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 speed, or in other words, speed of advance V A will be less than V S. Am I right in saying this?

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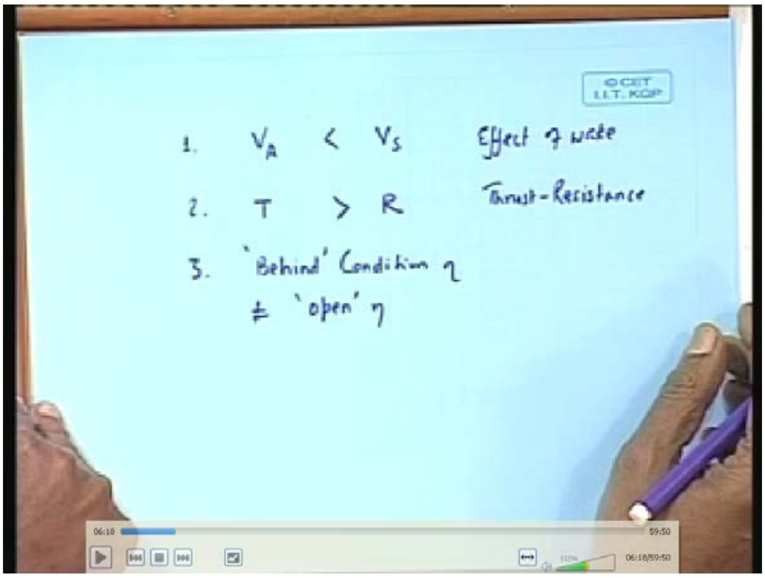

This is when the propeller works behind the ship because there is a wake we have already discussed. The speed of water that is falling on to the propeller will be less than the speed at which the ship was advancing. That is ok? So, that is one effect that we have - the effect of wake. Secondly, we have 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 an axial fan. The water flows fast 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, if I provide 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 propeller if the propeller was not there. Therefore, the force require to push the ship at the same speed will be higher than the resistance of the ship. So, thrust required will be higher than the resistance.

Then, there will be third effect, that is, we have seen the K T K Q versus J relationship in open water, that is, thrust torque r p m and speed relationship of the propeller alone. Now, we know the speed behind the ship; we know at which r p m the propeller is moving; we also now know the torque that is delivered to the propeller. Can we assume that the propeller characteristics remain same as that in open water? The answer is no. The thrust torque and propeller characteristics, that is, thrust torque speed and rpm characteristics represented by K T K Q and J would be slightly different for the behind condition than, if the propeller was in open water.

So, behind efficiency, behind condition efficiency is not equal to open, open, efficiency. So, this will be the basically when a propeller working behind a ship. These three will be the main effects by which propeller characteristics will change. What will do see is we will see the effect of all of these. We will we will try to understand all these three effect separately and see what effect does it have on propulsion characteristics of the ship and propeller combination.

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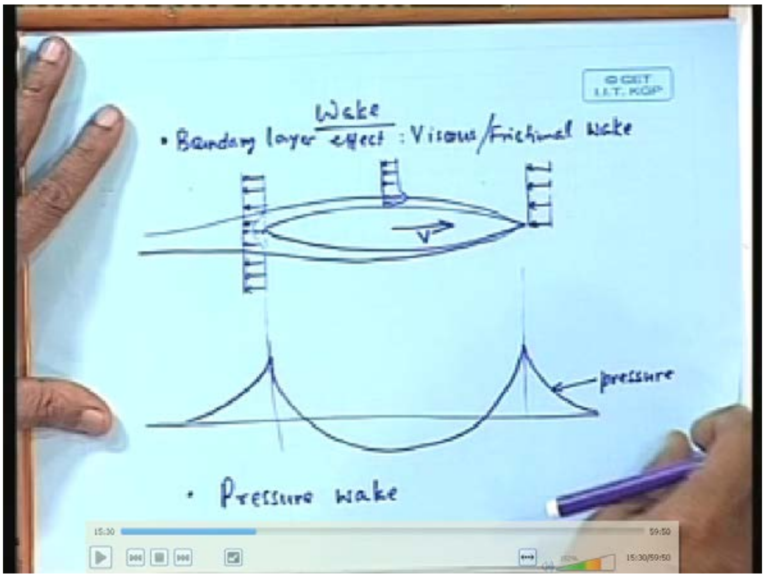

