Marine Propulsion
Prof. Anirban Bhattacharyya
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

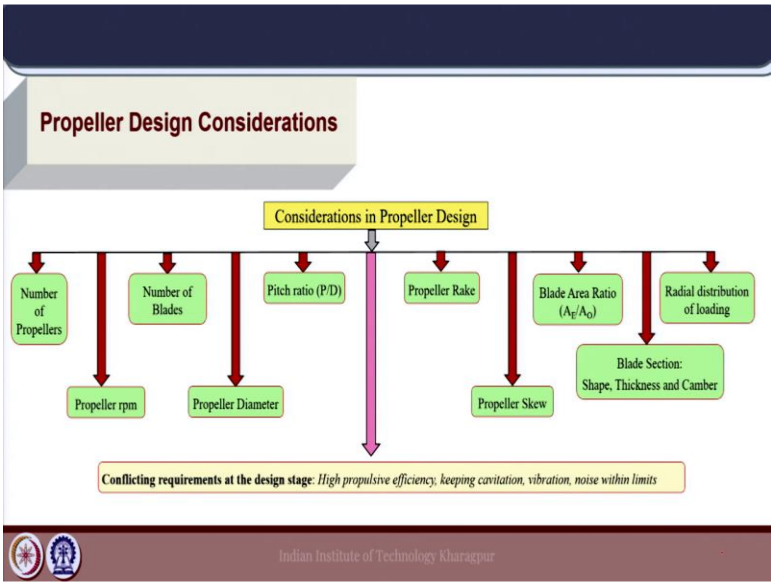
Lecture - 29
Propeller Design (Part - II)

Welcome to lecture 29 of the course Marine Propulsion. Today we will continue with Propeller Design.

(Refer Slide Time: 00:33)

So, the key concepts to be discussed in today's lecture are some general considerations for propeller design which we will continue from the last lecture and some basic discussions on methodical series based design for propellers.

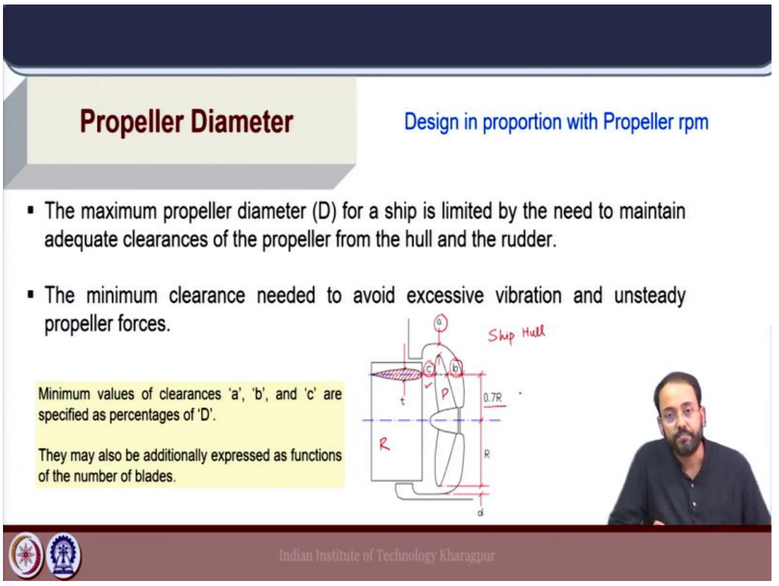
(Refer Slide Time: 00:51)



So, this table briefly gives the different considerations which are of prime importance in propeller design. We have the number of propellers, propeller rpm, number of blades of the propeller, the diameter, pitch ratio and some blade geometric parameters like rake, skew angles, blade area ratio, blade sectional parameters like shape thickness and camber and radial distribution of loading. Many of these factors give rise to certain conflicting requirements in the design process.

Finally, we need to obtain a high propulsive efficiency as much as possible for the design condition. But keeping cavitation vibration and noise within certain limits and also take care of the strength requirement for the propeller blade.

