Marine Propulsion
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Lecture - 38
Unconventional Propulsors (continued)

Welcome to lecture 38 of the course Marine Propulsion. Today, we will continue with Unconventional Propulsors.

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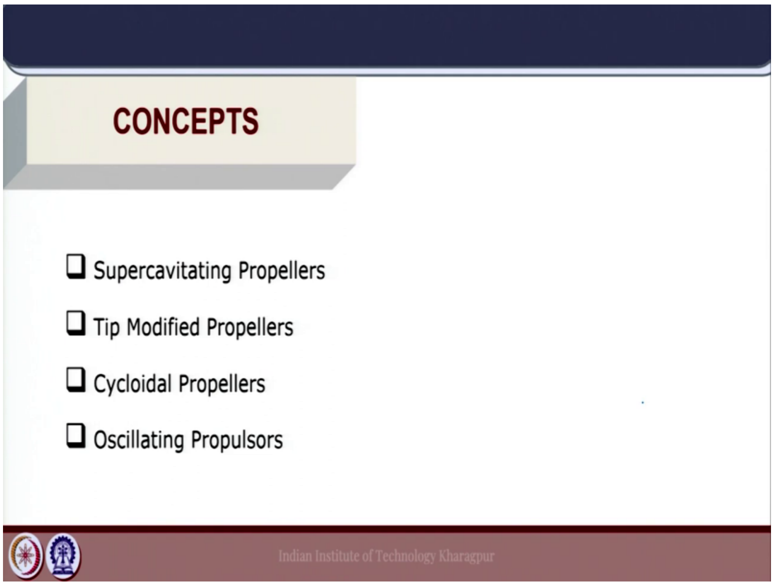

The key concepts covered in today's lecture are supercavitating propellers, tip modified propellers, cycloidal propellers which are also referred to as vertical axis propellers and oscillating propulsors. So, this is in continuation with our previous discussions on unconventional propulsors.

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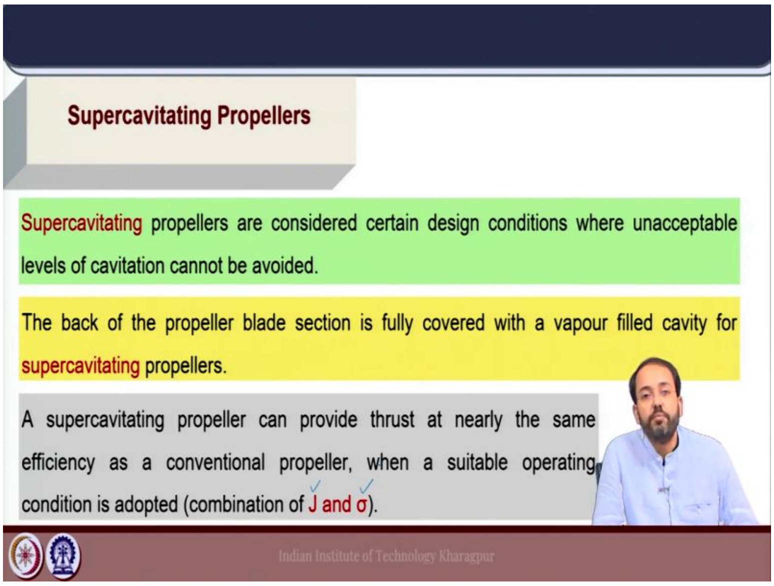

We will start with supercavitating propellers. In propeller cavitation section, we have seen that cavitation phenomena has an adverse effect on the thrust and efficiency for a propeller. And, hence for conventional propellers we try to avoid cavitation occurrence on the propeller blade. And, during propeller design, this is done by using suitable margins with respect to the thrust loading coefficient for a specific geometrical parameters of the propeller blade.

Now, there are certain types of propellers which are called supercavitating propellers, where cavitation is induced on the propeller blade by the geometric design of the blade. This is because for certain operation conditions, it is almost impossible to have a propeller which is a conventional propeller without cavitation occurrence due to critical operation conditions.

