Performance of Marine Vehicles at Sea

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Lecture No. # 01
Components of Resistance - I

Good morning. We will be starting a new course today on performance of marine vehicles at sea. There will be basically four subjects we will be dealing with in this course, each distributed equally as a quarter of the course. They will, the subjects that we will cover are: Resistance, proportion, sea keeping and maneuvering.

Today, we will start with Resistance of ships to forward motion. When we say resistance, what exactly do you mean? Resistance of ship to forward motion- normally it is considered as the force required to pull the ship by another ship at a constant speed, or sometimes it refer to as tow rope resistance; that means the ship should not be propelled by itself, but as I can draw it here. This is the ship for which we want to get the resistance

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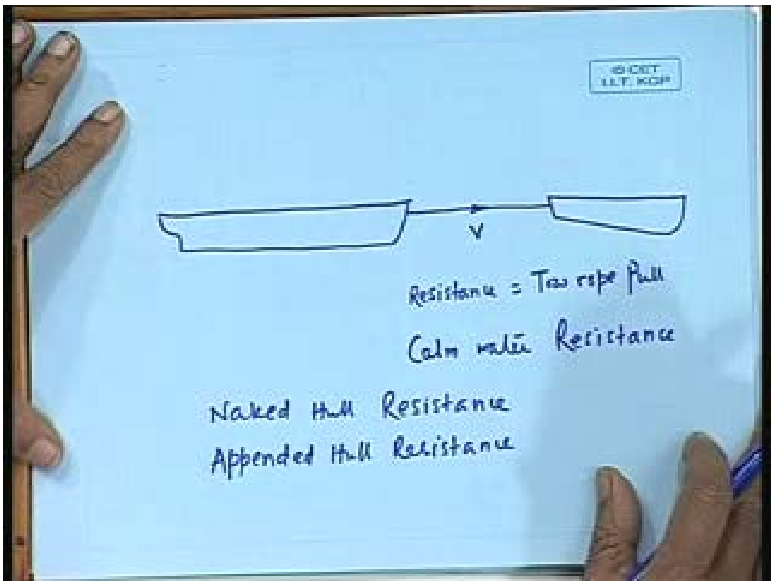

If the ship is pulled by another ship in this direction at a speed V, then the force required is, the resistance is equal to the tow rope pull- this is what is considered a resistance of ship to forward motion.

Now, in a sea way, there are of course a lot of disturbances such as air, waves, current etcetera; normally the tow rope pull is determined in calm sea condition without any disturbances other than the resistance to motion due to movement of water and some amount of air resistance- so, sometimes this is also called the calm water resistance. Now, in this case the ship could also be with some appendages or without appendages; if the ship is without any appendages outside this hull- you understand what is a meaning of appendages, I hope; appendages is structures or attachments to the ship outside the hull of the ship- so, if there are no appendages when you determine the tow rope pull, this is called the naked hull resistance, and if the appendages are there when you determine the Resistance of a ship, this is called appended hull resistance. Is that clear?

So, now, when we mention the speed of a ship we also indicate the condition in which the speed is to be measured for example, we have just mentioned that the sea, the resistance that we have defined is for calm water, that means there is no disturbance and the water is absolutely calm. The speeds with which ship operators are normally bothered about are either the trial condition speed which is called the trial speed or speed in actual service.

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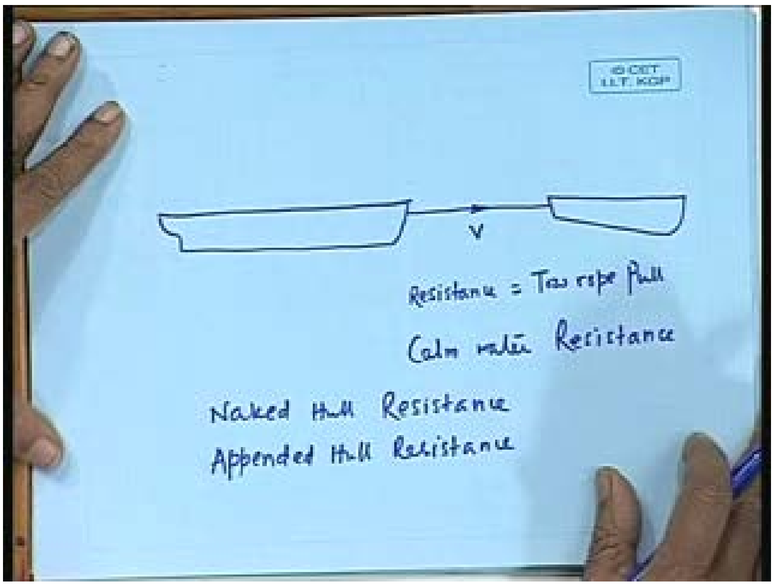

Now, the resistance corresponding to the trial condition is called the trial resistance or resistance in trial condition, which is more than the calm water resistance we have defined earlier. Similarly, when the ship goes into service there are additions to this resistance which are called trial resistance due to waves at sea, due to ocean currents that may be there and due to corrosion and fouling.

