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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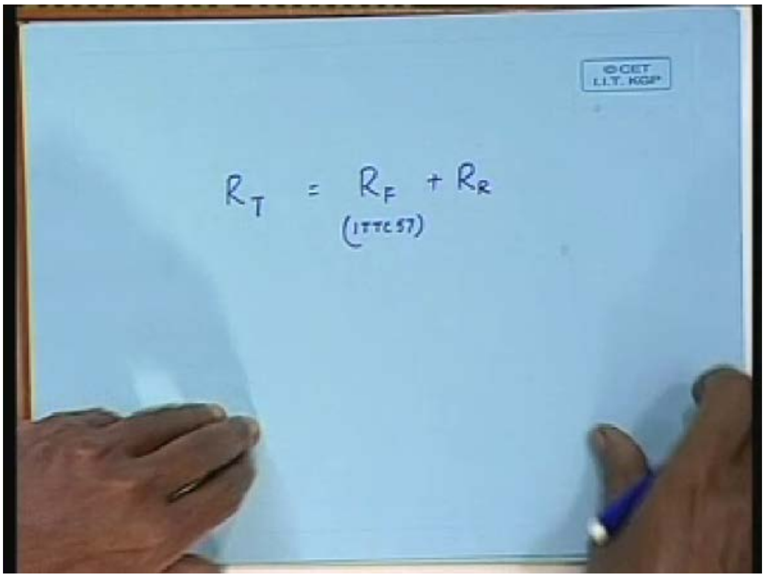

But before that just to brush up we had said before that total resistance of a ship comprises of two parts, that is, RF plus RR- frictional resistance plus residual resistance, this was based on Froude's law of similarity. R f, we had seen is primarily the two dimensional frictional resistance or something similar to flat plank resistance, frictional resistance. This RF we said we calculated using I T T C frictional line of 1957, and the residual resistance was told to be the remaining part of resistance. If we divided the ship's total resistance into two parts, that is, the two dimensional frictional resistance RF, then the remaining part of the total resistance was called the residual 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 57 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.

All those components are included in this residual resistance, the main component of which however, remains as the pressure resistance or the wave making resistance- have you understood now? Now, we look at the phenomenon of wave making in ships and see whether we can understand making of waves and resistance due to it in some greater clarity.

Whenever a body moves in fluid there is a pressure force which develops around the body and that is normal to the body surface; we have seen if the fluid was non viscous and completely submerged, then the forward components of pressure would, the axial component of pressure in the forward part of the ship would be equal and opposite to the axial component of the pressure forces on the half body, so they will cancel each other and body will experience no resistance to forward motion. But as the body comes up to the surface the pressure developed around the body generates waves, and the wave generation is a phenomenon due to the existence of, existence of a free surface between air and water and effect of gravity- all water waves are gravity based phenomena and they are basically created because a constant atmospheric pressure has to be maintained on the water surface by physical law.

So, when a ship moves because of the pressure forces around the body waves are generated on the ship surface, on the sea surface- this should also happen if the body was submerged just below the free surface. Wherever the dynamic pressure on the water surface is not equal to atmospheric pressure on the flat surface, waves will be created to make the pressures, make the top pressure atmospheric, for that purpose the shape of the free surface will change and waves will be generated. So, for submarines going just below the water surface also you would see generation of waves, though smaller, though less than, if it was moving on the surface, and as the submarine goes down the waves on that surface vanish.

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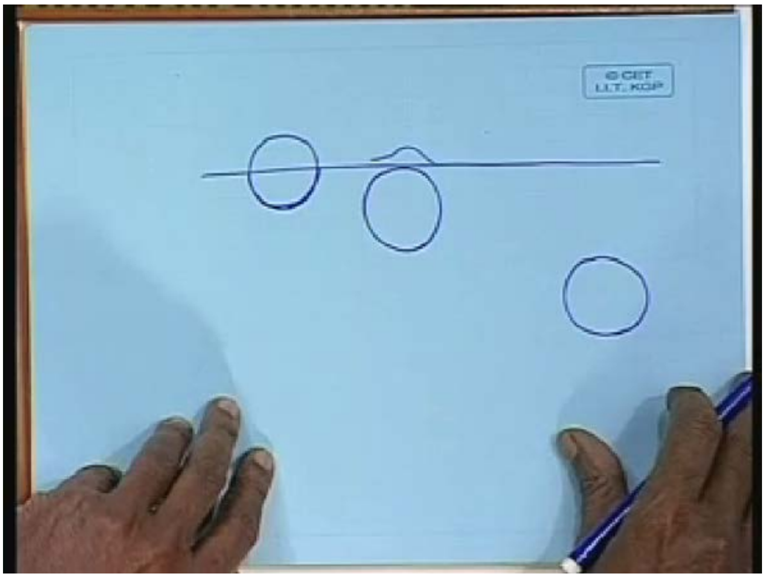

So, the drag due to a submarine just below the surface will be more than the drag due to a submarine deeply submerged, because just below the surface say for example, this is the water surface and a submarine is here floating in water, then the frictional resistance is due to this surface and wave making, now you put the submarine down below here, just below the water surface you have the full frictional resistance through the full surface and also you have wave making resistance on top, whereas, if the submarine is down below, very much down below, it has only the frictional resistance and not the wave making resistance at all, so this case will be the worst case in the case of a submarine.

