Performance of Marine Vehicles At Sea

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Lecture No. # 15

Propeller in Open Water Part – II

Good afternoon, let us start from where we stopped last hour, we have seen that propeller characteristics can be written in terms of.

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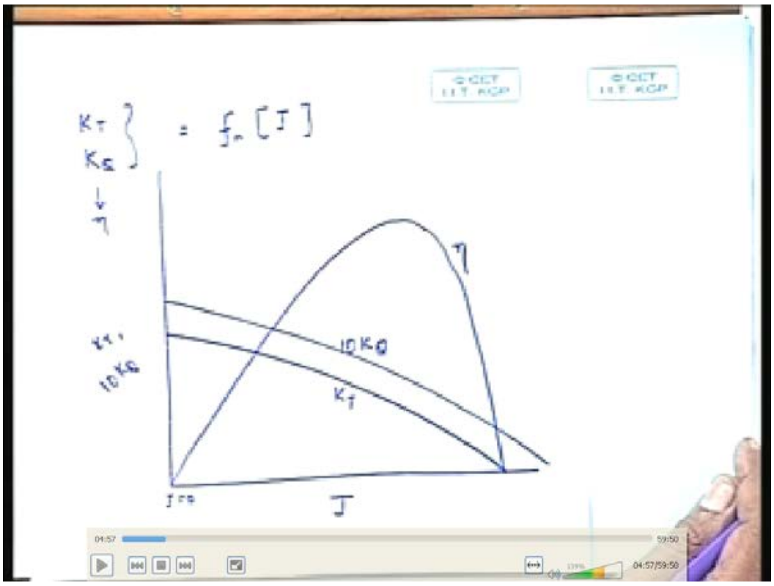

K T and K Q which are functions of J and from K T K Q, we can get the efficiency also as a function of J. Now, how does this? How do this characteristics look? If I draw a K T K Q diagram as a function of J for a ship, then (No Audio From: 1:40 to 1:48) K T would be highest at J equal to 0 and it would fall to a 0 value continuously, this is J equal to 0 here. And K Q is slightly higher than one tenth of K Q numerically therefore, you if you are plotting a K T and K Q on the same diagram, it is conventional to plot K T and 10 K Q on the same scale, 10 times K Q. Then as I mentioned K Q is slightly higher than one tenth of K T therefore, 10 K Q will be slightly higher than K T and that curve would look something like this.

And with this, if you plot the efficiency, efficiency will be 0 here, V A by n d you see the J being 0, efficiency will be 0 at J equal to 0, and it would go to a high value somewhere here, come like this, and go down like that. That is the efficiency curve, this will be K T, this will be 10 K Q and this will be efficiency curve. This curve is very interesting, you see, at J equal to 0 K P and K Q has some values have the highest values, but efficiency is 0. What is this condition physically? Physically, this condition represents what is conventionally called, the bollard pull condition.

That means, if I tie a ship to a bollard at port, I run my propeller and whatever be the speed of propeller, r p m of the propeller, there is no forward speed because the ship is tied. So, V A is 0 therefore, J is 0 and the propeller will develop some thrust which can be measured by the tension in the rope. And it will be consuming some power so, torque will be there. So, thrust and torque are there, which give you K T and K Q, but there is no forward speed, that is the so called bollard pull condition, or the slip is hundred percent. Here, K T equal to 0 this point, is the other interesting point. What is this condition K T equal to 0? That mean thrust is 0 at this forward speed V A, at particular V A the thrust is 0.

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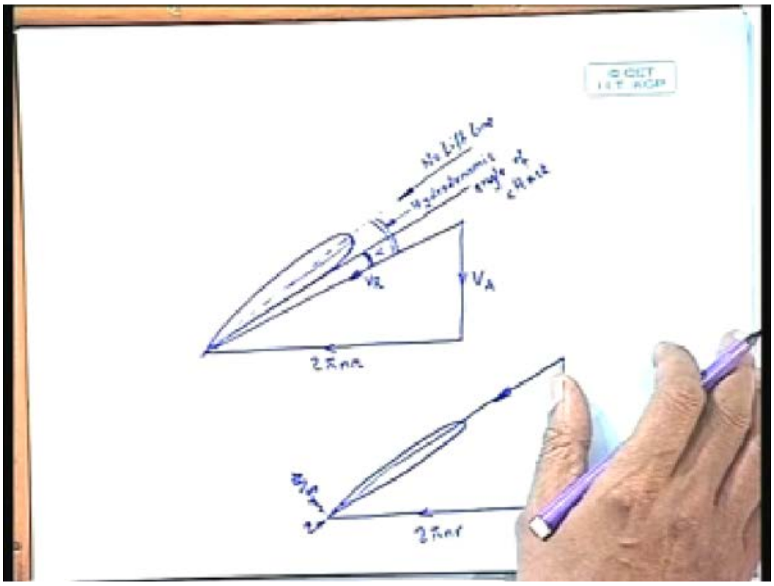

Now, what is the? We have see in a, in case of a aerofoil. (No Audio From: 05:22 to 05:32) This is the base line or sometime we can represent this as nose tail line, if the propeller was.