So, such resistance is over and above the allowances we have given for trial for estimating the resistance, and that is called service resistance or resistance in service condition. So, you can see that the calm water resistance is the lowest of these three conditions- trial resistance is slightly more than the calm water resistance and service resistance is more than the trial resistance. Now, obviously, service resistance will vary depending on the hull condition and depending on the sea condition. So, service resistance is something which will be continuously varying over the period of service of the ship; we will discuss this later on, how one can perhaps make an attempt to estimate what is the resistance in a particular service condition, but it is customary that we add an allowance to the trial resistance to obtain the service resistance for powering purposes.

Now, resistance is normally, in this, in this course, we will be dealing with all units in SI system, but we will have to refer back to the conventional units used in ship operation. Typically the resistance of a ship will be expressed in kilonewtons- that is the force unit. And speed will be expressed in meters per second in SI units and knots in conventional ship terms.

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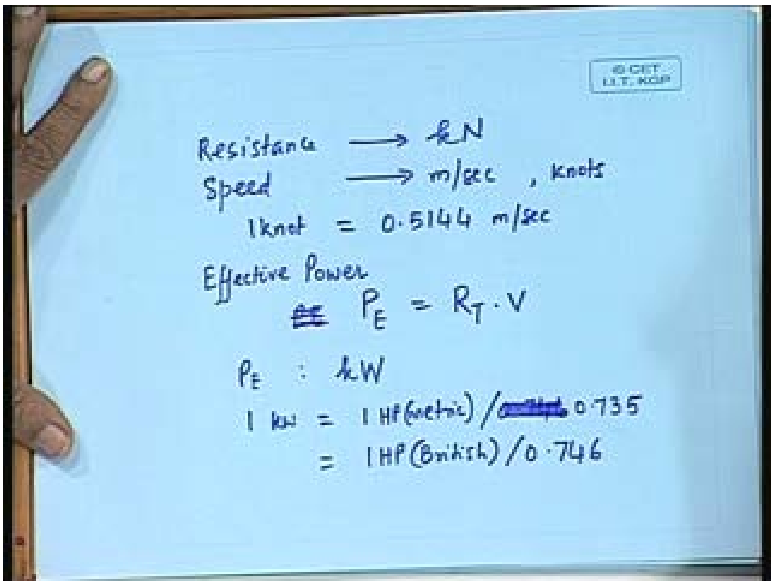

Now, one knot is defined as one nautical mile per hour, and a nautical mile is slightly more than a measure mile, conventional mile, and it is 1.852. In our unit, in SI unit one knot is equal to point 5144 meters per second, I will request you to remember this conversion.

Then, power, effective power, the power required to overcome this resistance without propulsion. Effective power or P E is normally prepended P suffix e that is equal to resistance R T, if I represent total resistance is R T into ship speed in meters per second where R T will be in kilonewtons, speed will be in meters per second and P E will be in Kilowatts. If R T is in kilonewtons and speed is in meters per second, P E will be kilowatts. So, similarly, if R T was in newtons, speed was in meters per second, then we would have got P E in watts. In British unit or in the in the metric H P unit there will be a conversion from kilowatt to...

So, one kilowatt is equal to one metric H P divided by 0.746, and no I do not think this is correct. (( ))735. One minute please, let us understand this, one British H P conversion is 0.746 and one metric H P conversion is 0.735, is that clear? So, these are the conversions which we will be frequently using in our course, in our numerical that we may be working out. Powering of a ship is normally given in metric H P and many times it is given in kilowatts, but all our calculations will be primarily done in SI units and converted at the end to conventional units for understanding.

Now, I think if we have understood the units that we will use, we will go ahead and see the various components of resistance to ship in calm water. We will discuss calm water first and then we will go to trial and service conditions.

Let us take the case of a submerged body, a body completely submerged in water; the only restriction we impose on the body is that it should be so called streamline shaped, that is, without any sharp curvatures on its surface. If such a body is immersed in water completely, that is, it is not at the interface of water and air, but it is completely immersed like a submarine, and if we assume the body to be non-viscous, that is, there is no viscosity in the fluid, then what will be, what will the body experience at a constant speed? Let us look at that.

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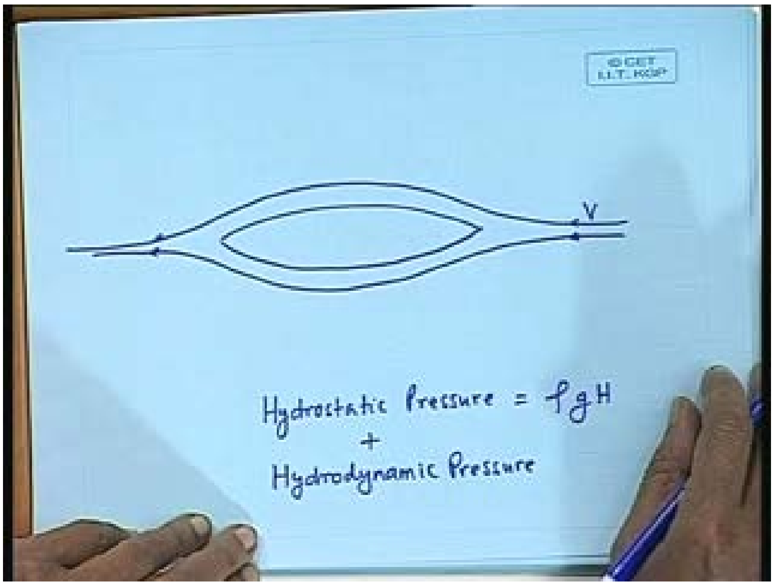

I got a body like this, if I move the body forward in this direction, it would be same as saying as if the body is stationary and the water is moving in the reverse direction. Am I clear? So, if the water was moving in the reverse direction, the water would come and encircle the body and go like this; this is speed V far away from the body. What will happen around the body?