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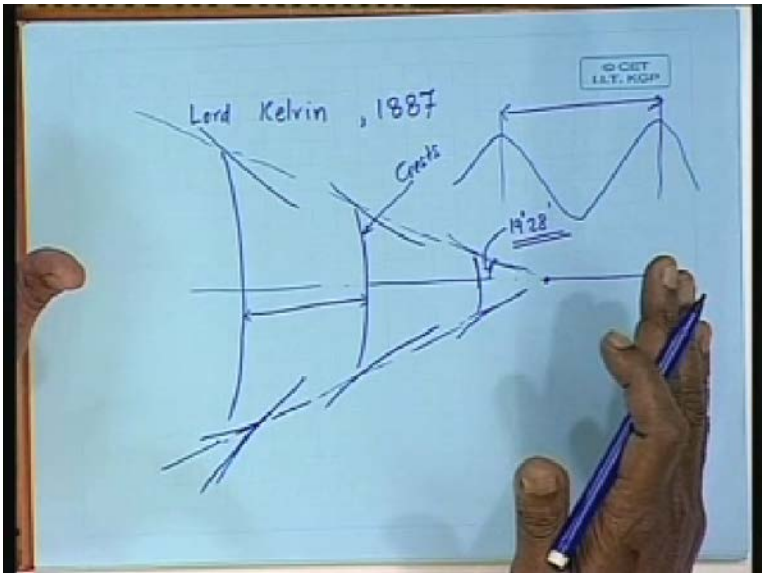

Now, way back in 1887, Lord Kelvin in UK, 1887, he by theoretical analysis showed that if you have a pressure point on the surface, on the free surface, flat free surface and that pressure point moved at a particular velocity, or water flows past pressure point in the opposite direction, then it gave rise to a set of waves- this is showed by theoretical analysis. And the wave should look something like this, this is a pressure point is here let us say, then you would get a set of divergent waves- give me one minute to draw the diagram- like this a set of divergent waves will emanate from the pressure point; as the pressure point moves forward the divergent waves will keep being generated and they will start moving aft, and you will get a set of transverse waves. I am only drawing the crests, there will be troughs in between- do you understand? There will be a set of transverse waves not straight, but slightly curved as they go away from the centre line and expand in length- this length is not wave length, please understand this.

A wave when it travels, this is the wave length from crest to crest, so, in this case, this is, if I am drawing only the crests, then the wave length is this, from crest to another crest, by saying length here I mean the width of the wave actually, the width of the wave goes on increasing as it moves away from the pressure point. The divergent waves as it moves away from the pressure point they diverge more and more, but surprisingly he also showed the entire wave system is contained within two straight lines emanating from the pressure point making a constant angle on either side with the axis of movement, and this angle is said to be 19 degrees 28 minutes- he showed that this is how it would happen.

So, when a pressure point moves in the surface two sets of waves are generated: one set is divergent waves and one set is transverse waves. Now, each wave, each transverse wave increases in length and therefore, reduces in height as it moves away from the pressure point. So, you can imagine that as you go away further and further the wave height will reduce, the transverse wave, and you will not see this as far away from the pressure point, what you will instead see is these divergent waves- this is what has been observed in ships, long thin ships moving on the free surface.

What we observe whenever we observe standing at the bow of a ship if you look behind, or even stern of a ship and look far behind, you will find a set of waves emanating from the ship going away from the ship as the ship moves forward, but you do not see those transverse waves. So, the transverse wave if you see very minutely, you will find a wave surface elevation near the forward part of the ship.

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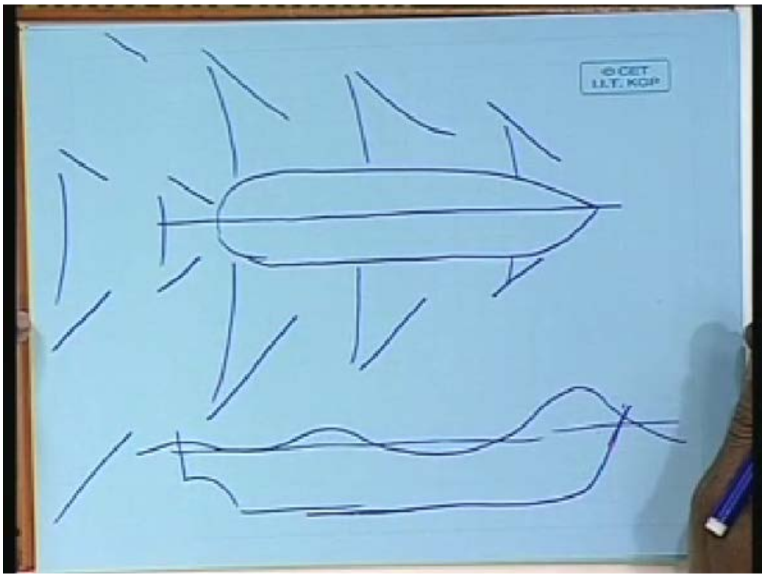

If the, if I put a ship here, let me put a ship, let me draw another diagram- sorry about the asymmetry of the diagram- but what we will get? We will get a set of divergent waves like this, wing further away and- excuse me- a set of transverse waves. Now, as we have explained if it was created due to the fore part, if the fore part could be repainted by pressure point, then these wave should be created, and we have said that the transverse waves reduce in height as it goes forward, so as it goes- sorry- as the waves are further aft from the ship the height reduces.