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In this case the angle of attack not (( )) we have done this diagram before, this is a, this is the radial velocity 2 pi n r, this is the axial velocity which are perpendicular to each other. Remember we had seen in the propeller when I had explained shown you the propeller, that if the propeller is rotating like this, there is a velocity water velocity in the opposite direction, which is equal to 2 pi n r, r p s into radius 2 pi r p s into radius.

And plus the propeller is going forward. So, that is like this axial velocity is perpendicular to this. So that is, this two velocities, the resultant of which is a velocity V R. Now, this angle is the geometric angle of attack, I am saying geometric angle of attack, you realize because this is the base of the propeller and this is just making the angle with it, this is the face of the propeller. So, the resultant velocity making an angle with the face of the propeller is called the angle of attack.

But since, there is an angle of attack there will be thrust, this is not a known thrust condition. When will known thrust condition come? Known thrust condition will come, if my propeller blade is like this, basically known thrust condition will come when the flow is on the no lift line, there will be no lift. You remember we have discussed about no lift line? That is if, I by controlling my r p m suppose, I keep moving this V A this side further and further. Let us say, by reducing my r p m or I increase the V A and lift this up, then my angle of attack will reduce.

I still keep getting lift even when the flow is exactly along the face line, I still get lift there will be a theoretical line if, the flow is along this line, there will be no lift generated, this is called no lift line. This should be the line from which the angle of attack should be measured, because actual lift will be now. So, this is called hydro dynamic angle of attack, it is not geometric (No Audio From: 09:10 to 09:18) (( )) clear.

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Yes it is different from nose tail line, it is different. Nose tail line can be something like this, if I have even otherwise nose is, nose central is center of the nose is somewhere here. Even if, we do not have a (( )), the nose tail line is there which is slightly higher than the pitch line, face pitch line. So, your geometric angle of attack is normally with respect to face line, but it could also be with respect to nose tail line, which is geometrically known. So, the angle measured with respect to a geometrically known line is called the geometric angle of attack, which need not be the no lift line. The geometric nose tail line is not normally the no lift line. The no lift line is slightly above that.

So, hydro dynamic angle of attack is slightly more than the geometric angle of attack, as shown in this diagram understood. Now, suppose this is my no lift line and I have V A and 2 pi n r in this fashion and the water flows exactly on the no lift line. There will be no lift. There will be (()) therefore, there will be no thrust. This is strictly not correct because if I draw the lift in this direction, this is the lift perpendicular to the flow, if there was lift, but there will also be a drag. Now, this drag will have a small component of thrust in this direction, thrust in this direction in the direction of V A.

If it is falling on no lift line this is 0, there is no lift, this is not there, but drag will be there, drag is a viscous effect. Now, this drag will have a small lift component. So, you will still get a small lift. So, depending on the scale of the model, that could be a change in the line along which there will be no thrust. That is the position when thrust equal to 0 which is very nearly equal to the no lift line am I understood. So, this is the here, thrust is 0 and therefore, efficiency is 0. And see, if you draw the efficiency curve now, you will find the efficiency is highest somewhat nearer towards this limiting J value, where K T equal to is 0 rather than J equal to 0 side. What is the slip here? There is no slip here, V A this slip here is 100 percent and here slip is 0 percent therefore, there is no thrust no lift.

Some the ships the propeller operates at maximum efficiency, somewhere with 10 to 20 percent lift; slip. You know what is slip know/now? The pitch.

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Right. n into p if, that is equal to V A, then there is no slip, that is more or less this condition. You see the efficiency curve this is, what is the most interesting part of it? The maximum of efficiency occurs somewhere here, which is having a 10 to 20 percent slip. But till here, the efficiency is increasing only slowly and after this the efficiency is dropping sharply to 0. So, this gives us a very good idea, how to design our propeller? Propeller must necessarily be designed slightly to the left of the optimum line. So, that in the event of an r p m drop and J increases, the propeller does not fall go to the right of this in which case the efficiency will sharply fall.

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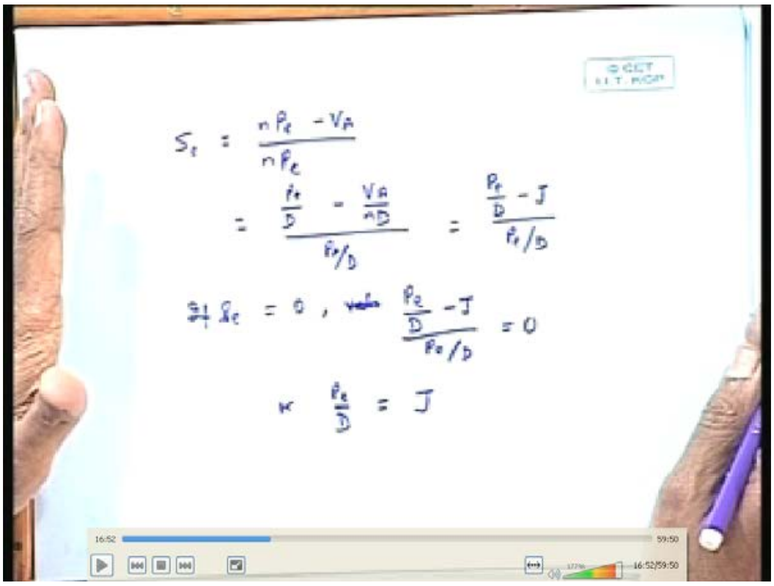

Now, effective slip S e if, I write that is equal to n P e minus V A divided by n P e, where P e is effective pitch we have defined effective pitch before. If the pitch keeps varying, then we can define a effective pitch. So, slip is defined as. So, this is the distance you should have travelled if there was no slip, if V A was 0 that is a 100 percent slip case. So, this is the slip if, there is some V A and it is not equal to n into P e. So, this can be written as P e by D.

