Performance of Marine Vehicles At Sea

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Lecture No. # 04

Frictional Resistance

Good afternoon, again. We will talk about frictional resistance now. William Froude in the 1860's and later on his son R E Froude conducted a number of experiments on Planck's to have a formulation for frictional resistance. William Froude gave a formulation for frictional resistance based on plancks experiments he did a number of experiments on plancks that is of a particular length and height submerged in water and (( )) them and measured the resistance.

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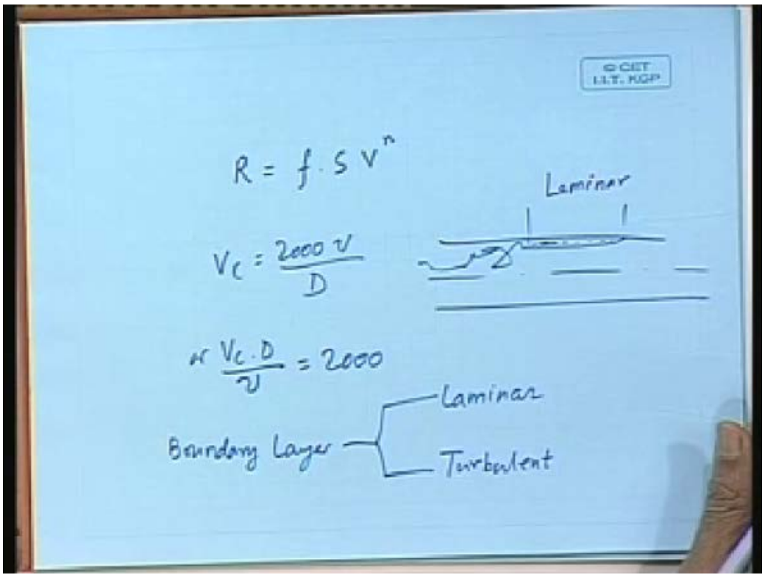

Based on the plancks experiments he gave a formulation: R is equal to- mind you, this is purely frictional formulation- f S V to the power n, this was the original formula. In the original formula resistance was given in pounds, pound force, S was in feet square and speed was in feet per second. But, now you can convert the formula to metric units, f and n being two constants where f n was dependent on length of the body- length of the planck- and f was dependent on the surface finish of the planck. That is William Froude was the also the first person to detect that frictional resistance would depend on the roughness of the surface.

So, since, Reynolds's number was not explicitly used in this the n factor varied based on the lengths, for which we conducted experiments for various lengths. And lengths were not very large, the lengths were up to a limit when you can tow it in a towing tank, mainly the towing tank at Torquay where he did most of his experiments in England. F was dependent on the surface finish, you have more roughness at the surface as f increased; he varnished the surfaces, he roughened the surfaces by sand paper he also put sand particles on the surfaces to make it more rough. So, from very smooth to very rough surfaces he tested, and he gave a set of values which were used till quite late- may be till mid fifties- as a method of estimating the frictional drag of Planck's two dimensional bodies and even ships.

Slowly, there came this gentleman Osborne Reynolds who said, who made a lot of experiments of flow through pipes. I suppose you might have read about Reynolds experiments of flow through pipes where, he allowed water to flow through pipes- through glass pipes- so that he could observe the flow pattern. And of course, if you take, clean water flows through nothing happened, but then he injected dyes at the surface; Osborne Reynolds realized that there must be a friction between the surface of the solid particle, solid pipe and the fluid flowing through, so he injected dye at the surface and saw the moment of the dye.

What he found is very interesting. That, as the dye started leaving the surface for some length, the dye flew in straight line form. That is, there is a pattern in the flow of the dye, it went, it separated from the surface. But it went more or less parallel to the surface slowly separating, but as the length of the dye injection point moved away from the fluid particles, that is, the fluid flew over longer distance, the fluid got disturbed and it mixed up with water, leaving no pattern. This also he found that the length, the distance over which the dye maintained a pattern- you understand what I am saying- the dye maintained a pattern of flow more or less parallel to the surface ,you know, if this was the dye, dye injected here moved like this and then it got mixed up. This distance was some distance, which he saw that the fluid would flow smoothly, and then got mixed up.

He observed that this smoothness of flow, the length of smooth flow reduced if we increase the speed- speed of water- that is, this length was dependent on speed.

Now, this, he said the speed at which the water, the dye got mixed up with water, he called it the critical speed, and a critical speed by experiments- repeated experiments- he found the critical speed as 2000 mu by D or Vc D by mu is equal to 2000. Now, you see what is this quantity? This is Reynolds number (( )), do you get that? So, he found that 2000 Reynolds numbers was critical for the fluid to mix up with the water, and before 2000, the water, this did not mix up with the water, what do you infer from this?

Yes, up to about 2000 Reynolds number in a pipe the flow was of one pattern and after 2000 the flow was of another pattern. Now, we know that a boundary layer will develop next to a solid boundary. Now, the boundary layer will be zero at the beginning and slowly increase in thickness, and up to a certain length the fluid inside it will have a predominant, will have a velocity which is predominantly parallel to the axis of the pipe till here- you understand- though there will be a velocity gradient, that is, velocity will vary from the pipe end, till the end of the boundary layer there will be velocity gradient as we have discussed previously, but at each point the velocity will be primarily in this direction- do you understand- that is how he can observe the fluid, the dye going like this, but beyond a certain point the fluid velocity will become totally random- a overlying flow will be there. But if you take what we call perturbation velocity, that over the flow of pipe, main flow here, the small little velocities that determine the particle direction at any point, that will be random, that can go parallel, that can go perpendicular upwards, perpendicular downwards or backwards, am I clear?

This is what he found, that is, though there will be overlying flow velocity in one direction, for a certain range of Reynolds number, the perturbation velocity of each particle inside the boundary layer will be parallel to the axis of the pipe, but beyond a certain Reynolds number that perturbation velocity will be randomly distributed in all directions- that is how the fluid gets mixed up.

