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 form, 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 wave 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 trough, where a bow wave crust exists, is it possible for me to do it? That is, if I have a bow wave like this, can I have something which will create may be a wave like this?

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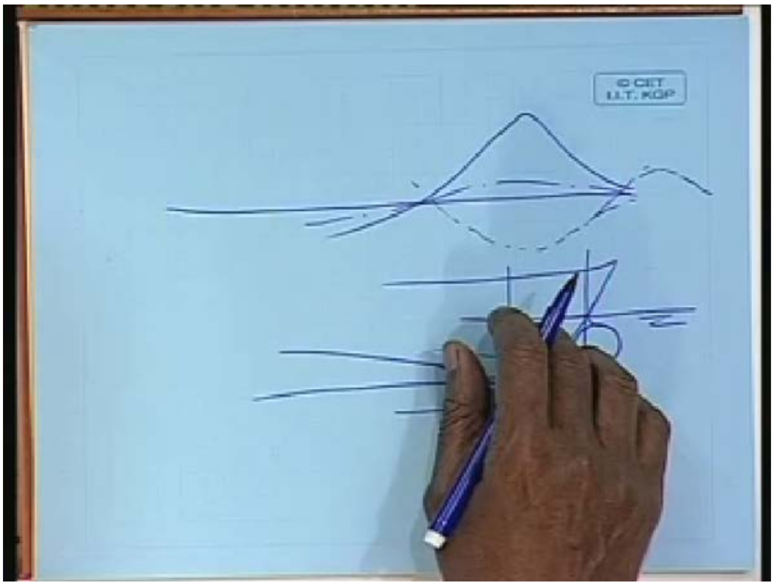

If I can, then you see this much will go out, so I will have a much reduced bow wave. And if I can design something which will generate me a wave of this shape, so this wave may come from a ship like this moving at this water level and this may come by putting a sphere here, and so I generate a bulbous bows. Bulbous bows have been in existence for long time, people did not know what is the effect of bulbous bows, but today it is fairly well known that ships who have a large component of their resistance as wave making resistance, if we have a forward bulb, then that can be controlled.

As I told before please do not think that we can make the wave free surface totally flat and wave making resistance is zero, that is not possible, what we can do is we can reduce the amount of wave making by reducing the forward crest of the bow wave which is the prime component of wave making resistance, and ways of doing it is by putting a bulb in the forward end in a manner that the crest of the bulb opposes the crest of the bow wave, or crest of a bow wave superimposes on the trough of a of the bulb if I could do like that.

Now, it has been found that if you give a bulbous shape this happens, the crest height reduces, the bulb, you have to be very careful in designing it because it can also add as we have seen. So, we have to be careful in designing in such a manner that the total height reduces.

What are their effects, the bulb has? I am bringing down the volume below by putting a bulb here, the volume that was here, I have brought it down- do you understand that?- my underwater volume increases therefore, the volume distribution of the free surface, area distribution of the free surface reduces. So, now, I am in a position to give a water line which is finer- can you understand that?

If I draw a section here, it will be like this, if I draw a section here, it will be something like this; so, we can see this and this are may water line widths here; so if I draw a water line here it will look something like this; this is my half angle of entrance. If I did not have this area below, then how would my section would have looked? Like that. That means, I would have had this breadth at this point that means, I would had a large breadth here. I talked about half angle of entrance, you can see by putting a bulb I am reducing the half angle of entrance considerably. Because I am reducing this I can also smoothen my shoulder, do you understand? So, I can do a lot of design exercise; if I put a bulb, my water line is more nicely shaped and supports reduction of wave making resistance apart from the interference effect. But one has to be careful that the bulb does not add the crest of, the crest due to the bulb wave and the ship bow do not coincide, is that clear?

So, that is the interference. So, this is one component of the other component, so called other components, we have wave, this is all part of wave making resistance, but wave making resistance is as we have seen is proportional to v to the power six, a constant power plus interference due to four wave systems, four oscillating terms interfering with each other and giving a addition to wave making resistance. We can design a ship with a bulbous bow in a such a manner that is oscillating terms can be drastically reduced. So, you can get some support by designing a bulb, bulb has also other effects, we will see that a little later in this lecture itself.

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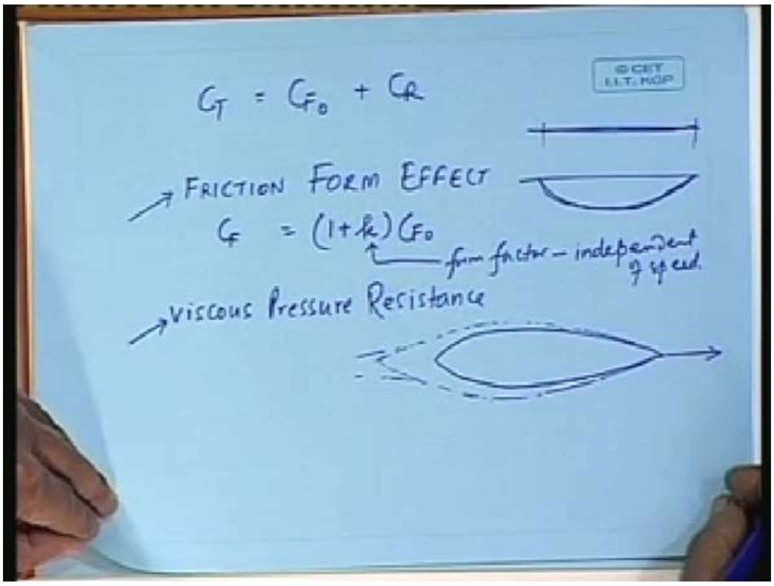

We have seen that CT is equal to CF0 plus CR where CF0 we have said is the ITTC based frictional resistance coefficient, which is primarily the two dimensional frictional resistance coefficient. Now, about the ship shape is actually three dimensional, there are two effects that happen: one is that the, compared to a flat plate the water line has to travel a longer distance because the ship is curved, a flat plate and a curved plate, if I take the same length, because Reynolds number is depended on length, the Reynolds number the flat plate and the ship is same.