(Refer Slide Time: 01:51)



Now, let us look into the other considerations for propeller design, if we continue from the last lecture. So, propeller diameter is a very important aspect of propeller design in certain design procedures that we will see the propeller diameter is one of the prime outputs. And also depending on the design requirement diameter can also serve as an input parameter.

Now, the design of the propeller in terms of the diameter or in proportion of the propeller with respect to the ship will relate to the propeller rpm. And the maximum diameter with proportion to the ship is limited by the requirement to maintain adequate clearance with the hull. Now, the minimum clearance that needs to be maintained between the propeller blade tip and the hull and also between the propeller and the rudder is defined by certain requirements. The basis is to avoid excessive vibration and unsteady propeller forces.

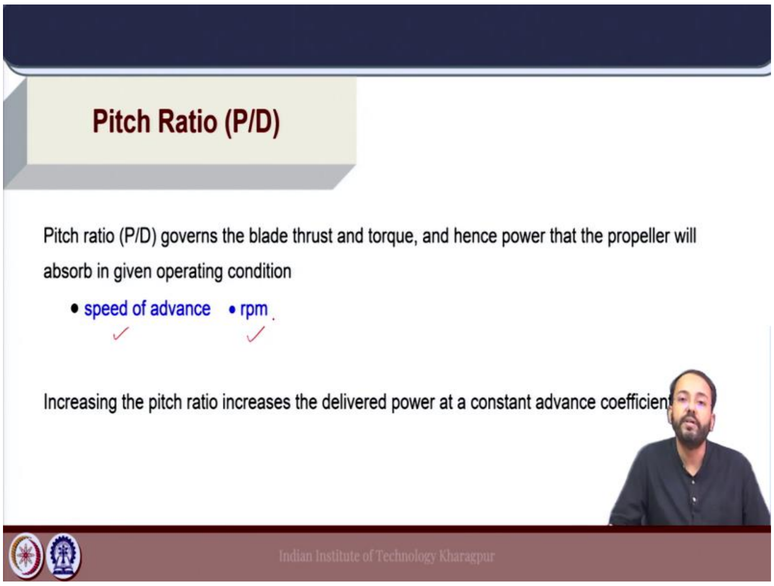
Because when the blade operates in an unsteady flow field, if the blade is in the vicinity of the ship hull and the clearances are not maintained, then the ship hull will vibrate and that will lead to both discomfort as well as structural problems. And also for the rudder, certain clearance between the propeller blade tip and the rudder is required in terms of the distance from the rudder leading edge here, this distance c. Because the propeller vortices which are shed from the propeller blades will interact with the rudder and they will lead to damage of the structural material for the rudder.

Now, there are certain clearances which are defined in this particular diagram. So, we have the ship hull here, only the stern part of the ship hull is shown in this diagram and we have the propeller blade here ok. We are seeing it in the profile view from the side and we have the rudder here. Now, the propeller has to maintain certain clearances with the hull as well as the rudder. Here a, b and c are the clearances which are shown from the propeller blade tip to the hull in the forward direction and between the propeller and the rudder.

Now, these values are defined at certain locations. For example, a is the value given at the blade tip and b and c are defined at the representative section which is at 0.7 R for the propeller. Now, what do these clearances depend on? They are specified as percentages of the diameter of the propeller in general. Now, certain classification societies have requirements for maintaining these clearances between the hull propeller and propeller rudder. So, they can be additionally also related as functions of the number of blades of the propeller.

The reason for relating the clearances to the number of blades is because the blade count of the propeller influences the propeller excited frequency and that should be taken care of while avoiding the excessive vibration for the hull propeller system. Now, these clearances are very important to keep the maximum vibration and unsteady forces within a certain limit. So, the diameter that can be chosen for a specific propeller in the design process should include these clearances while checking the available diameter behind the stun for the propeller design.

