Marine Propulsion
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Lecture - 40
Energy Saving Devices

Welcome to lecture 40 of the course Marine Propulsion. Today, we will discuss Energy Saving Devices.

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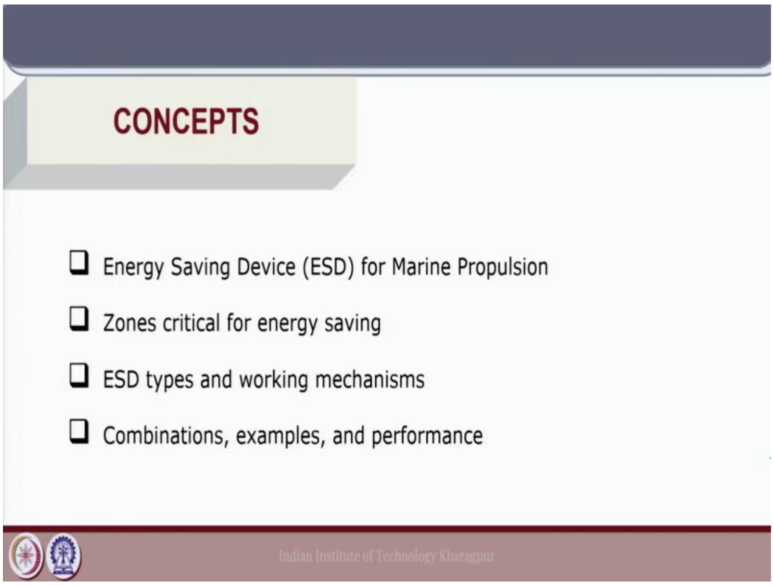

The key concepts to be discussed in today's lecture are energy saving devices for marine propulsion, some zones which are critical for energy saving with respect to the ship and propeller, types of ESDs or energy saving devices and their working mechanisms at different locations with respect to the propeller and combinations examples and performance in brief for these energy saving devices.

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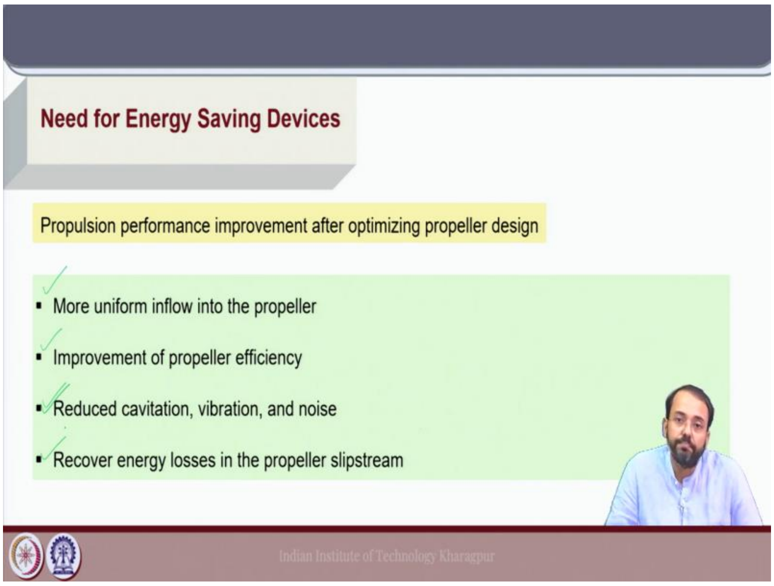

First, we need to understand why do we need these energy saving devices and what is their implication in the shipping industry. The propulsion performance for a ship is optimized with respect to the hull and propeller geometry. And, we have seen that based on the ship design its operation conditions and the powering requirement a propulsion system is designed for which we have the conventional propeller.

And other types of unconventional propulsions which can be designed for the respective operation condition it is observed that certain. Improvements in the propulsion performance can be obtained even after optimizing the propeller design for a specific application.

And these are related to certain hydrodynamic advantages that can be obtained by using these additional devices in and around the propeller behind the ship. What are these improvements? The flow into the propeller can be made more uniform now because the propeller works in the wake field of the ship the stern design of the ship impacts the flow into the propeller.

And for ships which have high block coefficients the flow into the propeller has different transverse as well as radial components apart from the axial component and there can be flow separation effects due to the formation of boundary layer using some additional devices in front of the propeller can improve these flow performance which are important to improve the propeller efficiency.

So, improvement of the flow characteristics into the propeller by improving the nominal wake field or even taking into consideration the swirling flow into the propeller can help in the improvement of propeller efficiency. Next these flow improvements will lead to better hydrodynamics of the propeller and hull system and that can improve the cavitation, vibration and noise characteristics of the propeller and finally, there are energy losses which are encountered in the propeller slip stream.

So, suitable energy saving devices can be placed behind the propeller to recover some of the energy that is lost in the propeller slipstream. And that can help in the improvement of propulsion performance of the ship.

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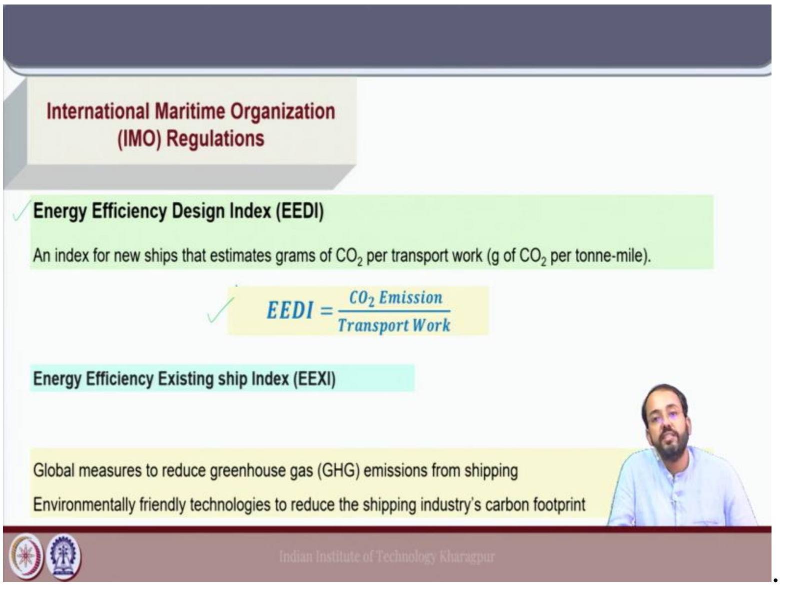

Now, there are certain regulations which are laid down by the international Maritime Organization IMO, which is related to the reduction of the carbon footprint of the international shipping industry. One of the most important design criteria is this energy efficiency design index which has been very important for the design of all new ships.

And this index estimates the grams of carbon dioxide which is emitted per transport work of the ship. So, EEDI simply is defined by this expression where the carbon dioxide emission per unit of transport work for a ship is defined and these levels of EEDI which are acceptable.