First thing that we will must see is wake. What is the cause of wake? So, far we have seen that, when a ship is moving in water, if I draw the ship like this, there is a boundary layer which develops around the ship and goes behind it. Here, if I draw a velocity profile along the y axis, then the water velocity will be constant, because there is no disturbance to flow in front of the ship or very near the front because there is no boundary layer developed in the front of the ship. Let us consider a submerge part, no wave effect.

If I draw a velocity profile here, how will it look? The velocity will, will, be 0 here and will increase till the boundary layer and then it will become equal to the free stream velocity, but what about at the boundary layer itself? What will happen at the boundary or the boundary layer? Will it be equal to the free stream velocity or slightly more than or slightly less than?

Velocity will be more, because if you recall, there will be a pressure developed due to potential flow. There nothing to do with viscous flow. If I draw the pressure around this body, we have seen pressure will rise at the front, then drop in the middle, rise again at the aft and go like this, is not it? On around a stream lined body, when there is no separation, we discussed this when we discussed wave making resistance of a ship the pressure distribution around hull form.

So, the pressure, this is pressure due to potential flow; there is no viscosity here. So, pressure will drop here and we say that that time that satisfying bernoulli's principle. If pressure is low, this velocity will be high. It will be more what it would be in the front. In fact, front velocity will be low. So, this will have a slightly higher velocity at the boundary layer itself and then it will reduce to free stream velocity. Is that clear? What will happen here?

Velocity will decrease.

Velocity will decrease; that means, here we will have free stream velocity. What will happen here? Here, the velocity will reduce because it is in the boundary layer. The water velocity is less at the centre and slowly increases to full value towards the boundary layer limit. So, you see, the speed of water here is less than the free stream velocity, or we can assume if you assume the ship moving in this direction V, as if its pulling a, pulling an amount of water with it. Am I clear? The pull, the, the, this, the amount of water it is be the velocity which is it is pulling the water is this velocity, is not it?

That is, actually the water would have flown at this velocity, but it is flowing at this velocity. As if the additional water, additional velocity is a forward velocity. Do you understand? So, there is a drop in velocity due to wake, due to boundary layer. This is one effect boundary layer or this is called viscous or frictional wake. So, this is one reason for wake. The other reason comes straight from here that, there is a drop in velocity due to increase in pressure. So, this is pressure wake. Am I clear? Then there will be a third effect. That is what would happen.

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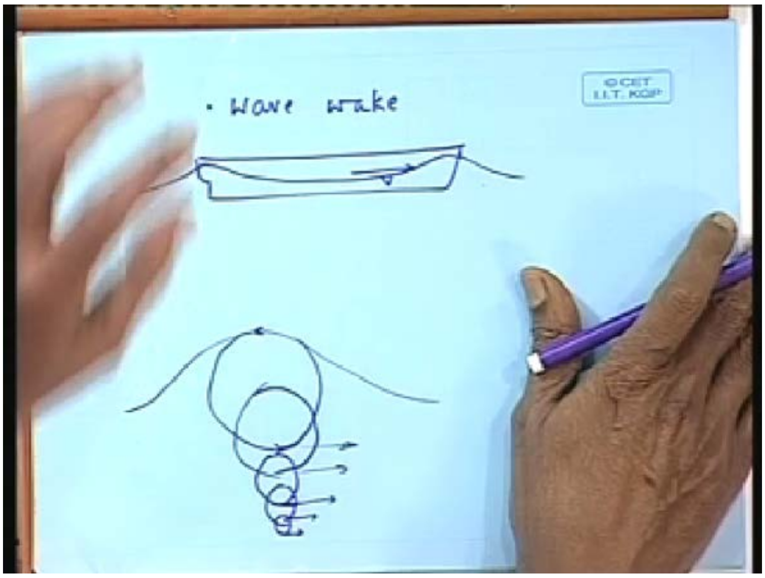

Let, let, me draw it. This is the ship moving with a velocity V forward. How will the wave profile look? Let say it generates transverse waves in such a manner that there is a wave crest at the front and wave crest at the back, and the waves travel this way in the reverse direction because the ship is going forward. What will be the velocity of water particle here? Can you tell anybody? What is the nature of movement of a water particle here? It would be circular.