And, hence if a conventional propeller is used, its performance will not be optimal due to cavitation and its efficiency will be low. In these conditions, where the loading is high and the cavitation number is sufficiently low, during such operation conditions for high speed propellers supercavitating propellers can be considered. And, in these particular cases they are found to provide suitable performance with respect to the thrust and efficiency.

Now, in this supercavitating propellers, the back of the propeller blade section is fully covered with vapour filled cavity. And, this can be done using special geometric sections of the propeller blade. Due to its special geometric characteristics, a supercavitating propeller can be adopted for specific operation conditions which is a combination of the advance coefficient J and the cavitation number as mentioned here, where its performance in terms of efficiency will be as good as a conventional propeller.

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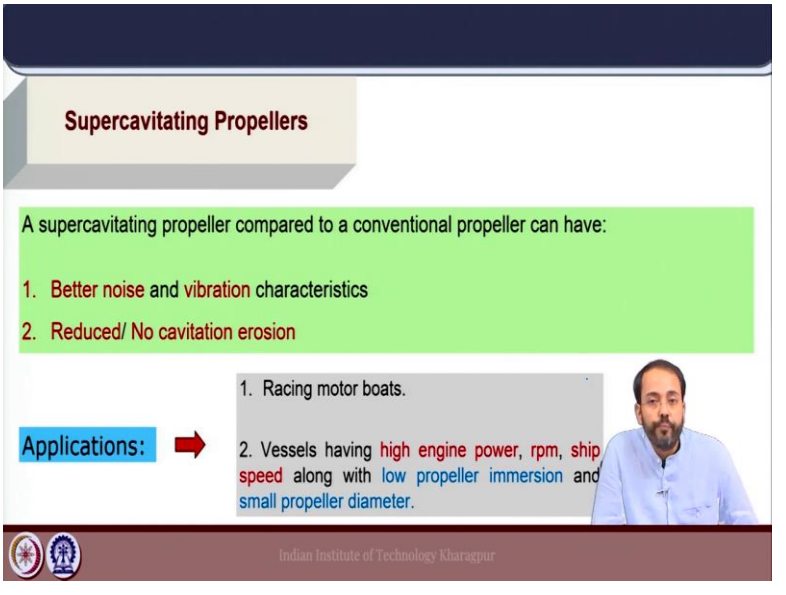

Compared to a conventional propeller, the advantages of a supercavitating propeller for high speed operations is that it can have better noise and vibration characteristics. And, it also leads to reduced or no cavitation erosion on the propeller blade, as the cavitation bubble covers the entire back side of the propeller blade and the flow is separated right from the leading edge.

So, there is almost no cavitation erosion which in conventional propellers can be a problem at high propeller loading, where the cavitation number can be critical and cavitation may occur which induces some erosion or damage on the propeller bed. So, in terms of application, this super cavitating propellers are useful for high speed vessels like racing motor boats, where in comparison to high engine power, the propeller rpm is also high. But, the propeller immersion as well as the available diameter is low.

So, these are the ideal conditions for cavitation to occur. And, hence conventional propellers are not good solutions for these particular cases and supercavitating propellers can be effectively applied for better performance.

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Now, in terms of the blade geometry, the idea of achieving a supercavitating propeller design is to ensure complete separation of the flow on the back of the propeller blade. And, also we have to achieve a high lift to drag ratio because that gives the proper thrust performance. Now, to achieve these conditions, the blade sections have typically sharp leading edges. And, different blade sections have been used, some of which are mentioned here.

The tulin section, a modified version of the same and cupped trailing edge section. Now, in all these sections, the leading edge is very sharp. So, we have the Leading Edge here, LE which is very sharp and that ensures flow separation on the back of the propeller blade, where the entire cavitation bubble is covering the back. So, the trailing edge is somewhat in the shape of a wedge and the leading edge is very sharp. And, in the third sectional geometry, the trailing edge is cupped. So, all these different sections have been effectively employed for supercavitating propeller design.

