Ship Resistance and propulsion
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Lecture - 4
Frictional Resistance and Turbulence Stimulation

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These are the general characteristics about resistance, resistance components. We also discussed about viscosity, viscous effects, boundary layer formation, type of ships based on which the resistance estimation should be performed. Now, coming to the details of for the components of resistance, first we look into the frictional resistance.

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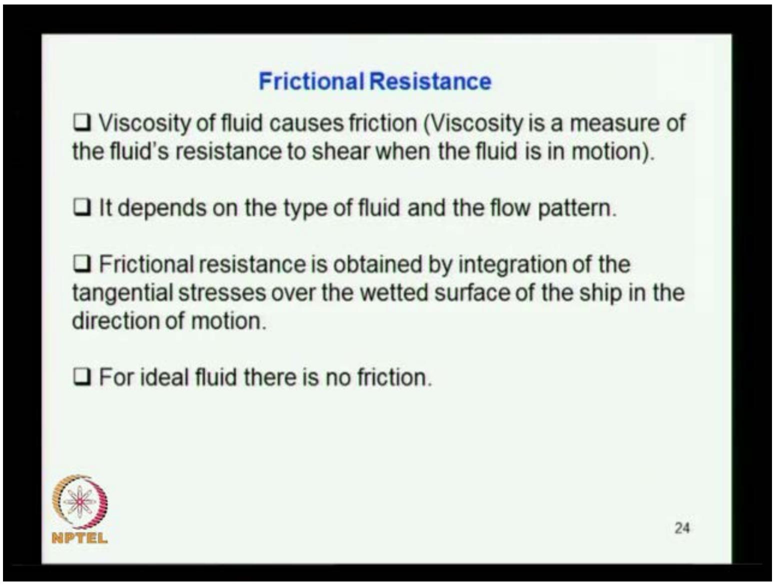

Viscosity of fluid causes friction. We know that we have already discussed viscosity results in shearing of layers, between the layers and between the fluid layer adjacent to the body and the body. There will be a shearing effect. The shearing effect leads to a tangential stress. We know that tau is equal to mu into dou u by dou y. That is the relation for Newtonian fluid, so that tau is the shear stress. So, if you integrate the shear stress over the wetted surface of the ship, you get a resultant frictional force which opposes the motion of the result that is due to the viscosity.

So, this again depends on the type of fluid. Now, here we consider water. So, here the only option when you can consider for ships is whether it is in fresh water or sea water. That difference matters, but you do not envisage any other fluid in which ship operates except air and water. The flow pattern, what type of flow that is? Is it turbulent? Is it laminar? What is the flow pattern depending on which viscous effect changes, frictional resistance changes? Frictional resistance is obtained by the integration of the tangential stress. That is what I said before. So, it is by integrating the tangential stresses or the wetted surface of the ship. So, for ideal fluid, there is no friction because there is no viscosity. So, that is obvious.

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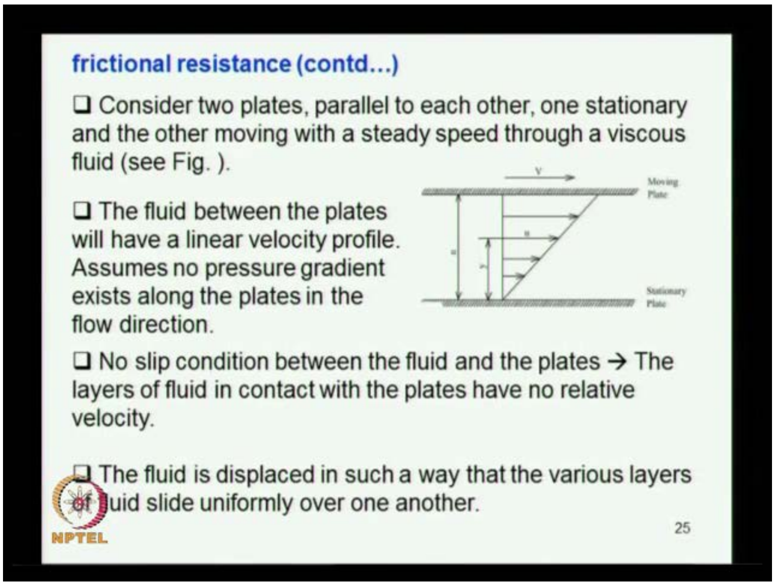