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So, if I put this, then

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Ok (No Audio From: 16:32 to 16:37) Is that clear? Let yes, this is same as K T equal to 0.

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No

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So, that is 0 slip.

Now, this is a very interesting observation you can make. Now, the ship is going, the propeller is behind the ship, we are not considering the behind condition. But imagine that the ship is going forward, propeller is rotating, we have got certain open water characteristics of the propeller. Now, we reverse the propeller, ship is still going forward. That is V A is positive, but n has become negative. So, how will the propeller behave? Similarly, now you have gone propeller is rotating reverse, you are going started going backwards. Now, V A is negative and n is negative both are negative.

So, you are in another domain and then after that you reverse the propeller to positive direction. So, V A is negative n is positive. So, 4 alternatives arise, V A is positive n is positive, V A is positive n is negative, V A and n both are negative and V A negative n positive. This is, this can think of this, 4 alternatives as the 4 parts of a quadrant. I will show you a diagram, how propeller thrust torque characteristics will vary? Can you see this? Is it visible?

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Yes, we have here, V A positive this side and negative this side. So, therefore, J is negative this side, J is positive this no J will V A by n D, J may be positive and negative. Let us say, V is negative V A is negative and V A is positive. Similarly, n is positive and n is negative. Then K T and K Q you can see, in the V A positive and n positive, V A positive this side and n positive this side. This is the K T K Q diagram like, what I showed you. When it is negative, when it is V A negative no n negative n negative and V A positive, these are the diagrams and similarly, n negative and V A negative this quadrant K T K Q and similarly, n positive V A negative this is the diagram.

This is called A 4 quadrant, representation of a propeller characteristics. Conventionally we do not bother about these 3 quadrants, our propeller mostly operates by this one quadrant, that is V A positive n positive. But there are cases, when you have to know the propeller characteristics when one of this is negative, one or both of them are negative.

How do you determine this? How do you determine propeller characteristics as well as this 4 quadrant characteristics of a propeller?

We have seen the similarity between model and propeller. So, it is possible for us to do a model test of a propeller in open water, how will such a model be tested? How can we test a model of a propeller in a testing facility when it is in open water?

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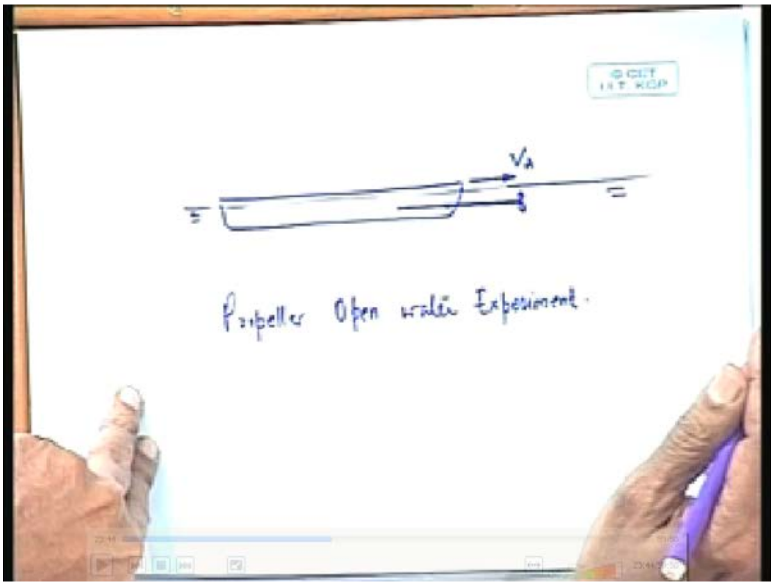

So, the best way would be, if I can have a boat, where the propeller instead of being fitted in the aft, it is fitted in the front, well ahead and my water line is somewhere here. So, I have this and the boat moves by means of the towing carries as I did the resistance test. I move the boat this way here and the propeller is moving into undisturbed water at a forward speed V A. That means, the water coming on to the propeller is V A and I am rotating the propeller.

And inside this rotating is being done by a motor, which is called a dynamometer, a propulsion dynamometer, which houses the motor as well as, thrust and torque measuring sensors r p m thrust and torque. So, I can measure r p m thrust and torque and I can move the boat at different speeds, I can vary the V A. So, V A n I can vary and corresponding measure thrust and torque. So, it is possible for me to measure J K T and K Q. What are the other conditions? We have discussed that geometrical similarity must be maintained and the propeller surface must be adequately prepared to generate turbulent flow. This type of experiment is called as open water experiment, propeller open water experiment.

