel each other to some extent, that reduces the rotational energy losses in the slip stream and pressure fluctuations and noise due to the propeller operation can be reduced.

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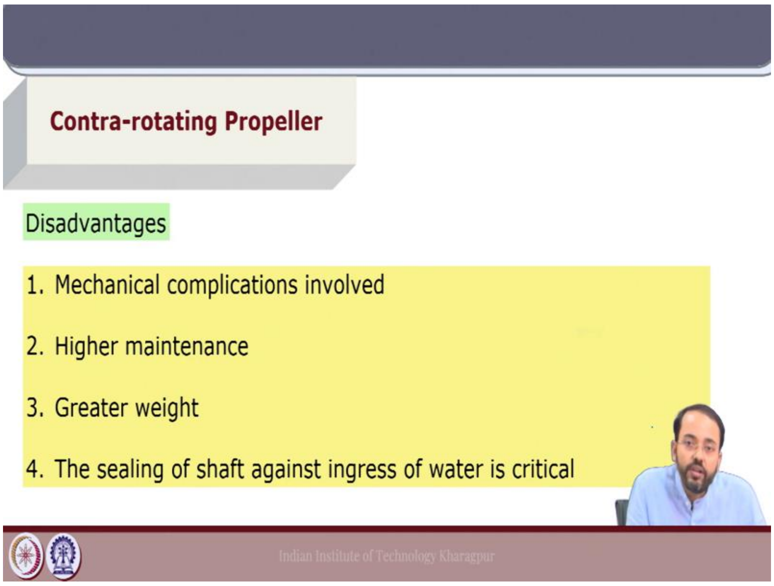

Next, there are some disadvantages which need to be considered while using a contra rotating propeller. There are certain mechanical complications which are involved because, here we have two coaxial shafts which are rotating in opposite directions. Higher maintenance requirement is necessary for the complex configuration of contra rotating propellers. And, also the bearings need to be designed to take care of the rotations in two opposite directions.

The assembly will have a greater weight due to the mechanical complexity and also because two propellers are involved. Finally, the sealing of the shaft against water ingress will be critical. And, this needs to be done in a proper way for the design of contra rotating propellers. This will be all for the present discussion. We will continue with other unconventional propulsor types in the next lecture.

Thank you.