For different ship types have been mentioned by IMO and all new ships which are built have to abide by these levels of EEDI. Now, one of the ways to achieve this performance level is by improving the propulsion performance of the vessel. So, energy saving devices with relation to the marine propulsion system help in achieving the goal of reduced carbon emission by the energy efficiency design index as approved by IMO for different vessel types.

Another similar index which is important for existing ships and which will be required from now on is the energy efficiency existing ship index EEXI and these factors are important in assessing the ship design with respect to its emission. And the goal is to reduce the greenhouse gas emissions from the shipping industry and finally, using some environmentally friendly technologies to reduce the carbon footprint of the shipping industry.

In this course, we will not go into the details of these design indices which are related to multiple design and operation characteristics of the ship. The use of energy saving devices will help in reducing the power requirement and improve the performance with respect to these indices and make the ships more acceptable with respect to the new design regulations.

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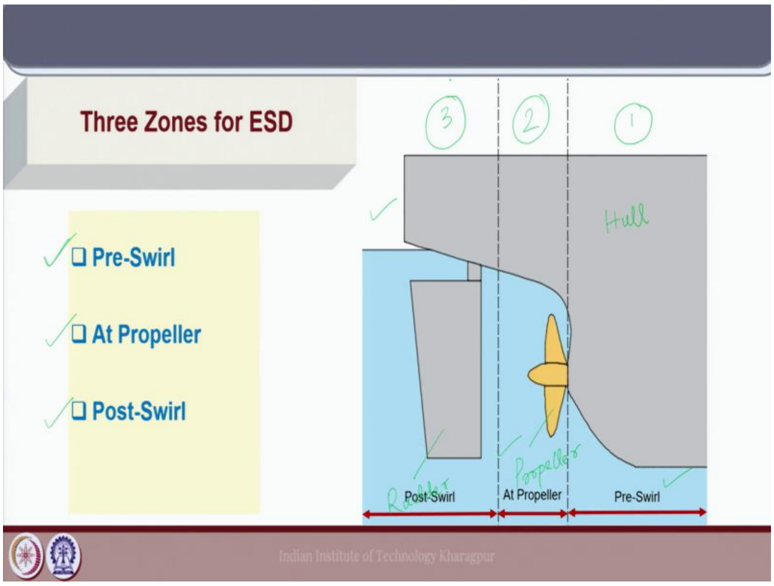

The energy saving devices for marine propulsion are devices or structures which are used as modifications to the ship propulsion system or additional structures, in the stern ahead of the propeller around the propeller or behind the propeller and these devices help in the improvement of the flow characteristics and the reduction of losses from the ship propeller system and finally, helps in the improvement of efficiency.

So, if we think in terms of the zone of application of these devices there are three critical zones. We have the hull of the ship and the propeller here and behind the propeller we have the rudder. So, the first zone here is a pre-swirl zone which is ahead of the propeller before the propeller generates a swirl in the flow. The next zone is at the propeller which is the zone in and around the propeller domain and the third zone is the post-swirl zone which is the region behind the propeller.

So, we have these three zones; number one is the pre-swirl, number two is at the propeller and number three the post-swirl after the flow has a swirling effect from the propeller rotation. The energy saving devices have to be applied according to the flow improvements that can be obtained in these three different zones.

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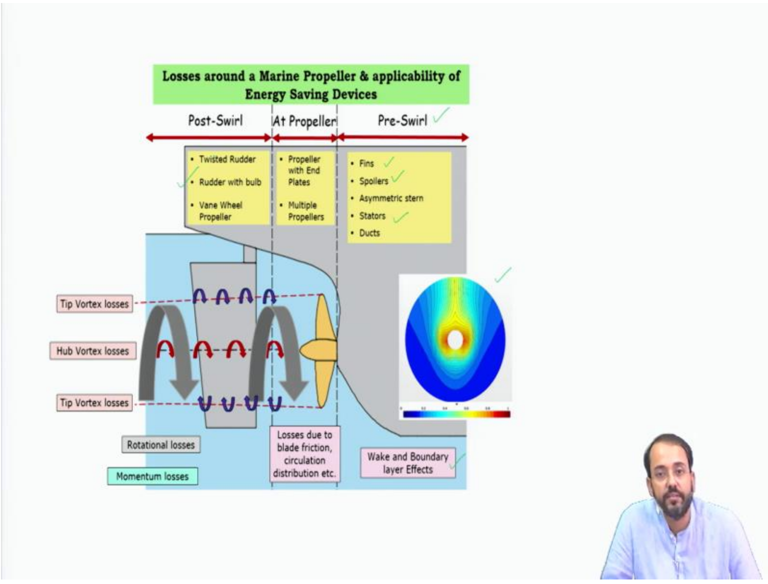

Here we will look into the losses around a marine propeller and the applicability of these energy saving devices in these three different zones. So, in the pre-swirl zone which is the region ahead of the propeller we have the effects of the hull wake and the boundary layer in the stern of the vessel. And we have seen how the wake is distributed in the propeller plane and the velocity is distributed in a very non uniform manner.

And hence, using a device which can make the velocity more uniform into the propeller plane can improve the propulsion efficiency. Next, we have the zone at the propeller where we have the losses due to blade friction and circulation distribution of the propeller blade which can be improved to obtain better efficiency.

And behind the propeller in the post-swirl region we have the losses due to the vortex generated by the hub and the tip vortices generated from the propeller blade. And we also have the losses due to the rotation of the propeller which imparts a swirling motion to the flow in the slipstream of the propeller. And we have momentum losses which is inevitable in the hull propeller system.

Now, we will look into some energy saving devices which can be applied in these three domains to reduce the losses and make the flow more uniform and finally, improving the efficiency of the propeller. In the pre-swirl region, we have fins spoilers concept of asymmetric stern which is a change in the stern configuration of the ship itself stators ducts etcetera, which can be used to make the flow into the propeller more uniform at the propeller.

One can use end plates to get tip modified propellers or use multiple propeller configurations to reduce the thrust loading of the propeller and get better performance and behind the propeller there are concepts like twisted rudder, rudder with bulb, vane wheel propeller and propeller boss cap fins which can be used to reduce the losses in the slip stream of the propeller.

Next, we will look into some of these devices based on their location with respect to the propeller and the benefits that they offer in the flow hydrodynamics.