(No Audio From: 23:31 to 23:44) From this experiment, we can determine the thrust and torque as functions of speed and r p m. We can, it is easy to measure the fourth quadrant characteristics in a towing tank. If, I have this facility I can move the propeller in one direction and move the carriage in the other direction. I can get the other quadrant behavior, I can move both of them in reverse direction and get the behavior and it is possible to generate the fourth quadrant behavior.

(No Audio From: 24:21 to 24:28) Now, you see, we have not seen, how propellers work? Propeller theory we have not studied yet, but you can imagine propellers are very complex hydrodynamic devices. So, one of the ways to get quick data, is that if, I had a large number of experimental values and if I could hit them into sort of as functions of J and various geometric quantities, then it would be easier for me to calculate the characteristics, open water characteristics of propeller. Now, how do you get large amount of data? And how do you feed them into a this thing? So, what has been done over the years is what is called the series?

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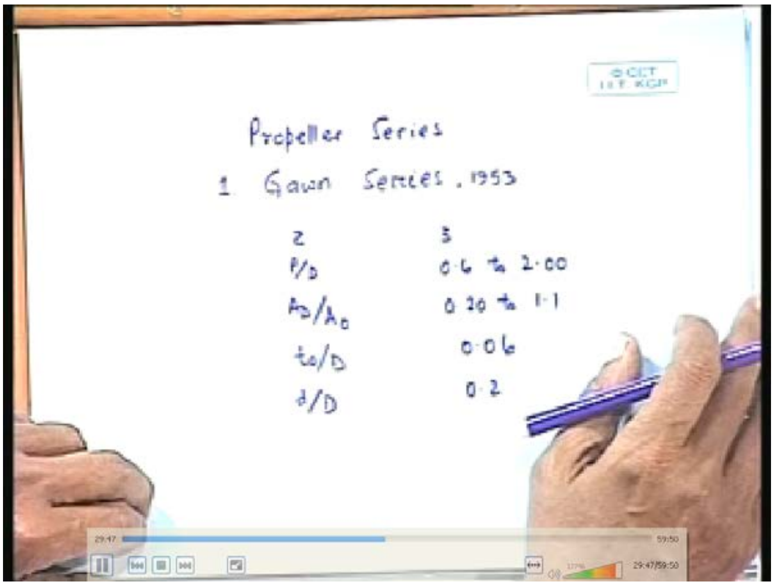

Propeller series have been manufactured and tested that means, some geometric parameters of the propeller have been varied at steps and the propeller detail geometry has been extrapolated from this variations and then they have been tested. And if, by testing a few propellers and if, we get the K T K Q verses J diagrams it is possible that within this parameters. We can extrapolate or interpolate for propellers, which fall within this group that is called series propeller. Do you understand what I am saying? I cannot take a supercavitating propeller, a normal propeller, a trawler propeller, a launch propeller and a bulk area propeller and form a series that is not possible.

To form a series I must have a parent propeller and the other propellers of the series must be side of this propeller. What do I mean by that? Suppose, I say my blade section would be segmental like circular, back will be circular, face will be flat is section. Then the 4 or 5 propellers I determine of this series all will have same geometric characteristics, that is face will be flat and back will be circular.

What I can vary? I can vary pitch by pitch diameter ratio, I can vary blade area ratio or I can even vary thickness, thickness fraction. I can vary these quantities and generate may be 10, 12 propellers. Now, when I have 10 12 propellers of the pitch, varying from one value to another, at steps of step. So, that I get 3 propellers of varying pitch, then if I want to design a propeller of these geometric characteristics, but a pitch in between these 3 things. It is possible for me to interpolate the K T K Q and J values between these, am I clear? So, such a series is called such a type of propeller testing is called propeller series.

And today, we have a number of propeller series one of them the one that came out first is the gawn series. Gawn series of propellers were developed and tested at admiralty experimental works A E W U K in 1953 and subsequently published. So, published literature is available for gawn series propellers, they were basically segmental sections, the back segmental face flat and the outline was elliptical. And the variations that were done were as follows z was fixed at 3, that is number of blades were 3 pitch by diameter ratio varied from point 6 to 2. Developed area ratio A D by A 0 varied from 0.2 to 1.1, thickness diameter ratio varied was fixed at 0. 06, and (( )) diameter ratio was fixed at 0.2.

So, basically as you can see gawn series propellers had 2 variations blade area ratio and pitch diameter ratio and the sections were all segmental, can you see this diagram?

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Sorry.

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Ok.

Dimensions you need not bother just see this, this is the elliptical section this is point 2 (( )) this is the elliptical section, elliptical outline starting from here point 2 blade area ratio to 1.1, and each section was segmental as I have told you. So, this is basically the gawn series, this series has been found useful in designing propellers for trawlers and torques.