Let us see, if the body was not moving, what will be the pressure acting on the body. If the body was not moving the pressure that would be acting on the body would be called the Hydrostatic pressure. What is Hydrostatic pressure of body, acting on a body? You should be knowing this- rho g H, H being the depth of immersion for that particular point; But when the flow, there is a flow past the body, this pressure would change, this rho g H will be there, over and above this there will be some pressure, which will be the hydrodynamic pressure because of dynamics of water around the body.

So, the total pressure acting on the body will be hydrostatic pressure plus hydrodynamic pressure. Now, hydrostatic pressure we will not consider because this will be more or less not constant, hydrostatic pressure gives, what does it give to the body? Buoyancy. Do you know this or you want me to explain this? Let us see, I will first explain the hydrostatic pressure then we will go to hydrodynamic pressure.

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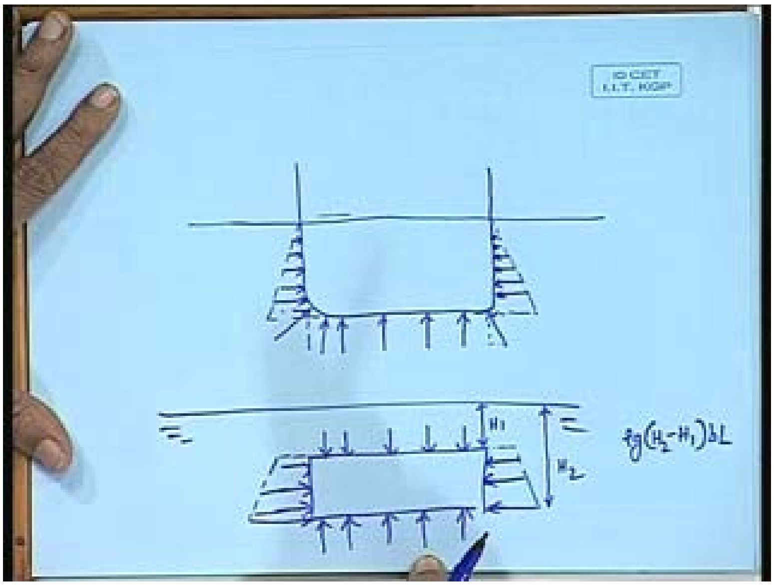

Take a floating body, we will take a floating body and take a submerged body. This is a floating body. Now, if you look at the pressure distribution on this body, since we have seen Hydrostatic pressure rho g H, the pressure here will be 0 at the interface and it will go on increasing as proportional to H, and the same will happen on this side, and we also know that the pressure acts perpendicular to the body, everywhere- is a normal force, hydrostatic pressure is normal force, is not a tangential force- therefore, the pressure will act like this, am I right? Then you can see that they will cancel each other, but look at the bottom what is happening? So, this will also have two components, this and this.

So, these components, the transverse components will cancel because of the symmetry of the body, so, what is existing is this pressure force which is trying to push the body up, and there is no pressure here pressure is 0, is equal to atmospheric pressure. So, what we are getting is a pressure which is trying to push the body up, and how much is this push? What is the pressure acting here? If it was a completely rectangular body, you can see it will be rho g H, H being the depth, and integrated over this breadth will be the total force, there rho g into b into H that is equal to area of the body multiplied with rho g gives the unit weight per unit length.

So, the force that is pushing the body up is equal to the mass of the water displaced; take a length l, any length, multiply with l, you will get the volume; rho g H into breadth into length, there is the force trying to push it up; breadth into H into l is the volume, multiplies the rho g is the weight- so, that is the total force which is trying to push the body up, that is what we have called buoyancy, and that is equal to- since the body is in equilibrium- that will be equal to weight of the body. So, that is how Archimedes principle is scientifically explained- that a floating body will have equal mass displaced, the weight of the water displaced is equal to weight of the body. You understand? Now, take this body down, let us see the other case, this body is down below here, this is the water, what is happening here?

These forces cancel as we have seen; this will also be triangular is it not? Do you understand this? Because the heights are different, so, the any case they will cancel. So, what is remaining? There is force acting here like this and force acting here like this, you get it?

Now, if this is H1 and this height is H2, the force acting on this will be rho g H2 minus H1 into breadth into length, whatever length you take, and what is this? This is also total volume. So, this is, the force acting on it is equal to the mass of the total water displaced, upward force, force is always upwards, we can see this is higher, is it not? So, if the body is in equilibrium in this condition, that means this upward force must be equal to buoyancy, equal to weight of the body, which is acting downwards, you understand? That is what we called neutral equilibrium of a submerged body; that means, left at any place it will stay there- if weight is more, remember the buoyant force is constant, that is not changing- so, if weight is more, the body will go down till it rests, not little more, till it rests on the ground, till it rests on the ground, there is no other case, it cannot float. So, then, when it is resting on the ground how is the equilibrium of forces?