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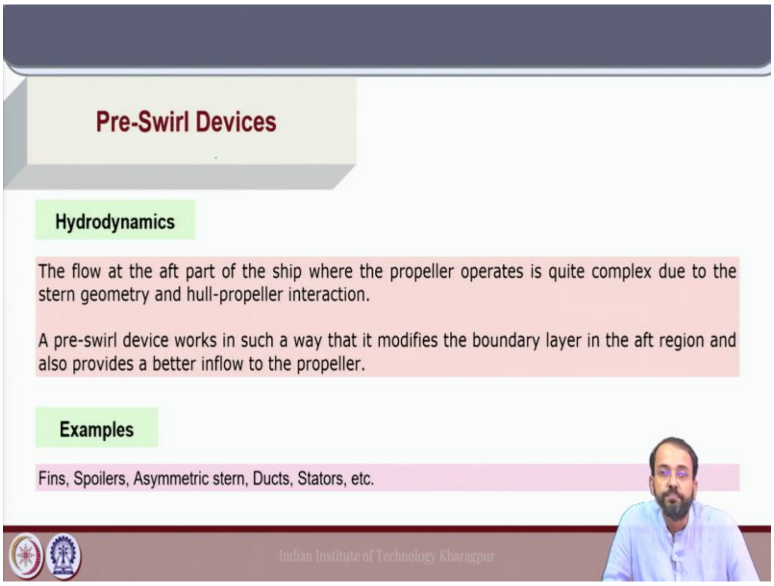

First, we have the pre-swirl devices; that means, the devices ahead of the propeller. Now the flow at the aft of the ship is very complex and three dimensional in nature. And hence, the propeller operates in a very complicated flow field due to both the stern geometry and the hull propeller interaction.

So, the pre-swirl device has to work in such a way that it should modify the flow into the propeller and make it more uniform as well as modify the boundary layer in the aft region in a positive way such that flow separation can be reduced and improvements in resistance and propulsion performance can be obtained. Some examples of these devices are fins, spoilers, asymmetric stern where the stern itself is configured in a different way, ducts and stators. We will look into some of these devices.

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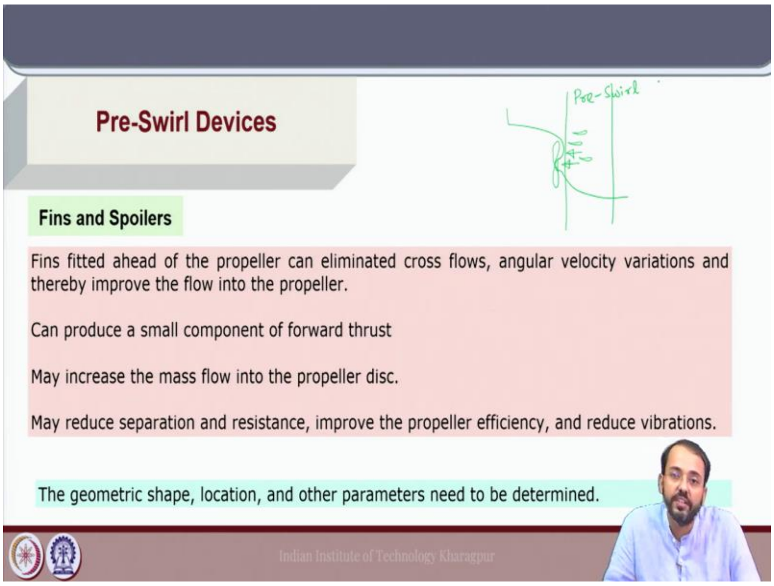

Fins and spoilers - so if we have the stern configuration of the ship here, so, there are certain ways where fins can be used or spoilers can be used ahead of the propeller such that they make the flow into the propeller more axial. So, these devices eliminate the cross flow and make the flow into the propeller more uniform by reducing the variations of angular velocity. And hence they improve the efficiency of the propeller.

Now in addition to this the fins and spoilers fitted ahead of the propeller in the pre-swirl zone here. They can also produce a small forward thrust because of the flow around these devices. And hence that can add up to the thrust already generated by the propeller. These devices if properly designed with respect to the geometry and the location can help in reduction of flow separation. And hence improve the resistance as well as the propulsion performance of the vessel.

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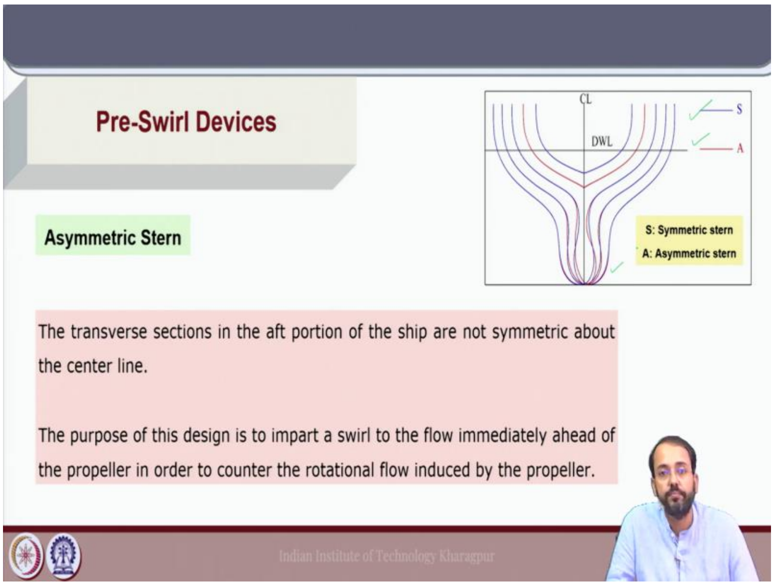

The next concept is that of an asymmetric stern. Now, this is not a separate device, but a change in the design of the stern, but because it helps in improvement of the energy efficiency this is listed in this energy saving device concepts. Now, asymmetric stern means that the stern design will not be symmetric on the port and starboard sides. It is shown with respect to the body plant in the stern region of the ship.

Whereas the blue lines are for a symmetric shape of the stern and A is the modified design with stern asymmetry a twist is given to the stern lines in front of the propeller such that a swirl is imparted to the flow immediately ahead of the propeller. Now, in this concept we want to impart a swirl to the flow into the propeller in a direction opposite to the propeller rotation that counters the rotational flow which is induced by the propeller and reduces the rotational losses from the propeller.

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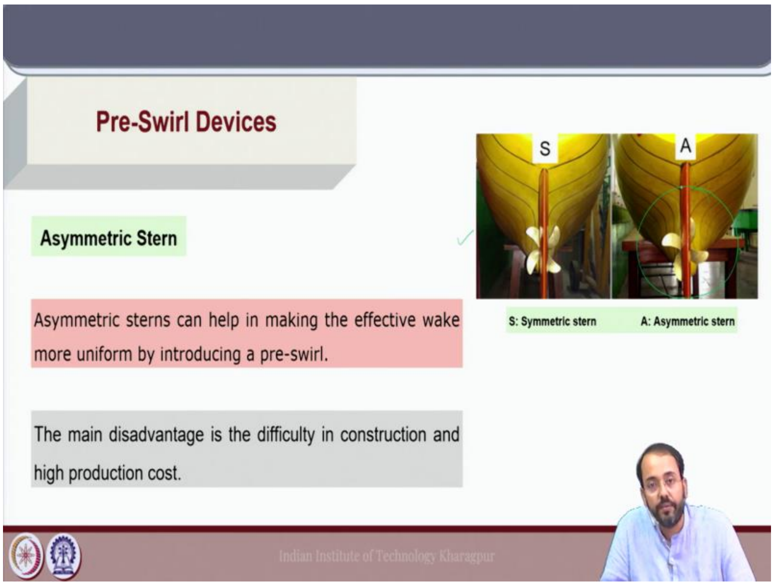

Now, asymmetric sterns can help in making the effective wake more uniform by introducing this pre-swirl. So, the two models of the ships with symmetric and asymmetric stern variance are shown here and we can see that for the asymmetric stern, the port and starboard designs are not symmetric about the center line of the ship. For a standard ship design which is symmetric about the center line the nominal wake will be symmetric, which is the wake without the propeller acting behind the ship.