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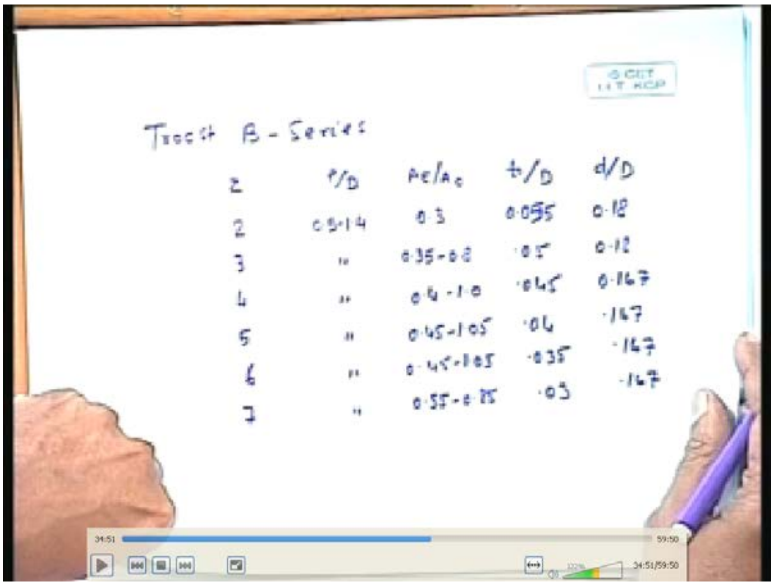

Now, the next important series is the b series is called Troost B series or Wageningen B series or n s m b b b series. This was developed in the n s m b Nether land ship model basin at Wageningen, and whole lot of test have been conducted in this b series propellers. And as I will show you what are the variations that have been taken place here? In fact, it has been tested perhaps most extensively this series both in Europe, in the united kingdom, in U S A and many other places. Starts from 9.

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2 blades, here the pitch by pitch ratio change from 0.5 to 1.4 A E by A 0 as fixed at 0.34 blades 5 blades 6 blades and 7 blades. Now, Troost B series propellers as you can see

have been tested form 2 to 7 blades, pitch ratio varied from 0.5 to 1. 4 and A E by A 0 is in different for different blades, can you tell me why? See simply, if you have 2 blades you cannot have a blade area ratio of one impossible then 2 blades will have to cover the entire blade surface the blades will be very big. And perhaps, that is not necessary it will only increase drag. But if you have 7 blades and of course, you can get any blade area ratio, but here they top testing after 0.850, normally you have 7 bladed Troost series fully immersed propellers.

And, thickness ratio has reduced as the number of blades have increased and D y boss diameter ratio is more or less or 0.167 the diagrams of this propellers are K T K Q diagrams are extensively available in literature. Let me see, if I have got something to show you. Can you see this? Is it visible? This is the Troost series propeller. What this the characteristics of this propeller? You see the face, it is more like an aerofoil section at the bottom till about 0.7, 0.6 r. It is like an aerofoil section with slight lift at the forward leading and trailing edge, but as you are going up, the sections are slowly turning towards segmental. So, the bottom where there are aerofoil’s, they are slowly changing towards segmental at top and you can see the outline of the blade and see the pitch ratio.

Pitch is constant above about 0.5 r, but below that slightly reduces towards the tip, but this is particularly for 4 bladed propellers for all other blades the pitch is constant the pitch ratio that is give is constant. The pitch ratio that is given for 4 bladed propellers apply at 0.7 r. So, if you are doing a Troost series propeller at 4 bladed, then you must give the same pitch distribution to get the same result. Can the propeller characteristics be represented by any other way? Since propeller has been investigated for a very long time, there are some other conventional methods by which propeller characteristics are represented, one of them is the so called B P delta diagram.

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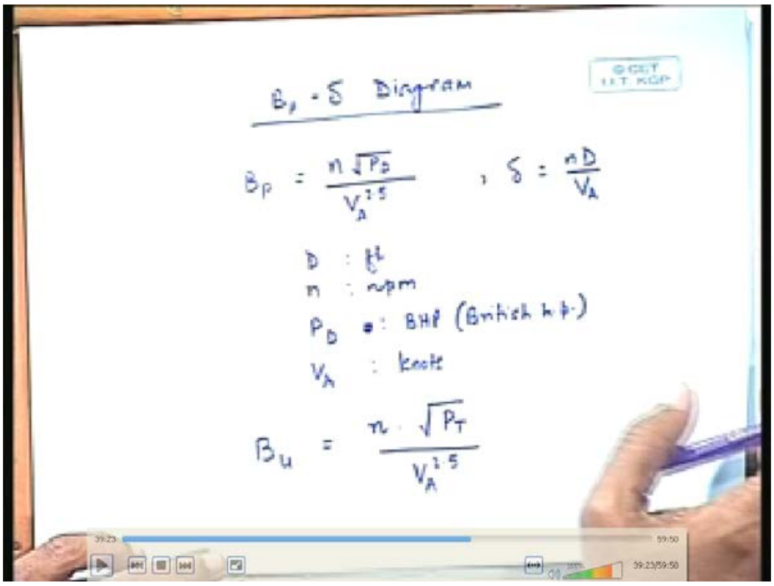

Heard of this, what is B P?

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This is very funny units this is not in S I unit first thing I must tell you this is not in S I unit. So, these are this quantities are not dimensionless, D is in feet, n is in r p m, P D is equal to P D is in B H P. That is British h p, not metric h p, you see in S I unit we use power in kilowatts and V A is speed of advance in knots. So, as you can see this delta outwardly looking at delta, you will know that this is inverse of J, but this is dimension this is not dimensionless. This gives you the relationship of torque with speed and r p m this relationship, that is you can draw a diagram of delta verses V p. And this will give the relationship of torque with speed and r p m similar to. Similarly, you can have the other diagram with regard to thrust, this is called B u.

