Performance of Marine Vehicles At Sea

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Lecture No. # 14

Propeller in Open WATER Part - I

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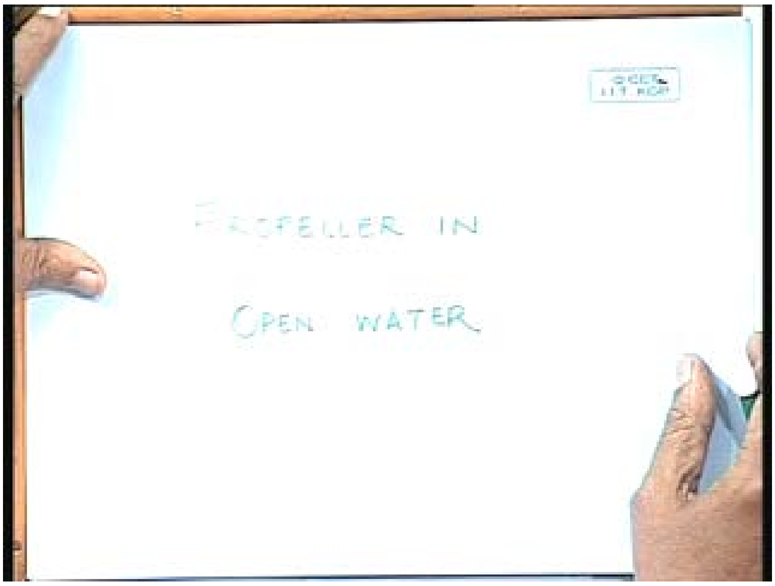

Good afternoon. Today we will torque about propeller in open WATER. We have seen propeller is a hydrodynamic device which generates thrust when a torque is delivered through the propeller shaft at a particular r p m, ship moving at a particular speed. This thrust and torque vary with the speed of advance and R P M. Further, the propeller behaves differently behind the ship than if it was not behind the ship. In other words, if we move a propeller at a particular forward speed and R P M without any disturbance of ship in front of it, then the propeller will should behave in a manner which is different from, if I fitted the propeller behind the ship.

This behavior difference would mainly be measured in terms of thrust and torque as functions of speed and R P M. But to understand the propeller behavior behind a ship where the flow is already disturbed, we have to first understand the propeller characteristics when it is moving in calm WATER, were immersed in WATER that is par below the free surface so that there is no wave effect and then we can extend it to behind condition. So, such characteristic of propeller is called the characteristics of propeller in open WATER.

So, if we want to understand the characteristics of a propeller in open WATER, how do you go about it? Imagine a full propeller, full size propeller for a ship we cannot really test it in open WATER. Because that propeller would always be behind the ship, we cannot fit it in front and then test it for various speeds and R P M s that is very difficult. So, what we normally do is we make a scale model of a propeller and test it in a facility where we can measure the thrust and torque at varying speed and R P M. And therefore, determine the characteristics of the propeller in open WATER and extrapolate it to full scale, like we had done it for ship resistance.

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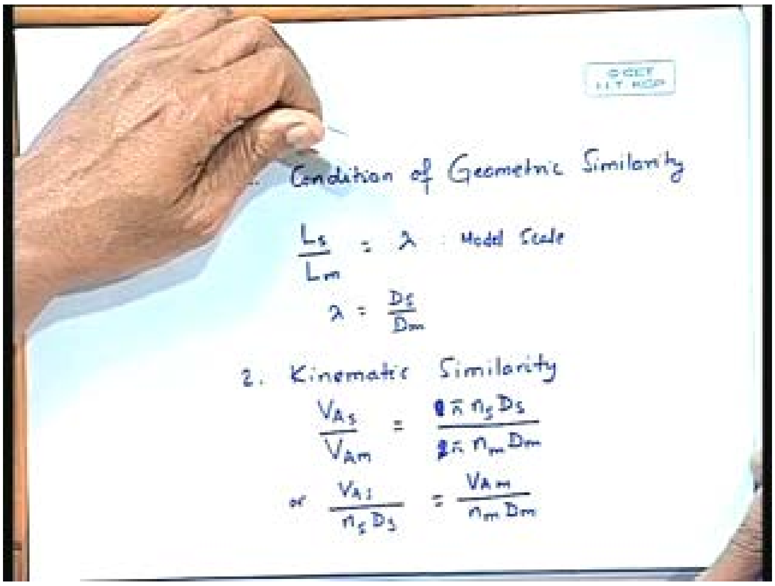