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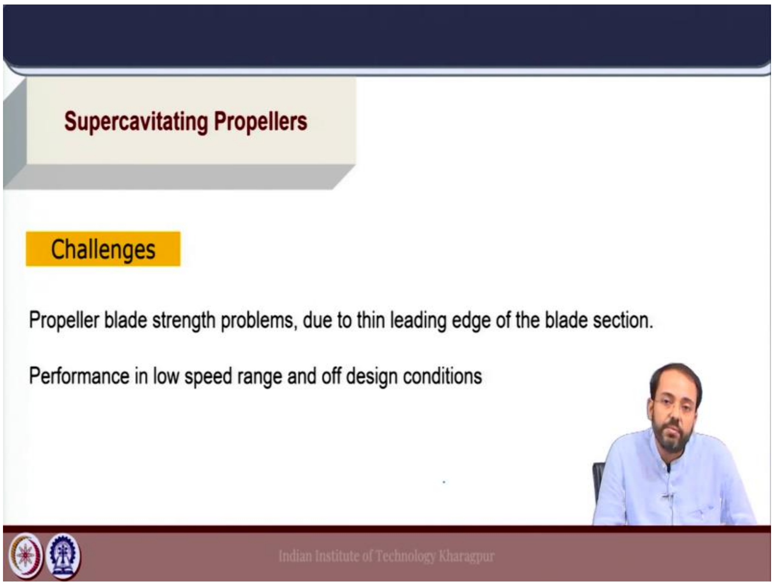

Now, what are the challenges for supercavitating propeller design? Here, we have a very thin leading edge for the propeller blade sections. And, because of that strength problems may arise for different operation conditions and they may be very critical for the propeller blades. On the other hand, the performance in the low speed range and off design conditions may also not be satisfactory.

Because, the supercavitating propeller is designed to obtain flow separation by the formation of cavitation bubble on the back of the propeller blade in the design condition. Now, that is for high speed operation. In the low speed range, the cavitation is not formed over the entire propeller blade. And, due to that the performance is not satisfactory. And, also in off design conditions the performance of super cavitating propeller is not satisfactory. And, these factors need to be considered while designing a supercavitating propeller for a specific application.

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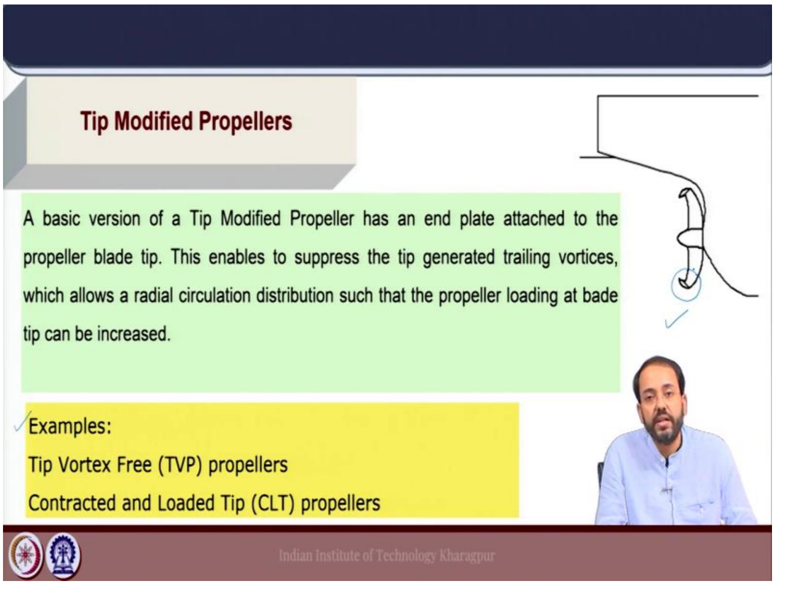

Next, we will look into another class of propellers where the tip is modified to obtain better performance characteristics and hence they are called tip modified propellers. So, a basic version of these tip modified propellers include an end plate which is attached to the propeller blade tip. And, due to that end plate, the tip vortices which are the trailing vortices generated from the propeller are suppressed.

And, this allows a better radial circulation distribution such that the propeller loading at the blade tip can be increased and this can lead to higher efficiency for the propellers. So, by modifying the tip of the propeller blade, where one can put an end plate; the circulation distribution can be modified by suppressing the trailing vortices from the propeller blade.