This is very interesting and that is what we call laminar boundary layer and turbulent boundary layer. That is, this we can call laminar boundary layer; that is, the boundary layer can be laminar or turbulent, am I clear? And what is laminar boundary layer? As we have said that the velocities inside the boundary layer will be predominantly parallel to the axis or parallel to the surface, if you say three dimensional surfaces, will be parallel to a surface; and in turbulent boundary layer the velocities will be random inside the boundary layer.

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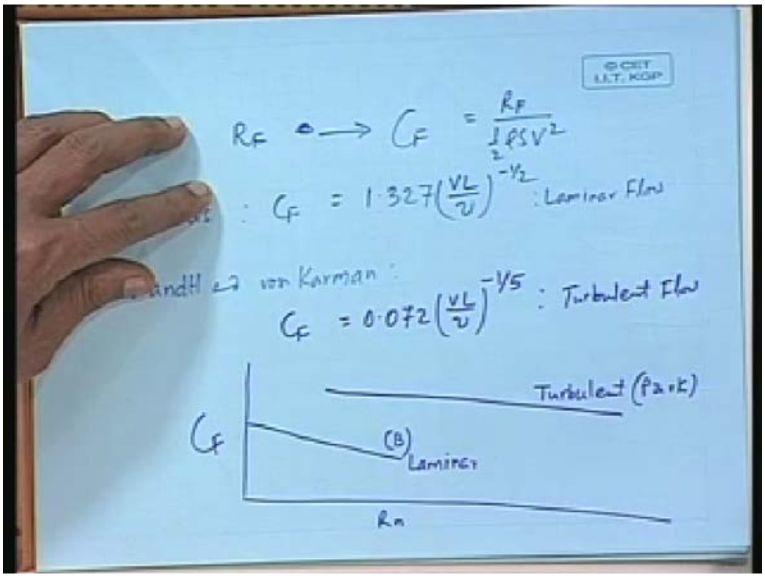

Now, we have already seen in case of ships R F can be represented by frictional resistance coefficient as R F divided by half rho S V square. To estimate C F we do not have much information from the pipe experiment, where people way back in early twentieth century, a theoretical exposition was given to flow around plancks for laminar flow by a man called Blasius.

So, we have the Blasius formulation for laminar flow and the resistance of a planck to laminar flow; that is the Blasius formulation for laminar flow. Now, this also does not fulfill our requirement because flow around ships is basically turbulent. Now, you see, we have given, Osborne Reynolds gave the critical Reynolds number for a pipe as 2000; now, in case of ships it will change because you do not have a diameter, and the flow phenomenon may be different, it will be primarily dependent on length factor, but how much length, we will see. There will also be a critical Reynolds number in case of ships where flow will change from laminar to turbulent.

Now, imagine the ship is a long thin body, water is flowing past it, initially, at the beginning of the flow where length is small just like in pipes there will be a portion when the flow will be laminar, and as the length increases, Reynolds number increases, flow will turn to turbulent. There will be a zone between laminar and turbulent where there will be a transition from laminar to turbulent and is very difficult to define where that zone will be, because, understand that ship will also have a surface which is not strictly smooth nor is it very rough if you are talking of a new ship. Similarly, ship is also different from the point of view that it is not like a planck, it is a three dimensional surface. So, much can be understood, that initially there may be a portion where there will be some laminar flow and then the flow will become turbulent. This is definitely shown in models, in ships this is slightly reduced, this effect of laminar flow is slightly reduced because the ship surface is generally having enough roughness to induce turbulence even at the early stages of flow, at the beginning. So, we consider the flow around a ship to be mostly turbulent flow.

Now, Prandtl and von Karman in 1921 gave a formulation. For theoretical formulation again, for C F in boundary layer, in turbulent boundary layer, which is, mind you, this was also Planck's, two dimensional flow without any edge effect and as if the flow was only in two dimension without having any (( )) So, this showed if I draw the two curves, if I draw as a function of Reynolds numbers, this should be something like laminar flow and this should be something like turbulent flow- this is C F, this is laminar, this is turbulent, now, say this is Prandtl and von Karman, and this is Blasius. See the difference- Turbulent flow has completely different characteristics from laminar flow. So, if you take laminar flow, then we are bound to get into turbulent- you will be underestimating the resistance.

Then in nineteen forties and early fifties, a gentlemen called Schoenherr in the United States did a lot of experiments or rather collected a lot of data on Planck experiments, took the Prandtl and von Karman formulation- see Prandtl and von Karman formulation is basically a theoretical formulation- so, he took all the Planck data available till that time, resistance data, and took the theoretical formulation of Prandtl and von Karman and tried to fit all the resistance data in a statistical manner following the formulation of Prandtl and von Karman, and he arrived at friction line for two dimensional flow- we will not elaborate more than this, we will only say two dimensional flow, now, whether it is correct or not was not known at that time, but it was thought to be better than the Prandtl and von Karman formulation.

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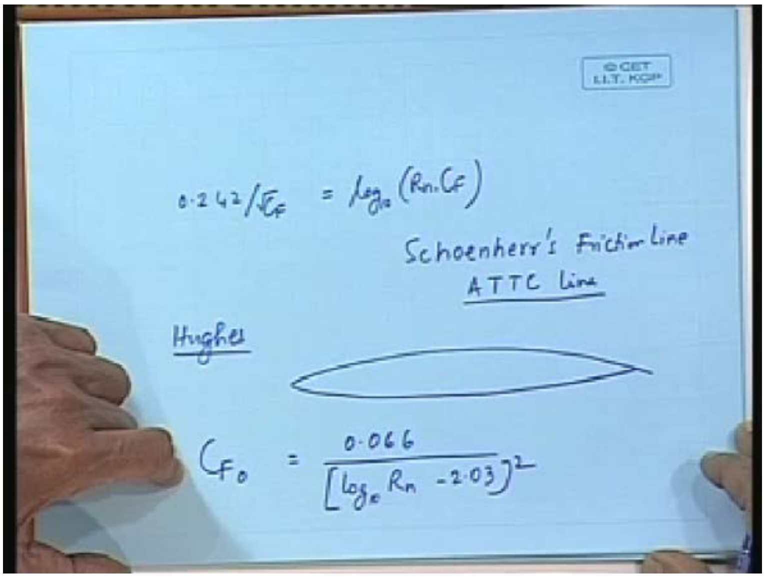