So, if you look at the vicinity of the ship, you will find a large wave crest somewhere here as the diagram shows and wave crest will be there as you go aft looking at the ship cell sight, but they will reduce in height, have you observed this, have you observed? That is, if I now draw the profile of a ship, what you will see is the wave height like this and then it will reduce and may be small wave should be there, you, all of you must have observed this.

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Most of when there is a Balboa's bow

We will come to Balboa's bow in a minute; I do not agree with you at this point, we will see what happens in the case of Balboa's bow. Now for the time being if I just mentioned to you that the pressure point represents existence of high pressure that is being generated as we have seen at the fore part and the aft part, we have seen the pressure distribution around the ship in the initial class, there will be two peaks at forward and aft and there will be a loss of pressure in the middle. So, that high pressure point in the forward end will give rise to a wave system like this, similarly the high pressure point in the aft will give rise to another set of waves. So, from here you will find there are two sets of waves- one at the forward end one at the aft end being generated.

Now, what is so unique about the forward and aft end, why is there a high pressure point in the forward end and high pressure point in the aft end? Because of a large slope at the forward end.

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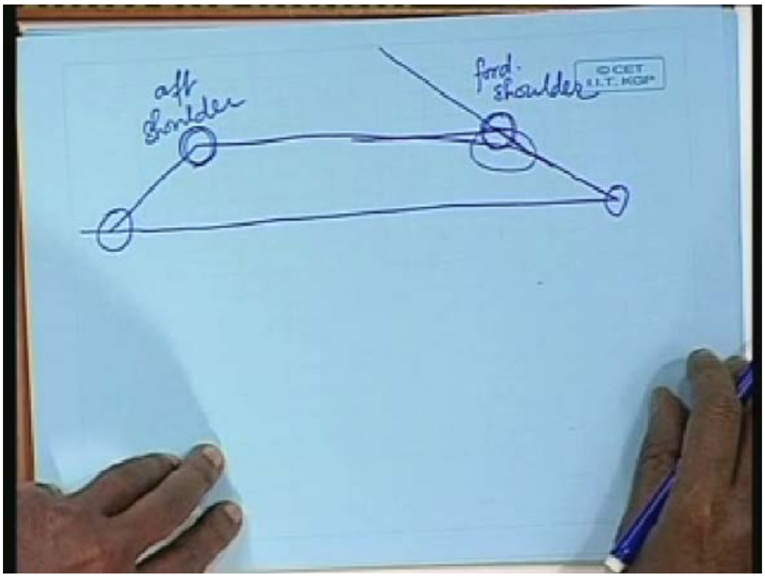

If you look at the water line, if this was a flat plate, you will not get any wave making resistance, because the slope of the water line here is zero- the water comes straight and goes past- when I am putting something here like this, certainly the water cannot go past here anymore, so it has to go like this therefore, there is a pressure point, the pressure point is coming primarily because of the generation of water line slope that is, gradient of the water line- do you understand this?

Now, I take the ship, ship's water line; let me draw the water line. You have learnt something about lines plan, so you know what a rule outline is, the plan of the rule outline you are aware. So, now, this, this is a pressure point we know because the slope starts, then suppose this went like, this continued like this forever, then this slope there is no other pressure point, there is only one pressure point unfortunately, we close it, we close the ship; so, when I bring it down like this I change the slope here again- do you get it?- in the ultimate, it is like, this is like a wedge, this as if it went like this and then it went straight, and then it went like this; if it went like this, there is a pressure point here, there is also a pressure point here, a negative pressure point, here also and here also- do you understand, is that clear?

So, there will be a wave system coming out from here and a wave system coming out from here, and this, what are these points in a ship? We call this point as forward shoulder and this is called aft shoulder; this is called forward shoulder and aft shoulder- representing this by means of a wedge.

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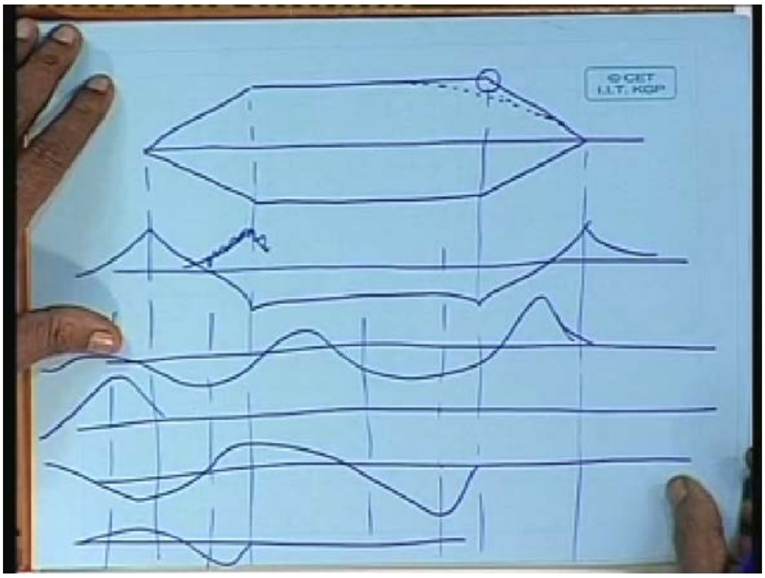

Way back in 1931, Mr. Wiggly made a number of experiments on a wedge shaped body as I have shown you and he gave very interesting results, which was experimentally found to be correct. First, he said that, there is a constant pressure distribution around the hull shape actually, he said there are five wave system; we have seen here four, there is a fifth one, a wave which as if stays with the ship, does not move, it does not take any energy, but a pressure, a basic pressure difference develops because of the shape of the body and such a pressure difference is the one we had seen before, sorry.