The buoyancy force (( )) reaction will be equal to weight of the body, and if the weight is less than the buoyancy, then the buoyancy force is more and it will push the body up, and it will come out of the surface till such time when the buoyancy is equal to weight, you understood? So, this is the hydrostatic force how it acts on the body, but here in resistance we are talking about the hydrodynamic force.

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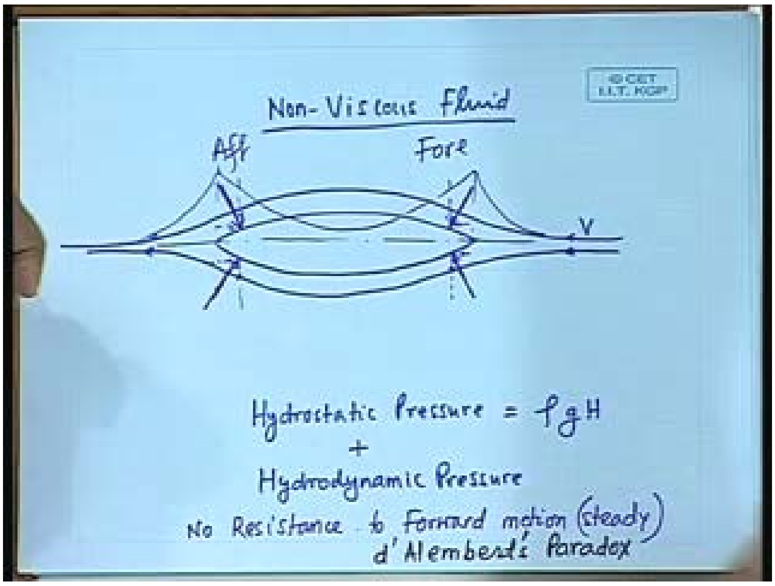

So, when you have a body submerged in water and we have assumed, let us assume a non-viscous fluid. Fluid means air or water, any liquid, so, same applies to air also, that is why I have written fluid.

That, it is, let us assume the fluid to be non-viscous, no viscosity, then the water will flow pass the body like this, since it is a streamline form, the water will flow past the body like this, and how will the pressure be? The pressure will be more at the ends and less in the middle. So, if I draw the pressure diagram on this, the pressure will be go up like this at both ends, mind you, do you understand? There will be two peak pressures at fore end and aft ends because of the discontinuity, and the pressure will fall in the middle, have you understood this?

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Because of the discontinuity body is closing in, that is why it will be, we have assume non-viscous fluid, there is no boundary layer, there is no friction, non-viscous means viscosity is not there therefore, there is no friction. Yes, or also on the body we have just assumed there is no friction of any kind, it is a very hypothetical assumption, but it gives us very interesting result, that is why this assumption is made; one of the reasons we make the assumption is that when we ignore viscosity somewhat, this phenomenon is somewhat amenable to theoretical investigation.

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((Sir normally we cannot them if the flow is in this direction I can understand the pressure rising at the empty point may be may be down why should the pressure will rise))

Because the body closes, the discontinuity is repeated here, the discontinuity that was here is repeated here, the pressure here, see here, there is a pressure raise then there is a pressure fall, in a moment you will understand. You have heard of Bernoulli's equation, have you heard? That is, what is that?

That is pressure and velocity are interrelated, if pressure increase- should I give you the Bernoulli's equation? I think you know, let us avoid the equation, let us understand first- if the pressure increases, velocity drops because anywhere in the fluid the pressure and velocity had combined is constant, am I clear? So, if pressure increases, velocity reduces, now we are ignoring the hydrostatic pressure, only talking about dynamic pressure, then only this is valid. So, if the pressure increases here, the velocity drops, and as the pressure reduces, velocity is maximum at the mid ship region, and then the velocity has to come back to the normal value, so the pressure has to increase velocity has to reduce.

This is a very crude explanation I am giving you, but if you represent the body in a mathematical form and do the potential flow calculation, that is, the flow is non-viscous, making that assumption, and further that there is no vorticity or no circulation, the flow does not circulate, then you can show that the pressure at two ends is high, basically because of the discontinuity, the body starts here body ends here, beyond this there is no body, so there is a discontinuity in the flow, the water that was pushed out will have to come in, it has to fill up this place.

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((Same principle of in airfoil))

Same, exactly same principle. Now, you see, let us draw the pressures acting on the body. Again, we said normal pressure acting here, and let us just take a pressure component in the aft, like this it will be acting everywhere; I have just shown diagrammatically at two ends.

Let see the let me explain this pressure to a larger value so that we can compute it, same thing here, the scales do not mean that there, the length of the arrow does not mean it is two scale. Now, if I compute it, you will see- can you see that?- now, you see these forces will cancel each other, but these forces are additive, you got that? Let see this side, these forces are cancelling and these forces are additive, but in the opposite direction to the force that is generated by the fore body; this is the fore body of the ship, this is fore and this is aft.

Now, this fore body forces are trying to oppose the motion, the ship is after going this way, so, the force is acting this way, this is trying to oppose the motion; and in the aft body, the force is trying to support the motion- again, assuming no viscosity, no disturbance to flow in any other manner like separation.