So, the formulation that we got by Schoenherr's line was like this. So, you see, the C F occurring on both sides, so, it is not a very straight forward calculation- C F equal to so much and you calculate the right hand side you get that- you have to do a little bit of iteration process to arrive at some value where the C F on the right hand side and the left hand side are equal. Anyway, this is Schoenherr's line, Schoenherr's friction line which was accepted by A T T C- American Towing tank Conference- called the A T T C line.

Till this time, till this line came the background of this is only plancks, smooth plancks stored in water and from there this line, this was the first early fifties. Then, around the same time a gentleman called Hughes was doing a large number of experiments in UK with pontoons which were not pontoon cross section- you see if you want two dimensional bodies and should be nice and smooth like long narrow bodies without any separation effect. And he did a large number of experiments with pontoons where this bodies were wall sided and he did large number of experiments, which is said were also having two dimension flow.

So, he went up to hundred feet length pontoons, moved them in open sea, not open sea, open tanks and collected all the planck experiment, all the pontoon experiment, put all the data together and he came up with the formulation of frictional resistance which is given as: I will use the term CF0 now, 0 indicating two dimensional flow. So, this was the Hughes frictional line. You see there are, this was predominantly two dimensional flow, which varied a little bit from Schoenherr's line, but nearly same- one would not say nearly same- but one would not say same, one can only say nearly same, having differences at lower Reynolds numbers, but at higher Reynolds numbers becoming more or less equal.

Around this time the international towing tank conference was meeting and this was a debate- what should be a ship friction line so that we can use it for model and ship as per our model experimental procedure? And they are debating quite a lot.

In 1957, Schoenherr's line and Hughes line were both brought to I T T C and I T T C reached wisdom, decided that Hughes line was more nearer to two dimensional flow friction line, and with this as basis they formulated a line which is slightly different from here, to make it easier what they did is, this 2.03 that you see here was reduced to 2 and this was slightly increased.

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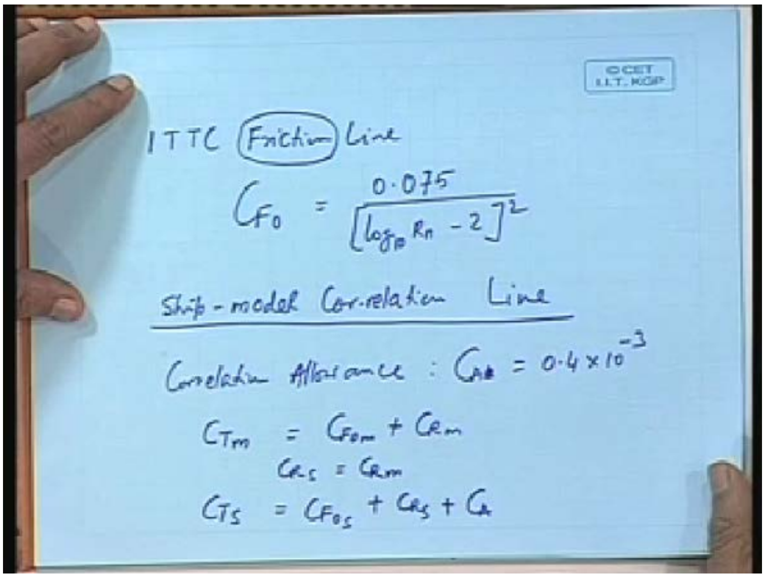

So, the I T T C line came to be, this became the I T T C friction line, which as you can see is slightly higher than Hughes friction. Now, at this point of time I T T C did not want to say this is a frictional line because, though large number of experiments were done by this time for two dimensional flow, whenever you are talking about two dimensional flow there will be a end somewhere- if you have a pontoon, that must have a closure that disturbs the flow.

Plus what happens to three dimensional flow? That was also something not known and people were still groping in the dark and the resistances that were predicted from model experiments were using any of this three lines did not match very well with full scale trails that were done in various, at various times starting with way around in 1800's.

So, there are still some lacuna therefore, I T T C in its wisdom thought that tailing it as a friction line will be limiting it. So, they said this line as ship model correlation line that is, this line will be used to correlate the model resistance with the ship resistance that is, the same line will be used to calculate CF0 for model and for ship, am I clear?

There is another difference between a ship frictional resistance and a model frictional resistance model. Model, normally made of wax or wood finished to very nice finish or f r p is very smooth; and ship is whatever you do, you can never get that smoothness. If we measure the ship roughness in microns, it will be the order of 100 and 25 microns- micron is 10 to power minus 9- and if you measure that for a model, it will be 25 microns- nearly that of glass, a well finished model. So, then, you can see the roughness in ship is much more than the model- that had to be accounted for extrapolation to model scale.

So, apart from that they also said the ship must be given a correlation allowance- this is correlation line- on top of this there must be written, given a correlation allowance CAA they called it or CA as 0.4 into 10 to the power minus 3- for extrapolating the ship resistance, model resistance to ship resistance, that is CTm is equal to CF0m plus CRm; CRm is equal to CRs; and CTs is equal to CF0s- using the same formulation- plus CRs, which is nothing, but equal to CRm plus CA, is that clear?