So, to do a model experiment of a propeller what sort of similarities we should be aiming at? One which we have already mentioned for ship towing test is the scaling of the model that is condition of Geometric similarity. What does this mean? Means, that any length dimension of the ship to length dimension of the model will be constant, that is model scale called the model scale lambda. In propeller case, what does it mean? What is the length dimension for a propeller? Typically it is the diameter. So, we can say for a propeller it is lamda is equal to all the Geometric properties of a propeller will be scale down in similar manner. That means, all the properties that we have seen pitch, thickness the shape of the chamber that is of sets of the face and back from the nose tail line, every single dimension will scale down in the same scale. And similarly, the area will be scale down in square of scale.

Therefore, you will find that the pitch ratio which is non dimensional will remain constant between the model and propeller and so will the area ratios. Sometimes it may be difficult to scale down thickness and manufacture a propeller in model scale, that is it may not be possible to really scale down the thickness and manufacture an accurate propeller. So, it is therefore, advisable make as big a propeller as possible. So, that you can scale thickness, but sometimes compromises are necessary to be made.

Next similarity we have is, you have seen this in the in the resistance case also, kinematic similarity. What does kinematic similarity say? In case of a propeller it would be that speeds are also scaled in the same proportion or in other words the speed ratios between model and ship are constant, whatever may be the speed we are considering, that is V s by V m will be constant. We have seen two speeds coming on to the propeller blade, one is the axial speed, the other is the rotational speed this we have seen last time.

So, for kinematic similarity, it is necessary to maintain the Geometrical ratios of the speed which can be written very simply as velocity of advance of ship to velocity of advance model ratio is equal to.

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No, this 2 will not come we have used D, so 2 will go. This is our condition of kinematic similarity. Now, or you can see what we are getting V A s divided by n s D s is equal to V A m divided by n m D m.

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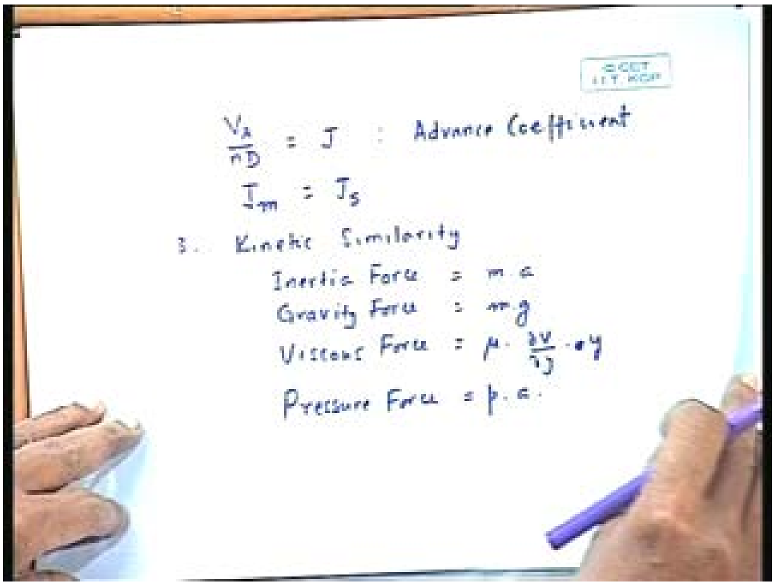

This quantity V A by n D is denoted as J, that is advance coefficient. So, what we get? We get the advance coefficient of model is equal to advance coefficient of the ship for kinematic similarity. Am I clear? Then, we have, what we have said in case of resistance? Kinetic similarity this relates to forces, that is the ratio forces acting on the model will be same as ratio forces acting on the ship. And, if we think what are the forces that are acting on the model and ship? What we get? What are the forces? Inertial force of course, mass into acceleration, I am writing general, gravity force, m g mass into acceleration due to gravity.