For the same Reynolds number if I take the same length, then the water has to travel this distance whereas, here the water was travelling on this distance, is that right? So, therefore, there will be an addition to frictional resistance in three dimensions, in fact, I have drawn it in two dimensions, in three dimensions when there is a vertical component also that water, the length that a water particle travels should be still more understood. Also another thing will happen, as we have said before, because of the existence of a boundary layer the pressure distribution will change as we go to the aft, forward end the boundary layer is nonexistent, but as we go to the aft the pressure distribution will change and that will change the velocity magnitude of the water particle on the ship form. So, you will have generally a higher velocity in the mid ship region and lower velocity in the aft region- if this happens, the frictional resistance will change again because it is a function of velocity after all.

So, there will be, this is called the friction form effect- the effect is primarily three dimensional effect over two dimensional effect. So, if I write total frictional resistance as CF, I would like to write it as 1 plus k CF0 where k is the form factor and one assumption I make, this is independent of speed. Let us see what happens to pressure? I have got a ship here, let me draw a ship, this is the ship going in this direction, a boundary layer develops and it does not close at the end, there is no way the boundary layer closes, this water inside the boundary layer is being dragged along with the ship because the water is having less speed (( )).

We have also said that the boundary layer is defined, thin boundary layer is defined, by definition, the flow beyond the boundary layer thickness is of potential nature- is it not?- we have said that the nearly total velocity, fluid flow velocity is reached the end of boundary layer, what does it mean? Flow beyond this is potential nature. So, what happens, strictly speaking, as if the body is elongated, instead of being this body it becomes this body with slopes much less than the original body, so the pressure distribution changes than if there was no viscosity. And since the slope reduces, the contribution of aft body for, aft pressure, forces for reducing the resistance reduces. So, effectively you have an augment on the pressure resistance because of the existence of boundary layer. The waves get damped, pressure is getting damped actually, high pressure is becoming slightly lesser pressure. So, the waves that would have been created by the stern wave has now got damped, am I clear?

So, this is adding a portion to the total resistance because the support that it was given is not there anymore, it is reduced. So, the augment of pressure due to existence of boundary layer is called viscous pressure resistance, so you have this, you have the viscous pressure resistance.

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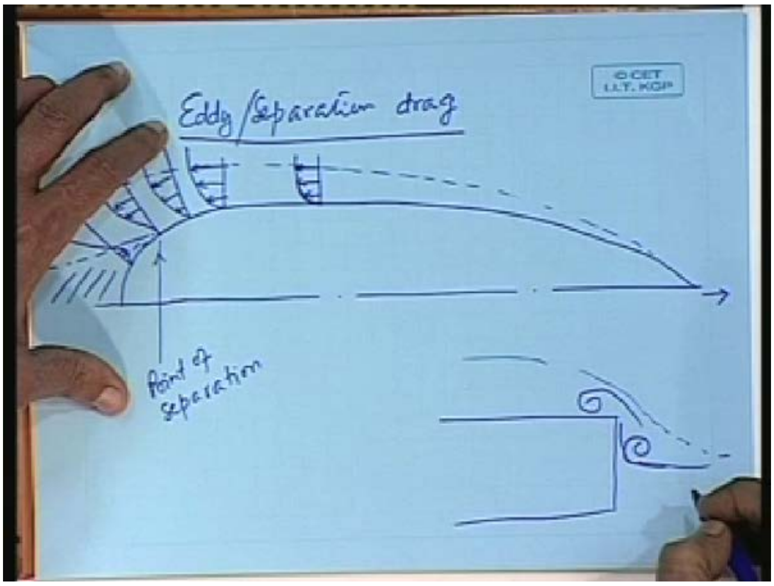

And apart from that because of the shape of the body and boundary layer you also have eddy or separation drag, what is this? We have seen that the slope of the body is an important parameter in determining what should be the pressure on the body; when we talked about wave making resistance we said slope of the body determines the pressure distribution. In the forward part pressure increases if the slope is moved; in the aft part pressure may reduce if there is a drop in- you remember in the pressure curve there is a peak in the aft, but just forward of aft there is a drop at that place, if I have a large curvature, then the pressure will drop further, pressure will drop means, velocity will increase.

Imagine the other way, pressure increases because of the slope closing the aft of that drop, if you consider, if you consider aft of that drop, pressure will increase, because of curvature there if the pressure increases further, then the velocity will drop- there may come a point and velocity becomes zero if pressure drops to a, pressure increases to a large extent due to curvature closing of the body the velocity may come to zero. And if the pressure increases further the velocity may reverse itself that is, I will explain this by means of a diagram, you will understand.