Now, comes, we still have not talked about the three dimensional effect on friction, ship body is three dimensional; I have been telling this from the beginning. So far whatever formulation we have got, including the I T T C formulation, is predominantly two dimensional- do I make myself clear? - if it is predominantly two dimensional, I T T C has made a very feeble effort at adding a small allowance to Hughes resistance, but it is not really three dimensional, because three dimensional effect on two dimensional resistance should be quite large- should be. So, for this purpose a lot of work has been done and we can try and find out if we can determine what is a three dimensional form effect.

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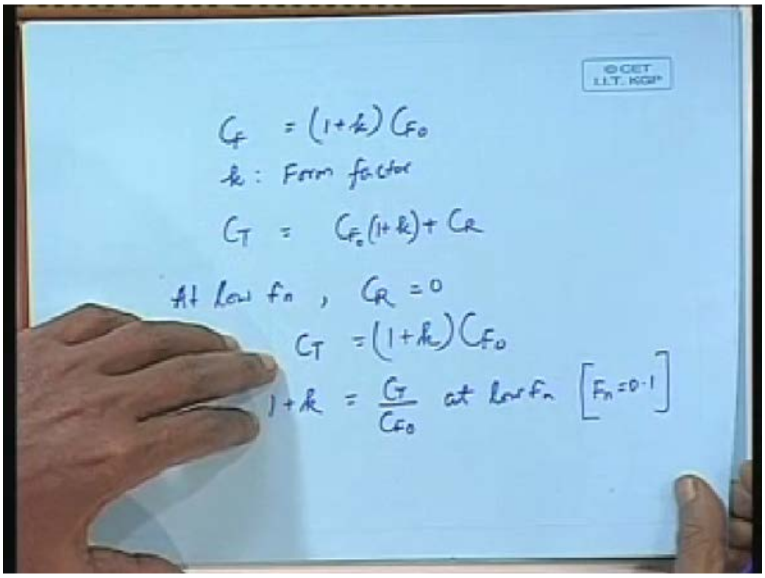

In that case, we can say CF is equal to one plus k CF0; so, CF0 is two dimensional frictional resistance co-efficient and the k is the so called form factor or a factor by which the frictional resistance increases for a three dimensional body above a two dimensional body. It can be understood that CF0 here will be using I T T C frictional line. You see, when we said CT is equal to CF plus CR, this CF was function of Reynolds number, this CR was function of Froude number, now we are saying that, actually this CF is slightly more than the I T T C CF. So, if I say this CF0 into one plus k, if I write it here like this, then this whole thing is depends on Reynolds number, and this thing depends on Froude number, am I making myself clear? The extrapolation laws are different, the CR extrapolation is same as that of ship, CF extrapolation is by using the I T T C friction line which we have discussed, this k is a part of CF. So, previously this k was not a part of CF and it was taken same as this component of k into CF0, was taken same as ship and models (( )) am I understood, are you getting what I am saying or you are not getting?

Now, the problem is, suppose we say this is correct, how do you determine k, how do you determine k, after all when you move a ship we are getting the total resistance, how do you get, in fact, we did not get even CF0 so we have taken a I T T C line, how do we get k now?

We can see, we can use some basic physical phenomena to understand this. Suppose, my ship is moving at very low speed- one or 2 knots- I have hardly any wave making, we have seen that wave making is a phenomena of speed, so if my ship is moving at very low speed the total resistance is only frictional in nature. So, I can tow a model at very low speed, measure the resistance- that gives me total frictional resistance. If I write it down at low fn, CR is equal to 0, so CT is equal to 1 plus k CF0- c f 0 I know-so, 1 plus k equal to c t divided by CF0 at low Froude number, am I right? This is the basis on which we can calculate k for the model and use the same k for the ship. There are some assumptions we have made in this that k is independent of speed, that is k will be same over the entire speed range, otherwise doing it at low speed we cannot use it at higher speed- it is a fair assumption, I do not think it is very unfair, that is a fair assumption.

But there are some practical problems; at low speed the resistance itself will be very low, you know, in any experimental procedure there is always some small error, and this small error over a small quantity when you manipulate with this by dividing things we can get a very large error- that is, k itself can be largely erroneous while dealing with small speeds. If your experiments are very accurate you will tend towards getting the accurate result, but this is a method which has been accepted by I T T C, and if you can do speed measurements and resistance measurements at very low speed accurately this should give you reasonably good value of k. Normally, it is recommended that this measurements should be done at f n equal to 0.1, Froude number 0.1, normally, you should do this speed measurement. There is another method by which we can estimate k value, I will briefly tell you.

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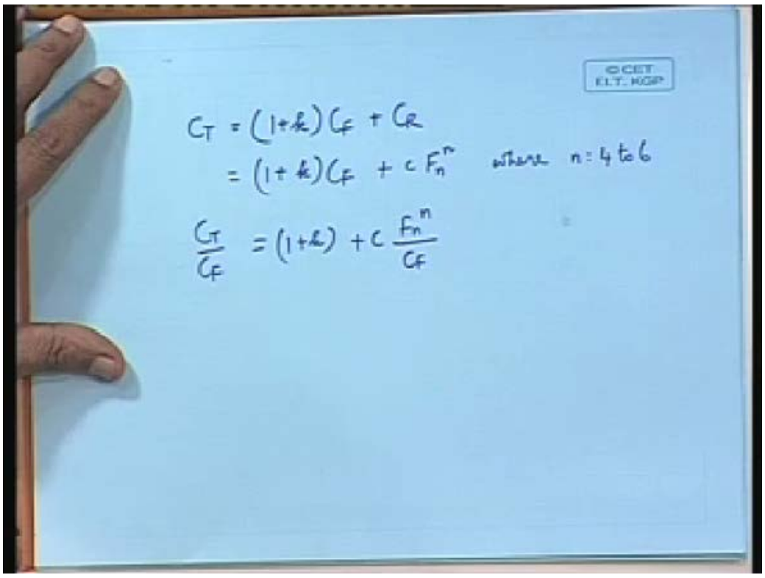

If I write down CT is equal to 1 plus k- now, I can drop CF0 and write CF always, meaning CF means 2 dimensional or I T T C line and when I write 1 plus k it becomes three dimensional- CR, we have seen is a function of Froude number, it can be roughly said to be a function of a power of Froude number between 4 to 6. So, I have this, I divide the whole thing by CF, then I get CT by CF is equal to 1 plus k plus CFn to the power n divided by CF. So, then, if I know this n value and this C value, then I can calculate 1 plus k. Now, this is now possible using some mathematical technique, you can fit a curve to the equation, to a resistance curve, find out the value of n and C to the ((residuary)) resistance and calculate the value of k.