Assuming the entire flow is streamlined, these forces will equal aft forces, that means, the opposing forces, the total opposing forces on the fore body will be equal to total supporting forces of the aft body. Therefore, the resultant force in the longitudinal direction will be zero, that means if the fluid was non-viscous and we moved a body in this, the body will experience no resistance to forward this motion. So, that means, no resistance to forward motion, steady motion, let me also mention steady, if it was unsteady, things will be different, constant speed. Now, this gentlemen you will find is not an acceptable phenomenon. How can a body move without any resistance? However, this can be proved scientifically and this is a paradox, this paradox was first mentioned by a French gentleman D'Alembert. So, it is called Alembert's paradox- that in a non-viscous fluid, in a non-viscous fluid the resistance to forward motion is zero.

Now, let us go a little further than this. We know that there, fluids are not non-viscous, all fluids have some viscosity, it may be small, very small as in air, or a little more as in water, or much more in a more viscous fluid. So, what is it that we can immediately understand from the viscous phenomenon? We are trying to find out the components of resistance, we are not going much into viscosity at this point. We can imagine the viscosity is basically the friction force between two layers- a body moving against another body, a particle moving against another particle and a force generated due to their friction, that is a viscous force or that is a frictional force, which is the major component of viscosity.

Now, when water is flowing past the body, the body surface and the first layer of water will be in contact with each other, and if there is any viscosity at all, the particle in contact with the body will move along with the body and will not move separately, do you understand? That means the result, the relative velocity of particle to that of the ship will be zero at the body surface, which was not the case previously- do you understand, we said the fluid is flowing past at the constant velocity- now we are saying that the fluid will not have any velocity at a point in contact with the body, but as the fluid particle moves away from the body it will slowly have velocity; but fluid is also getting into friction with each other, so, it is not that the just the particle after outside the fluid, that the particle in contact with the this thing will have a full velocity equal to the velocity of water, what we have taken earlier, it will take some time, it will take some distance from the body for the full velocity to develop. Am I clear?

Let us understand this; we will see how it affects our resistance slowly. Also you will understand that water that is flowing at the forward end is just in touch with the forward body, and because the distance from the forward end of the body is less, the thickness required for the full velocity to develop will be small, as the distance increases friction force will build up. Am I clear? Not area.

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((Area of the body Resistance))

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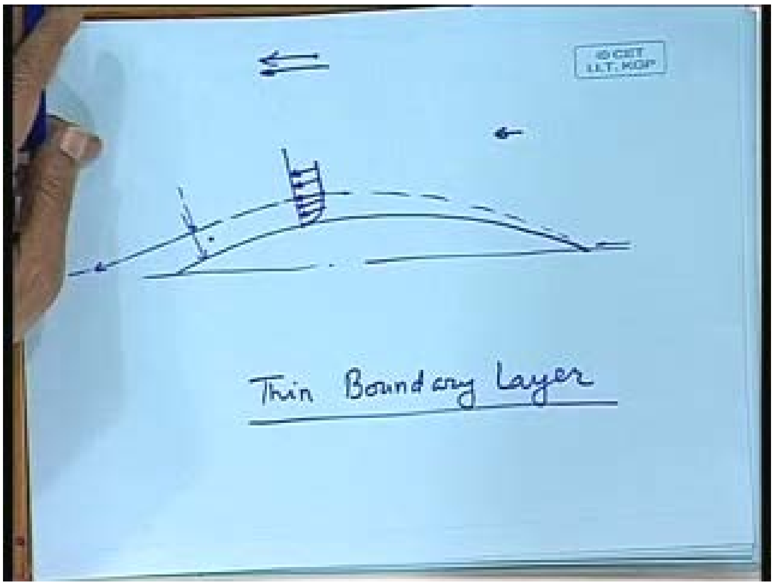

See, this is the body, now, fluid is flowing past here, let us say, what happens here? Body has started, but it has, the fluid has not gone, this particle, if we trace a particle, it has not gone any further than this, so, it may be, it will just gets struck here, but beyond this the velocity will quickly attend the full velocity; whereas, if you take a particle here, because of the history of the particles being struck here it will require some distance to develop the full velocity- a function of the length over which the fluid has flown- this gives you the concept of boundary layer. Am I clear?

Let me put it another way, there is a friction between the body and fluid on this surface, so, we have said that velocity on this surface of each particle in contact with it is zero, but previously we have said that the velocity is low here, high here, low here, pressure is high here, pressure is high here, low here, so, take a velocity somewhere far away from the body- we are talking about relative velocity- so, that velocity will be same as what we have calculated with non-viscous fluid because viscosity effect is only near the body. You understood? So, there will be some velocity of water here, but at this point the velocity will be zero. How does it develop from here to hear? We may- coming due to the great scientist Prandtl- we have what is called a thin boundary layer over a long narrow path.

The thin boundary layer theory, that is, a boundary layer develops around a body which is thin, thin meaning the thickness of the boundary layer is small compared to the main dimension of the body that is length, do you understand? What is this boundary layer? We assume that beyond the boundary layer the flow is as if there was no friction, do you understand? That means, all the frictional effects are bounded within this boundary layer, is that clear?

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((We assume that a real sticks to the surface.))