And, examples of these tip modified propellers are tip vortex free propellers or Contracted and Loaded Tip propellers, CLT propellers which have been effectively used to obtain better efficiency. And, they have slightly different configurations of the end plate which is attached to the propeller blade tip. So, this is an example of CLT propeller, where the blade tip is modified and that leads to the suppression of the trailing vortices from the propeller blade.

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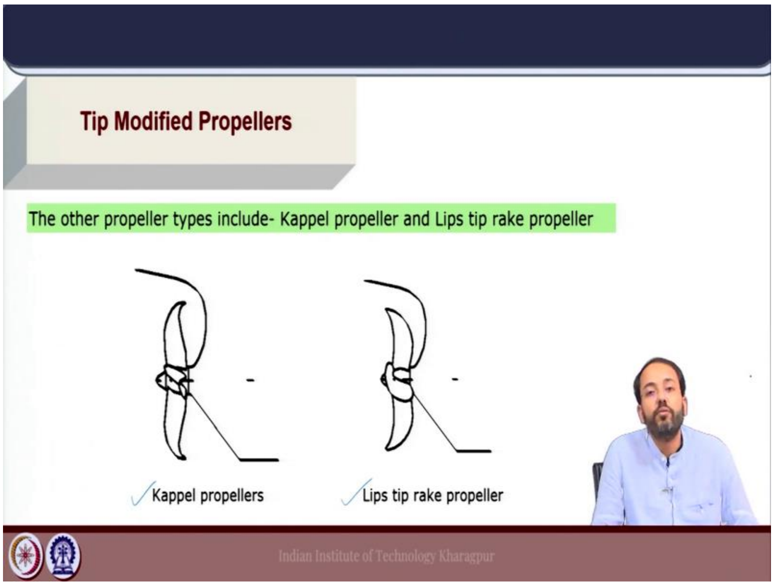

Now, there are also some other designs of the propeller blade which have been developed in the same concept by modifying the blade tip in such a way that the tips are provided with a small curvature or rake. They are the Kappel propeller and lips tip rake propeller which also have the same concept where the tip is modified to finally, get a different circulation distribution and better performance of the propeller blade.

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What are the advantages of tip modified propellers? By modifying the propeller blade tip, the strength of the trailing vortices which are shed from the propeller blades is reduced. Now, the occurrence of cavitation in the core of the vortices shed from the propeller blade will depend on the vortex strength. And, higher the strength of the tip vortex at high propeller loading conditions, the greater will be the chance of the code of the vortex to be at a much lower pressure, where the cavitation can occur which is visualized as the tip vortex cavitation.

Now, in these tip modified propellers because the strength of the trailing vortices can be reduced, the chances of the occurrence for tip vortex cavitation is also reduced. Next, improvements can be obtained for the propeller efficiency. Now, by modifying the propeller blade tip, we have discussed that a more convenient circulation distribution can be used for the propeller blade. And, the blade tip loading can be slightly increased because of the strength of the tip vortices can already be reduced by the inclusion of the tip modification and this leads to the improvement of the propeller efficiency.

And finally, these tip modified propellers due to the end plate design for certain operation conditions can have additional thrust, due to the thrust contribution from the end plate. So, these advantages can be obtained from tip modified propellers.

From the disadvantage point of view, these tip modifications typically by end plates may increase the drag of the propeller blade and which may result in the reduction of the efficiency. So, the modifications and their design should be considered with respect to these effects that it can bring on the performance of the propeller blade.