That is what we discussed in relation to their d Alembert’s paradox. Now, we just explain these viscous effects here. You consider two plates, one is stationary. You can say that the bottom is a stationary plate and the top one is a moving plate with a constant speed of v. So, here we consider there is no pressure variation or pressure gradient over this between the two plates. If there is a pressure gradient, there will be a velocity. Now, the only thing is the flow is induced not be a pressure gradient. It is induced by the plate moving. It is still water.

We have one plate, which is stationary. If another plate which is moving with a constant speed, so here that means the flow adjacent, the fluid particle adjacent to the plate attains the velocity of the plate. Isn’t it? So, if the plate is stationary, the fluid particle adjacent to that gets a zero velocity. If the plate is moving with a velocity v, the fluid particle adjacent to that plate will get the same velocity as the plate.

So, you have v here and here you have zero and in between, it varies in the linear form like this. So, there is a flow variation across these two plates. When one plate is stationary and other plate is moving, so that is what this is no slip condition between the fluid and plate. That means what does it mean? That is that is what I said. The fluid particle does not slip. There is no slip with the boundary. It means it attains the same velocity as the body.

So, that is what you called there no slip condition. The layers of fluid in contact with the plates have no relative velocity. That means it will have the same velocity as the plate. So, that is why, you have the zero velocity here and the plate velocity here for the fluid particle. The fluid is displaced in such a way that the various layers in the fluid uniformly slide over one another. So, that is why, we said uniformly, we have a linear variation. So, each layer will slide with a uniform variation of gradient.

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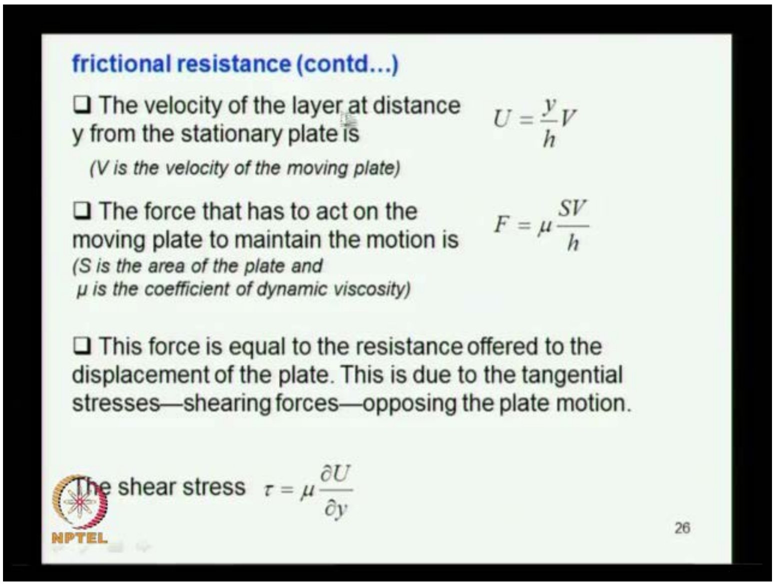

So, if you look to that velocity, it is the velocity at the layer at a distance y from the plate. That is if you look here, this is the u, small u that is the velocity at any position, then this is y. Then this is a distance separation of the plate that is h that separation. So, the velocity at any distance, we can give U is equal to y by h into V. We consider linear variation. So, this is the velocity and the force F is equal to this. This is the dynamic viscosity into S into V by h.

S is the surface area, area of the plate here and h, we have seen that V by h, this relation gives the velocity gradient here. You can see it is coming from this. This is the relation which I mentioned shear stress, tau is equal to mu into dou U by dou y. You know this relation. So, this is the relation which I defined Newtonian fluid. If we know the stress, this is the stress. Stress into area gives the stress is equal to stress and area gives the force. So, you get this relation from this one using the relation over here. So, you just get this relation.