But when the propeller revolves in a particular direction that induces a swirl to the flow which comes into the propeller and hence if we give a swirl in the opposite direction by making the stern itself asymmetric, that can negate some of the effects due to the propeller rotation in the effective wake which is the wake after the propeller is put behind the ship.

The main disadvantage of this asymmetric stern is the difficulty in construction and high production cost, because the stern has to be made in a different way where we do not have the port and starboard symmetry.

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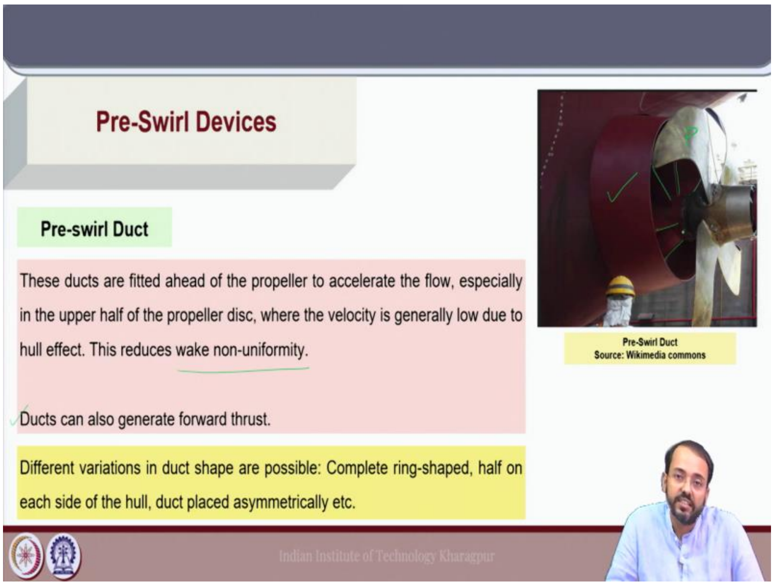

The next device is a pre-swirl duct; that means a duct which is used ahead of the propeller. We have discussed about ducted propellers in this course where the propeller was surrounded by an annular duct and that helped in higher propulsion performance at high propeller loadings especially close to the bollard conditions. Now, this particular duct is located ahead of the propeller.

So, its characteristics with respect to the hydrodynamic advantage is completely different from that of a ducted propeller. Here, we want to achieve a better flow into the propeller which will be more uniform and enhance its performance. So, these ducts ahead of the propeller will accelerate the flow specially, on the upper half of the propeller where the wake fraction is higher due to the effect of the hull.

And that reduces the non uniformity of the wake. Now, non uniformity of wake results in higher variations of thrust and torque on the propeller disc and transverse forces on the propeller and leads to vibrations and noise. So, if we have a pre-swirl duct which can make the wake more uniform in the propeller plane that will improve the propulsion performance and also some of these ducts if properly designed can generate forward thrust under some operation conditions. And that adds up to the propeller thrust.

Here we see a pre-swirl duct ahead of the propeller, because this is the blade of the propeller. And the duct is located ahead of the propeller and in addition to the duct we see that there are some structures here which are basically inner part of the duct in the form of stator vanes.

So, we will see that stators in combination with ducts can be used to improve the flow and reduce losses in the hull propeller system. Now, different variations of these ducts are possible. There are ducts which are completely ring shaped or half ducts half on either side of the hull or placed asymmetrically on one side.

Depending on the vessel design and the operation condition one needs to design these ducts and the improvement of the wake required depending on the stern configuration will decide the shape and configuration of these ducts.

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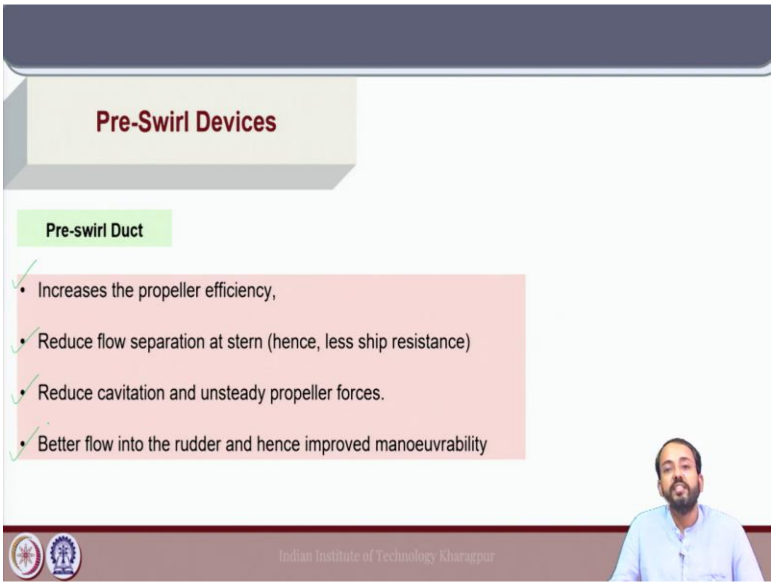

Now, what are the positive features which lead to hydrodynamic advantages in the hull propeller system using these peaceful ducts? First, we have a more uniform loading on the propeller which will improve the propeller efficiency. The duct increases the axial flow in the stern region of the ship and that reduces flow separation for ships where the block coefficient is high and hence the resistance of the ship can also be reduced.

But one must also consider that using any additional object will also have an effect from the drag of the duct itself. And that will also be required to be taken care of in the powering estimations when these devices are used reduce cavitation and unsteady propeller forces. If the wake is more uniform and the velocity field on the propeller has a higher uniformity in the circumferential direction, that will reduce unsteady propeller forces and the cavitation performance will improve.

Now, from the point of view of the rudder a better flow which can be obtained using these pre-swirl ducts will help in better rudder performance and that will lead to improved maneuverability for the ship.