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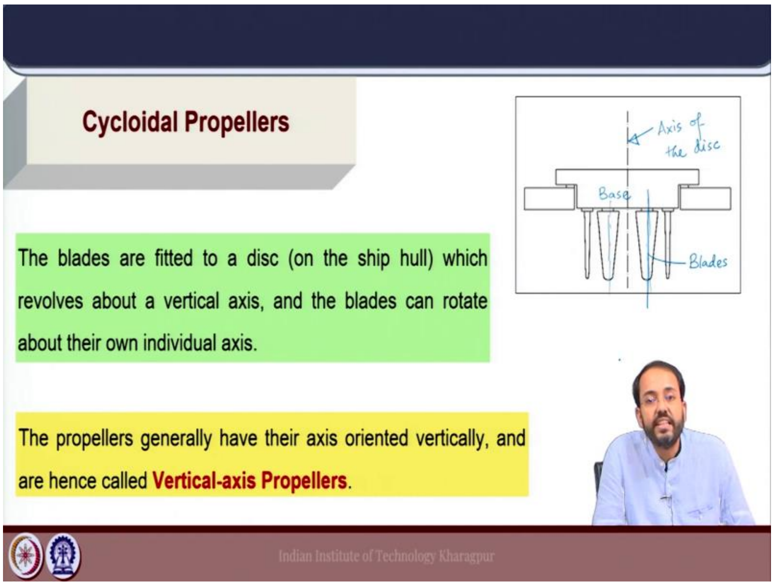

For the next unconventional propulsion type, we have the cycloidal propellers. These propellers have blades which are typically oriented in the vertical direction. So, these are the axis of the propeller blades and they are fitted on a base which is horizontally fixed at the stern of the ship. And, these blades can be rotated about their individual axis and the disc on which the blades are fitted is also revolving about the axis here.

So, in these class of propellers which are called cycloidal and also because they have their axis oriented vertically, they are named as vertical axis propellers. The propeller blades are fitted on a disc which revolts about its own axis here and each of these blades can rotate about their individual axis. These propellers can give very good maneuvering capability to the vessel. Now, depending on the path traversed by the blade sections, these propellers can have different types.

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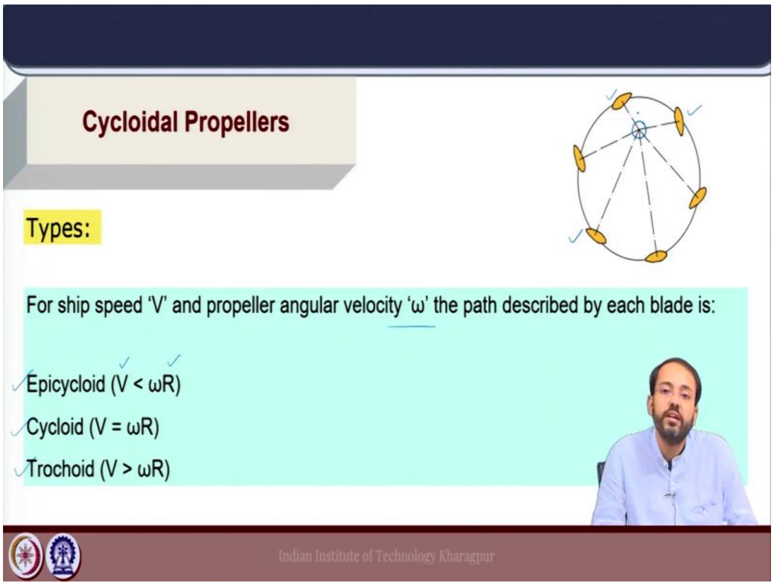

So, if V is the forward speed of the ship and ω is the angular velocity of the propeller, the path described by each blade as shown here can be epicycloid, cycloid or trochoid; depending on the relative value of V and ω R, where R is the radius of the propeller. Now, these vertical axis propellers have many blades.

The number of which depend on the propulsion performance required and these blades can be rotated about the vertical axis. And, we have a steering center here which governs the path of the propeller blade for different operation conditions. And, that directs the thrust of the propeller blade as per the requirements of forward motion or maneuvering.