We can have B P delta diagram and B u corresponding B u delta diagram. So, this will give us the relationship with thrust B u, and B P will give relationship with torque. So, you see B P will be related to K Q, delta is related to J, and B u is related to K T, but these are not unit less.

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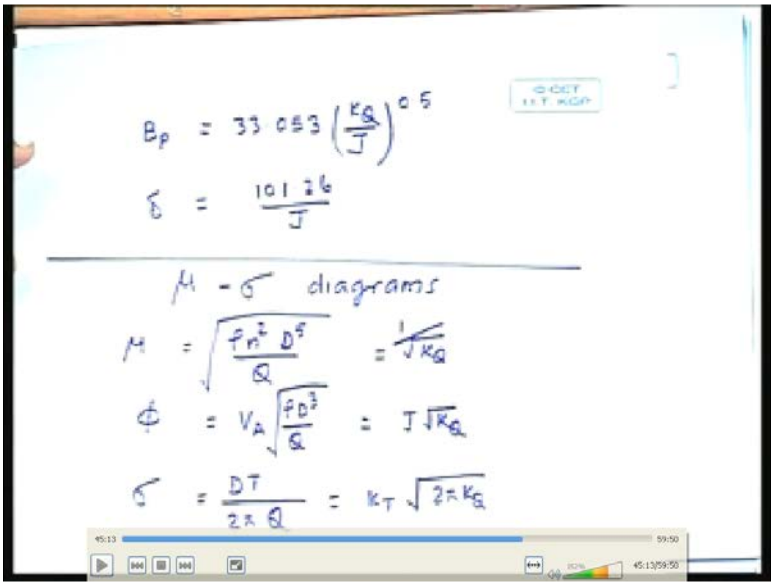

So, if I write the relationships, it would look like this, you can derive it yourself, you will arrive at a constant. And similarly, you will get B u, I am only giving you the B P. And in fact, B u will be related to K T in a slightly different manner, because this, these divisions are same, here we have this is represented only in terms of t not t into V A in K T. So, how does this diagram look? Can you see this? So, you have B P here and pitch ratio here, and these are the delta lines constant delta lines. So, if you have got a pitch ratio for your propeller, you enter that go to the corresponding delta, where it where that constant pitch line is intersecting and from there, you go down and read the B P value from there you can get the power.

That also gives you the, these are constant efficiency line. So, that point will also tell you what will be the efficiency of the propeller. What do you see in this efficiency lines? They are more or less reverse of the type of efficiency lines we got, like in the K T K Q diagram we got a optimum point in the efficiency line. Here in this efficiency lines, here you get the maximum efficiency point and through that we can draw a optimum efficiency line, this is the optimum efficiency line. Therefore it is possible for us that for a particular pitch ratio to know what is the optimum efficiency? What is the b p? And form there, we can calculate what will be the power for a particular pitch ratio.

Now, mind you in this diagram, this is only a typical diagram, such diagram will be available for each parent of the Troost b series that has been shown to you. That table that I gave you, for each pitch ratio each bladed area ratio, each thickness ratio there will be one such diagram B P delta diagram. These are the initial representations of propeller characteristics that were tested.

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It is just that where the B P is maximum, that is the optimum efficiency line, maximum power it takes. There is another way of representing propeller charts which is not very commonly used, but sometimes it has been represented. It is called mu sigma diagrams (No audio from 43:31 to 43:41) where this is just a representation, sometimes it is thought convenient. So, it is done like that.

(No audio from 43:49 to 44:23)

Sigma is thrust and torque.

(No audio from 44:24 to 44:38)

So, sometimes propeller diagram is represented in the mu phi sigma nomenclature as has been explained here, well you may ask me why is it represented like this? People who used this must have found some use, but it has not been generally accepted as a method of representation.

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Which one?

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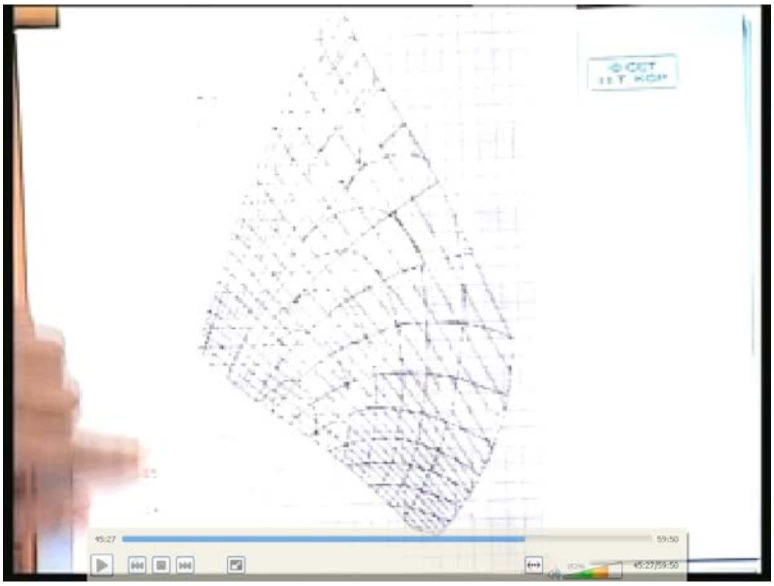