If basic pressure change that stays, apart from that there are four wave systems- the one that is due to forward end will have a predominant wave crest generated due to the forward discontinuity and it may look something like this. Then, as we have seen, there will be a wave system due to aft end, which may look something like this- am I clear? And due to the aft shoulder we will have a third forward shoulder, we will have a third wave system- as we have seen this will generate a trough, so you will have a wave system, which may look something like this. And finally, due to the aft shoulder you will have another wave system. So, you will have four wave systems, the most prominent ones are the forward wave and the stern wave with crests being generated at the forward end and stern end, and the shoulder waves generating troughs at the forward shoulder and aft shoulder will also be there.

Now, in the case of a wedge like this, this shoulder waves are very prominent and you can see it because the shoulder is very well defined. In case of a ship, once we make it like this, make it smooth, these waves are not so easily definable, though a trough is visible it is not so well defined, there will be a depression here and elevation later on- do you understand?

So, what do you see when you look at the side of a ship, what do you actually see, you do not see those four waves and a pressure elevation here like this, so what do you see? What you will see is a combination of all these wave systems and this combination, very easy mathematical solution is there for combining waves, which is called the linear super position of waves, that is as if they are just added, the resultant wave will be, resultant wave elevation will be an addition of, linear addition of all the waves together, we just put plus, plus, plus, plus.

Typically, what it would mean is that in this diagram till about here the waves that you see will be due to forward wave, but the wave that you will see here will be addition of this and this, you can see as the diagram shows the trough will increase- can you see that?- and if you come here again, the two waves will add, but when you come here, there will be three waves that are being added up, and when you come here there are four waves which are being added. So, the resultant wave may look something quite different from any of these, but one thing to notice is the forward wave crest, which is a most prominent of all this, stay as it is, that is not disturbed by the other waves- do you understand this?

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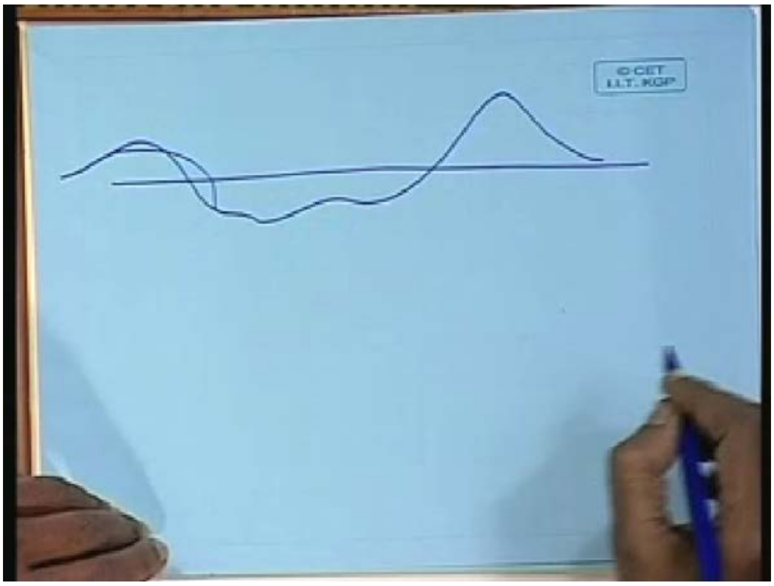

So, the resultant wave may look something like, you have the forward wave here coming up- sorry- may look something like this, it may look something like this. What do you see when you are standing on the ship and looking behind is primarily the divergent waves created by the forward wave system.

Please, understand that the other wave systems coming behind the ship, behind the forward wave system, have, get affected by the forward wave system because the water is already disturbed, so the waves generated after the fore body get disturbed and the waves may not be so easily diagnosed- that is one thing. Second thing that happens is that as I mentioned shoulders are smooth, so again shoulder waves are very prominently exhibited. And thirdly, we have discussed this before, that as the bounded layer develops towards the stern the pressure changes and therefore, the waves of the aft system are not so well defined. So, mostly what you will see if you are standing on a ship and looking behind and you see a set of divergent waves, it would be primarily due to the forward wave system.

So, these waves carry away energy from the ship, the generation of waves will require energy and since they are completely travelling they are carrying energy with them, so this energy will have to be supplied by the ship, which we call the wave making resistance, the force that generates this energy, we call it the wave making resistance- is that clear? We have said that this is due to pressure. So, if I actually calculated the pressure around the ship hull whole body and calculated the longitudinal components and integrated it over the whole length of the ship, I will get a certain resistance, I will call it pressure resistance. Now, I have generated these waves, the final wave form that is behind the ship, if I take the total energy content by making a wave cut on the free surface, measuring the wave profile and seeing the rate at which the wave is travelling, this elevation is changing, I will get the force required for generating this energy- experimentally I can find it out, that is called the wave making resistance. Now, people have done a number of experiments leaving aside the errors coming due to the existence of bounded layer, it has been found that the wave making resistance and the pressure measurement on the body surface and integration of it gives nearly same result. So, we can say with certain amount of clarity that wave making resistance and the pressure resistance- resistance due to generation of normal pressures on the body surface- are same.