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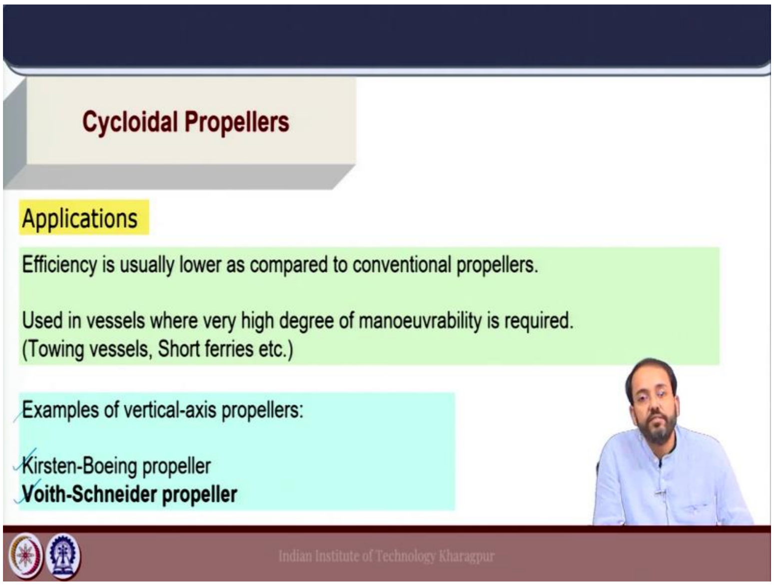

Now, the efficiency of these cycloidal propellers are generally lower as compared to conventional propellers. So, they are used in specific vessels where a very high degree of maneuverability is required which is not possible with conventional propeller and rudder system. Typically, towing vessels and short sea ferries where these vertical axis propellers find their applications.

Some design examples of vertical axis propellers are the Kirsten-Boeing propeller and the Voith-Schneider propeller which is the more popular design and has been effectively applied to different tugs and ferry designs for very good maneuverability performance.

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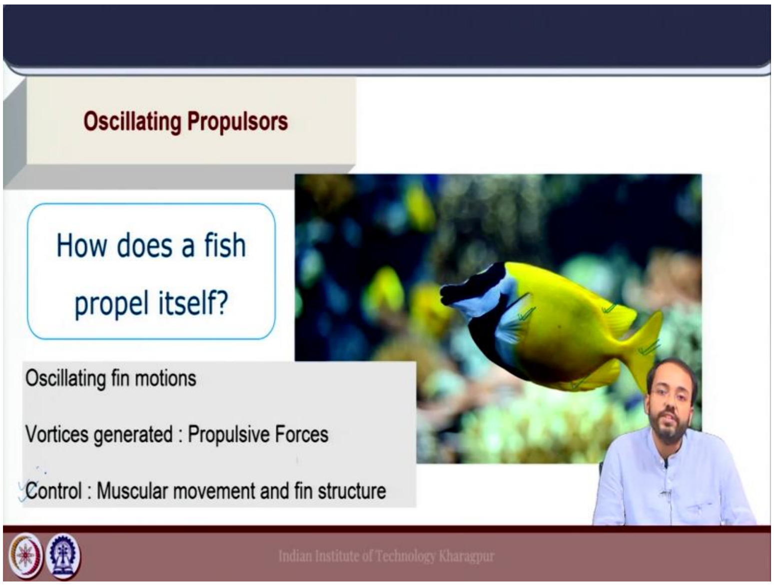

Finally, we will discuss oscillating propulsors in brief. Now, the swimming motions of fishes and other aquatic animals have inspired scientists and engineers to develop these specialized propulsors which are oscillating propulsors which mimic the flapping fin motion of fishes. Now, how does a fish propel itself through water? A fish has different types of fins on different location of its body, on the dorsal and ventral sides, on the sides and the tail fin.

Now, these fins have different types of flapping motions and in coordination to a part of the body which is flexible, a fish can generate the thrust force which allows it to move ahead and also for its different motion characteristics in both the vertical as well as the horizontal plane.

So, these oscillating fin motions result in the generation of vortices and finally, propulsive forces are generated which aids the swimming movement or the locomotion for a fish. And, these movements are controlled by muscular movement as well as the structure of the fins for the fish.