No, it does not stick, it does not stick. I am explaining. A layer which develops from the forward end slowly enlarges itself and goes like this, and same in the aft body, this is the boundary layer, this area between the body and this outside line I have drawn is called the boundary layer. The definition is that here the velocity of a particle is equal to ninety nine percent of the velocity that you should have got if there was no boundary layer- am I clear?- that is nearly equal ninety nine percent. Is that clear? Yes? Very interesting phenomenon occurs here, you will find. What is the velocity profile of the water particle inside this boundary layer?

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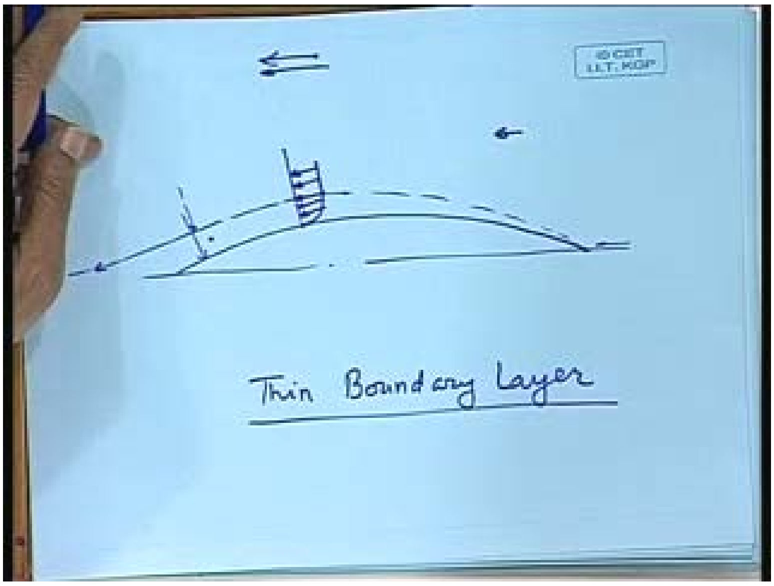

Let us do something here, let us find out how the velocity varies. We say water velocity is equal to ninety nine percent or whatever it is- so much, nearly full, potential flow at the end of the boundary layer- we have also said here it is zero. So, from here it will go to some value and from there it will be constant, you understood? So, if I drew the velocity profile as against the distance from the body, it would go something like this- do you understand? Yes, have you understood this?- the velocity profile as you go away perpendicular to the body surface.

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((If the normal velocity of the body)).

Not normal velocity, what velocity you would get in non-viscous fluid flow. This we discussed, imagine the body is moving therefore, there will be a pressure distribution, so, it is not same, the velocity here is not constant everywhere. Do you understand? Is that clear? Far away it is constant, far away, but just outside the boundary layer the velocity distribution will be as per non-viscous fluid flow, is that clear?

Yes, just imagine a fluid particle here inside, somewhere here, how does it look? See, you are standing on a ship looking at the flow around, you know your ship is going at a constant velocity, 16 knots, you would expect water particles here everywhere moving at 16 knots, far away- is it not?- but here you have seen that the velocity is less than 16 knots, much less than 16 knots, here it is much less, it may be two three knots, as you go forward you will find 14 knots, 15 knots, like that going up to 16 knots, let us say.

So, as if a lot of water is being taken along with the ship, do you understand this, you have to understand this as if a lot of water is being pulled along with the ship, this pulling if you have noticed a ship flow any time on a full ship, you will find this pulling is within a small region, only you can see it very clearly at the stern- moving with the ship, and it is not large, beyond that the sea is as before- so, this is the boundary layer that develops, what is this effect on the pressure resistance we talked about?

Now the pressure resistance, we said would have been higher at the stern and higher at the, pressure would have been high at the forward end and aft end, non-viscous fluid, now, let us bring that to the viscous phenomenon, what is happening? Actually, pressure and viscosity will act together, now here the velocity is low, and in effect when we say the potential flow is actually beyond this layer, that means, the phenomenon that is controlling the motion here is the viscosity, and beyond this pressure is acting normally.

So, you see, the slope of this body is less than the slope of the actual body, so, as if the pressure would instead of acting like this it is acting like this; beyond the boundary layer, the boundary layer blunts the flow, pressure distribution around the stern.

No, just one minute, we have not gone into this thing, I am just dealing with the pressure resistance we have discussed earlier. You see, what we said here, the pressure was acting on the body surface, now we are saying, from this diagram you can see that the fore body is remaining more or less as it was, so the pressure forces on the fore body would be as for non-viscous fluid flow, but in the aft body, because of viscosity and development of a boundary layer the body is blunted, is smoothed more- not blunted- smoothed more. So, the pressure that is acting on the boundary layer will be now reduced, do you understand this? What is this effect? That, you remember, aft components were supporting the motion, now since the pressure is reduced the pressure that is supporting the motion is reduce. It is not equal. So, you have got a resulting opposing force.

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((It is because dominant mode))

It is there, dominant or not we will see later. It is there, this component we now call viscous pressure resistance, that is, a pressure resistance coming due to viscosity.

We saw previously that the pressure resistance here was zero, resistance due to pressure. Here we are saying that it is no more zero in a viscous fluid, but a little bit pressure resistance now starts acting because of the development of the boundary layer, is that clear? So, this is called viscous pressure resistance. So, we are still on the submerged body. Now, let us take a case when the body is made more blunt than what it is.