This is other method which is also recommended by I T T C. But as you know since the errors are not constant over the entire speed range, measurement range and neither are there positive errors- always the error can be positive or negative- this type of fitment, regression equation fitment to find out what is the value of n and c can also give erroneous results. So, the result is, why am I talking about all this things? The result is, though we know that there is a three dimensional friction resistance and we make an attempt to estimate it our estimation is always a suspect, am I clear?

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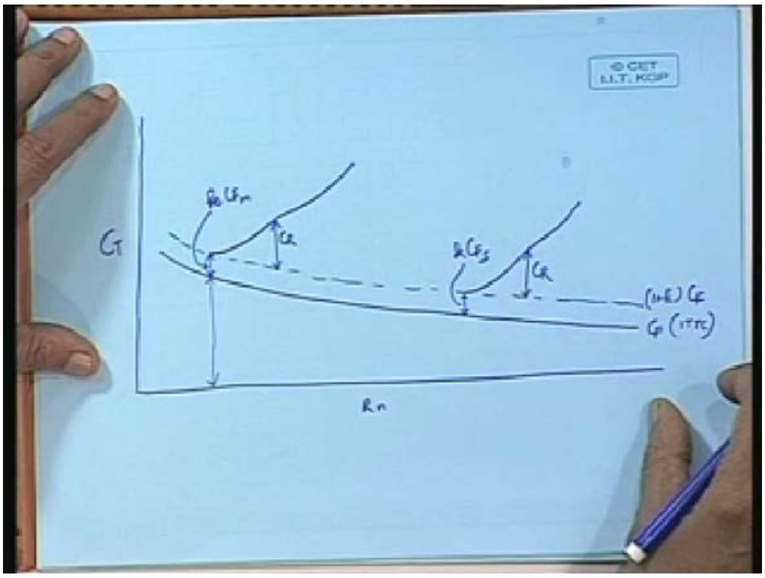

Let us see by plotting the resistance graph what information we can get. If I put Reynolds number here and CT here, CT CF, we will see what. The I T T C friction line will go like this, if you see the friction formulation we have given, you will find it will decrease with increasing Reynolds number, so this is CF, I can write here I T T C so that we do not confused. As the Reynolds number increases CF reduces. On top of this let me plot my model resistance curve, let me plot this; now at lower speed- this is actually low speed, this is higher speed, this Reynolds number range for the model is accelerated here, it would not even be so much, it will be something like this- so, at low speed, as we have discussed, this resistance, there is no wave making resistance or no CR and the entire resistance is CF because this is I T T C friction line, what we see here is our actual resistance is higher than the I T T C friction line, so if we take that as the friction line as if that gives us the k, here this value divided by this value gives us 1 plus k, so if we now plot, multiply this c f I T T C with 1 plus k we will get a line more or less parallel to the this line . Now, we can plot the ship resistance curve on top of this- this is the ship Reynolds number. So, if the, this was CR, same CR will come here; this CR is same, how much is this? This is k into CF, this much; similarly, this much will be the CFm k into CFs. So, this whole amount will be 1 plus k CFs, is that clear?

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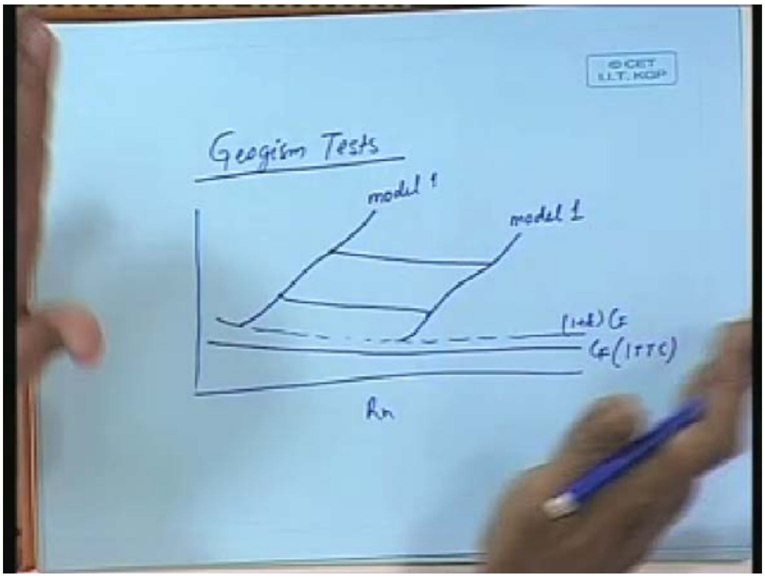

This we can utilize, this principle we can utilize for determining the k by doing a set of tests which is called Geogism Tests. That is, I make two models of the ship to two different scalars; I can make a model of 5 meters length of a 125 meter Blasius scale- 1 is to 25 ratio and another I can make 1 is to 36 ratio. If I do two models and I get these two curves- actually, this is Reynolds number- I get a CT of one model and a CT of the other model; then, at the constant Froude numbers the CR will be same and the remaining part will be one plus k CF ; if I got my CF here, CF ITTC already got, and if I join the same Froude number lines, this should be parallel to each other if what I am telling is correct because the CF is same, and from here I can see which line it is parallel to and I can draw them as one plus k CF.