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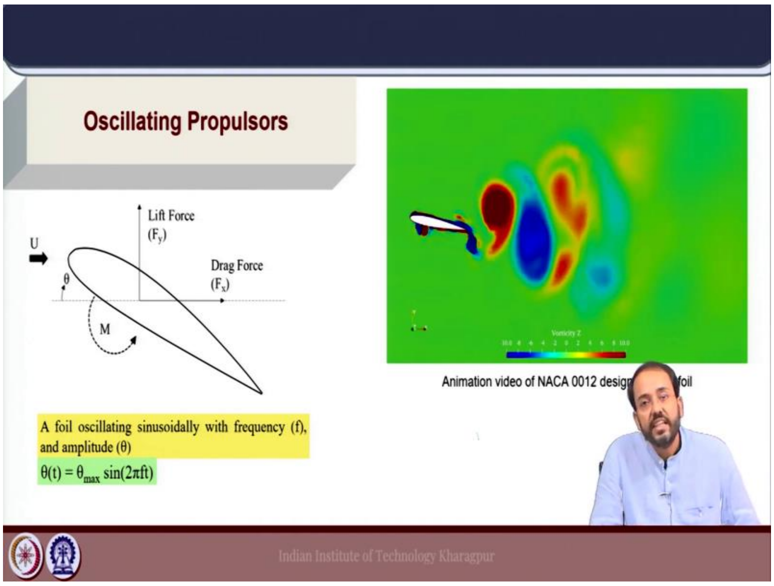

Based on this concept, oscillating propulsors have been developed which have standard airfoil sections. Now, these airfoil sections by their oscillation, they produce lift forces. The component in the direction of motion is a thrust and because the foil is oscillating at a particular frequency and an oscillation amplitude that generates a periodic force

So, the thrust generated by an oscillating foil is periodic and we assess the performance depending on the thrust over a complete oscillation cycle. And, a combination of heave and pitch motions can also be adopted for specific applications. Here, an animation is shown for an oscillating foil in pure pitching motion and the vortices formed in the wake are visualized.

So, we have an alternating set of vortices which are rotating in opposite directions and for thrust generation, the set of vortices are typically named as reverse von Karman vortices which lead to thrust generation for oscillating foils.

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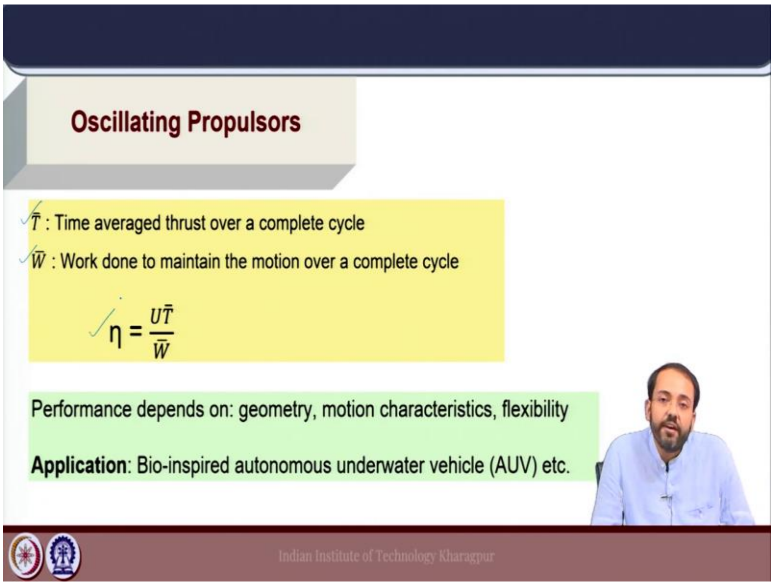

Now, for oscillating foils, we have the time averaged thrust T bar over the complete cycle and W bar is the work done to maintain the motion over a complete cycle. Then, the efficiency for the oscillating foil is given by this expression and these oscillating foils have performance characteristics depending on the thrust generation and efficiency which depend on the geometry, motion characteristics and also the flexibility.

So, if we have a flexible foil, it provides a higher efficiency in general as compared to a rigid foil. Now, with regards to application, these oscillating foils has been employed on Autonomous Underwater Vehicles or AUVs which have bio inspired propulsion systems; that means, the propulsion system or the flapping foil is inspired from the flapping fin motions for aquatic animals.