So, if I draw this elongated form, the particle will move like this velocity being this way; that means, at the bottom, the water velocities this way, and how will this circular radius, circular velocity reduce considering deep water? As the water particles go down below the surface of water, this circle will reduce in diameter, and after sometime, it will vanish and all this will have the same velocity. Do you understand?

That means if there is a crest at the stern, the water velocity will generally have a movement to the forward particle velocity. In a trough, it will be just the other way. The water particle will move like this. Therefore, the velocity will be backwards. Now, suppose there was not a crest, but there was a trough at the this thing. I have just drawn a single wave, wave, length equal to ship length, but suppose it was not like that. Suppose the second wave appeared here and the trough appeared there, then a wake would have been created which would have been supporting the movement of water.

So, there is the third component which is called the wave wake. So, wake has three components - one is the boundary layer effect or viscous and frictional wake; the other is the potential wake or pressure wake and the third is the wave wake. This will not occur in case of a submerged body like a submarine, because there is no wake, and the nature of this wake will vary if the draft depth of water was not deep. The nature of a deep water wake is quite different is from that of a shallow water wake.

So, this nature of the wave wake will vary. The other thing to note is that, whereas frictional wake and pressure wake both were providing a velocity forward. The wave wake we cannot say that, it can provide forward or it can provide backward also depending on where the crest or trough is at the stern. Is that clear? Very interesting phenomenon you can observe from here.

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Opposing the general direction of motion of water; that means, it is adding to the wake. Interesting observation, let us consider the case of a single cruise ship and twins cruise ship.

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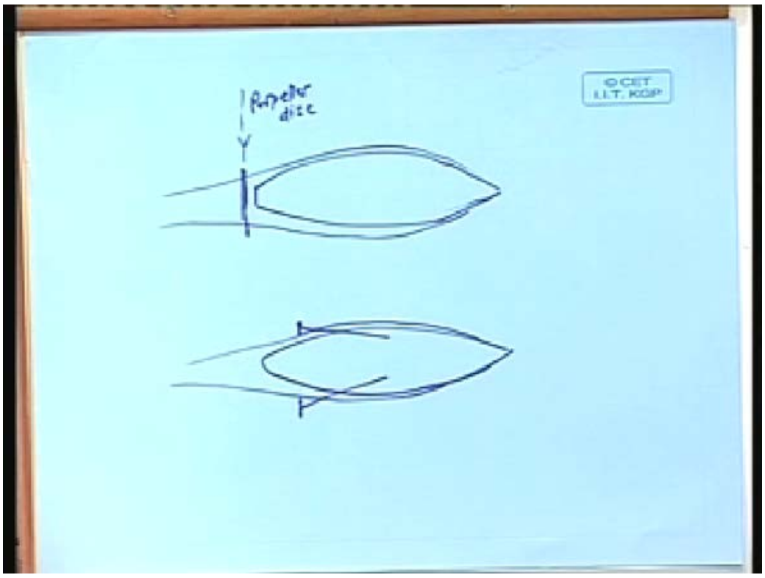

Now, a single cruise ship, this is a single cruise ship; this is the area of the propeller disc. I have draw the plan. So, what we see here? The boundary layer will form there like that and the propeller is inside the boundary layer. It may be partly inside partly outside depending on its diameter.

Let us look at a twins cruise ship. Your propeller is here some sort of a arrangement like this whatever it is, but it is outside. Now, you see the effect. The geometry of the ship is such that, when you put the propeller in twins cruise ship, it is away from the central line where the main wake was situated. So, it is not being affected so much by wake as the singles cruise ship was affected. So, in a twins cruise ship, the wake effects are generally less. Next, we look at the thrust. What have we said regarding thrust?