Now we have a boundary layer developing around the body. If I take the velocity profile here, since the ship is going this way, if I take a velocity profile here, it will go like, this we have seen, this is the velocity profile, the water flowing past like this, at the end of the boundary layer it is nearly equal to six feet, here also same thing, but now slope has not started. So, let us repeat this. Now, it has started sloping. So, what will happen here? If I draw a velocity profile perpendicular to the ship hull, there is an increase in pressure therefore, decrease in velocity and that will affect the point near the body, so instead of going like this it will start going like this, where this velocity is reduced; go a little further down you will get a point where the velocity will be zero; and if you go further down, the water will start moving in the direction of the ship itself- do you understand?- this is happening because of the large slope of the body here, large curvature. So, what happens, as if a layer is being formed here with this being the zero velocity point where this flow is separated flow, inside the boundary layer- clear?- this is the point of separation.

Now, this separated flow will affect this portion, it will affect the wave making, it will affect the potential flow, all the that will happen, but basically there is small vortices will be formed inside this will take more energy than what the boundary layer alone would have taken. So, you will have this track coming up for bodies that are blunt, the same thing will happened in the forward end- mind you, forward end is not different- if I have large slope at the forward end, then the water will find it difficult to negotiate the large curvature and it will separate.

Typically, if I have blunt end at one extreme, if I say the water here cannot turn like this, the smooth flow will be like this, but within that this will separate here like this, and similarly here eddy will be formed. So, there will be two points of eddy making here as you can see on a blunt body, it can also happen underwater when the, I have mentioned this to you before near the bilges, forward bilges, the flow cannot negotiate the soft curvature at the bilges and it will separate, same can happen in the aft end, clear?

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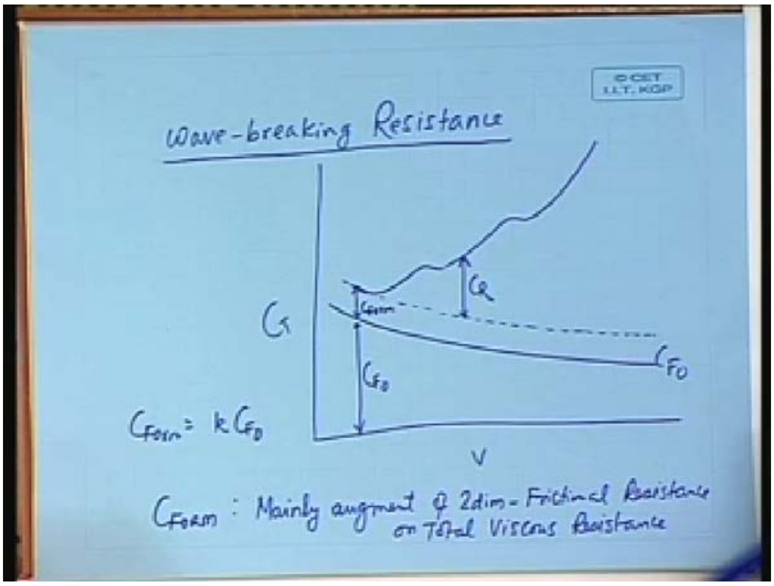

So, you will have this separation drag, which is, which will be a part of the total viscous track, then you will have... We have mentioned this before, wave breaking, wave breaking resistance, the breaking of waves due to stiffness of the wave- the slope cannot be, the wave slope cannot be maintained by the wave itself, so the wave breaks. This will happen when the waves generated has a shorter length and larger height, and this is a phenomenon typically of full form ships having very large angles of entrance in bulk areas and tankers. Wave breaking can also occur at the stern- stern wave can also break for the same reason.

The point to notice, that wave breaking also will reflect itself in viscous resistance and if we can reduce the pressure distribution around a blunt form, then it is possible to reduce the wave breaking resistance itself because there will not be any wave breaking. If you can reduce the wave slope by reducing the height of the wave generated, then it will not break and then we may reduce this component of resistance. Why I bring this up? We talked about bulbous bow at the beginning; we said that when the wave making is large if I put a bulb, then wave making will be reduced.

Now, if you take a container ship with a Froude number of about 0.3 or a passenger ship, wave making resistance will be nearly sixty to seventy percent of the total component of resistance, and by putting a bulb we can reduce that component of resistance, frictional resistance remaining more or less same. But when you come to a tanker bulk area, super tanker bulk area, which has a Froude number of 0.15 to 0.2, moving at very low speed compared to its length, we are talking about two hundred to two hundred fifty meter ship moving at fourteen knots, sixteen knots, we can calculate the Froude number is very low. Wave making resistance is only ten to fifteen percent, most of the resistance is viscous, but we still find ships with bulb there, why do we have a bulb there? The bulb basically reduces the steepness of wave making at the forward end and therefore, this component of resistance, wave breaking, reduces. The resistance created due to breakage of waves comes down, so we can reduce that also by a bulb. So, bulbs are today used across the ship forms for high speed forms as well as for low speed forms, but the design considerations are different- where there you are trying to reduce the wave making itself here you are trying to reduce the wave breaking.