Then, viscous force working in a viscous medium WATER is viscous that is equal to mu d V by d T, no, d V by d y into d y into y, the gradient of the velocity. You do recall, we did this in the resistance case also, the gradient of velocity because the shear force will be there the drop in velocity across the layers into the distance that will be the total force. And finally, the pressure p into area. This is the general I have written I have not related to propeller so far. But if the inertial force on the propeller was represented by m into a, gravity force was represented by m into g viscous force as this and pressure force as this.

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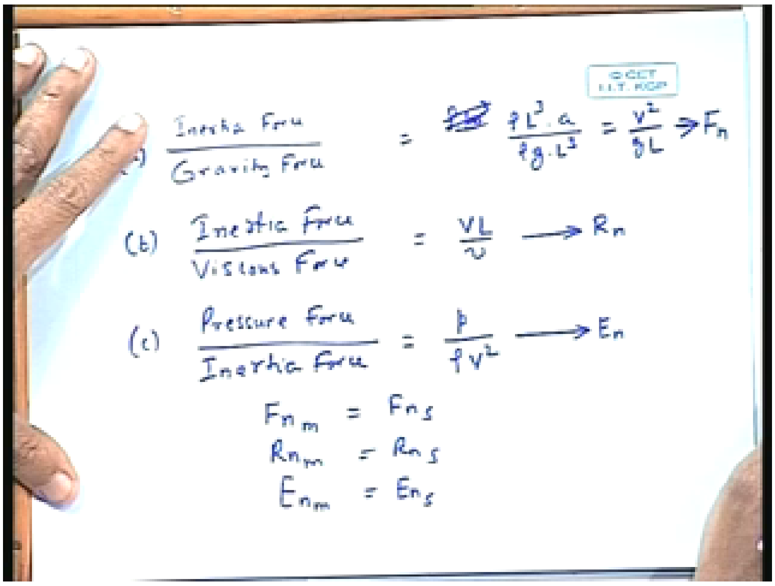

Then, we can find out what will be the ratios of forces look like. Inertia force divided by gravity force will be same for model and ship. Similarly, this is one ratio, another ratio will give inertia force to viscous force and the third will be pressure force to inertia force, I am writing, you could also write the inverse of it. If we just put the units of this, this you can show to be, should we out the units? Mass, what is mass? rho into m cubed rho into L cubed rho into cube of some linear distance into acceleration divided by rho g L cubed. This can be shown to be, I mean a to g.

a to g.

That is.

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a to g is not one, it is the ratio.

But the units are same, sir?

Units are same, this also unit is non unit less. We will see it in another form later. Inertia to viscous force similarly can be shown to be, the reason I am telling you this at this stage, we can make out what is V square by g L? Froude number square. So, this is related to Froude number, this is related to Reynolds number and this is related to pressure constant which can be, which is called the Euler number E n.

So, the kinematic similarity would be exactly obtained, if F n model was equal to F n ship, R n model equal to R n ship and E n model equal to E n ship. This is what we started with, is it not? The kinetic similarity we had defined this four forces that act on the propeller and the ratios, this is the three ratios we have defined as ratios of any two of these. And, they give us three numbers, dimensionless numbers and if the kinetic similarity is to be maintained then these three numbers that is F n model must be equal to F n ship, R n model equal to R n ship and Euler number model is equal to Euler number ship, this is what we should have.

So, if this is attained, then doing a model experiment on the propeller we would get the relationships between torque and thrust with R P M and speed. And, we could assume that the same relationship holds for the full scale ship, full scale ship propeller, we are talking about the propeller.