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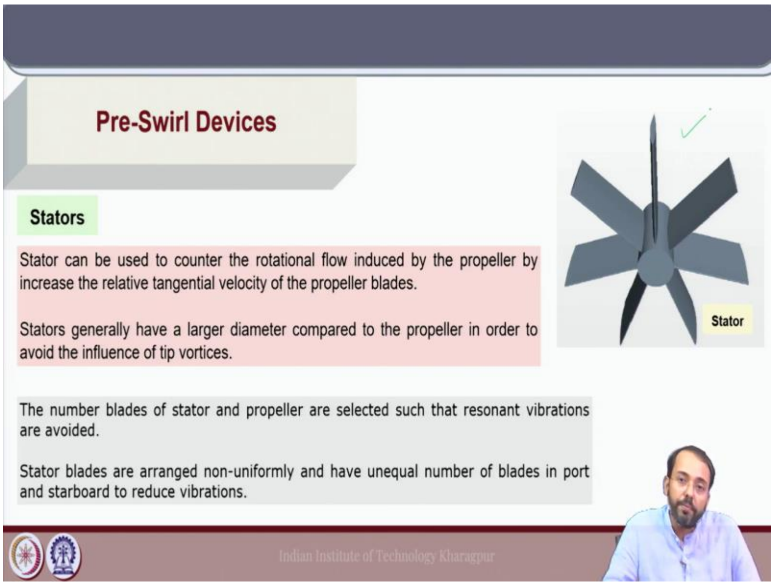

Next we have stators which are in the shape of a number of vanes fitted to a central hub in front of the propeller. And that helps in the reduction of the rotational energy losses due to the swirling flow induced by the propeller. Now, these stators can counter the rotational flow, which are induced by the propeller.

And they increase the relative tangential velocity of the propeller blade, because the tangential velocity which is induced by the water close to the propeller blade is reduced if the stator is used as it reduces the rotational effect of the propeller. And hence the relative velocity between the blade and the water which is close to it in the blade element diagram will be higher if we use a stator.

In general these stators have larger diameters as compared to the propeller, because the tip vortices from the tips of these stator vanes should not impact the propeller performance. And the number of blades or vanes used in these stators should be different from the number of blades of the propeller. This is to avoid resonance and reduce vibration in the propeller and stator system behind the hull.

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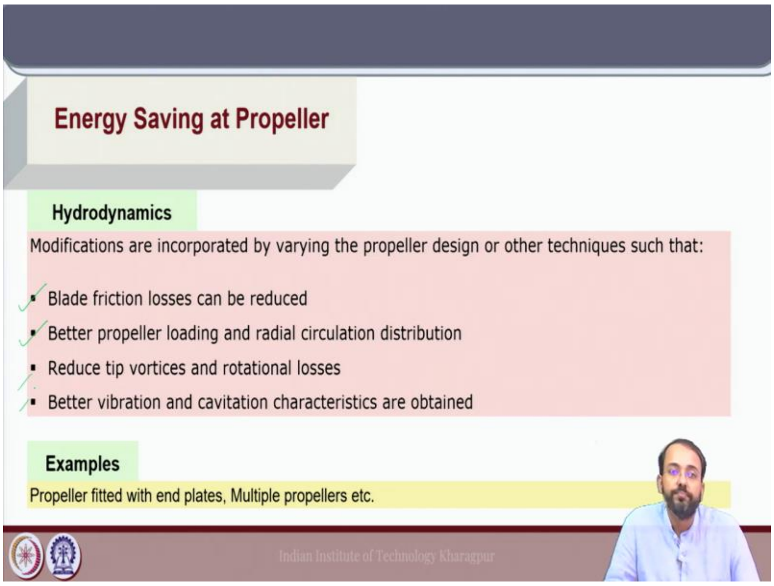

Next we will look into the energy saving mechanisms at the propeller. Now because the propeller itself is present there are not many options of energy saving devices as such at the propeller plane, but certain methodologies can be adopted to improve the propulsion efficiency by reducing losses.

Blade friction losses can be reduced by suitable design methodologies by adopting a suitable propeller geometry with respect to the operation condition limitations. Better propeller loading can be achieved by the radial circulation distribution. We can have tip modified propellers to reduce the tip vortices from the propeller and also reduce the rotational losses.

And finally, better vibration, cavitation and noise characteristics can be obtained by optimizing the propeller design. Here we can have propellers fitted with end plates; that means, tip modified propellers that we have discussed. And concepts of multiple propellers can be used to share the thrust load between multiple propellers which can help in the improvement of the propulsion performance.

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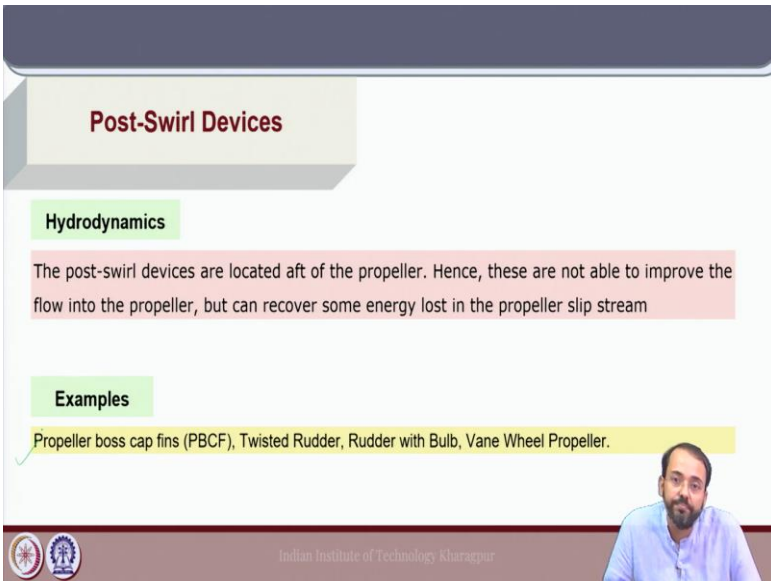

Next we have the post-swirl devices; that means, the devices which are located aft of the propeller. Now, because these devices are behind the propeller typically in and around the rudder or at the boss of the propeller these will not help in improving the flow into the propeller, because any device which makes the flow field more uniform into the propeller has to be placed ahead of the propeller.

The post-swirl devices are typically used to recover some energy which is lost in the propeller slipstream and hence improve the propulsive efficiency of the ship. So, these devices will include propeller boss cap fins which are fitted on the boss cap on the hub, twisted rudder with bulb and vane wheel propeller. These help in recovering the energy losses by reducing either the tip vortex or hub vortex or rotational losses in the slip stream and helping in improving the energy efficiency of the ship propulsion system.