Now, you see, these four wave systems, we have seen bow wave, forward shoulder wave, aft shoulder wave and stern wave; these four wave systems will super impose on each other and they would make the total wave making resistance. For the time being let us consider just two wave systems- the bow wave and the stern wave, which are more prominent. Now, if a crest of the bow wave and a crest of the stern wave match, then we will have a bigger crest there at that point- am I right?- what is this effect? If the crest is on the, near the ship, if the crest is against the ship body, not far away, then the effect is pressure at those points will increase and therefore, the axial component of the force supporting motion will increase, do you understand this?

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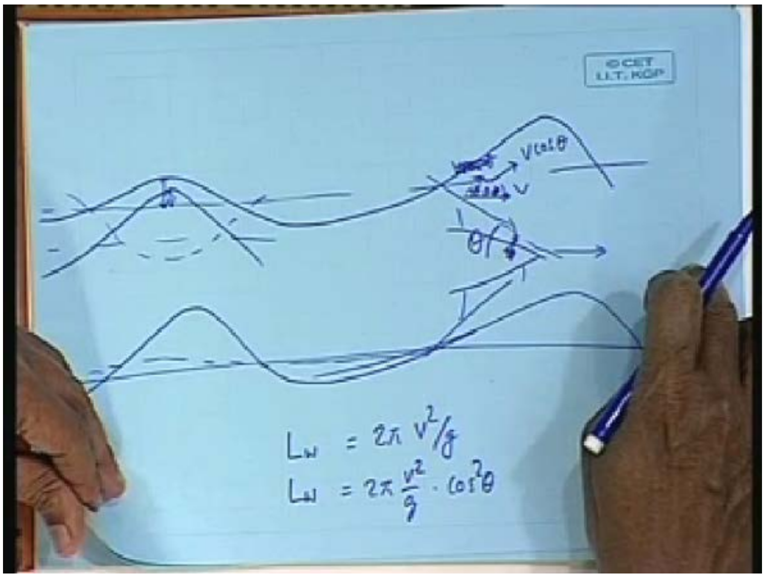

I have got a wave like this, now I have got another set of waves starting from here going like this, and this is my water line here and this is for this wave, this is the water; if I add this up, what am I getting? This wave will come like this as it is coming and here it will increase, this plus this- 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 trough- then what will you get? This will flatten out, that means the support that you are 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 these 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 waves 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, these are the transverse waves, these waves will move at the same speed as a ship. And the divergent waves, let us take the divergent waves, how will this move? This will also, the axial component of velocity will be same as that of the ship, otherwise they cannot keep on getting generated and you cannot, you will not see the waves as if they are moving along with the ship, is it not?

So, the axial component will be equal to the speed of the ship that is, if I draw it just here, if the ship speed is v and this will be v, the axial component of the wave whereas, the actual ship, actually this velocity will be v cos theta where this is theta, the enclosure, the envelope angle, this is theta, this is theta. So, then, the length of the divergent waves will be into cos square theta where this is theta, this angle is theta that is, this angle now, making mistake this is, this is not the, this thing, this is the velocity v cos theta, this is the theta angle, this is the velocity of the divergent waves in its own direction whereas, axial direction the velocity will be equal to ship velocity.

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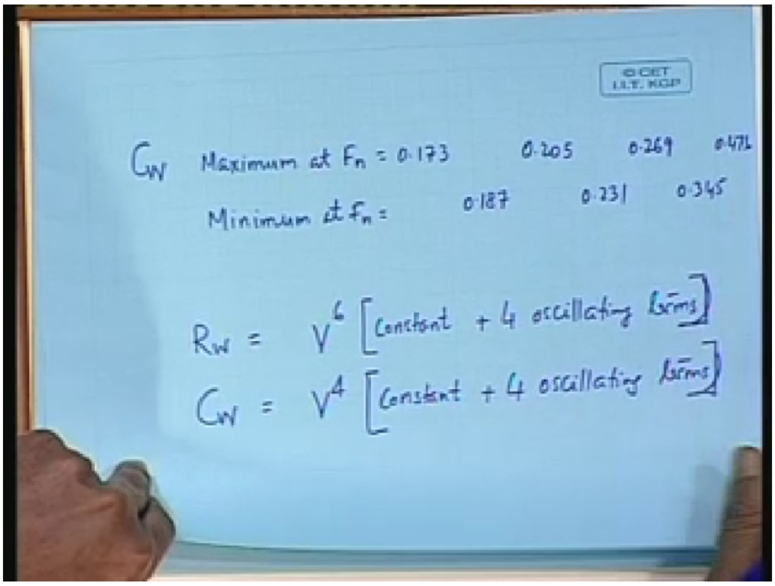

We can calculate from here how the interference will take place and we can draw some norms- this has been done and it has been found that Cw will be maximum at f n equal to and minimum at f n equal to- I write these things.