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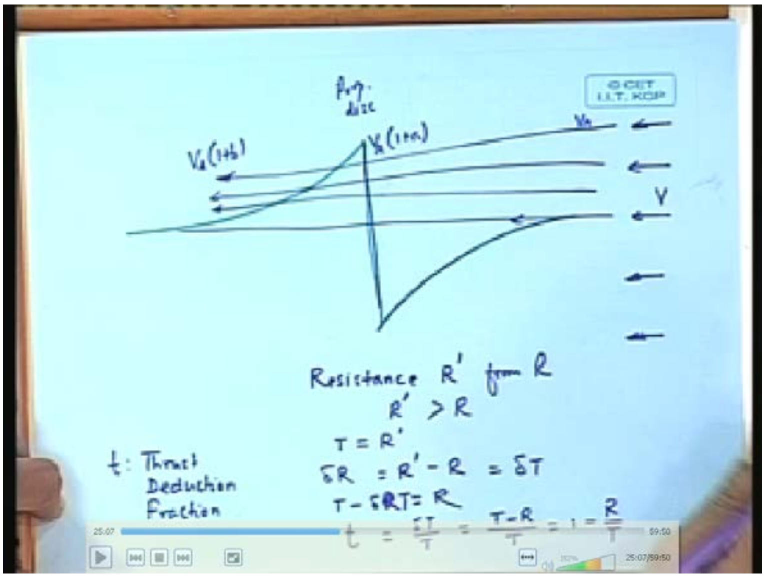

We have increased the velocity. I have made a small sketch which I will have to show you. I have a propeller here. I am drawing the plan. The water was wave forward, far forward of the propeller disc. The water was moving at some velocity V. Let me say or V V a or will speed of advance. Let me for the time being V. This is the propeller disc.

You can imagine a very simple propeller theory will go to propeller theories later, but right now this so much I can say that propeller could be consider as if it is pulling this water and throwing it on the other side at a higher velocity, changing the momentum of water. Then there will be a reaction and you will get a forward thrust. Very simplest of the theory I am telling you.

So then, what will happen? What will that propeller do then? What will happen to the velocity and the pressure across the propeller disc like a pump? It will work like a pump, pulling the water and throwing it on the other side. So, the velocity will be increased and same this way. I am only drawing half. So, if V was the velocity here, this will be or let me write V A so that we do not confuse. We are all talking about velocity will be increased across the disc over a distance. What will happen to pressure? How does this velocity will increase? I must provide a pressure difference across the disc.

So, the pressure would let me draw with a green. There will be a change in pressure at the disc itself. Am I understood? That is, as if the propeller disc is providing a high pressure across itself, therefore the velocity is increasing. It is pulling the pressure from one side. What is the meaning of pulling? A plane pressure. So, a pressure change occurs across the disc. So, because of change in velocity, the pressure drops here. There is a pressure change here; pressure increases tremendously. Then again pressure drops and velocity increases. This is what happens.

So, across a certain distance forward and after of the propeller, the velocity keeps on increasing. Now, imagine the ship. The ship is there and we have increase the velocity. The ship is at the stern, sorry, propeller is at the stern after of the stern. We have increase the velocity around the stern which is fluid in front of the stern and pushing it forward.

So, since the velocity is increasing, the resistance of the ship in that condition increases which we have not tested, because we never tested the ship for resistance with the propeller working, and in fact, we cannot test it. We cannot test the resistance because as soon as the propeller works the ship provides the thrust. Therefore, our definition of resistance we cannot measure as per the definition of resistance that is, pulling the ship by a towrope.

So, what happens in this is that the resistance increases to, resistance increases to something like R dash from R, where R dash is greater than R, and we, the propeller must provide thrust which should be equal to this R dash, T minus T should be equal to R dash. So, as if there is a augment on resistance and the augment B equal to R dash minus R. In other words, we can say as if there is a the thrust has to be deducted, an amount of thrust must be deducted from the thrust generated T to equal resistance.