This is how a mu sigma diagram looks this side is mu, this side is sigma and these lines are constant pitch ratio lines and there is a optimum diameter line here going like this and these are the efficiency lines. Basically, all representations are from the same thrust and torque that you have got so only representations you change So that you can use it for your convenience. Today, these representation is no more necessary with the advent of computers, you can write K T K Q for a particular propeller as a function of J numerically, you can write a polynomial of J K T K Q as polynomial representation of J and then you can do all your calculations using that polynomial that is one way.

This series diagrams have now, been put into regression analysis and the entire K T K Q J for b series as well as gawn series. Now, available as functions of J and geometric characteristics such as pitch ratio, blade area ratio, thickness ratio and boss diameter ratio so this regression analysis has been done and coefficients are available. So, it is easier to use them, rather than the charts. However having a set of diagrams with you is welcome because anytime you do some calculation it is easy to check from diagrams rather than only figures.

I finished what I wanted to say today any questions if not, we will stop. Thank you.

Performance of marine vehicles at sea

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Lecture no. # 16

Propeller 'behind' A ship

Good morning gentlemen, let us start talking about propeller behind a ship, we have seen how the propeller behaves in the open water in the last class. What happens when you put the propeller behind a ship? First of all as we have discussed earlier the propeller works in the wake field of the ship. Therefore, the speed that you get water speed falling on the propeller would be less than the ship's speed or in other words speed of advance.

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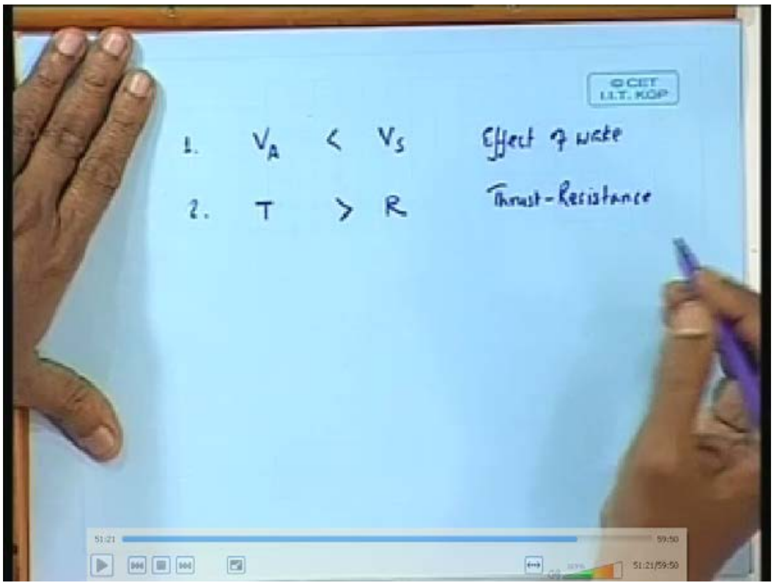

V A will be less than V s am I right in saying this. That is when the propeller works behind the ship, because there is a wake we have already discussed. The speed of water that is falling on to the propeller will be less than, the speed at which the ship was advancing. So that is one effect, that we have the effect of wake. Secondly, we have seen that the when the propeller was not there, the resistance of the ship was equal to the tow rope resistance. We have defined the resistance of a ship as the force required to pull the ship by means of a tow rope when the propeller is not there.

Now, we have fitted the propeller, propeller basically is a hydrodynamic device which pulls water from ahead and throws it back, like a axial fan. The water flows past the propeller impacts energy to the water so water flows at a higher velocity around the ship.

Now, we have seen that the velocity of water is related to resistance of the ship. So, when the propeller is moving behind the ship, due to change of velocity of water in the stern part, there will be a change in the force required to push the ship forward which will be higher. In other words the thrust that the propeller would give, would not be equal to the resistance of the ship, but will have to be higher than the resistance of the ship, can you understand that.

So, T will be greater than R that is we say thrust effect thrust resistance effect thrust resistance relationship is not equal to we had said earlier that effect provided a thrust equal to resistance the ship will move forward. Now, what we find, because of the action of the propeller since, the velocity of water near the stern will be increased the resistance of the ship with the propeller working would be different from if the propeller was not there.

How do you determine what is the quantity (( )), we will come back to thrust (( )) again. If we can measure the velocity all over the propeller disk, we will have a 3 dimensional velocity field, an axial component will be there that is along the access of the propeller in the direction of the ship's access. Another will be, may be transverse, may be vertical that is basically 3 dimensional flow or in pollard coordinates, we can say a velocity component in the tangential direction at any point or tangential and another radial.