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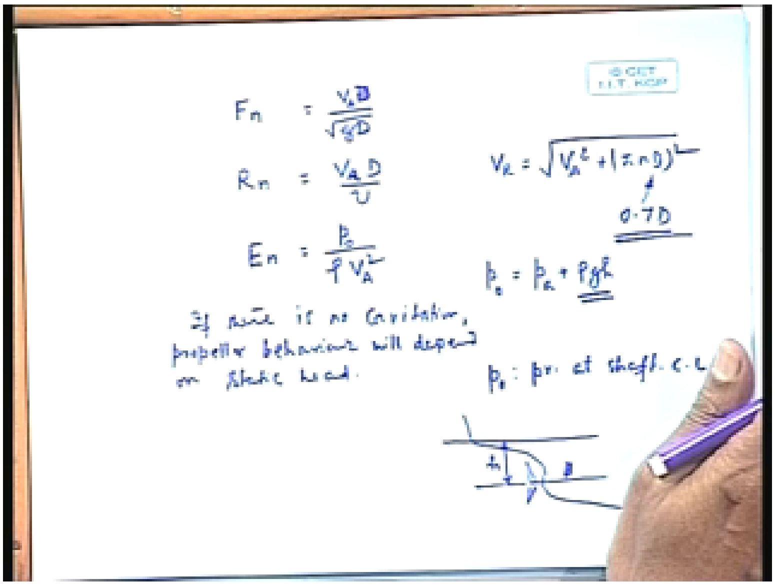

Now, in for the propeller what is the characteristic length is diameter. Therefore, Froude number in case of propeller will be V D by root g D and Reynolds number will be, what will be the Reynolds number? Mind you this V is V A. This V A I am talking about, is the speed of advance we have generally said speed on to the propeller is denoted as speed of advance, V A. Reynolds number is V A D over nu. Is this correct? Is this Reynolds number correct?

Propeller.

Is this correct? The speed on to the propellers plate is not V A. The speed of advance is V A, but speed of WATER on to the propeller is not V A, what is resultant velocity is equal to? The circumferential velocity is there, please remember that. So, Reynolds number is actually defined as V r into D by nu, that is the resultant velocity on to the propeller blade. This is, you see here there is a little inconsistency here this D, I have written is the maximum diameter of the propeller. But each section of the propeller blade, the resultant velocity is different because of this quantity, can you understand that? So, this resultant velocity at any section will depend on its distance from the centre from the propeller axis

So, many times we take this at a standard distance from the propeller axis, typically 0.7 D, that is 0.7 at that distance, what will be the Reynolds number? Sometimes, it is taken as the characteristic Reynolds number.

Sir, I do not think V rs are written also.

Froude number is related to gravity force, I would have told this later, but let me tell you now. Froude number is related to gravity force, the gravity forces act as the interface of air and WATER. So, since we have immerged in the propeller fully in WATER, the gravity forces act very little on the propeller plate. We assume that no waves are generated due to the propeller; do you get what I am saying? Because the propeller is far below, the wave's generation is not there on the surface due to the propeller. That is an assumption which sometimes is not strictly followed, but mostly it is true propeller does not suffered from effects of gravity forces.

Therefore, this Froude number is not an important criterion for propellers. I would have come back to this later, but I am telling you right now, Froude number does not affect propeller behavior if the propeller is fully immerged in WATER. So, whether we V A or V r or whatever, it does not really matter. Euler number let see, what did you say this as p divided by rho V square and it is pressure. So, obvious it is V A only. Now, this p, what is this p? Typically you can take the characteristic pressure as the p at the centre of the shaft centre line, that is P 0 let me call. p 0 is pressure at shaft C L, that is (No Audio From: 21:32 o 21:40) if this is the propeller, then I am taking this is the WATER line then I am taking the pressure p 0 here.