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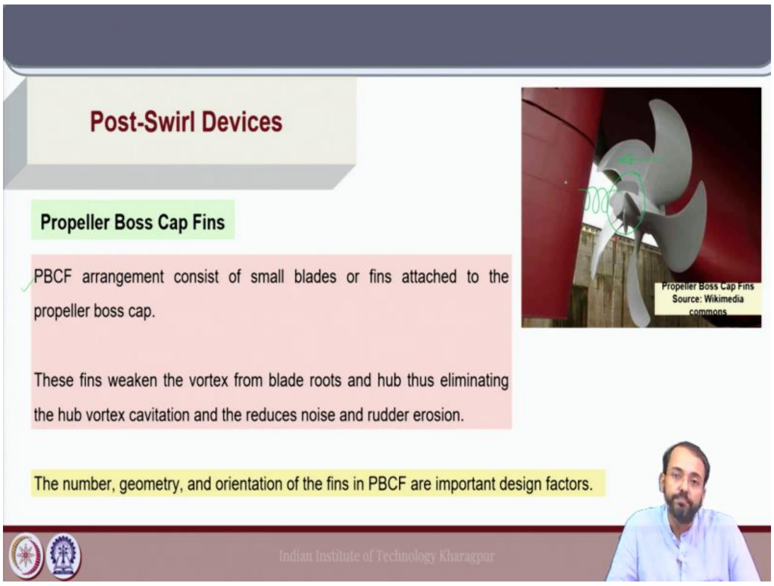

First, we will discuss propeller boss cap fins. Now, these fins are small structures which are placed on the boss cap of a propeller which is behind the propeller. So, in the slipstream of the propeller that is why this is a post-swirl device. These PBCF consist of small blades which help in breaking down the vortex shed from the hub and the root of the propeller blade.

And because these vortices are weaken they eliminate the chances of hub vortex cavitation and reduce noise and rudder erosion because the vortices which are generated from the hub they interact with the rudder and can cause erosion and damage to the rudder. So, propeller boss cap fins can reduce the hub vortices which are generated in the propeller slipstream and hence it helps in the improvement of the energy efficiency and also rudder erosion can be avoided.

Now, in terms of design of these propeller boss cap fins normally the number of fins is same as the number of propeller blades, but their shapes and orientation have to be designed in such a way that their performance is optimal with respect to reduction of the vortex strength generated from the hub.

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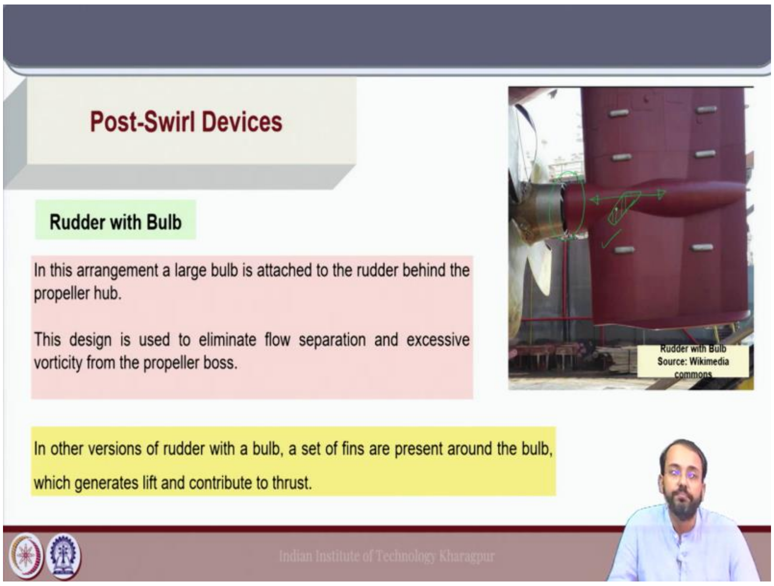

Next, we will discuss rudders with bulbs or additional modifications which help in energy efficiency. So, here we have a rudder which is behind the ship which has a modification in terms of a bulb along the length of the rudder such that it is in line with the hub of the propeller. Now, this eliminates flow separation and also excessive vorticity which is generated from the propeller boss and hence reduction of the vortex as well as rotational losses can help in the performance improvement of the propeller.

Now, there are many variations of rudder modifications which are used for efficiency improvement. So, these are also post-swirl devices because rudders are placed behind the propeller. Now, in these modifications additional fins can also be used on the rudder surface perpendicular or at different angles to the rudders.

Now, these fins or other modifications on the rudder can help in reduction of rotational losses in the slip stream and also generate some lift which can contribute to the thrust from the propulsion system.

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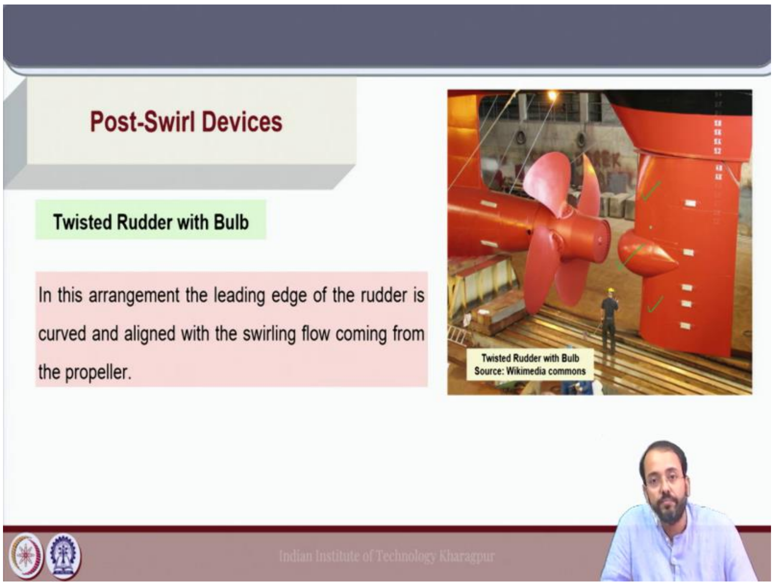

Another rudder modification which can be used for energy saving is the concept of a twisted rudder. Here the leading edge of the rudder is given a twist with respect to the central line such that the flow into the rudder becomes more parallel with respect to the rudder leading edge as the flow itself has a swirl due to the action of the propeller.

So, depending on the propeller rotation direction the twist angle at the rudder leading edge has to be defined and that improves the performance of the propulsion system. And this twist of the rudder can be used together with the concept of rudder bulb to provide higher efficiency by reducing losses in the slip stream of the propeller.

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The next device is a vane wheel located aft of the propeller. It is called grim vane wheel propeller after the name of the inventor Otto Grim. This device is a very special example of energy recovery from the propeller slipstream by recovering some of the rotational energy that is lost in the propeller slipstream. So, the Grim vane wheel consist of narrow vanes or blades attached to the hub of the propeller.

So, this device is coaxial with the propeller and freely rotating behind it such that it can recover the energy from the propeller slip stream. And the sections of these devices are made in such a way that it can recover energy from the inner radii and impart that at the outer radii to the flow such that it also generates a thrust which adds up to the propeller thrust and improvements in the propeller efficiency can be obtained.