The force that has to act on the moving plate to maintain the motion is given by this, which is coming from this relation and substituting this over that. This force is equal to the resistance offered to the displacement of the plate that is for the movement of the plate. So, this we are not considering any wave making identity here. This is due to the tangential motion also, shearing force opposing the plate motion. It has to overcome that and move the plate.

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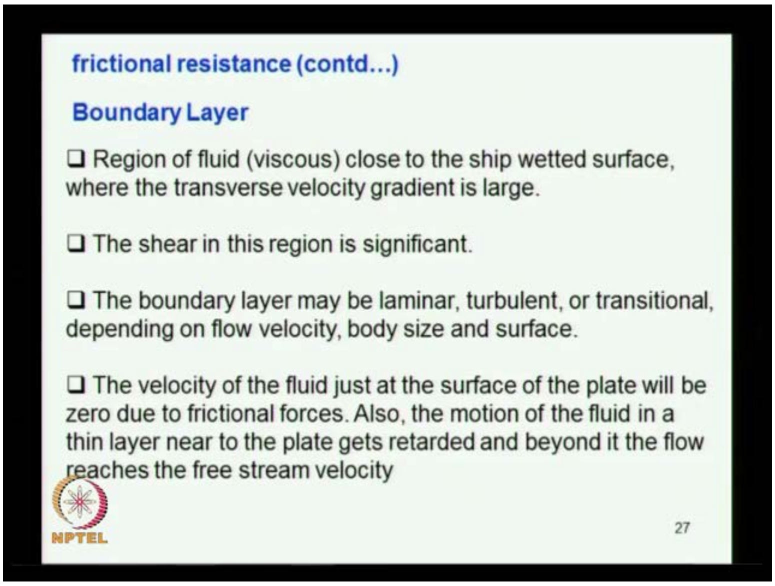

So, this is the force related to move the plate. So, when you look to the boundary layer, the region of the fluid close to the ship wetted surface boundary layer, you know that it is very close to the ship surface. Depending on the type of surface, depending on the speed and all that, boundary layer thickness varies, but usually thickness is quite small compared to the ship dimensions. So, in this boundary layer, the shearing effect is significant. We have already seen that the velocity gradient over the surface, the velocity gradient is strong.

We know that boundary layer definition itself is that that the flow velocity transition from zero at the body to the free stream velocity that is usually taken as 99 percent of the free stream velocity that is the point of boundary layer. So, in that region, there is a velocity gradient. When there is a velocity gradient, there will be a shear stress. That is this quantity is there inside the boundary layer. So, that means there will be a shear stress inside that boundary layer. So, the boundary layer may be laminar I said.

Then, we know the laminar and turbulent or may be transitional also. It can depending on the Reynolds's number, body surface, body pattern or body curvature and flow velocity and all that body size, everything matters here. So, this depends on the flow velocity u, body size l and surface roughness. So, all these matters for the type of boundary condition whether it is laminar or turbulent or transitional.

The velocity of the fluid just at the surface of the plate will be due to frictional forces. So, at the body surface, it is due to the friction forces. There is a shearing of the layers which will lead to shear stress and lead to a frictional force. So, there we have already seen that the fluid velocity distribution is zero at the body. Then it increases, and then finally, it reaches a free stream condition. So, that is how the flow gets, you know the inside boundary layer flow varies.

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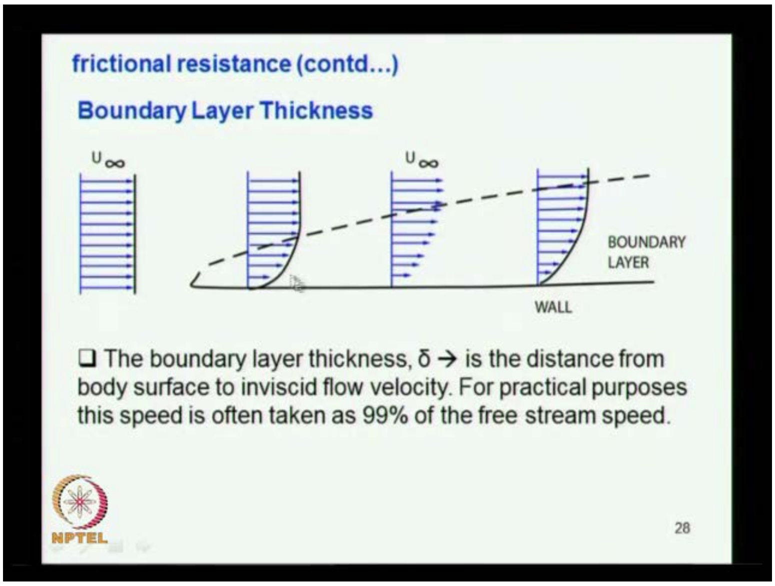