We have seen that the pressure resistance depends on a Froude number that is, speed of the vessel, we have seen that wave length is a function of speed- that is why I wrote this. So, therefore, the interference will depend on how long the wave is, what is the wave length crest to crest, then only interference will occur- If the wave crest is not falling on the next wave crest, it will not occur am I right?

So, if I write the wave resistance Rw, it has been found that it is a function of- I had mentioned this before- to the power of roughly, to the power of sixth power of speed. So, this will be some sixth power of speed into a constant plus four oscillating terms, oscillating because of the waves, correct, am I understood?

Then Cw, half rho v square if you write, it will become, v square will cancel, will be some other constant plus four oscillating terms. So, you see how, what is going to be the nature of the wave resistance curve, this will increase with speed, this part at the rate of fourth root of, fourth power of speed for Cw and sixth power of speed for Rw and there will be four oscillating terms, which may coincide to give a hump in the wave resistance curve or hallow in wave resistance curve- hump means there is a rise in the curve, which is represented by these Froude numbers, and hallow in the curve, which is represented by this Froude numbers.

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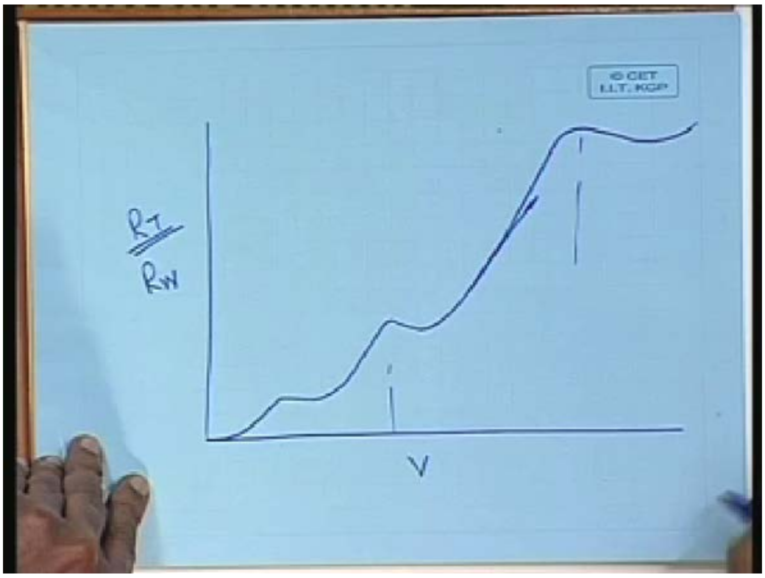

So, if I look at a ship's wave resistance curve as a function of speed, what do I see? Rw, let us write Rw- at very low speed- I will also write Rt, let us write Rt and Rw both we will plot on this, at very low speed Rw is zero and as the speed increases there will be this maximums and minimums coming up. So, if I plot the Rw only against V, what I will get is, this will go until about 0.4 Froude number, if I go on increasing the speed, it will go on (( )) 0.4 Froude number, after which the vessel will generate sinkage, it will sink to a larger depth and then it, then some other phenomenon will occur, we will discuss that later. But for displacement ships the Froude number is normally of the order 0.2 to 0.3 within where the characteristics will be like this. Now, if I am plotting this on a, so, this power, this power will be the sixth power towards the end, towards the limit 0.4 east, we have seen this, you see there are two humps- one hump here at 0.205, so this should be roughly 205 and next hump is at 0.269, which would look, which would perhaps occur here, this may be 0.269.

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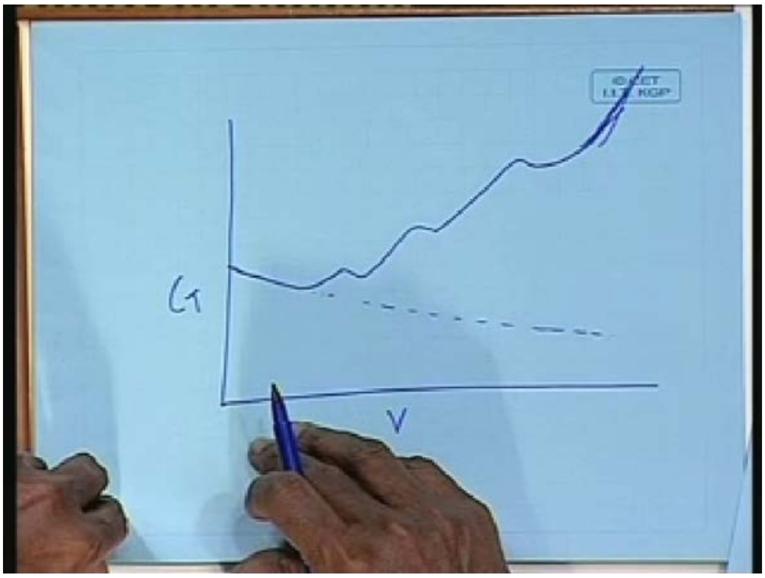

Now, if I plot this and see, let us plot Ct now, how will the nature of the curve be, how will be the nature of this curve be with regard to Ct? What happens at zero Froude number, is Ct zero? There will be frictional resistance coefficient, will it be there or not? So, we will have a frictional resistance coefficient, which will reduce as speed increases- am I right?- because Rn will increase, and ITTC formulation if you remember Rn is in the denominator, so the frictional resistance will diminish.