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With the, resistance is always without propeller. That is why I said R dash. So, this I can call that equal to delta t. That is that augment of thrust that must be reduced from T to get R. So, T minus delta T is equal to R, delta T or delta R. Let me write delta T. So, you can understand T minus delta T equal to R. We can define a quantity small T which is equal to delta T by T which is equal to T minus R by T 1 minus R by T. This is called, this T is called thrust deduction fraction.

So, now, we had defined wake. Did you define wake? I think we did not define wake. We, we, found out what is the physics of wake, but we did not defined what is the quantity of wake. How do you determine? What is the quantity of wake? We will come back to thrust deduction here.

If we can measure the velocity all over the propeller disc, we will have a three dimensional velocity field - an axial component will be there, that is along the axis of the propeller in the direction of the ships axis; another will be may be transverse, may be vertical. That is basically theorems not flow or in polar coordinates. We can say a velocity component in the tangential direction at any point R tangential and another radial.

Now, normally this radial and tangential components can be ignored. They are small in comparison to axial wake axial velocity. So, whenever we are defining wake, normally we tell in terms of axial velocity field only. That does not mean other velocities do not exist. That for convenience we consider axial velocity which is the major portion of the wake, major percentage of the total velocity feet.

That means, in general, you can appreciate that is 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 and at any circumferential direction, if I measure the velocity at various radii, that is various theta angles axial velocities, then I can say the average if if v r theta is the velocity of water at any point r and theta.

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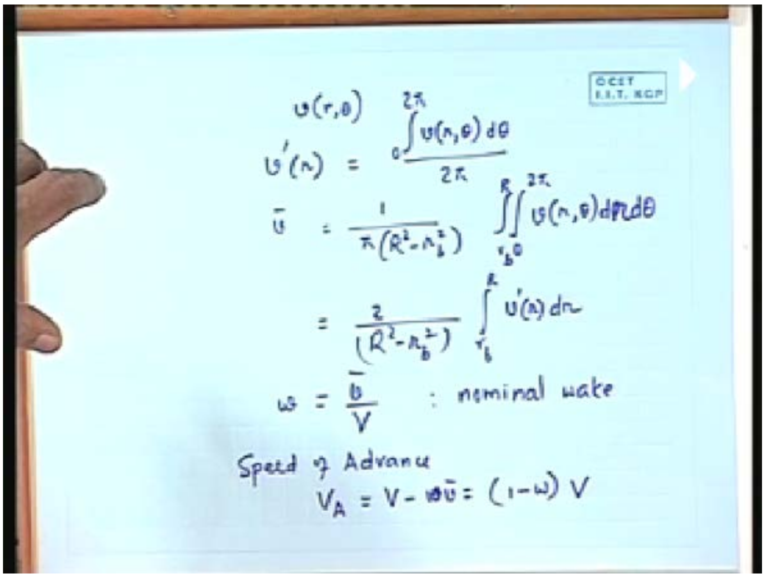

Then velocity of, the average velocity of water in that circumference, I can write v dash r equal to v r theta v theta divided by 2 pi from 0 to 2 pi. At all thetas, I integrate the velocity and take the, this is basically taking average. This is at one radius R. So, the overall wake over the whole propeller disc will be if I integrate this over R. Am I right? So, that can be given as 1 by pi R square minus root square 0 to 2 pi and this R b to R which is equal to, we have found out this V dash R. That integrated over the whole radius. That is all we have done from the boss to the propeller d.

So, this wake, the wake due to this is defined as v by v. This is called nominal wake, and then speed of advance V A is equal to V minus wake is equal to 1 minus wake into V, sorry, V minus V dash V bar velocity of advance. This V bar will be reduced now from the ship speed. So, that can be written as this. Have you understood?

This way of determining wake can only be done if we know the velocity distribution in the entire propeller disc we can integrate it over theta then integrate through R. So, this is only possible if we have the entire wake distribution on the propeller disc that various R and theta values, then only we can calculate this.

This can be done experimentally by removing the propeller fitting a pitot tube rake along the radially at various points the pressures holes will be there, and you take the pressure readings on top. Get the pressure distribution at various R and theta values on the propeller disc and integrate and get the velocities. That is one way it is called a wake rake method of measuring wake.