Now, we talked about form resistance and we said that the form resistance is primarily the three dimensional form resistance, three dimensional effects on friction, but we have got this other component of viscous resistance now, viscous pressure resistance and we have got wave breaking resistance, how do we take this into account? We take all these into account in something called form resistance, do you understand? Now, let us say there is a little gray area here, I want to make it clear that there is a gray area, if I draw the CT curve against speed; if you remember the CF curve would have gone like this, CF0, and we said that the wave resistance at the low speed range will first, the coefficient of total resistance at low speeds when there is wave resistance will follow the CT curve, and then it will go up like that, this is what we had said and therefore, we had said that when the wave resistance is zero, that C T, this we had called Cform- right, am I correct?- and this then we had said as wave making resistance or CR, let me call it C R- and this CR was primarily wave making.

Now, we have talked about other resistance components like separation, we have talked about wave breaking and all these, how do we represent them in this diagram? Whatever component of resistance existed at low speed we have taken this into account here, and those components of resistance that come at higher speed they are not represented in this line, so, perhaps, they are represented in this residual resistance component- are you getting me what I am saying or not?

What is this Cform? We have defined it as the three dimensional friction form effect. That is, Cform we have said is equal to 1 plus k CF0. So, total frictional resistance is 1 plus k CF0. But now we have said about other small components of resistance which may exist, like separation drag and like viscous pressure drag etcetera. We are not very sure that this Cform has some of these components. So, may be they are in this Cr where the major component of Cr is wave making resistance. So, it would not be fully scientifically correct if I say Cr is equal to CW and Cform takes all other components of resistance- that may not be fully correct.

Therefore, to this extent we can say Cform is the form component which takes into account the major difference, 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? That is, Cform I can say is mainly augment of two dimensional frictional resistances on total viscous resistance. So, we can say Cform includes the three dimensional frictional 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 is something at low speed, it cannot be the same at high speed. So, truly speaking we have not taken this into total into account that is why I am saying mainly, the word mainly is important there, it is not total.

Why is this important, why are we talking about this? Because this forms the basis of extrapolation of resistance to full scale; we have said at the beginning a theoretical exposition of resistance is till now impossible- errors are too large. Therefore, we have to have an experimental method by which we can estimate resistance of a ship from model and extrapolate to full scale- and this is all important for full scale measurement that is why this is being talked about.

You can imagine as the ship becomes fuller and fuller this component starts playing more and more role and therefore, we get into an inaccuracy zone which is higher as you go to fuller and fuller ship. For example, if I have a bulge, with a flat ended bulge where there is large amount of separation at the front end, this method of extrapolation may not be very accurate- do you understand? Froude’s method of extrapolation works very well for normal ship forms, where the components of resistance we have defined that is separation drag, the viscous pressure drag etcetera.Wave breaking drag, acts small compared to total resistance and we have taken that in account in some form in this Cform, is that clear?

Now, what are the other components of resistance that we are interested in when the ship goes to sea? We have talked about correlation allowance- we have talked about it before? I think I did- That is, when you do a model experiment, the model is very smooth and when you come to a ship, a new freshly painted ship, the smoothness of that surface is slightly different from model.

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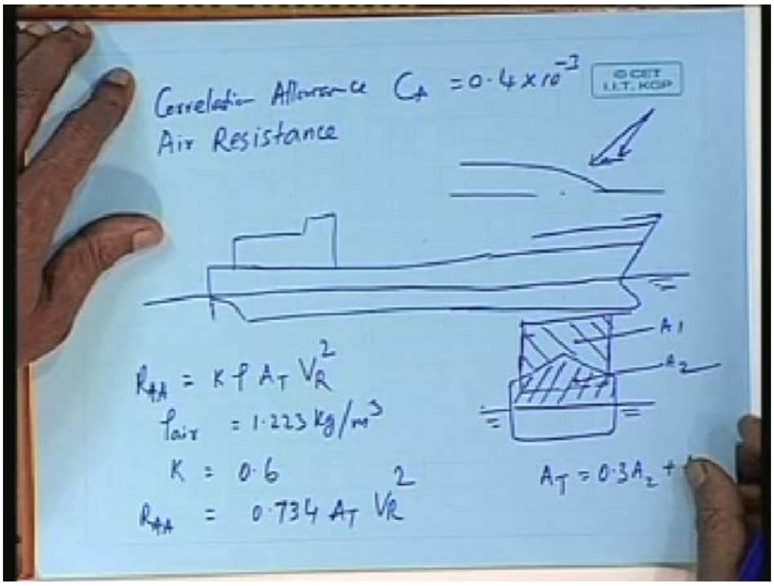

So, to take into account the roughness of the surface we put a small allowance called CA, or correlation allowance; CA equal to 0.4 into ten to power minus 3- this standard is recommended by ITTC, but ITTC in 1978 has updated it, we will see that later.

You can imagine that if the ship is very long, you have a CA of 0.4 into 10 to the power minus 3, also if a ship is very short, but you can imagine the roughness will play a more role in a shorter ship than in a longer ship. So, roughness allowance will be proportional to, or will be somewhat dependent on length. So, now, ITT C has given a formulation for correlation allowance which is dependent on length- that is given in 1978 ITTC resolution.