See, in this case, we extrapolate it- please understand this- this is ship, this is model; in the previous case, we had only this line and we had this line, we estimated k and drew this line, plotted this and found the ship curve, we extrapolate it. Here in Geogism test this is model 1 and this is model 2, both these are available with us, both the data is available with us- understood?- so, it is easier for us to calculate the k by drawing the constant Froude number lines right till the end and if there is an error we can fair the curve so these are parallel to each other because the CR is constant, and then we can have a better estimate of k value, am I clear, no?

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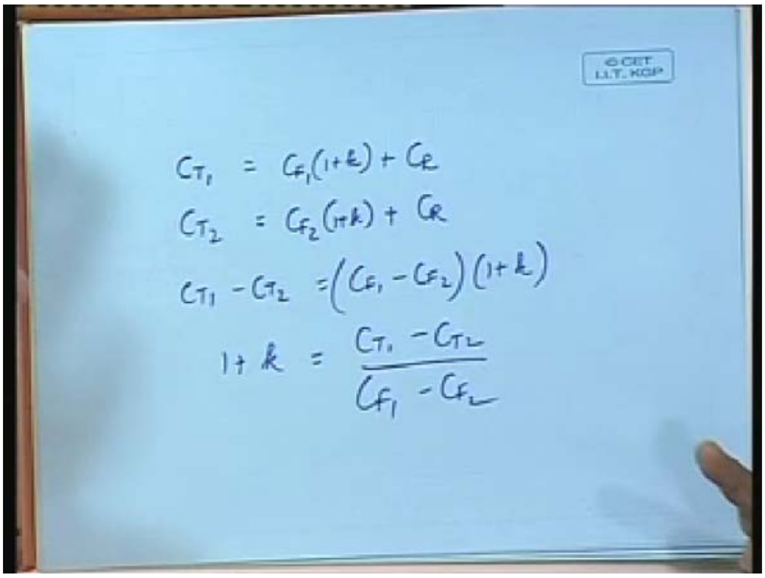

CT model 1 is equal to CF into 1 plus k, CF1 into 1 plus k plus CR. CT model 2- remember, we are doing at corresponding speeds, I need not mention it every time- CR is same. So, now, deduct CT1 minus CT2 is equal to CF1 minus CF2 1 plus k- all these four quantities are known. Yes, we do it for a number of speeds, number of Froude numbers, and you will get 1 plus k values, they should be same, but because of experimental inaccuracies you will not get the same values, but you will get nearly same values and we can take the average, that will give us the exact k value. From Geogism test it is possible to estimate the k value exactly, but of course, it is very expensive and should we be doing it at all, should we be doing the test so much, what are you looking for? You are looking for an estimate of resistance so that you can satisfy the trial condition requirement and the service condition requirement.

Service condition requirement as we have seen is not very well known, we can just leave a margin on the trail resistance to satisfy any service condition. We will go for more accurate prediction process- spending more money by doing Geogism test or whatever only if it benefits us in an economic sense. Now, if, suppose we did not use k, what will be extrapolated?

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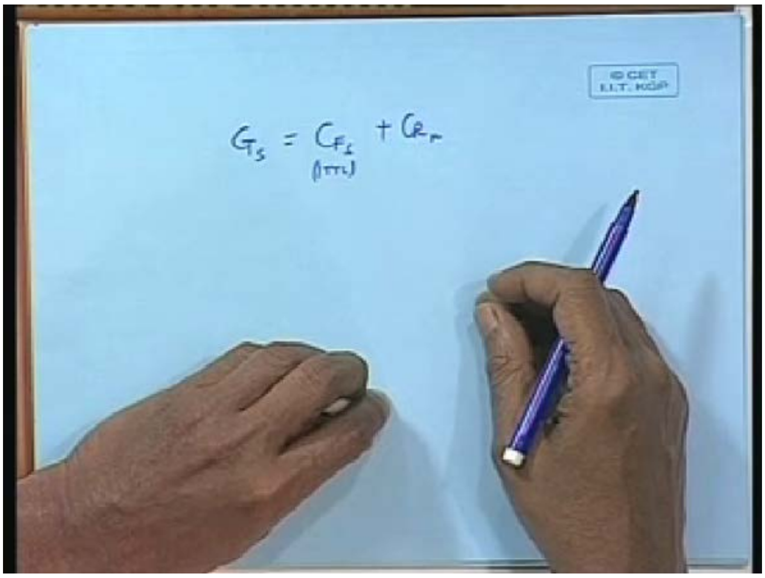

Suppose, we extrapolate ship resistance as this only, this is as per I T T C, and CRm as we have calculated by deducting I T T C, what are you doing, are you over estimating the ship resistance or are you underestimating, can you tell me, if we do not use one plus k what are you doing we are?

For the ship we are overestimating, we are on the higher side because the CF which is reducing the speed is a small value, we have not multiplied with 1 plus k, CR has remained same, more percentage of resistance we have taken to the residuary part and that is remaining same. So, actually, you are predicting the resistance which is higher because you have ignored the three dimensional frictional form effects. So, you are on the safe side. If you take from factor, then you will become more accurate and your power prediction will reduce. So, that is beneficial from the point of view of actual economy- did you get it?- but it is fraught with the danger if it is not estimated properly, then you may underestimate this. So, the k has to be estimated very well, if you are unable to estimate k properly, do not use it- that is the advice that can be given.

So, if you look at the towing tanks world over, you will find that sometimes you use a form factor sometimes you do not use a form factor, I T T C has left it open by saying that the phenomenon of three dimensional frictional resistance effects are not very well known, is that clear? So, now, you do your model experiments, the procedure is known to you and you can extrapolate from models scale to full scale. We will stop here, thank you.

Preview of Next Two Lectures

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Performance of.

Marine Vehicles.

At Sea

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Lecture No. # 05

Wave Making Resistance

Gentlemen, yesterday, we had seen, we have talked about frictional resistance of ships, let us talk about wave making resistance today.