Now, what is this pressure p 0? Is this height h plus that must be atmospheric pressure, that is p equal to, p 0 equal to p a plus rho g h. Now, if there is no cavitations, a phenomenon which will discuss in greater detail later on, if there is no cavitations, then we can assume that this p 0 behave the dependence on of the propeller behavior would be mainly on the static hydro g h, like we did in case of ships ship similarity. So, if I am also writing down there is no cavitations, propeller behavior will depend on static head. So, if that is so, then this h is geometrically similar to that of the ship, is it not? The ratio of static head will be same equal to lambda. So therefore, if there is no cavitation, a geometrically similar propeller immerged at geometrically similar height we will have the same Euler number or pressure condition will be satisfied.

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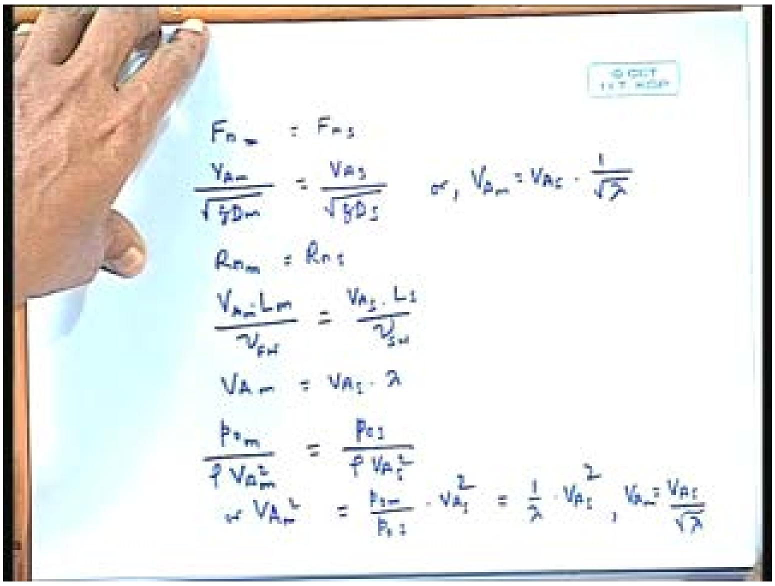

Now, you see if we want to satisfy Froude similarity, what we have to do? If I want to say F n m is equal to F n s, then I have V A m over root g D m equal to V A s over root g D s or V A m is equal to V A s into.

Root g r lamda.

Right, this is exactly the same Froude condition we had got for ship. That is the velocities are in the ratio of square root of lamda between the ship and model, correct. Now, if we take R n m equal to R n s, what do we get? Let us write for simplicity V A, we will see the effect of V r later. V A lm V A m L n m by nu is equal to V A s L s by nu. Now, nu fresh WATER and nu sea WATER are nearly same. So, what do we get V A m is equal to? You get this, you could as well write V r in this.

In other words, you look at Froude similarity here and look at the Reynolds similarity here; we land up with similar situation. That if you want to maintain Reynolds similarity then the speed of the model, the axial speed of the model will be lamda times higher than that of the ship. That means, if I have a got a 25, one is to 25 scale model, then speed of the model will have to be 5 times higher than that of the ship, sorry 25 times higher than that of the ship, which is impossible to attain in a WATER medium. Therefore, Reynolds similarity cannot be attained.

Now, pressure forces if we equate, what do we get? It is already, p 0 by rho V A square p 0 m by rho V A m square is equal to p 0 s by rho V A s square or V A m square is equal to p 0 m divided by p 0 s into V A s square, is that correct? This is equal to 1 by lamda rho g h into V A s square or V A m is equal to V A s divided by square root of lamda, which is same as Froude similarity. Automatically, Euler similarity is retained in propeller testing, if we maintain Geometric similarity and move models at similar speeds.