(Refer Slide Time: 06:14)

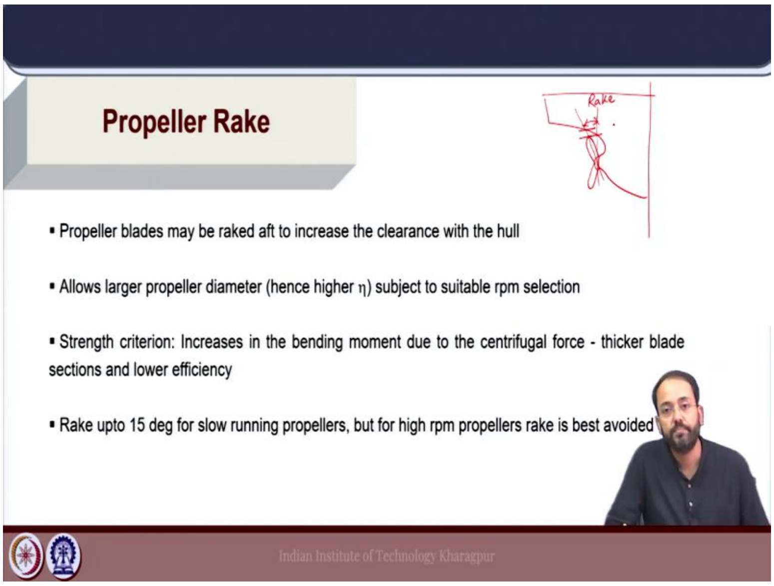


Now, the next factor which is very important for designing propellers and it will play a big role in defining the thrust torque and efficiency of the propeller is the pitch ratio. We have seen that pitch ratio of the propeller blade relates to the angle of attack of the propeller blade, if the flow conditions are kept constant. So, for the same inflow conditions; that means, for the same combination of speed of advance here and rpm if we increase the pitch angle.

That means, if we have a higher pitch ratio for a particular blade section the angle of attack will be higher and that will lead to higher thrust and torque generated by the propeller blade. That means the propeller will absorb more power for the given operating condition and we have seen that in engine propeller matching, the power absorption characteristics of the propeller needs to be matched with respect to the engine. And hence the choice of pitch ratio is very important in propeller design.

Now, increasing pitch ratio will increase the delivered power at the constant advance coefficient. Because we have seen that in the open water diagram if we increase the pitch ratio of the propeller blade when we have studied the series propeller blade diagrams for the open water characteristics. The increase of pitch ratio results in higher thrust and torque and finally, the delivered power will be higher for the same advance coefficient.

(Refer Slide Time: 08:00)



Now, next we will move on to some other geometric characteristics which are the rake and skew of the propeller blade, first the rake is basically given to the propeller blade to maintain a higher clearance with respect to the ship hull. So, if we simply look at the propeller blade and a rake is provided here this angle with respect to the vertical is the rake angle that we see from the side.

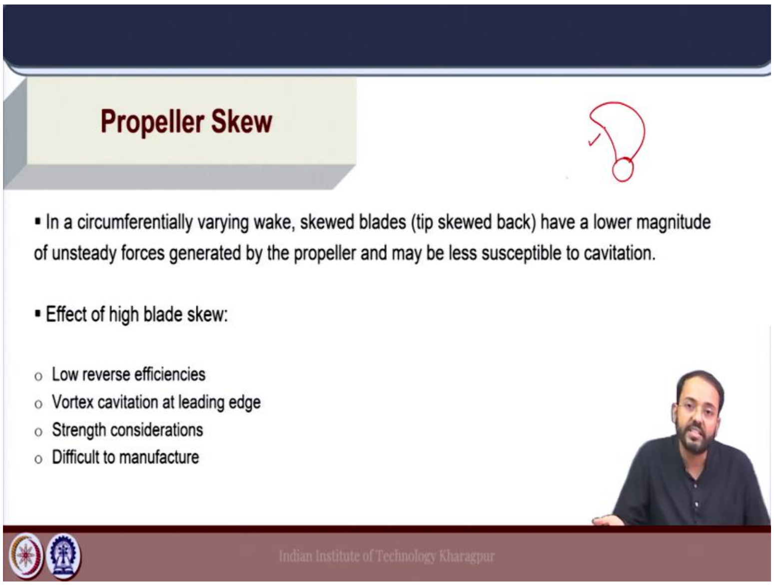
So, this is only the stern of the ship with the propeller. Now, why is rake given? It is given to allow a larger propeller diameter where the available diameter due to the design of the ship is small as compared to the requirement. So, if we give a rake a larger propeller diameter can be accommodated by maintaining a proper clearance with the ship hull here.