Then, for trial condition, for ship trial, there is another component of resistance which we must take into account that is, air resistance. When you talk of resistance to air we will mainly consider air coming from front and we will not consider the waves generated due to wind. Suppose, it is totally calm, there is no wind and a ship is moving, will it experience any air resistance? It will experience the same way as water resistance, that body is moving in still air as if air is moving past it in the other direction. So, in still air, air velocity is equal to ship velocity, the relative velocity of air with regards to ship is equal to ship speed; but if there is a wind blowing then, if it is a wind blowing head on, then it will be added to the ship velocity, if it is supporting, it will be subtracted, but if it is wind blowing at an angle, then you can resolve it; if the wind is blowing like this and the ship is going like this therefore, the wind is coming like this and the component of, resultant component will be something like this. We can actually calculate the resultant wind velocity on the basis of which you will calculate resistance, clear?

Now, we are mostly interested in the drag to forward motion. So, wind coming from front, when wind coming is coming from front, what is the windless area that it faces? Let us see. The ship is like this, this is the upper deck, there may be a forecastle, there may also be a bulwark, and the wind is blowing from here, so that entire frontage of the ship above the (( )) line will come into play. If I draw a section of that, and this frontage will increase as we go forward to a full mid ship section, mid ship body, so the frontage, the middle of the ship looks like this, this is the water line and this till here it will look something like this, from front if I look- do you understand?

So, the transverse area projected to the wind is this area, this point being this point. Then, you will have, far away from here you will have the superstructure here. Now, this superstructure will start from somewhere here, it will go up something like this, so, this much of superstructure you can imagine to be protected by the ship, truly it is not because the distance is large, but temporarily we can assume that this is protected and this is the area. So, if I call this A1 and this as A2, then the resultant transverse area can be written as 0.3 A2 plus A1 that is, 0.3 times this area into this area plus this area. So, this is the total transverse area used for calculation of air resistance, I am not saying this is a scientific method, I am saying this is the transverse area used for calculation of wind resistance.

And wind resistance to forward motion if the wind is blowing from front is given as, I am just giving you a formula, wind resistance is fairly completed, where I give a formula why a formula? Because when the wind is flowing past the ship unlike water it is not flowing past a streamlined body, the transverse area is not a streamlined body, it is all flat, superstructure take for example, superstructure it gives mainly eddy resistance rather than nice pressure resistance, most of the resistances caused due to wind air because of the blunt body, so you have separation and eddies. So, this can only be estimated by experiments.

So, lot of people have done wind tunnel experiments to find the wind resistance and statistically it has been shown that wind resistance RAA is- normal representation is R double AA- k rho AT VR squared where VR is the relative velocity in the direction of the axis; AT is calculated like this, rho is the air density equal to- how much is the rho?- 1.223 kg per cubic meter, and k is a constant equivalent a drag coefficient which is given as 0.6. So, this is the total air resistance is given as 0.6 rho AT VR squared, which if we take the Rhoair as this, then RAA can be given as 0.734 AT VR squared.

Now, there is a very interesting phenomenon in the wind resistance case. If the ship is very tall, if it has got large windless area on top, then there is a problem, because the wind velocity changes from the water surface to a height.

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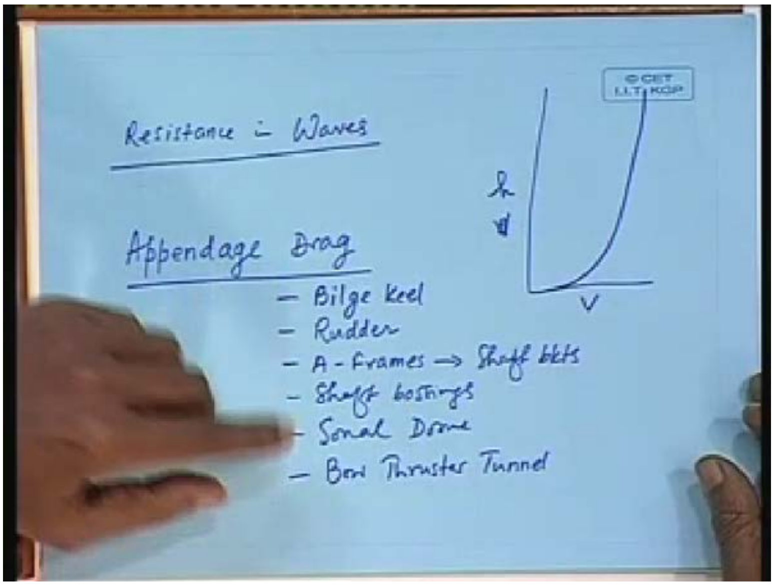

Water surface, you can imagine there will be friction between wind and water, so theoretically the wind velocity is zero and it will very quickly pick up to full speed. So, if I draw a height, wind velocity in this way and height this way, then wind velocity will go like this. So, therefore, the area near the water surface will have less effect than area far away, that is why in this AT formulation this is taken into account by reducing the lower end of area- if there is a tall ship, then you must calculate the height based on this formulation.

There is another problem with windiness. Suppose, the wind is blowing at an angle- the ship is a long narrow body- if the wind is blowing at an angle, then it generates some sort of a perpendicular force equivalent to lift; if I have a long narrow body and fluid is impinged upon it at a small angle, then you generate a perpendicular force which is called lift force. So, same thing happens in ships. If the wind is blowing at an angle, then the axial component of velocity- the resistance that you calculate by using this formula at an axial component, as the axial component- you will find the actual axial resistance is more than this till about thirty degrees of angle of attack, the wind resistance will increase, then only it will decrease, and mostly in the beam wind condition, it will be very high, it will not decrease, it will increase slowly because as the wind direction changes the area exposed to wind increases, beam wind condition you get maximum drag in that direction, transverse direction, axial direction is zero, is that clear? So, this is wind resistance.