But this is not a common practice. It is pretty involved depends on having a wake rake and measurement device for the pressures and integration and all these things. What we know otherwise do is can we not measure the velocity or find out the velocity when the propeller is working behind the propeller, behind the ship.

So, actually what we do is we run the propeller and move the ship forward. The ship runs with its with the ship propellers thrust and torque, and from there, we calculate backwards. Thrust and torque we can measure, rpm we know and we know the propeller characteristics because we have move this propeller in open water before.

So, then it is possible for us to estimate what would be the speed; what would be the average speed to give me this thrust and torque. Do, do, you understand me? I am running the propeller moving the ship forward. So, I know the V S. I know the r p m at which propeller is moving. I am measuring the thrust and torque of the propeller.

So, knowing the thrust and torque of the propeller, I know the resistance also. So, I know the thrust reduction fraction, and using this n t and Q, I can calculate K T and K Q. Do you understand? K T is T by rho n square d 4 and K Q is t by rho n square d 5, and from there, I can go to J from the propeller open water diagram and get the V A. There is only one assumption here that, the thrust and torque that I have measured would be the same thrust and torque at same speed and same rpm in propeller open water, because I have use the same diagram. Are you understanding me?

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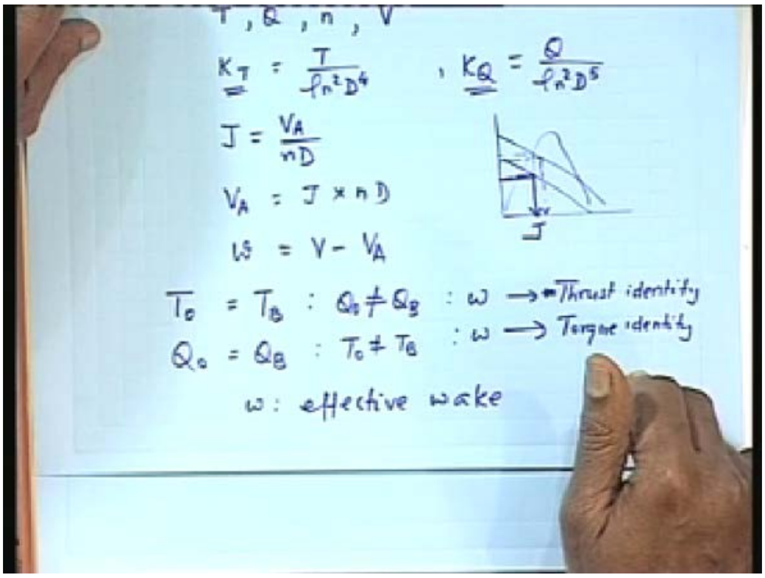

On area on a model, let me explain again. I am measuring T Q n and shift speed V. So, this will give me K T equal to T by rho n square D 4 which I know K Q is equal to Q by rho n square D 5 which I know Q I have measured. Then I know K T and K Q. I know my propeller diagram, open water diagram. If I assume that the propeller is generating the same thrust and torque as in open water at the same r p m and speed, then I can enter the K T chart and get the J. This J is V A by n D.

Therefore, V A is equal to J into n D. I can calculate my wake. Is that correct? Good. One assumption only I have made that, when I enter this chart, I assumed that the propeller open at a characteristics and propeller behind characteristics are same. That immediately you will note that it is not same, because I have got K T. I have entered the chart with K T. What if I enter the chart with K Q? I should have actually got this value this, but I will find that my K Q is not here, but somewhere here, which means then I getting a different J and different wake.

So, therefore, by this process, I can get the wake, but it will be dependent on whether I assume thrust is same or torque is same. Do you understand? So, if thrust is same, that is, T 0 is equal to T B in open water and behind condition if thrust is same; this means torque is not same and I get one wake. This is called wake by thrust identity. Thrust is considered as identical.

Similarly, if I take torque identity, which means t 0 is not equal to t b and I get wake. This is called torque identity. Am I clear? Good. So, by running a ship model actually in that rake, by the process I have described how the model has to be scaled under the things. I can measure the thrust torque rpm and speed of the ship and propeller and therefore, get a wake value.