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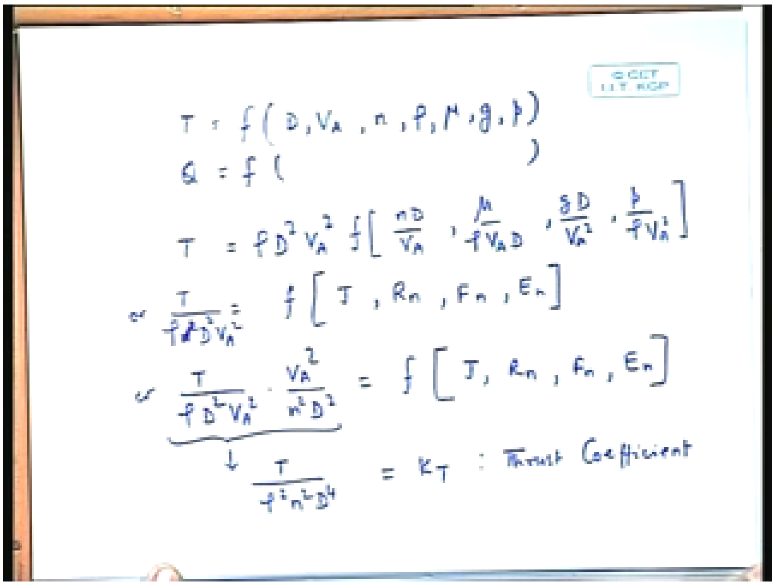

Now, if we did a dimensional analysis like we did in resistance, what will we get? if we do a dynamic dimensional analysis, we can write T as a function of, remember how we did it? We just, one of the advantages of dimensional analysis is that we do not know the exact nature of dependents of variables on the outcome. So, we say that the outcome is equal to general function of all the variables and we try to equate the dimensions. So, if I write T as a function of, we can write now, D V A n rho mu g and p. Similarly, I can also write Q as a function of the same things, T and Q are the two things I want to know how they vary with V A and n. And, these are the propeller characteristics and medium characteristics.

Then, do you wish me to work it out for you? I think I will just give the results because the working method will be exactly similar, you raise each of these into different powers and equate the powers of dam, put them in three fundamental dimensions, L length dimension L, mass dimension m and time dimension T. With that raising them with two different powers and equating the powers on left hand side and right hand side, we can show that T is equal to rho D square V A square into a function of n D by V A mu by rho V A D and g D by V A square and p by rho V A square or T divided by rho n square D 5 D square rho rho D square V A square is function of, what is n D by V A? Sorry, what is it?

Inverse.

Right, yes, inverse of V A by n D, so n D by V A is same, advance coefficient. This is mu by rho is nu. So, this is Reynolds number, this is Froude number and this is Euler number, is that correct? So, the dimensional analysis show us that T by rho D square V A square is equal to function of J Reynolds number, Froude number and Euler number or we can write T by rho D square V A square into V A square by n square D square is equal to function of, what have I done here? I multiplied this V square by n square D square. V a by n D is J. So, I have multiplied with J square, J is a non dimensional number. So, multiplying this with J square and multiplying this side with J square will make no difference. I am just trying to find a convenient factor on the left hand side by multiplying with a non dimensional quantity on both sides.

This quantity is then becomes, what does it become? T by rho n square D 4, this is written as the thrust coefficient, (No Audio From: 32:45 to 32:58) is that understood? So, you see on the left hand side my purpose of doing this multiplication was to remove the V A term from here.

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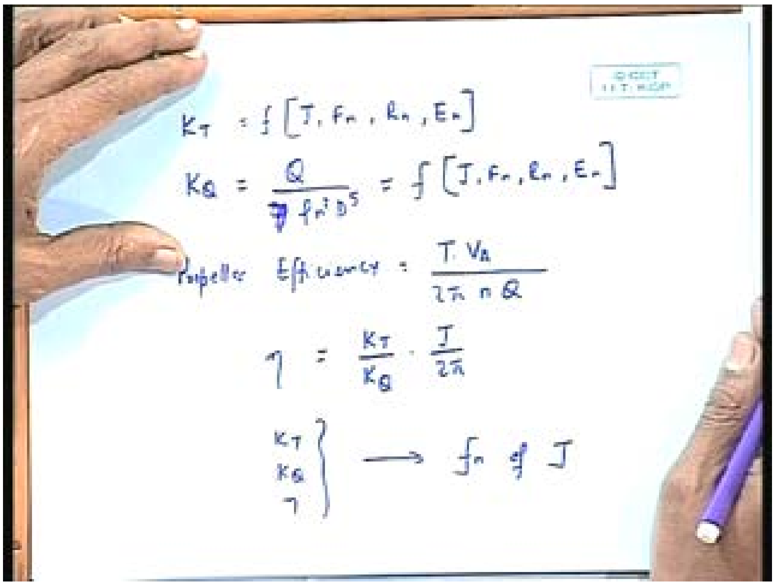