As we have seen that clearance should be maintained due to maintenance of the maximum vibration below a certain level. Now, what is important here? If we give a rake the propeller blade as we have seen in blade strength calculations the rake will lead to a bending moment due to the centrifugal force and the rake. Now, this bending moment due to the centrifugal force and the rake angle will lead to higher stresses at the root section and that will require thicker blade sections.

Now, thicker sections will have lower efficiency, so this strength criteria should also be taken care of while providing rake. And finally, for slow running propellers a rake of up to 15 degree can be given if required. So, if there is no design requirement, then rake will not be given. And if it is required we can provide a rake of up to 15 degree for slow running propellers, but for high rpm propellers where the thrust and torque loading are very high on the propeller blade, then rake is best avoided.

Why? Due to high rpm the centrifugal force will be high, which will lead to higher bending moment and stress and hence the blade sections to be designed for that conditions will be thicker and that will lead to lower efficiency.

(Refer Slide Time: 10:45)



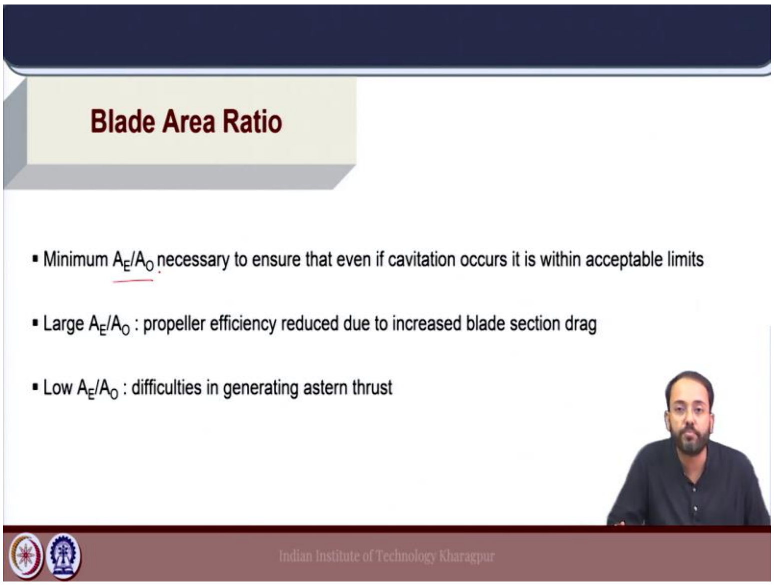
The next factor here is the skew of the propeller blade. So, if we have a propeller blade which is skewed back, the blade geometry will look something like this, when the propeller operates in a circumferentially varying wake it is common to provide a skew. Because that leads to a lower magnitude of unsteady forces, when the propeller operates in an unsteady wake field and it is less susceptible to cavitation.

If the skew provided to the propeller blade is very high it can lead to certain problems. The first one is low reverse efficiency, when the skew is very high then the propeller efficiency working in a reversing condition. That means, when the propeller is being rotated in the reverse direction and the leading and trailing edges are reversed, then highly skewed propeller will have very low efficiency.