This is a picture for that. You can see that this is, if I take this is a boundary layer and you see this is a velocity profile. This is a wall which is stationary. So, it is zero velocity here at the wall, but away from the wall, it also attains the free stream velocity. So, this is a free strain velocity. So, here it should be free stream. So, the transition from here zero to the free stream velocity here at this point, this is taken as 99 percent of the free stream velocity. So, when it comes here, the line is missing here. So, here this point is a 99 percent of the free stream velocity and here this is at 99 percent.

So, you connect all these 99 percent U infinity points. You get the boundary layer. There is no physical boundary layer. It is only an assumption. So, that is easy to calculate or manipulate the viscous effects. So, because one of the advantages is, if it is a real fluid, if it is an ideal fluid, the viscosity complexity can be avoided in the mathematical formulation. So, we need to consider the real fluid cases inside the boundary layer and outside the boundary layer, often people deal it as potential flow where the formulation is rather easy and computation becomes less tedious. So, that is the reason.

So, this I have already explained. We have seen that it is taken, the velocity profile of the boundary layer phased to be like this. The wall is stationary here and zero velocity here adjacent to the wall for the fluid particle. There is a point where you have the velocity getting to 99 percent. Similarly, you get the profile over the, along the length of wall or over the body. Then you join the points at 99 percent of free stream velocity. Then connect these points with the line, which you say it is a boundary layer.

So, inside the boundary layer, the viscous effects are more and outside the boundary layer, you have the viscous effect not significant and often the flow analysis is performed using potential flow theory away from the boundary layer and inside the boundary layer, can be treated as a real fluid and where Napier's docks equation should be applied.

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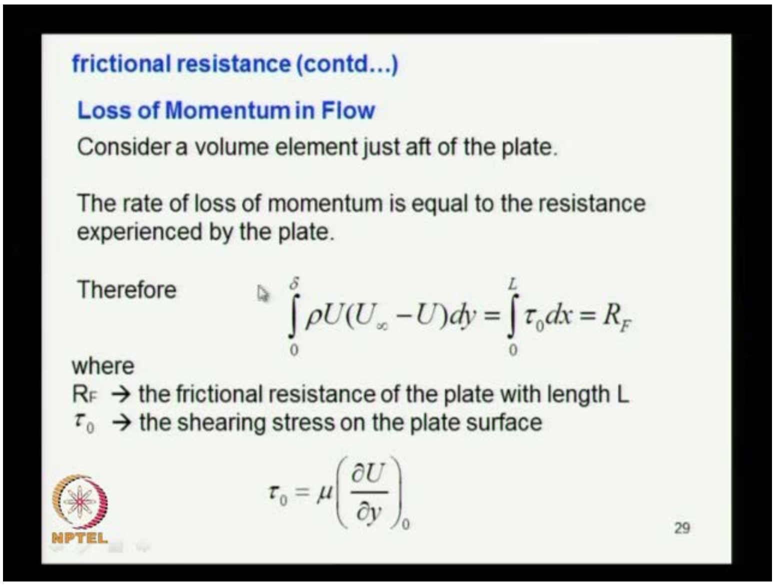

Loss of momentum flow, you can just look into the forces coming on this surface due to the viscous effect. You are considering a volume element just aft of the plate that is what is the change of momentum occurring to the fluid when it crosses over the plate, before the plate and after the plate? So, the change in momentum of the body is obviously the frictional force coming on the plate. So, here this is represented by the momentum equation here. That is the loss of momentum occurring to the fluid volume when it passes over the plate. So, that is equal to the resistance of the plate. So, here you can see that this represents the momentum change of the fluid component.