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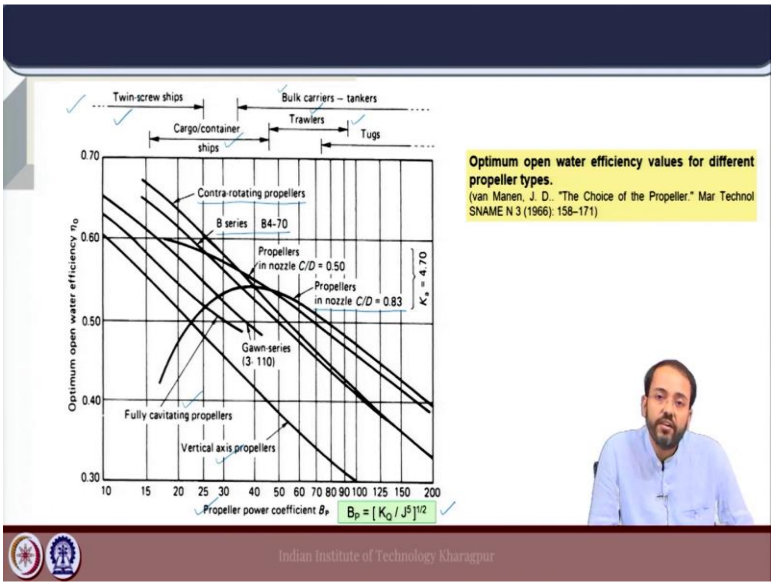

Now, in this particular course, we have studied different types of propulsors ranging from conventional screw propellers to ducted propellers which are propellers in nozzle, two supercavitating propellers, vertical axis propellers and contra rotating propellers etcetera. In this figure, the optimum open water efficiency which can be obtained from different propulsor types is shown as a function of the propeller power coefficient which is given by this particular expression.

So, we have the conventional B series propellers which have very good efficiency in the optimum operation range. And, we have propellers in nozzles which provide high efficiency in high propeller loading conditions. And, other propellers like vertical axis propellers and fully cavitating propellers which have efficiencies over a range of power coefficient as given. And, the contract rotating propellers which have very high efficiency even in comparison to conventional propellers.

So, this figure gives an idea of the optimum efficiency for different power coefficient value which corresponds to different propeller loading conditions. And, if we see the different ship types, which are mentioned here which corresponds to these different propeller loadings in general, we have the tugs and trawlers which operate at high loading conditions. And, then cargo and container ships, bulk carriers and on the other side we have the twin screw ships.

So, this figure gives a simple representation of the applicability of these propulsion designs for different conditions. This will be all for our discussions on unconventional propulsors.

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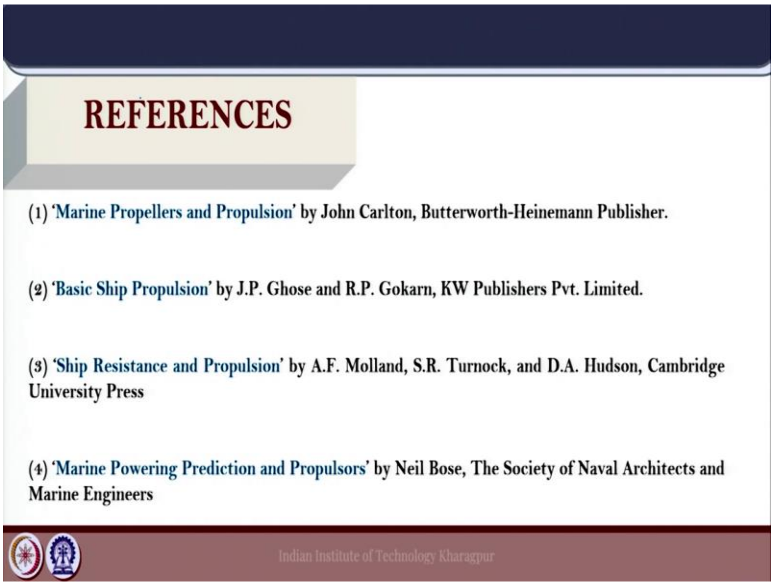

Some references are mentioned here which can be useful to study different types of propellers.

Thank you.