Vortex cavitation at the leading edge can occur if the skew is very high and we have seen that again under strength consideration for very highly skewed propellers, the moment due to the centrifugal force and skew will play a role in the total stress of the propeller blade. And also it is difficult to manufacture, if the skew is very high it becomes a problem for the manufacturing of the propeller.

So, propeller skew should be provided in a moderate manner as per the design requirement and providing a balanced skew helps in reducing the vibration with respect to unsteady forces generated by the propeller and it is less susceptible to cavitation.

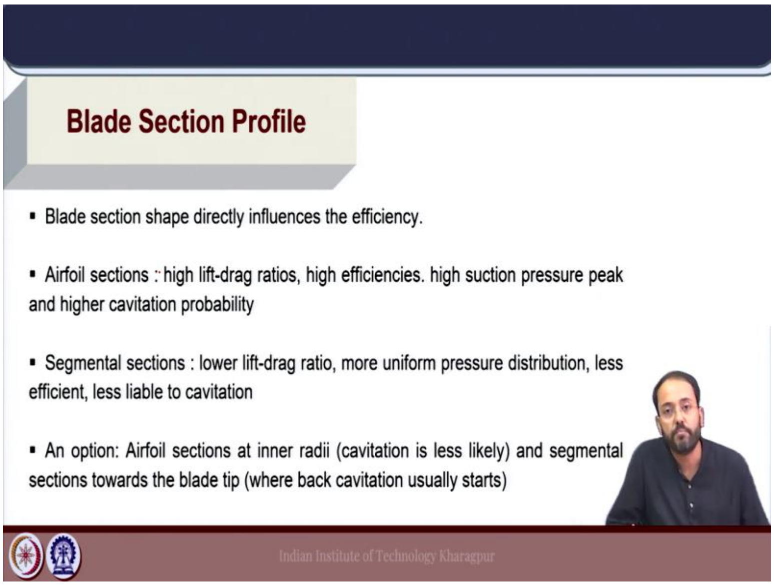
(Refer Slide Time: 12:37)



The next factor which is very important in the perspective of propeller design specially from the point of view of cavitation is blade area ratio. So, it is defined here by A_E/A_0, which is the expanded blade area divided by the area of the propeller disc π $d^2/4$. Now, a minimum value of this blade area ratio is required to ensure that even if cavitation occurs it is within acceptable limits. And we have seen these Burrill's charts for different types of propellers where these limiting values have been used for calculation of cavitation requirement.

So, if we keep a very large ratio of A_E/A_0, what will happen? It will not cavitate in that sense because we are allowing a very high blade area ratio, but on the other hand the propeller efficiency will be reduced because the blade section drag will be increased. And on the other hand if the blade area ratio is very low then cavitation will occur and on top of that it will be difficult to generate astern thrust. So, the idea here is that we maintain the minimum requirement for blade area ratio so that cavitation is avoided and a small margin is provided on that in the design process.

(Refer Slide Time: 14:04)



The next factor is the blade section profile which have a strong influence on the propeller performance and its efficiency. So, we have studied airfoil sections which typically have very high lift to drag ratios, which lead to high efficiencies in general and also it has a high suction pressure peak, so which increases the cavitation probability. On the other hand, if we look at segmental sections they have lower lift to drag ratio and they have a more uniform pressure distribution on the suction side and hence they are less liable to cavitation.

But the efficiency for those sections is lower in general compared to airfoil sections. Now, each of these section types can be used or combinations of these section types can be used at different radial locations for the propeller blades. So, airfoil sections can be used at the inner radii where cavitation is less likely and towards the blade tip segmental sections can be used.

But it must be mentioned here that when we do propeller design using methodical series data, the section profile is already given by that methodical series. So, that is not chosen by the designer. On the other hand if we design from the first principle, for example using circulation theory then one has the opportunity of choosing the section profiles at different radial locations on the propeller.