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The Grim vane wheel is a very special device which works in a combination of both the turbine concept as well as the propeller concept a turbine absorbs energy from the fluid flow and converts that into other forms of energy; whereas, a propeller imparts momentum to the flow to provide thrust to the ship. Now, this Grim vane wheel has pitch distribution designed in such a way that at the inner radial locations, it acts like a turbine where it absorbs the energy from the slip stream of the propeller.

And at the outer radial locations it works similar to a propeller where it produces thrust which adds up to the propeller thrust. And hence this Grim vane wheel has a diameter which is larger than the propeller diameter. And typically the number of blades which are used in the vane wheel is larger than the number of blades for the propeller.

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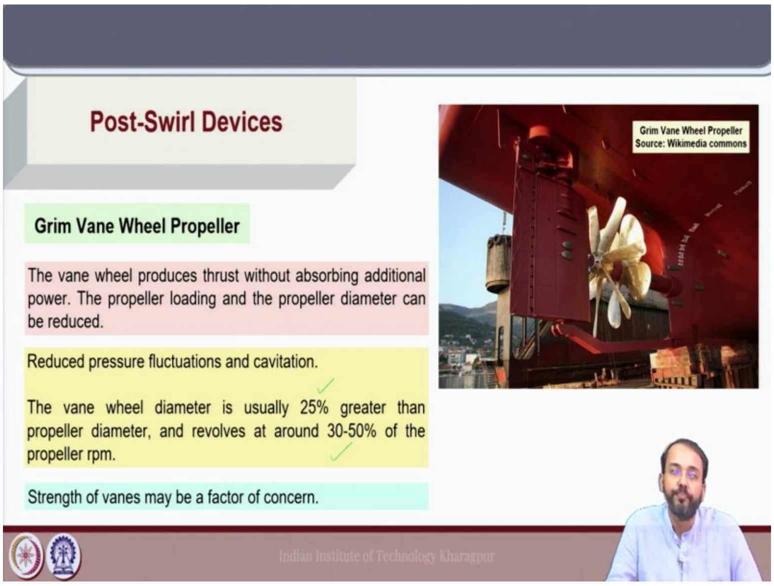

Now, the vane wheel can produce additional thrust without absorbing any additional power just from the slipstream of the propeller. And this helps in improving the propulsion efficiency significantly and use of Grim vane wheel can also help in reduced pressure, fluctuations and cavitation due to the reduction of the rotational velocity components in the slip stream.

The diameter is typically around 25 percent higher than the propeller diameter and because the vane wheel is freely rotating depending on the slip stream of the propeller, it is observed that the revolution rate is around 30 to 50 percent of the propeller rpm. For practical applications, the strength of the vanes in the vane wheel should be considered in the design process.

Now, all these energy saving devices which have been discussed can be used according to the benefits that it can offer with respect to the location of the propeller behind the ship.

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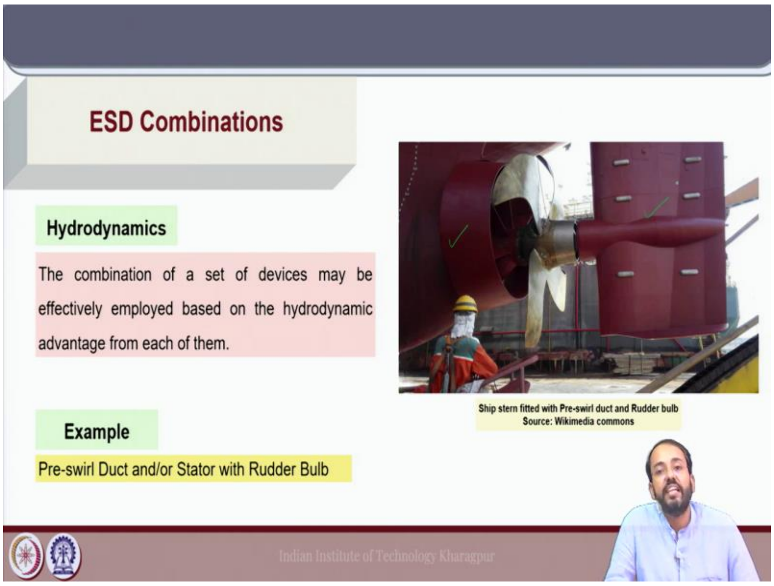

Next, we will look into the hydrodynamics of combinations of these devices which can be used to improve the propulsion performance. So, we have different locations of these energy saving devices with respect to the propeller; pre-swirl and post-swirl for ahead of the propeller and behind the propeller respectively.

Now, we can also use combinations of these devices to improve the propulsion performance of the ship. This is a classical example of the use of different types of energy saving devices on the same ship. We have a pre-swirl duct with stator fins and a rudder with bulb behind the propeller. So, the duct will improve the flow velocity into the propeller by making it more uniform.

And the rudder bulb will help reducing the strength of the vortices which are shed from the hub and reduce rotational losses in the slipstream. Similarly, other combinations of these energy saving devices can also be used depending on the benefits that they offer in different locations of the flow.

And many of these devices have been patented by companies and large corporations, and they are used for efficient energy saving on different kinds of ships. In terms of percentage of the powering demand the typical range of energy savings that can be obtained by using these energy saving devices or their combinations is in the range of 1 to 7 percent.

For some specific cases or combinations it can be slightly higher, but in general this is the average range of energy saving that can be obtained.

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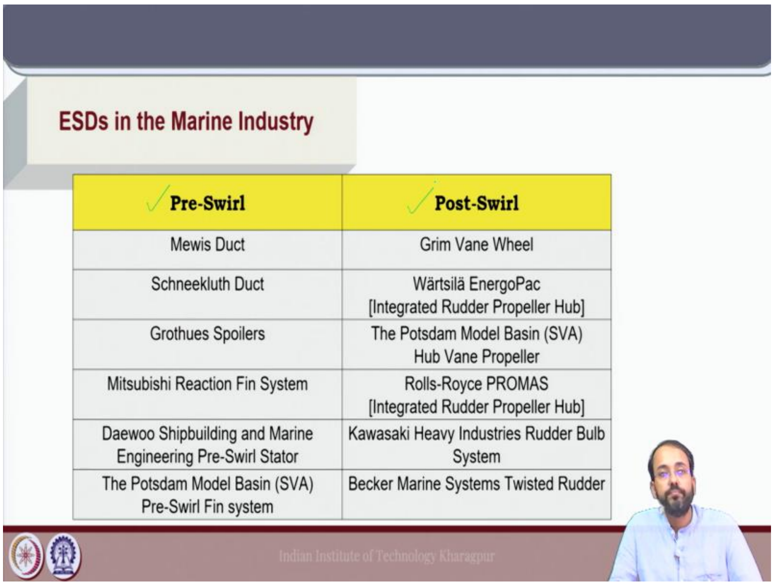

Some energy saving devices which are widely used in the marine industry both in the pre-swirl and post-swirl domains are listed here.