If this is integrated over the boundary layer thickness, delta is the boundary layer thickness, so this will be equal to the total sheer; you know stress integrated over the length of the plate, which gives the total force resistant force. That is due the frictional force here it is written as RF is a frictional resistance along the plate. Tau you know, it is coming from the relation of the Newtonian fluid where the shear stress is equal to, is proportional to velocity gradient. It is taken at 0, which obviously refers to that at the wall.

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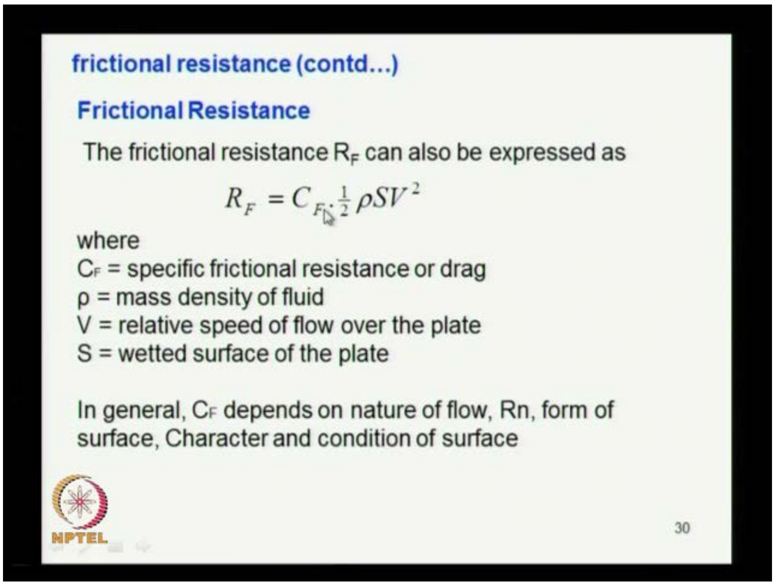

So, frictional resistance usually, we have this is if you know the coefficient of frictional resistance, CF is the specific frictional resistance coefficient and frictional resistance or equivalence frictional resistance coefficient. CF is equal to frictional resistance RF divided by half rho SV square where S is the wetted surface. Rho is the density of fluid and V is the flow velocity. Here, the CF depends on the nature of flow that is whether it is a laminar flow or turbulent flow or transition region that depends on that which again in turn depends on Reynolds's number.

Then, it depends on the form of the surface that is what is the shape, the whole stream line, the shape is where there is perfect change in the continuity and all that also matters. This is because whenever there is a sudden change in the curvature, there will be a flow separation. Then the flow separation results to subsequent, you know increase in resistance, then character and condition of the surface that is whether it is a smooth surface or rough surface depending on which the frictional coefficient differs. So, all these parameters contribute to the resultant frictional resistance. So, if you look to the boundary layer, our intention is to find out what is the relation of this frictional resistance with reference to the velocity.

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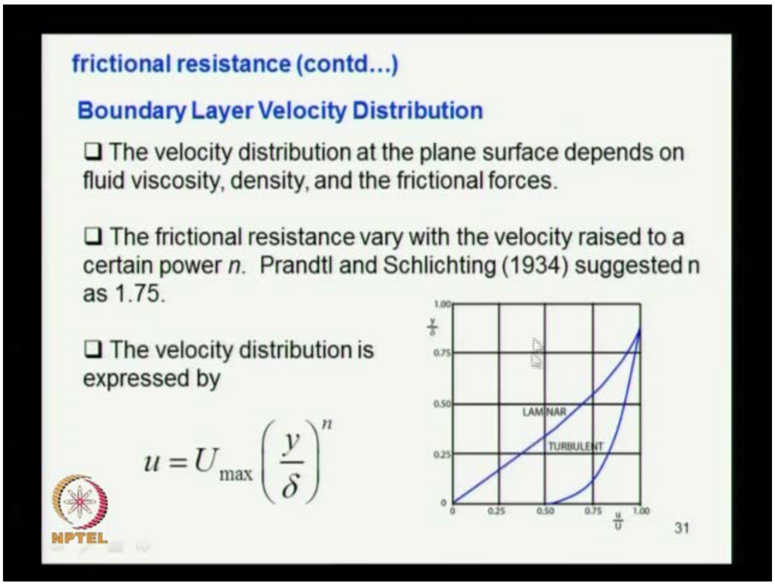