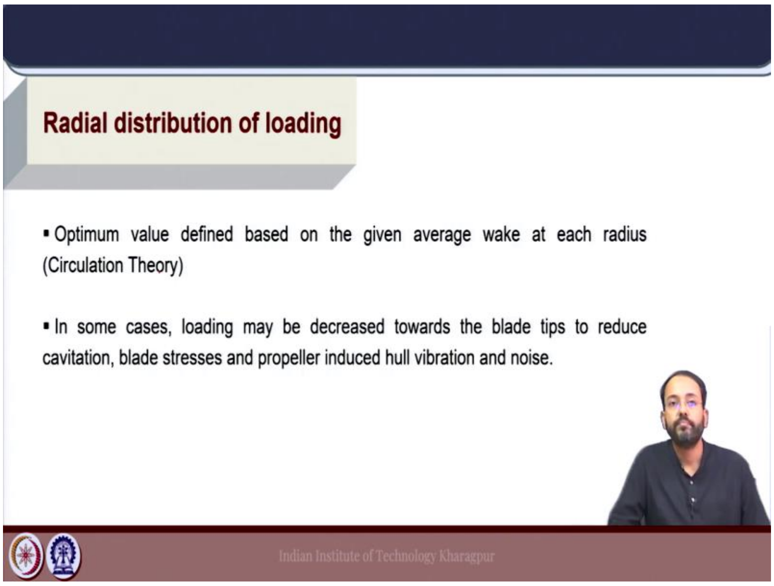
(Refer Slide Time: 15:40)

The other parameters for the propeller blade geometry like blade thickness and camber also influence the design. And here also it must be mentioned that only while using circulation theory based design, the parameters can be chosen by the designer when a methodical series design approach is used these are also defined by the series. Now, the blade section thickness is mainly governed by strength requirement that we do while the strength calculation is done and the maximum stress generated is compared with the allowable stress for the propeller blade material.

A low thickness by chord ratio is good in terms of a reduced drag increased efficiency, but it has a lower strength and also the cavitation free range of the angle of attack is reduced. On the other hand if the thickness by chord ratio is high the efficiency is low, but the cavitation free angle of attack in terms of sheet cavitation is increased, but it is more prone to bubble cavitation as we have already seen in the cavitation bucket diagrams of section profiles.

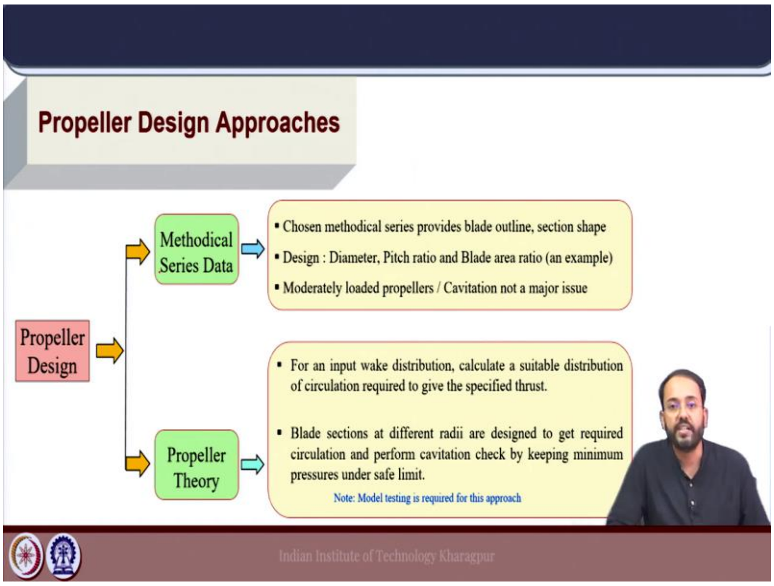
Now, the blade section camber basically depends on the loading at the different radial locations of the propeller blade and the camber can be chosen in association with the angle of attack to generate the required lift coefficient of the propeller blade section.