This wake obtained in either of these methods is called the effective wake and it is different from the previous nominal wake which we had defined earlier; that means, the wake measured this way would be slightly different from if we measure the wake over the whole propeller disc without the propeller and calculated it, because we know that when the propeller is there, the water speed is increased. So, there is a slight difference from the ideal condition if the propeller was not there.

So, there will be a difference between the nominal wake and the effective wake, and the effective wake can be experimentally determined either by thrust identity or by torque identity. Now, this brings us to the third point, that is, the efficiency difference of the propeller between the behind condition and the open condition that is called Relative Rotative Efficiency.

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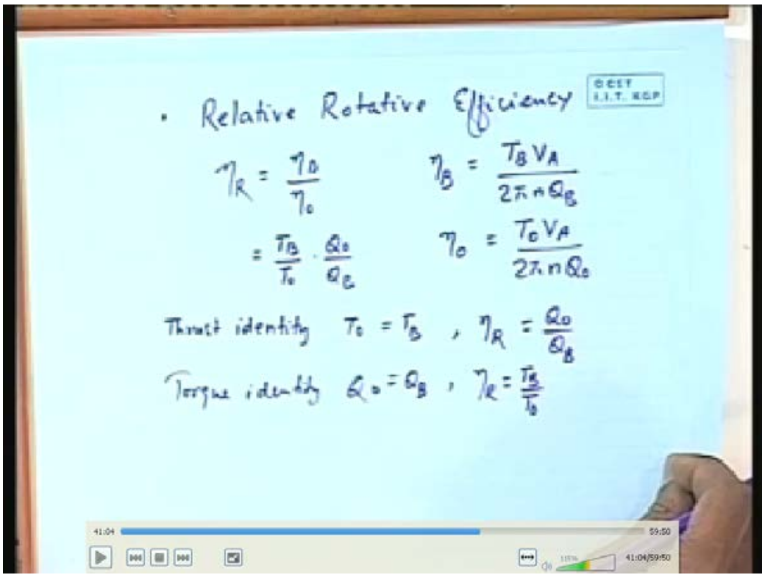

Eta R, what is the open water, what is the efficiency? We can define this like this eta b behind propeller efficiency, propeller in behind condition. What will be its efficiency, its efficiency? Only the propeller efficiency. It will be T B into V A divided by 2 pi n Q B thrust power by torque power. This is how we have defined efficiency.

Now, what is, how is T B and Q B related to T 0 and Q 0? That is what we do not know. Propeller open water efficiency is, so, the Relative Rotative Efficiency which is the ratio between eta B by eta o. That is the efficiency ratio between the behind condition and the open water condition.

If write this, what do I get? T B by T 0 into Q 0 by Q B. Am I right? Now, here, again we come across the same problem. We do not know both T B and Q B. So, we have to make some assumption. So, if we take thrust identity, I have already defined what it is T 0 equal to T B. Therefore, eta R is equal to Q 0 by Q B and torque identity Q 0 equal to Q B or eta R equal to T B by T 0.

Sir, how can the V A in the open water and back of the ship is same?

You have taken it to be same.

Then we know the V A in open water, but we do not know in that what is V A.

You are just calculated know; you are just calculated what is the V A by measuring wake. We have done that just now. The open water test must be done at that speed not at shift speed. That is how the V A will be same. Do not confuse with the open water test being done at ship speed, no. The open water speed test is done at that speed V A which you have calculated.

You cannot do like that. So, what you do is run the propeller at different speeds, open water characteristics. So, you get the J versus K T K Q diagram. That diagram you use for everything else. Automatically the V A that you use for your behind condition will be corresponding to a same V A.

So, we have got this three things that we have discussed now. Now, when you have, we use the reverse of these papers later on. I have to go for the next hour. When you have the engine is connected to the propeller by means of a propeller shaft. So, if I have a diesel engine, how do I know what is the power of the engine? I can measure the indicated pressure inside the cylinder and again calculate the power which is called the indicated horse power or I h p and or I can do a brake test of a engine through a dynamometer and I can get the break horse power or B H P.