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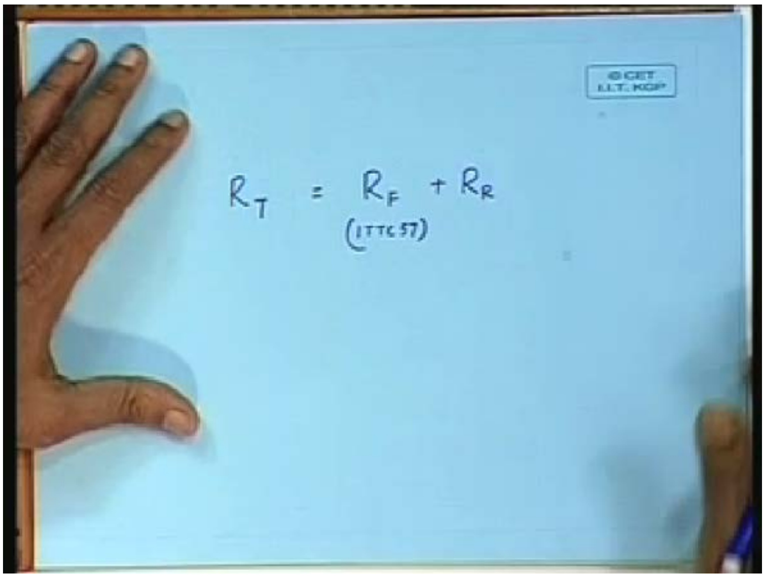

But before that just to brush up we had said before that total resistance of a ship comprises of two parts, that is, RF plus RR, frictional resistance, plus residuary resistance- this was based on Froude's law of similarity. R f, we had seen is primarily the two dimensional frictional resistance or something similar to flat planck resistance, frictional resistance. This RF we said we calculated using I T T C frictional line of 1957 and the residuary resistance was told to be the remaining part of resistance. If we divided the ships total resistance into two parts, that is, the two dimensional frictional resistance RF, then the remaining part of the total resistance was called the residuary resistance.

If we go back further than that, in our first class have decided the various components of resistance, which we will again see in the next lecture, you will recall that we had said that the frictional resistance, the two dimensional frictional resistance alone is not the total component of viscous resistance, there would be some other components of viscous resistance, which may be small in quantity, but they are there and they are not included in this I T T C fifty seven line. Similarly, when we talked about pressure resistance, we said the pressure resistance is equal to the wave making resistance, but there could be some interference between the frictional resistance and pressure resistance there by giving something we called viscous pressure drag

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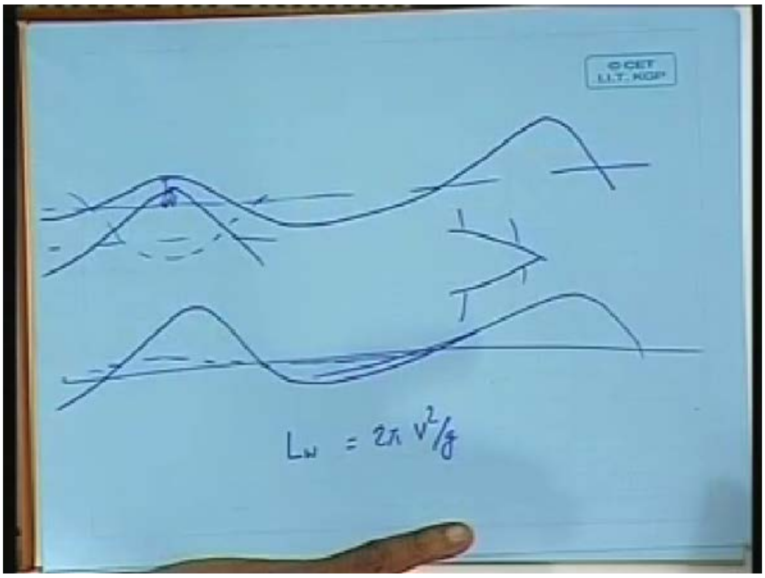

I have got a wave like this, now I have got another set of waves starting from here going like this, and this is my water line here, and this is for this wave, this is a water line. If I add this up what am I getting? This wave will come like this, as it is coming and here it will increase, this plus this- is it not- and this is after the ship. Therefore, it will push the ship forward, we have seen the pressure increase in the aft, supports motion- is that clear?- that means, the resistance will reduce, yes.

On the other hand, if there is a trough here, suppose this was a tough, then what will you get? This will flatten out that means, the support that you were getting, at least here, you are not getting any more, so there is an increase in resistance, am I understood? So, the interference of the waves will either increase the resistance or decrease the resistance, or it may not matter- any of this can happen- this interference will depend on the speed of the ship. Now, when the wave is moving forward, the ship is moving forward- since it is generating waves- as it moves forward the transverse wave will have a velocity equal to the velocity of the ship.

Therefore, the transverse wave length, wave length of transverse wave will be equal to two pi v square by g, where v is the speed of the ship. You imagine this is my ship, they are the transverse wave, these waves will move at the same speed as the ship. I have identified wave crest as one parameter which will give me the wave making resistance, forward wave crest is the prime component of the total wave making resistance- prime variable. So, to reduce that one of the matters I can adopt is to reduce the angle at the water line itself because as I go down the effect of the slope will be reduced on the free surface, I know that, it will be there, but it will be reduced as the height, as the point dips more and more below the free surface. So, maximum impact is of that slope near the waterline. So, if I can reduce the slope on the water line, then I can control my wave making resistance.