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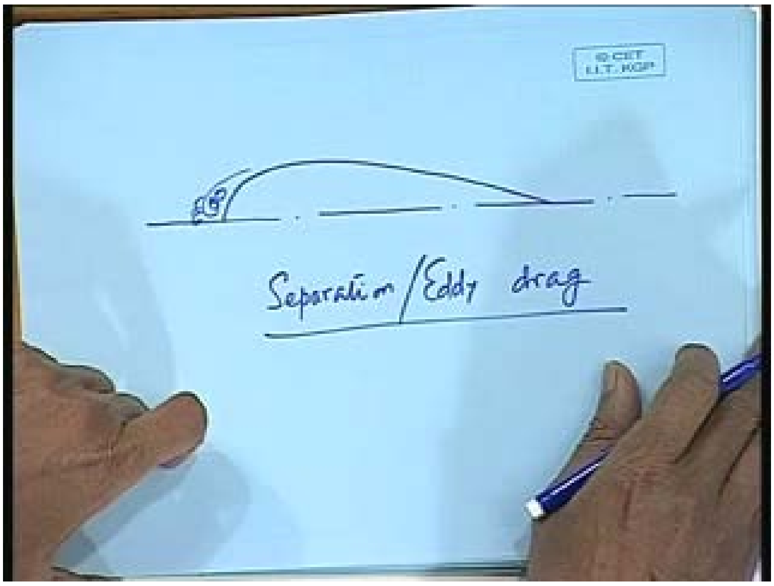

I am drawing a body which is like this, symmetrical, I am not, I am just drawing one side, you see here the fore body, the aft body of the, aft shape is blunted quite a lot. You see here, in the previous case, we had a smooth body and the pressure reduced here on the body and we had a augment of resistance from the forward side. Here what will happen? Here the same thing will happen, in fact, it will happen more prominently.

Layer will not be more, no, that will not, till here the layer is being developed on the forward basis, how can the layer certainly thicken, that will not happen, what will happen is, the pressure drop here will be more prominent. It may so happen that there will be a negative pressure at some point, negative pressure means the flow will separate from the body, flow instead of going past the body like this it will go further and then curl in- there is no body. Do you understand? Flow will come and go like this, it cannot negotiate the sharp curvature because there will be large separation, as if the flow is coming like this, it will further and then form eddies, you will have eddy formations here, do you understand?

This is also, this can happen due to viscous flow- some separation can take place- also it can happen due to non-viscous flow. But primarily at the stern of the ship, it will occur due to viscous flow, there is no non-viscous flow near the body in the up portion of the body; like we saw in the fore body, a forward portion is more or less like non-viscous flow because the boundary layer has not developed fully, you understood? Is that clear?

So, you have this phenomenon where the flow separates from the body creating eddies, this is called separation or eddy drag- drag due to creation of separation or eddies. In the previous case, I did not complete this, because of the tangential forces between the layers and creation of this boundary layer, which, where you see that a mass of water is following the ship, that energy that is given to the water so that you can follow it comes from the ship- otherwise how can the water on its own start moving- that energy that comes out of the ship is what we call frictional resistance, purely due to friction.

So, this gives frictional resistance, we look at this in more detail later on. And here you have separation or eddy drag, which is again in case of a ship, is mostly a viscous effect; if it was not viscous, perhaps the flow would have gone around it or some circulation might have created, but not separation or eddy as we understand behind a ship.

So, primarily, now, we have seen that for a submerged body, you may have some amount of viscous pressure resistance, you may have frictional resistance- you will have frictional resistance because all fluids have having friction- and you may have some separation or eddy drag; this is the same case with a submarine or even a airplane.

If the flow is at an angle, you may get some perpendicular force with the direction of flow which we call lift, but in ships there will be no lift, there is no angular, angle flow causing airfoil effect, unless we mean it to be. So, this also we will see later.

But in normal ships there is no lift force or no vertical force. See, the water is flowing like this, if there is any perpendicular force, it will be pushing it up, dynamic lift, we have seen there is a perpendicular force called buoyancy, but that is static, that is depending on the geometric of the body not on the flow- you understood- there is a vertical force which is buoyancy, but this is purely because of the geometry of the body, it has nothing to do is flow. But if there is a vertical flow generated, a vertical force generated due to the flow then we call it a lift force, in case of a ship if there is a lift force, it will lift the ship up.

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((that is will be change that this thing during landing.Lift is also due to the design on the)).

Yes, of course, if we intend that a lift should be generated, then we have to generate the body so that maximum lift can be generated, and we know that a airfoil shape is the best shape for lift generation- there are other problems. As you go through this whole course, I believe there will be, we will, we will understand something more about lift generation. But right now it is enough for us to understand that in a displacement ship, that is, a ship which is based on the displacement phenomenon, that is, buoyancy equal to weight, there will be no lift force, the weight will be completely supported by buoyancy- if we want to generate some lift force, we have to do some, take some design measures so that a lift force can be generated- but right now there is no lift force.

So, this is all about frictional resistance and pressure resistance for a body under water, inside water. In the next hour we will see what happens when the body comes to the surface. Thank you.

Preview of next lecture

Lecture no. # 02

Components of Resistance – ii

Gentlemen, we will talk about a ship coming to the surface now. What is the main difference between a submerged body and a body floating in the surface? The main difference is, now, the body is moving in two media instead of one medium, and between the media there is a surface which is free, we call it free surface. That surface, the geometry of that surface will depend on interaction between the two media and basically the pressure. Do you understand?