Similarly, I can define the torque coefficient. So, K T now is a function of J, F n, R n, E n torque. Similarly, I can show K Q is equal to rho n square D 5 is equal to function of J, F n, R n and E n. And, then we can define propeller efficiency, what is the definition of efficiency? Output by input. What is the output power of the propeller?

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No, output is thrust; the torque is being supplied to the propeller. Output is the thrust, thrust is a force. So, what is the thrust power?

T into V A.

T into V A, this is the output. And, power?

2 pi n Q.

2 pi n Q.

Now, if we write it in terms of K T and K Q, then we can show it to be (No Audio From: 34:47 to 34:58) T and Q, T by Q will be K T by K Q with D going up. So, V A into D divided by n will give J, 2 pi will remain as 2 pi. So, propeller characteristics are defined by K T and K Q as a function of J and other numbers, we will see how, what is the dependence on these numbers. And, efficiency can be found out once we know the relationship of K T and K Q with J. We have seen K T and K Q are related to J, so we can find that out. Now, just looking at this diagram, I have already explained to you that Froude number has very little effect on propeller behavior. So therefore, from this equation from physical fact that gravity forces do not have an effect on propellers, this F n can be removed, clear?

R n we have seen cannot be maintained between ship and propeller. So, how do you maintain the kinematic similarity between ship and propeller in this case? See, this is the problem, if we do not maintain kinematic similarity then our results are likely to be erroneous and cannot be extrapolate to full scale. At the same time we cannot maintain Reynolds similarity. Fortunately, for us propeller is mainly a pressure based device, that is pressure on the case and pressure on the back the difference of that gives us the lift force. Lift force is not dependent on Reynolds number, whereas, drag is, but in propellers drag is relatively low less.

So, the thrust that we get it will only have a small component as viscous component, but that will be erroneous. Extrapolating from what you had talked earlier in case of ship models, if the propeller works in laminar flow regime which is, which it is likely to work in case of a model scale and we try to extrapolate it to full scale, definitely there will be large difference in drag, do you understand? If Reynolds number is low we know that the flow can be laminar and the drag of laminar flow is much less than that of turbulent flow. So, if we allow laminar flow to persist on propellers in model scale, then our extrapolation of thrust and torque will be erroneous in full scale.

So, an effort must be made to see that at least laminar flow does not exist and how do you do that? One way to do that is make as large a propeller model as possible. So, that the simple relationship V into D, V will be larger because you are maintaining speed similarity or Froude similarity, V will be larger and D will be larger if you have a larger model. So, that is one way. The other way is an additional way is to make the propeller blade of mat finish rather than absolutely polished like a ship propeller. A ship propeller is very well polished where as a model propeller if there is a possibility of laminar flow, then the surface of the propeller blade should be mat finished rather than absolutely polished.

Once, we assume that laminar flow has been eliminated and we have turbulent flow and model propeller. Then, kinematic similarity is more or less achieved, though that drag cannot be extrapolated like lift. But that error is minimal and can be ignored or today there are many methods by which you can make the viscous corrections, if there is a large scale difference between model and propeller. So, Reynolds number also can be eliminated from this square bracket, these two brackets. We had eliminated Froude number earlier, now we are eliminating erroneous number. Because we cannot really use, find the functionality of Reynolds number from experiments. And, number is automatically attained if we move the propeller at corresponding speed of the corresponding speeds between the model and ship.