For a speed something like corresponding to Froude number 0.1 or 0.5 after which wave resistance will start taking off, and when it takes off, see the friction resistance would go like this, so this wave resistance curve that we had previously drawn this will be added to that, and this will be to the power of four, speed to the power of four, am I clear? So, this is the nature of wave resistance, wave making resistance of a ship and the wave making resistance coefficient can be represented as I have shown you.

How do you estimate this? There are two methods of estimating this: one is the experimental method, which follows the Froude hypothesis, and the other is the theoretical method. And do we have a theoretical method for calculating wave resistance due to a ship? I will just spend five minutes in telling you the developments in theoretical evaluation of wave resistance.

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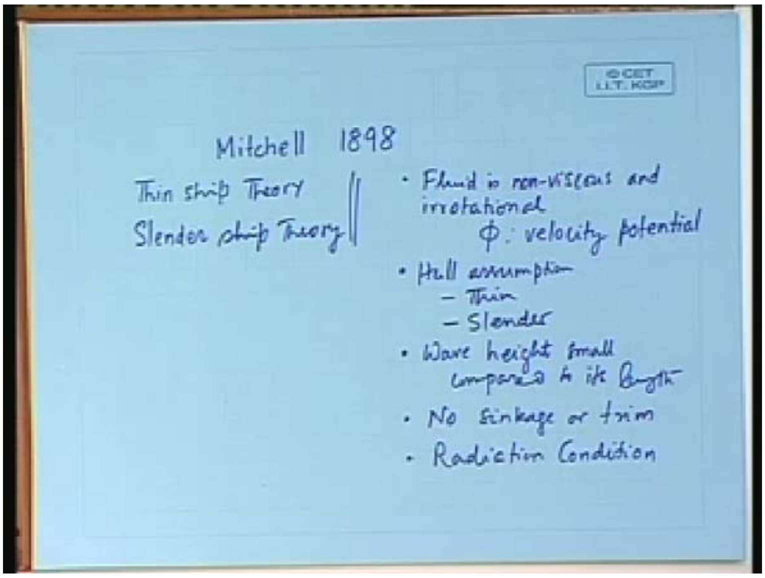

Way back in 1898 the first person who suggested that wave resistance could be calculated, a gentleman called Mitchell in 1898- the estimation, the theoretical evaluation of wave resistance started from way back in 1898- he proposed what is now very well known as the thin ship theory. Thin ship theory which was followed later on by a theory called slender ship theory; both of this had the following assumptions, the only assumption between these two, the change in these two was with regard to the body- I will mention that also.

The assumptions that were made by Mitchell and later on followed till date are as follows: the fluid is non-viscous and irrotational- did I explain to you what is irrotational? Irrotational means, if the fluid particles do not have a rotational component of velocity, all velocities are linear, what does that mean, where does that fluid particle have a rotational velocity, can you tell me? A vortex which need not be in bounded layer, which can happen in non viscous fluid, that vortex or circulation- that is rotational flow. But for ships the assumption was there is no rotational flow and this gave rise to what is known as a velocity potential, this makes life much easier, this assumption gives rise to a velocity potential phi- and this is the basis of all theoretical calculations, we will not go more into this.

What are the other assumptions? The hull condition, hull assumption in thin ship theory, we said that any breadth dimension of the ship is small compared to the length dimension that is, ship is thin, b is small compared to l everywhere on the ship, or slender, slender said that both breadth and draft are small compared to length. These give very nice mathematical formulations either of these theories, but different, so, I will not go details into of this. The other assumptions are the wave height is small, waves generated, the height of those waves is small compared to its length; wave height is small means what does it imply? That if I take square or cube of the wave height, it can be neglected small compared to length small. So, the small quantities if you take the square or cube of small quantities, they become still smaller, do you understand?

If some quantity is 0.1, you take the square if it is 0.01, cube is 0.001. So, small quantities squared and cubed, they become negligible. Then we had no sinkage or trim, this is very important assumption; that means, the speeds where such that vessels did not sink- I told you that high speeds there is sinkage, assumption was no sinkage. And finally, there are so called radiation condition, which means the waves travel only, waves exists only in the one half of the horizontal plane that is, aft of the ship and they can travel into infinity in that direction, but there will be wave in the forward side.

So, with these assumptions, it was again Havelock who showed that you could represent a pressure point by what you called a source.

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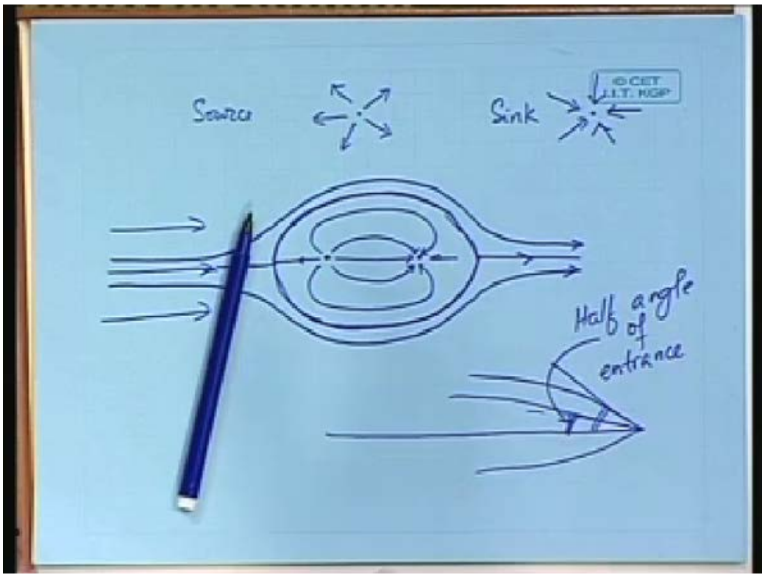