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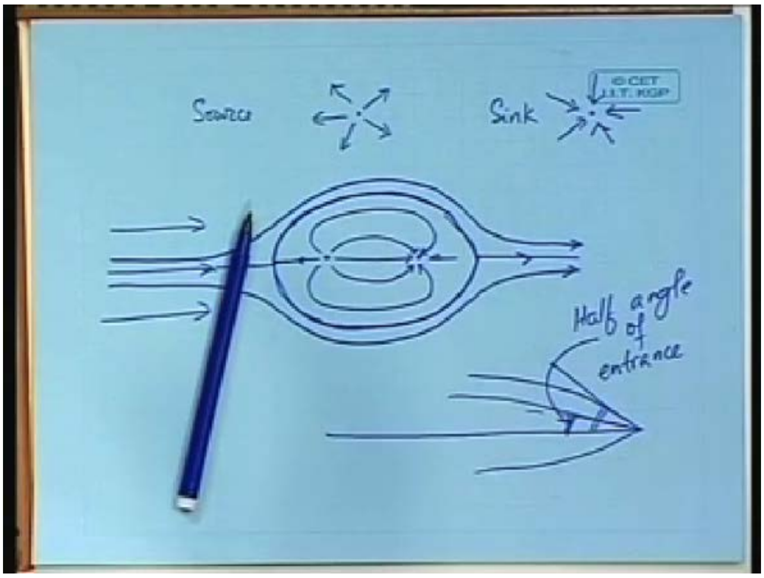

And this angle is called half angle of entrance, is that clear? So, I have, we have seen the effect of length on wave making resistance, we have seen the effect of speed on wave making resistance, now we have seen the effect of half angle of entrance. Now, this gives you a very interesting observation, if I reduce the beam, see after all a ship has to carry a lot of, it has to have a particular volume of displacement, that I can give over smaller length larger breadth or longer length smaller breadth. So, if I have a narrower ship, then this angle will be less that is, if my l by b ratio is increasing, then my wave making resistance is coming down, my half angle of entrance is automatically down- that is one way, and there are many other ways. In the next hour we will see what is the effect of the (( )), thank you.

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Performance of.

Marine Vehicles.

At Sea

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Lecture No. # 06

Other Components.

Of Resistance

Good afternoon, we will talk about other components of resistance. We have actually seen how the frictional resistance around a ship can be estimated, we have seen the physics of wave making around a ship hulk (( )), we have also seen that waves when they interfere with each other it can be supportive to motion or opposing the motion. Basically, we have seen that wave making resistance has a component, a major component which is proportional to speed raised to the power six and over which there are small humps and hollows created due to interference of the bow stern and half shoulder, forward shoulder waves- this what we have seen in the this thing.

Now, can we utilize this interference in a manner that we can reduce the bow wave component itself? We have said before that if I have a submarine below the water surface I will still have a wave effect, just below the water surface, because the depth is not very large, so that the effect will not be there, can we utilize this? For example, I have got a ship which generates a bow wave system, can I have a body, a sphere for example, somewhere below the surface in the front of the ship, which is placed in such a location that it creates a wave turf, where a bow wave crust exists. Cform is the form component which takes it to account the major difference, the major portion of the augment of resistance, augment of viscous resistance over two dimensional form factor, two dimensional friction resistance, do you get my point?

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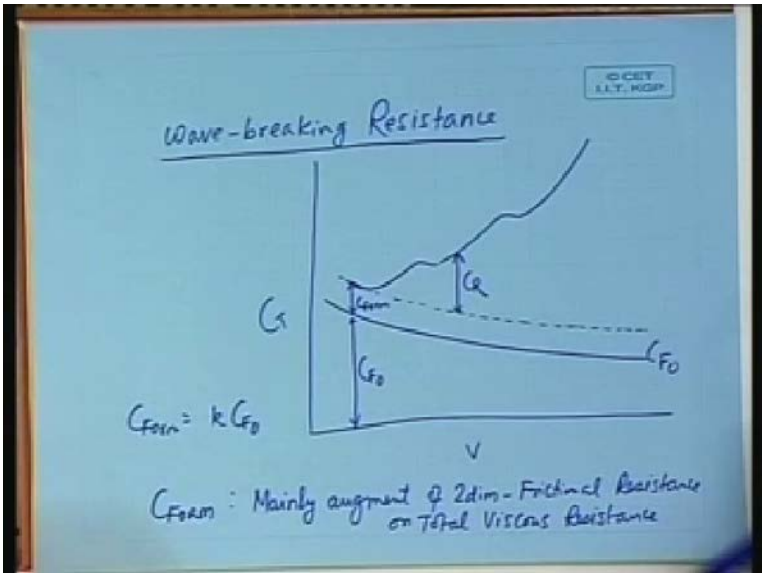

That is, Cform I can say is mainly augment of two dimensional frictional resistances on total viscous resistance, so we can say c form includes the three dimensional friction form effect, it also includes some amount of separation drag component and viscous component. Imagine, separation we have said is related to velocity and pressure, they will change with velocity of the ship so if it something at low speed, it cannot be the same at high speed. So, truly speaking we have not taken this into total account, that is why I am saying mainly- the word mainly is important there, it is no total.

There is a problem here, we have already discussed for a normal ship how difficult or how accurate it is to extrapolate to full scale, in the, we have said the c form- form co-efficient, we have talked about- we have said there are some inaccuracies and is not exactly understood. On top of that you have now added appendages, so extrapolation may create problem. So, to be on the safer side one could do a naked hull resistance test and another the hull modified with appendages and test it; so, estimate the appendage drag separately, and extrapolate the ships naked hull resistance separately and appendage resistance separately and add them together- that is another way you can go ahead and do it.

So, these are some of the methods by which the ship resistance can be estimated and extrapolated. We will talk about extrapolation once again because that is the most important thing- accuracy of the extrapolation method to full scale for power prediction.

We may look at this if time permits once again later on. What other resistance can be there, can you name? For very high speeds there may be a spray drag or if the rudder or some such appendage is piercing the water, it may generate spray. So, there can be sometimes a spray drag, but normal ships do not have this and even then the spray drag may be of less magnitude, so we do not normally consider it. And if we go for higher speed, the high speed crafts the resistance characteristics quite different and we will talk about it when we talk about when we talk about high speed crafts. Thank you.