When you do the trial speed prediction you have to add the correlation allowance and the wind resistance, allowance due to wind, because I mentioned to you that normally the trial condition is specified as: at zero before, or before three. So, zero before wind speed means, wind speed is zero, so the relative velocity of wind is equal to ship velocity; and if it is before three, then you have to add the wind speed to the ship speed and do the calculations to get the total wind resistance. It is assumed that at before three, the sea condition does not change, if the sea condition changes, or at sea whether there is wind or not, but there is wave may be as well, may be a wind, a wavy condition created by a wind which has blown away at mid seas, then there is an augment of resistance due to- it is called resistance in waves.

The ship already has waves, it is not the ship waves, the ship, the sea has waves and the ship has to negotiate the waves, then, there is an augment of resistance called resistance in waves. Now, this is something which is not required in trial condition, because normally we will take out a ship for trial when the sea is calm, but in service this will invariably be there at sea. So, we have no way of knowing what is the resistance of a ship in a random sea condition. Or even taking a simplest case of a sinusoidal water wave, whether, what will be the augment of resistance for a ship moving in a wavy condition where the wave profile is sinusoidal- we have no wave knowing. So, most of these are experimental and we have to do large number of experiments to know what will be the augment of resistance in various wave conditions.

Such experiments have been performed on series 60 ships in the David Taylor model based in USA in the 60’s and 70’s. And data is available for average increase in waves in various sea conditions. As I mentioned to you the sea conditions vary depending on the sea itself apart from the time or the year etcetera, for example, North Atlantic is generally rougher than the pacific. So, the augment of resistance in North Atlantic will be more than in pacific. So, to avoid doing a theoretical calculation, which is inaccurate and not available, and also the sea condition is not exactly known, what we do is we add a percentage of resistance to get the resistance in service condition. Normal standard is about fifteen percent increase in the resistance that we have estimated as the service allowance- that gives us the resistance in actual service condition.

We have not talked about the appendage drag, I had mentioned it to you before, but we have not really talked about appendage drag that is, attachments to the ship on the outside of the hull and typical attachments that merchant ships have or conventional ships have. Let us name a few, first that comes to mind is bilge keel, then you have rudder- yes, sorry- A-frames or shaft brackets, shaft bossings, in naval vessels you may have sonar dome, then you may have other attachments such as bow thruster tunnel- a tunnel in the forward end to provide a bow thruster will add to the resistance. So, most of these add to the resistance and how do they add to the resistance? These bodies being small if the water flowed past them is streamlined, they will add only to the frictional resistance.

So, you know, the Reynolds number at that point, you assume the flow to be turbulent, calculate the water surface and based on the wet surface, get the CF and multiply it by the wet surface, you get the frictional resistance since they are submerged there will not be any pressure drag due to this. But it is not so simple, because unless it is in the orientation of this is streamlined by itself and oriented in the direction of the overall streamline of the ship, the flow will be disturbed and they may create eddies and separation. So, there may be added drag.

To know the streamline ship in the in the towing tank we do what is called a paint flow test. So, by the flow of the paint we can see the direction of the flow and orient our appendages in those directions, but certain appendages such as sonar dome cannot be oriented because it is a spherical structure, wherever you put it, it will create eddies and separation, the only thing you can do is see that the quantity is less, the drag due to this is less, or bow thruster tunnel, it will definitely create some local separation of flow.

So, there are some formulations given by various authors for estimating the drag due to each of these in various literatures, the most famous one being given by Holtrop and Mennen in 1984 in the international ship building progress that came from the Netherlands ship model basin in SMB. But other people have also given formulations, you can find the formulations from various literature for each of these separately alternately, you make a model with appendages and do the testing so that you get the model with the drag with the appendages.

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 Cform, a form coefficient, we have talked about, we have said there are inaccuracies and it is not exactly understood. On top of that you have now added appendage, 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 ship's 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 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 there rudder or some such appendage is piercing the water it may generates 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 are quite different and we will talk about it when we talk about high speed graphs. Thank you.

Preview of next lecture

Lecture no. # 07

Model experiments

Good morning. Today, we will talk about model experiments and extrapolation to full scale.

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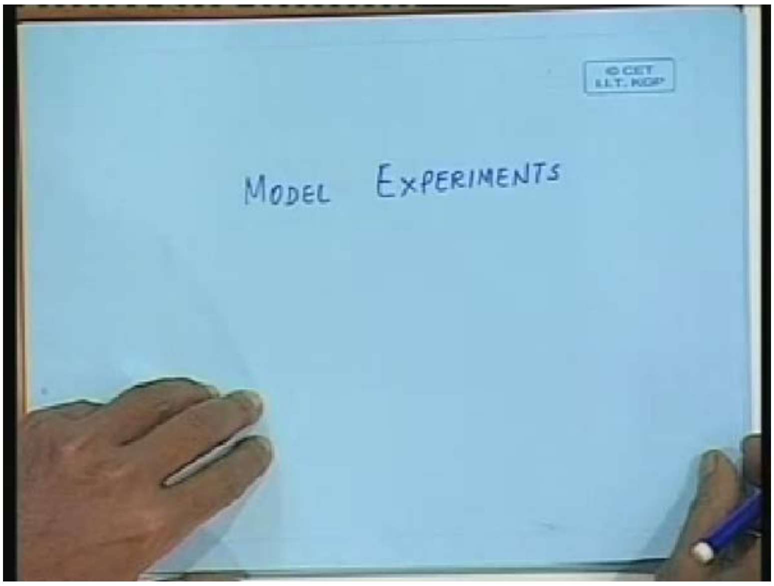

Of course, our model experiments will be limited to resistance thrust only and sometimes this experiment is called towing experiment because, as we have defined resistance before, it is the resistance of towing a vessel without its propeller working in water, so sometimes this is called towing experiments or resistance due to towing a model in a tank.