A source is a point which gives out fluid continuously- it does not accept anything- a source is a point that gives out fluid continuously; you can understand that this is not a practical point it is an imaginary point which generates fluid continuously. And a sink is just the opposite of a source which accepts fluid from everywhere to itself, a sink is place where fluids come and come to. A source and a sink can be represent at discontinuity, let me explain how. If I take a source and a sink nearby- this is a source, this is a sink, this gives out fluid and this takes in fluid- so, you can imagine that fluid will straight go from here to here, and sinks is giving out fluid in all directions, the fluid next will go like this, and the next fluid will go like this, is that clear, am I saying anything wrong?

Now, just imagine the fluid rate is emanating from here, where does it go, and there must be a fluid which is coming down here... This will give rise, imagine that the flow velocity is in this way, water is flowing fast, that is how this source is giving out fluid here and this going there, a source and sink in a uniform flow- we are discussing source and sink in a uniform flow- now, this fluid that is coming here, where will it go? This fluid is coming out of the source, this fluid is going, there will be as if a boundary where this fluid that is coming will separate and go here and another line which will go like this, this line, then, the next line will of course go like this, is it understandable?

Inside the source and sink, source gives out fluid and sink takes in fluid, but as if the boundary is created when you put it in a uniform stream, as if a boundary is created around which the fluid goes past it, fluid cannot enter this place, is that clear? So, if I have a source and sink, this is very interesting, because it generates a body; now, you have got a body and this body can be represented by a source and a sink, and it satisfies all those conditions that we discussed.

So, now since the ship is a closed body I can represent the ship by a number of sources and sinks, and what is it, what is the strength of the source? The strength of the source is the slope of the water line that means, I have large strength sources in the forward end and large strength sources in the aft end, and in the middle I may have sources and sinks with lesser strength. The source and sink distribution should be such that it represents the body. Now, the mathematical formulation is primarily this, but this gives us very interesting observations, the reason I am telling you this is that we get some very interesting observations. What we get is, that the strength of the source is proportional to the water line slope, slope of the water line- we have discussed this before, slope of the water line, the discontinuity at the beginning, there is large source strength there because the slope is the highest. So, if you say that the forward wave crest is a phenomenon of the strength of the source of the forward end and we want to reduce wave making resistance, one of the ways to do it is to reduce the source strength of the forward end or reduce the slope at the forward end, am I clear?

Therefore, if I have a water line like this, you see the slope here is something like this, this angle, and if I have water line like this, the slope here is this. I have two ships, one ship giving a water line like this and another ship giving a water line like this, which one will give me better wave resistance? Obviously, the one with the smaller slope that is, wave crest will be small. 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 methods 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 reduce as the height, as the point dips more and more below the free surface. So, maximum impact is of that slope near the water line. So, if I can reduce the slope on the water line, then I can control my wave making resistance, and this angle is called half angle of entrance, is that clear? So, we have seen the effect of length on wave making resistance, we have seen the effect speed on wave making resistance, now we are seen the effect of half angle of entrance.

Now, this gives you a very interesting observation, if I reduce the beam, say 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 width or longer length smaller width. 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 bulk. Thank you

Preview of next lecture

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 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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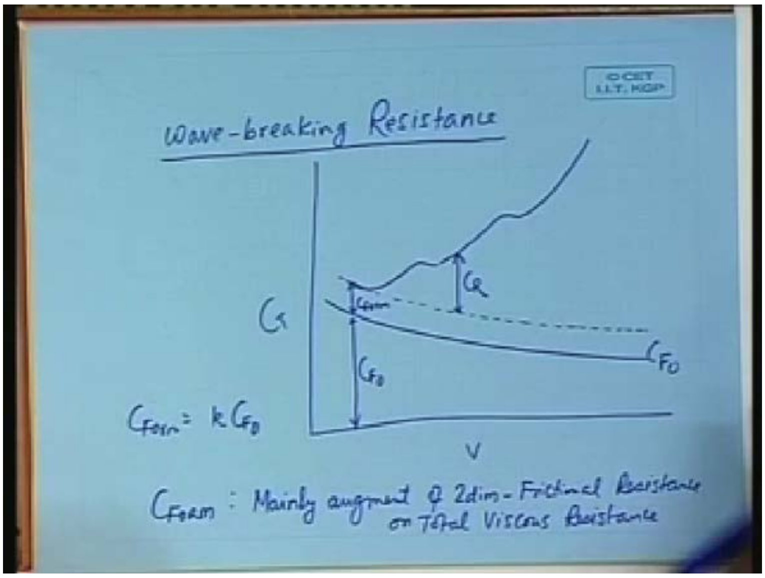

That is, Cform I can say is mainly augment of two dimensional frictional resistances on total viscous resistance, so we can say c form includes the three dimensional friction form effect, it also includes some amount of separation drag component and viscous component. Imagine, separation we have said 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.