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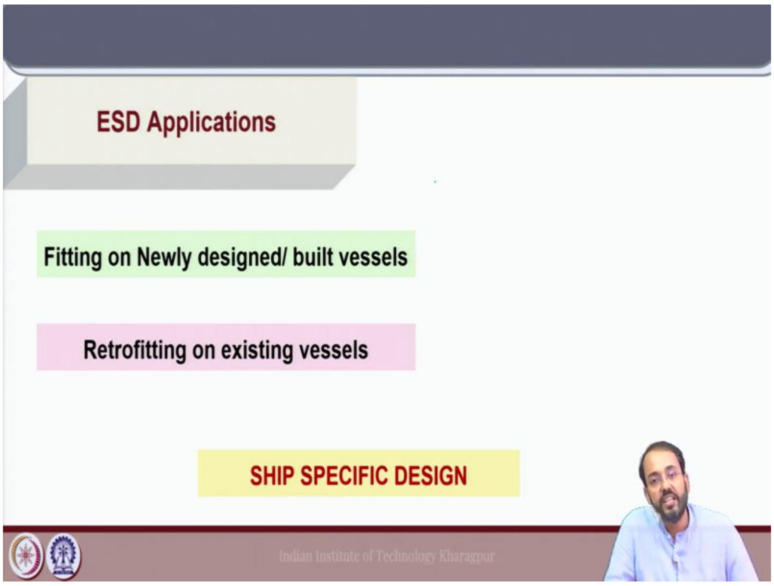

In terms of application these energy saving devices can be used on newly built ships where the stern part of the ship can be designed along with the energy saving device in the pre-swirl region; or the rudder can be designed with respect to these concepts of rudder bulb and fins so that the hull and propeller along with these energy saving devices can be designed as an integral unit.

Also for existing vessels retrofitting can be done, by using these energy saving devices to improve the flow into the propeller or to improve the efficiency by recovering some of the energy losses from the propeller slip stream. The bottom line is that the specific energy saving device that needs to be employed has to be designed with respect to the specific ship design and its operation condition.

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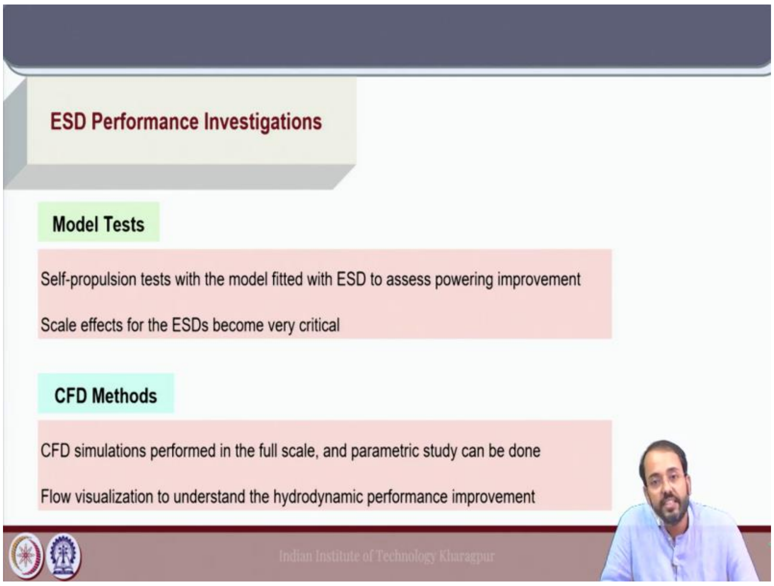

Finally, the methods of performance investigation of these devices: We have the standard model tests and CFD approaches which can be used to assess the performance with respect to the hull propeller configuration. Now in model tests we can use these energy saving devices in the self propulsion tests as per their location relative to the propeller and the powering performance can be assessed.

There is one critical aspect which should be considered is the scale effects of these devices because in the model tests we cannot maintain Reynolds number similarity. The boundary layer pattern in the stern of the ship around these devices will be very much different as compared to the full scale ship. And hence, it is often observed that the performance benefits that they provide during the model tests are very much different as compared to the performance benefits that they provide in the full scale.

And hence, scale effects should be taken care of while using model test for assessing the performance of energy saving devices. On the other hand, we have computational fluid dynamics simulations which can be performed directly in the full scale with the ship propeller as well as the energy saving device to assess its performance with respect to energy savings in the ship propulsion.

Another advantage of CFD computations is its capability to include a parametric study which can be easily done by variation of certain geometric as well as location parameters of these devices. This is of prime importance as variation of geometry and location of these devices needs to be studied to get the optimum flow into the propeller.

For pre-swirl devices and for post-swirl devices this helps us in optimum reduction of the energy losses in the slip stream when these energy saving devices are used. Flow visualization which is also an advantage of these numerical methods can be employed to look into the hydrodynamic aspects and get the alignment of these devices with respect to the hull propeller system.

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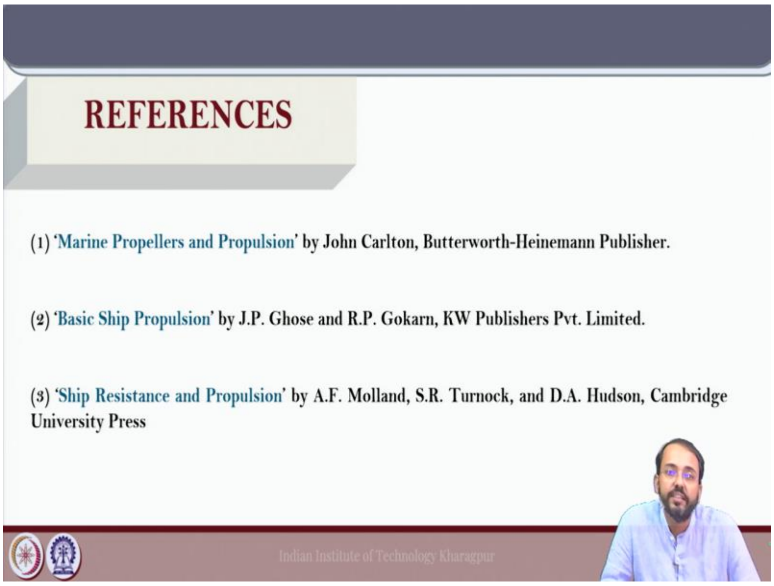

This will be all for our discussion on energy saving devices. Some references which can be used for this part of the course are listed here. This concludes the last lecture of the marine propulsion course. I want to thank all the participants of the course, the teaching assistants Kiran George Varghese and Rajni Kant for helping with different parts of the course. And, Sourav Sahu for recording and editing of the different lectures of the course and the entire NPTEL team for effective conduction of this course.

Thank you.