So therefore, K T K Q as well as eta will finally, become functions of advance coefficient J, given a particular property of the propeller, that is pitch ratio, blade ratio, thickness ratio, section shape etcetera. Is that understood, am I clear? If that is so, it is very easy for me to represent the propeller characteristics in terms of propeller characteristics K T K Q and efficiency as a function of J. And, that is how propeller characteristics are represented. And, between ship and propeller, since we have already seen J shift is equal to J model at corresponding speeds, then the relationship between ship propeller and model propeller represented in terms of K T and K Q as function of J will remain same.

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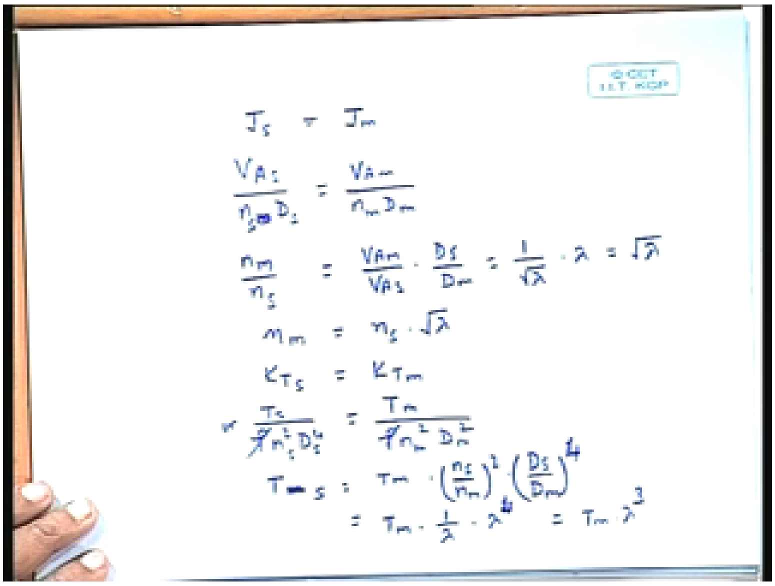

So, if that is so, let us see what will be the R P M of the model propeller? You have seen J s equal to J m, that is V A s by V A by n d. (No Audio From: 42:12 to 42:21) So, what is n m, n m by n s? That is, what is the ratio of model propeller to ship propeller? (No Audio From: 42:33 to 42:42) V A m to V A s, what is that? (No Audio From: 42:54 to 43:03)

So, model R P S is, ship R P S into square root of lambda. That means, if you are talking of a 25 scale ratio of 25 and my ship propeller moving at 100 R P M and the model propeller move at 500 R P M, we are right, is that clear?

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Good.

So, you have seen speed will be reduced, model speed will be reduced by lamda times that is axial speed, but the rotational speed will increase by square root of lamda. And, then what will happen to thrust and torque? K T s is equal to K T m or T by rho n square D 4 for ship is equal to, assuming these two are nearly same. What we get? T m is equal to or T s, let us say if T s equal to T m into n s by n m square into D s by D m square. N s by n m square is.

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Yeah, something has gone wrong here.

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That is equal to T m into lamda Q, is that right? If rho is same, we will not use this relationship because rho is not exactly same, one will be fresh WATER one will be sea WATER. Actual calculation will use K T s equal to K T m from there we calculate thrust. But if you assume rho same, then thrust ship will be equal to thrust model into lamda Q. It is similar to the Froude hypothesis, that forces will be multiplied by Q of scale. And, Q similarly, will be, can be shown to be lamda to the power 4. So, we now get all the relationships between the ship and model propeller. We have seen, what we have seen further is that the ships behavior and the propellers behavior will not be influenced by gravity forces. And, we should take care between module testing that the turbulent flow exists around the model.

And, we have observed that Reynolds similarity cannot be attained. But the error due to that should not be very large and therefore, with that assumption, we can say that the propeller characteristics obtained from the model in terms of K T K Q and efficiency as function of J, we will also hold in case of a scale in the full scale propeller which is Geometrically similar to the that of the model. So, if we change the propeller the characteristic will obviously change. So, we will stop here and next hour we will see something more. Thank you.