Why do we require model experiments? One, of course, we know, is to obtain the resistance of the ship in full scale; there is another reason why we do model experiments- as I have explained earlier we know that the resistance of a vessel cannot be accurately predicted by theoretical means, this also means that we cannot calculate the flow characteristics of water around the ship hulk theoretically very accurately, we also know that if the flow characteristics are bad, then resistance may go substantially, so it is sometimes necessary to do model experiments to find out how good the flow is around a ship, and if the flow is not as we have desired, it may be a necessary to change the model shape at particular locations, or even change the entire fore body or aft body of the model till such time that we can get a better flow hence, less resistance.

Flow is important not only from resistance point of view, but also for many other problems such as flow induced vibrations. Imagine a strut projecting out of the ship for some purpose such as forming a bracket, for holding the shaft, if the bracket is not aligned in the direction of flow, there is bound to be eddy shedding or separation near the bracket, in the aft end of the bracket, this separated flow may cause flutter of the shaft bracket or vibration. Similar thing can happen due to flow around a rudder behind a ship, or due to unevenness of flow there can be vibration of the aft body, which is not fully supported by buoyancy that is, the overhang of the up portion.

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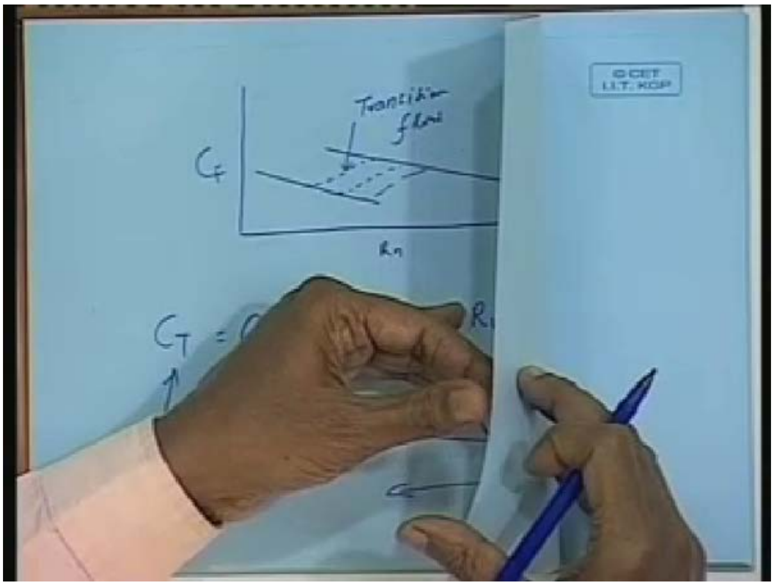

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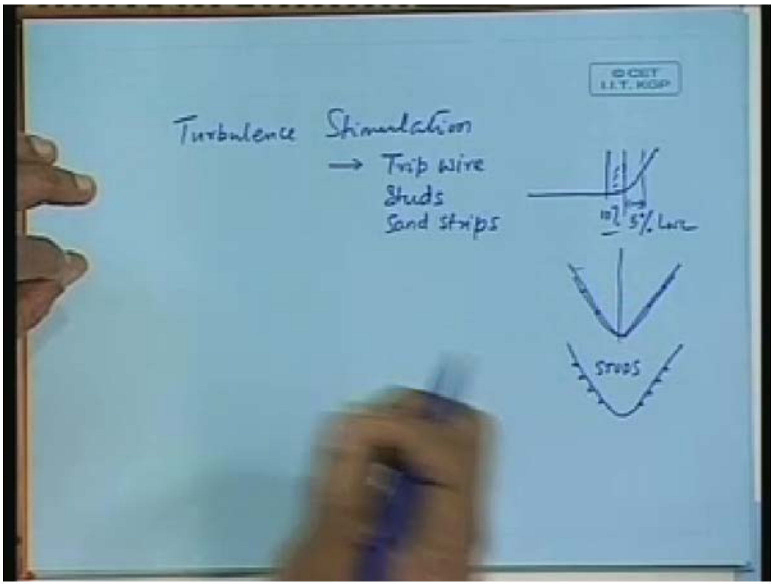

So, use turbulence stimulators. Turbulence has to be stimulated, we have to stimulate turbulence in the fore part of the ship and how do you do it? We have to introduce artificial roughness at the front end of the ship so that the flow becomes turbulent because of existence of rough surface we, as if we are introducing forcible turbulence on the ship fore body.