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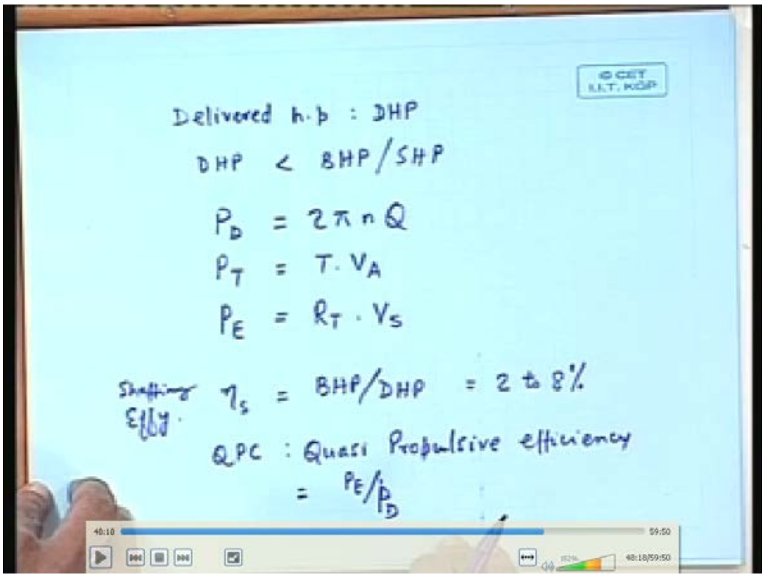

That is the horse power that is available to me at the crank shaft end where I am attaching my propeller shaft. Generally B H P slightly less than I h p. What about a steam turbine? I do not have a I h p. Do I have a B H P? Normally what we get in a stream turbine not by brake test, but by measuring the torsion on the shaft end. So, we get the torque on the shaft; we know the r p m. So, we get the power which is called the shaft horse power or S H P.

So, in a steam turbine, we get S H P, and in a diesel turbine, we get B H P. A diesel turbine is, a diesel engine is normally a constant torque machine. So, if the r p m drops, the power also drops. If there is reduction of r p m, then engine power also drops, because within that range, the torque should remain constant.

On the other hand, a steam turbine or a gas turbine, if the rpm drops, what happens? It is a constant power increased machine. Therefore, the torque can be increased to maintain the constant power. The torque of a turbine based shafting system can be increased at a reduced rpm, so that your power become remains constant. So, turbines are generally called constant power machines. So, at the engine end, we can measure the torsion in a turbine ship or the brake horse power of an engine and the relationship between r p m and power.

I can also, if I have torsion meter mounted anywhere on the shaft, I can also measure the power at any intermediate position on the propeller shaft. I can also measure the thrust by some amount of strain gauging or fixing instruments in the shaft. I can get the thrust and torque at any point, and power that is delivered at the engine end is reduced slightly as it comes to the propeller end.

That is the power that is available at the forward end of the propeller is called the delivered horse power or simply D H P. This D H P is less than B H P of a diesel engine or S H P of a steam turbine. Why is it less? There are few losses because of the gear box, the thrust plot, the other bearings that may be supporting the shaft, and finally, the stern gland.

Now, normally the engines are aft now a day's most of the ships have aft engine, and if it is a direct drive system, then easily assume a 2 to 3 percent power loss because of the these item I have mentioned. In the other hand, if it is a gear drive, then the power loss will be more the engine between 4 percent to 8 percent depending on whether the engine is extreme aft or it is moved forward like in naval vessels.

So, if we reduce this amount, we can easily know what is the D H P available at the propeller end. This is, at that rpm, we can also calculate the torque. So, that is the torque available to the propeller at that rpm with that forward speed, and if we know the resistance, if we know the characteristics of propellers, we can calculate wake thrust at fraction etcetera.

So, we can say D H P or p d is equal to 2 pi n q; q you 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 the V S ship speed. Please recall we had defined this before. So, now the drop in speed a 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 or whatever.

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 required, 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, but I can finish it now. I could not finish it, sorry, sorry about that.