(Refer Slide Time: 17:11)



And finally, the term radial distribution of loading means the radial distributions of the circulation based on the thrust loading on the propeller blade. And an optimum value based on the required parameters can be chosen when the designer is opting for the circulation theory based design. And in some cases, the loading may be slightly decreased towards the blade tip where cavitation issues can occur. So, these are the different geometric parameters which impact the propeller design in terms of its performance as well as strength and cavitation requirements.

(Refer Slide Time: 17:54)



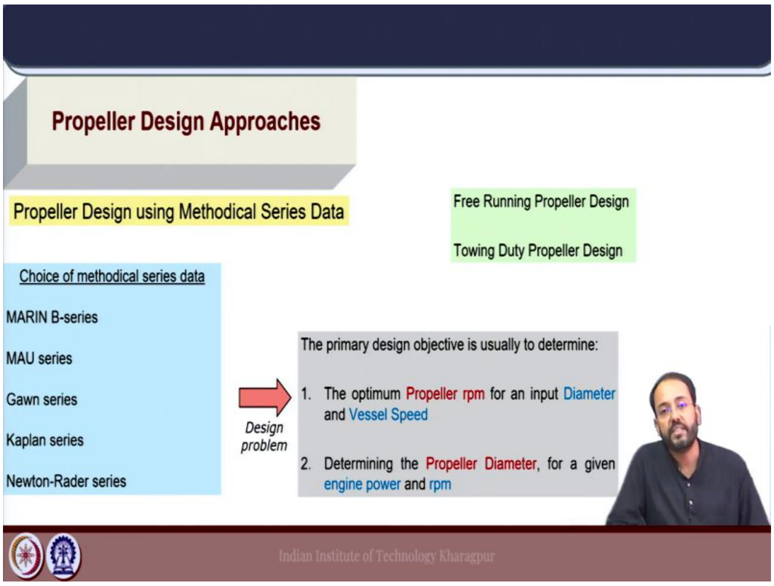
Now, we will look into the design approaches for marine propellers and as discussed the two main approaches are the methodical series based approach, where we have the series data which governs the geometric parameters of the propeller blade and we use that to design the propeller blade parameters like pitch ratio, blade area ratio and propeller diameter this is just an example.

And they can be used for certain range of propeller design typically where cavitation is not a major issue and every methodical series has its own application with respect to the propeller type, that is being designed. On the other hand we have the circulation theory based design for propellers where based on an input wake distribution a suitable distribution of circulation can be assumed to obtain the specified thrust.

And here model testing is required because the designs that are the output of this approach are new, because there is no methodical series which is used here and the designer can choose different types of blade sections to develop the design. And one can do model testing to validate the outcome of the design with respect to the propeller performance.

In this particular course we will discuss the different aspects of methodical series based propeller design, where different types of input parameters are used to arrive at the propeller design using the open water charts that are available for series propellers.

(Refer Slide Time: 19:39)



Now, looking into propeller design using methodical series data, we have different methodical series some of which have been discussed earlier in this course. The MARIN B-series, MAU series, Gawn series, Kaplan series, Newton-Rader series these relate to different propeller blade geometry, the variations of which are related to the thrust torque and open water efficiency for the respective propellers.

Now, we will use these series data based on the design problem to define the final geometry of the propeller. Here the primary objective is usually to determine the optimum propeller rpm for an input diameter and vessel speed or on the other hand to determine the propeller diameter for a given engine power and rpm. So, in general these are the two objectives which are met during a propeller design process.

Either the diameter and vessel speed are the input for which we get the optimum propeller rpm or the engine power and rpm are provided as an input and we get the propeller diameter from the design process. Propeller design approach using methodical series data can be applied to the design of both free running propellers as well as towing duty propellers. In the next lecture we will discuss different methods in which methodical series data can be used to obtain the final propeller design from the input parameters. This will be all for today’s class.

Thank you.