Now, normally these radial and tangential components can be ignored, they are small in comparison to axial, axial velocity. So, whenever we are defining wake normally we tell in terms of axial velocity field only that does not means other velocity do not exist. That for convenience we consider axial velocity which is the major portion of the wake, major percentage or total velocity field; that means, in general you can appreciate that if the ship is moving this way water velocity also will be parallel in this axis mostly. So, when we have that, we can if I have the propeller at any circumferential direction, if I measure the velocity at various radii, that is various theta angles axial velocities.

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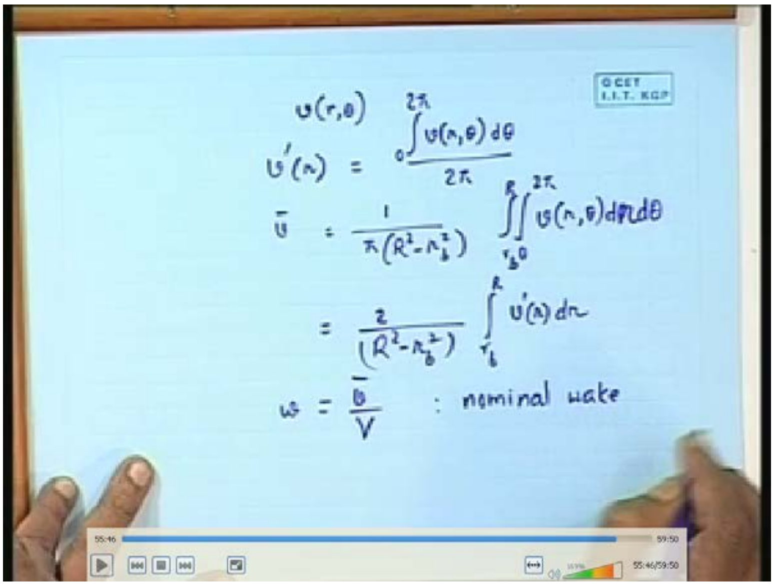

Then I can say the average if v r theta is the velocity of water at any point R n theta. Then velocity of the average velocity of water in that circumference I can write d dash R equal to v r theta v theta divided by 2 phi 1 0 to 2 pi. At all thetas I integrate the velocity and take the this is basically taking the average this is at 1 radius R. So, the overall wake, over the whole propeller disk will be, if I integrate this over R so that can be given as 1 by pi R square minus root square 0 to 2 pi. And this is r b to R which is equal to, we have found out this b dash R that integrated over the whole radius that is all we have done from the boss to the popularity.

So, this wake the wake due to this is defined as b by V, this is called nominal wake these items I have mentioned. On the other hand if it is a gear drive, then the power loss will be more ranging between 4 percent to 8 percent depending on whether the engine is extreme (( )) that is moved forward like in naval vessels.

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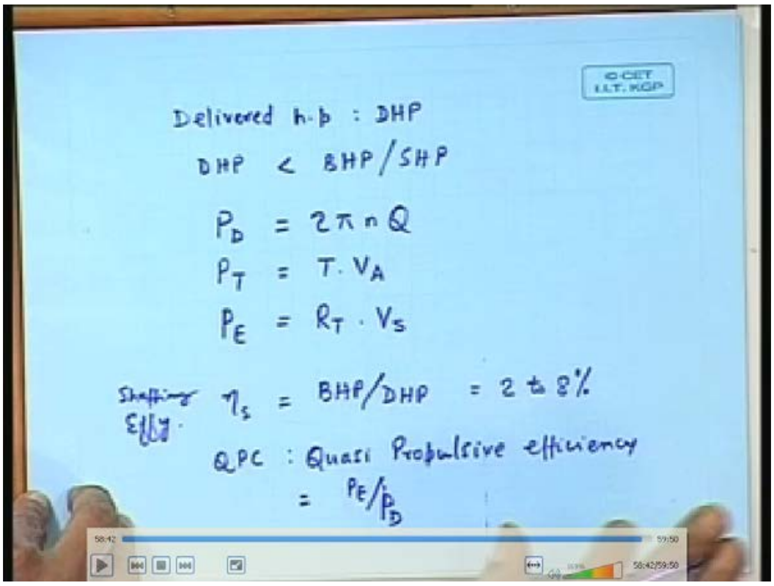

So, if we reduce this amount, we can easily know what is the D H P available at the propeller T. This is; at that R P M, we can also calculate the torque so that is the torque available to the propeller at that R P M with that forward speed. And if we know the resistance, if we know the characteristics of propellers, we can calculate wake thrust and (( )) etcetera.

So, we can say B H P or P D is equal to 2 pi n Q, Q we are measuring on the shaft. So, we can get the D H P thrust power, what is thrust power? T into V A. And effective power? R T into V, V S it is V V S ship's speed, please recall we have defined this before. So, now the drop in speed power from P B that is B H P to D H P is defined by an efficiency called shafting efficiency is equal to B H P by D H P which we have seen can vary from 2 to 8 percent depending on gear drive or non gear drive aft engine or slightly mid ship engine (( )).

The other efficiency between P D to P E if I define the efficiency, I call that as Q P C or quasi propulsive efficiency which is equal to P E by sorry P D that is, if this is my output require, this is my input to the propeller then the efficiency is the ratio between output by input P E by P D. We will see in the next hour, how this can be broken up into components and how we can utilize it, we will stop here. Thank you.