And what we use is called trip wire, this is the normal turbulence stimulator used in ships that is, I have got a ship model here, I can put a wire right on the front of the ship, or if this is the f p about five percent length, aft of f p, lwl, length on water line, normally for model test we use length on water line. So, I can put a trip wire here that is, if I draw the section here, the section of the ship may be like this, I put a small trip wire all along the model with small anchors holding it by pins, if I have got a wax model, I can put pins and hold the trip wires, small pins which will insert (( )). Now, suppose I have put a trip wire here, what is the guarantee that the flow here is turbulent? The initial flow here will be turbulent, but because of pressure difference we have seen- there is a relationship between pressure and velocity- because of such pressure differences the velocity may further drop if the pressure difference is high, pressure is high, then velocity may drop further, if velocity drops, turbulence again may fall because Reynolds number will be local, absolutely regional Reynolds number will come down again, so the turbulence that you created may be suppressed again and laminar flow may take over. So, it is common practice to use not only one, but may be two trip wires at another, may be ten percent distance, or seven and half percent aft, depends on the type of model, type of fullness etcetera.

So, this is how the turbulence is stimulated; sometimes instead of trip wire we may use studs- studs are again, if I draw the section here, studs are small little projections here at small intervals, this is a studs. Or we may use sand strips, sand paper strips, small sand paper trips may be fixed at around the ship's girth at the forward end at five percent aft of f p and ten percent- sorry- five percent aft of f p and ten percent (( )).

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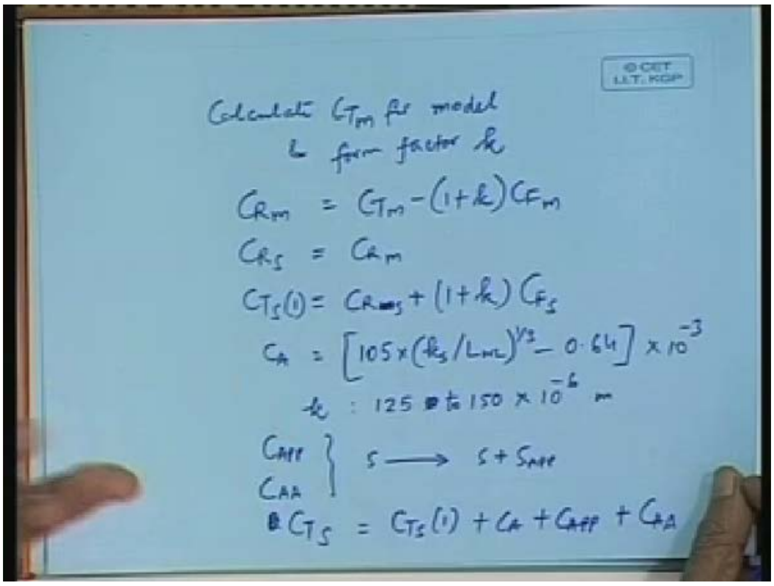

And similarly, you have to have the wind resistance coefficient. Again, calculate the total wind resistance, divide by the total weighted surface, how the CT is calculated, half rho s v square, that S, that S may be changed to S plus appendage weighted surface; then, you can calculate resistance for the total ship including that of appendage weighted surface.

Then, you get CTs is equal to CTs1 plus CA plus CAPP plus CAA- all these will give you the actual ship resistance either at zero before or at before three- the CAA will determine that depending on what sort of trial condition you want.

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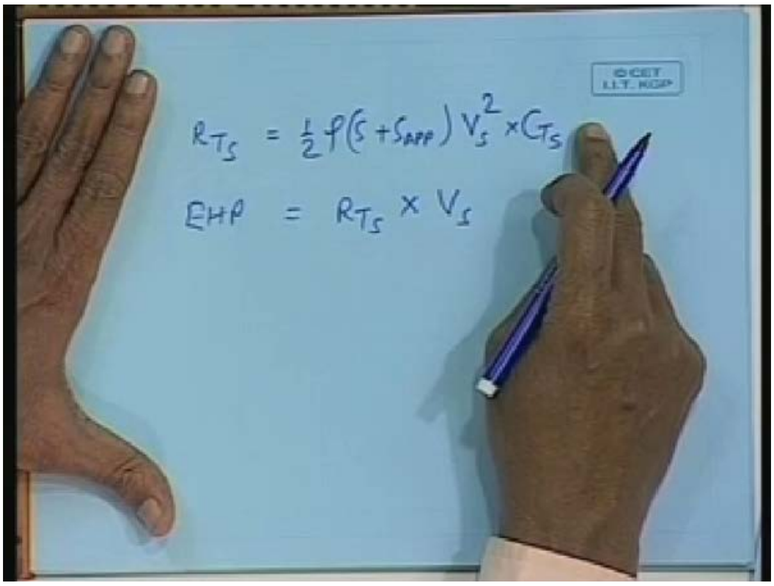

Once you get CTs you can calculate RT as half rho S plus SAPP rho s p a p Vs square for various speeds. And EHP, effective horse power, we have seen will be equal to total ship resistance into (( ))... -Sorry?- into CTS. And if this is in kilo newtons this will be in kilowatts, this is meters per second, this will be kilowatts.

Now, you have to be careful because the whole calculation we have given is in newtons, so somewhere along the line you have to convert it to kilo newtons, may be dividing by thousand. So, this is the way you have to extrapolate from model scale to full scale. We will stop here today. Thank you.