Now, suppose for example, you see a water wave on the sea surface, can you tell me what is the pressure on the top of the wave surface? Top of the surface.

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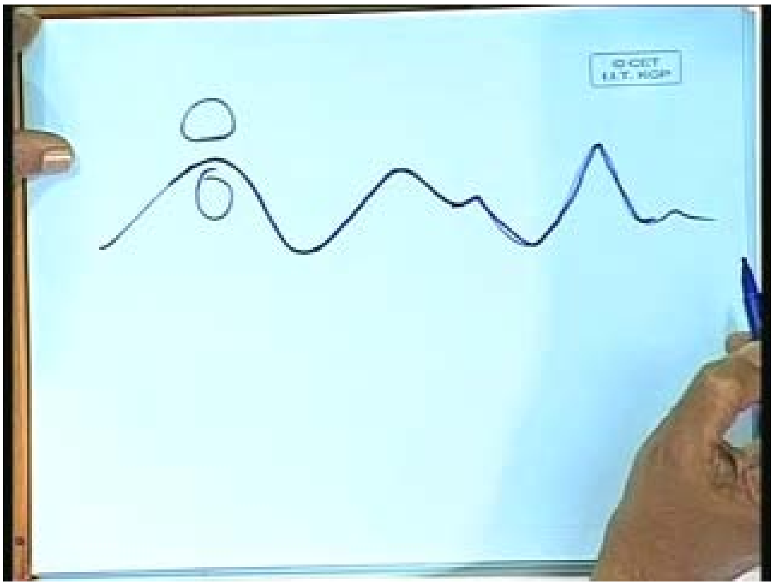

Suppose, I have got a wave surface like this, what is the pressure here, here and here, is it constant? No? Then you are in big trouble; it has to be constant and equal to atmospheric pressure.

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((Pressure must be less that then only it is going on pressure)).

No, pressure here and here are different, they are adjusting themselves in such a manner that the pressure on the surface is constant- it has to be constant, that is the atmospheric pressure.

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((Sir bringing that (( )) other than the normal condition then there is a total straight line))

Yes, if it is straight line, there is no wind, pressure is same- pressure is atmospheric.

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((Sir that is usually we can make out that, but this one is changing))

On the free surface it must be constant pressure, this is simply one of the conditions imposed on any flow that the pressure on the free surface- otherwise it will not remain free, it is constraint, it is a free surface-therefore, the pressure at any point is equal to atmospheric pressure on the free surface, it will vary drastically as you go down, it will vary as you go up; the atmospheric pressure will be changed because of the velocity of the air. Here it will change because how can you have a high pressure, a pressure here, and without any variation? So, that will change, but on the surface itself the pressure will be constant.

You do not see large waves far beyond you, will see waves in fines smooth ships, but in large bulk carriers and tankers you will not see those big nice waves that you saw before, but you will see in the front the white fluid, flower like things. So, there is a big difference between these two phenomena. In one case, the waves that carrying away the energy as wave making resistance; in the other case, though the waves are generated due to a potential flow effect its manifestation is in breaking waves, in that this thing, that also take some energy. Initial formation of this was due to taking away of the energy, but its manifestation is in the form of wave breaking. So, you see when somebody tells you that in a slow full form ship wave making resistance is almost negligible, it is true because you cannot see waves, but there is a large amount of wave breaking resistance. Do you understand?

Similarly, in the forward and bottom there may be eddies and separations exactly for the same reason as we had in the aft because of the sharpness of the curvature, again, it is a phenomenon of full form ships; in fined form ships like frigates or naval vessels or container ships and passenger ships, this may not be there, but in case of full form ships this is something which you may expect, that some drag resistances, some formation of eddies and vortices, and going away from the bilges of the forward end, forward bilges take away energy. So, there will be that component of resistance also coming

So, on a surface ship you will have the wave making resistance depending on the fore body shape, you may also have wave breaking resistance, you will have the frictional resistance, you will have the separation drag or eddy drag, and you may also have the viscous pressure drag, which may be substantial, maybe we do not know, that has to be take into account.

So, but in general we do not bother, because you see, previously ships were riveted- lap jointed and riveted- that used to add a large portion to various things; after the welding has come, and with a thorough supervision the weld mark, the discontinuity due to weld mark, it is not so prominent.

So, what we do actually, if we are talking of model experiments and full scale tow rope resistance comparison, model vessel is very smooth, either in wax or in fiber glass or whatever you make, the model surface is very smooth, but in actual ship the surface is rough, it can never be to that smoothness. So, what we do is, we add what is called a correlation allowance, that is a small increase in the resistance as we extrapolate it to full scale, to take into account the initial roughness of the ship, which includes weld marks and any discontinuities in the hull surface. One thing must be understood, any discontinuity must necessarily be small, if it is large, it will create separation- that is not taken into account.

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((Due to))

So, we will talk about this when we talk about extrapolation from model to ship, which is going to be our main theme in this set of lectures, we will see how we can take into account such discontinuities that happen. So, next class we look at, I think we will first look at frictional resistance, and then look at wave making resistance, and then we will see model experiments.

Thank you.