Here that is a boundary layer velocity distribution. You can see that here is y by delta that is distance inside the boundary line that is like boundary line thickness. Here you have the velocity proportional velocity that is u by small u by capital U capital U for free stream velocity. So, that means a wave from the boundary layer, it reaches one that is the free stream. The boundary layer velocity goes to a free stream velocity. So, this is the distribution in a laminar flow condition. This one is in the turbulent condition. You can see that in both cases, it is coming to zero at the surface that is when this value is equal to zero.

Then, the velocity distribution at the plane surface depends on the fluid viscosity. Of course, it is a variation. The velocity profile will be different for different fluids. So, it will depend on the viscosity, again depending on density and then also on the frictional forces, frictional forces, frictional forces again depending on the surface type. We have seen the other parameters. The frictional resistance varies with the velocity raised to power n that is v power n is n. The value of n we have to find out and prandtl and schlichting, they are based on their experimental studies. They came up with a factor of 1.75 for the value of n. That is the frictional resistance based on their studies proportional to v power 1.75.

So, that is the conclusion based on their experimental study, but it got revised later. We will see that subsequently. So, the velocity distribution, you know if the velocity distribution here is expressed by this u is equal to, u at any point within the boundary layer is equal to u max that is the free stream velocity and y by delta power n. This value of n is that is what we have put for that 1.75.

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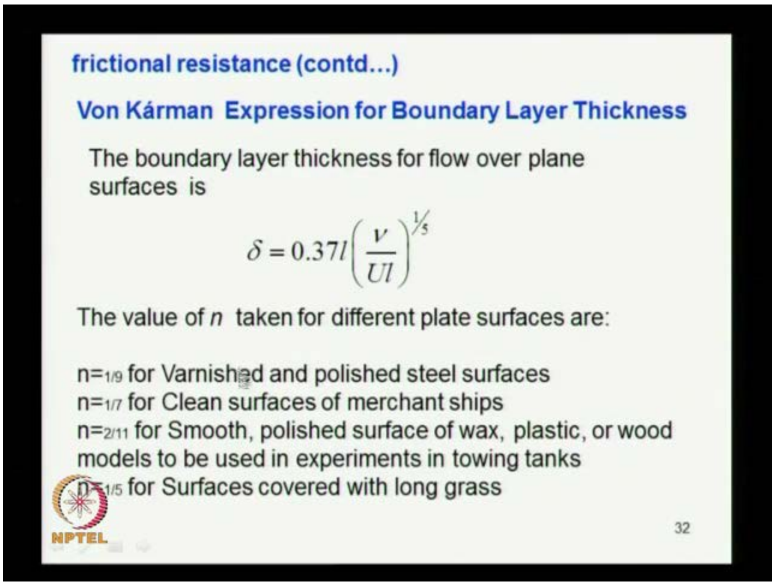

We just think the boundary layer thickness for the flow, there is Von Karman expression for boundary layer thickness is given by this expression over here, delta boundary layer thickness given by this and the parameters, we have already explained there l is the length of the plate and all that. So, here value of n is taken for different plate surfaces.

We can see that how the value of n varies for different surfaces. If it is for varnished and polished steel surface, it is 1 by 9.

For clean surfaces of merchant ships, it is 1 by 7. For smooth, polished surface of wax, plastic, or wood models which are used for experiments, so there it is 1 by 11. Here surface covered with a long grass that is basically accumulation of molecules or sea weeds, so it may resemble to that say steel. So, it is rougher whether due to the operation nature. So, the power of n is equal to 1 by 5. So, these are all based on their studies. They have done towed plate of different sizes at different speeds with different surfaces. They have consolidated the experimental results and came up with this relation. Just see what the flow separation is.

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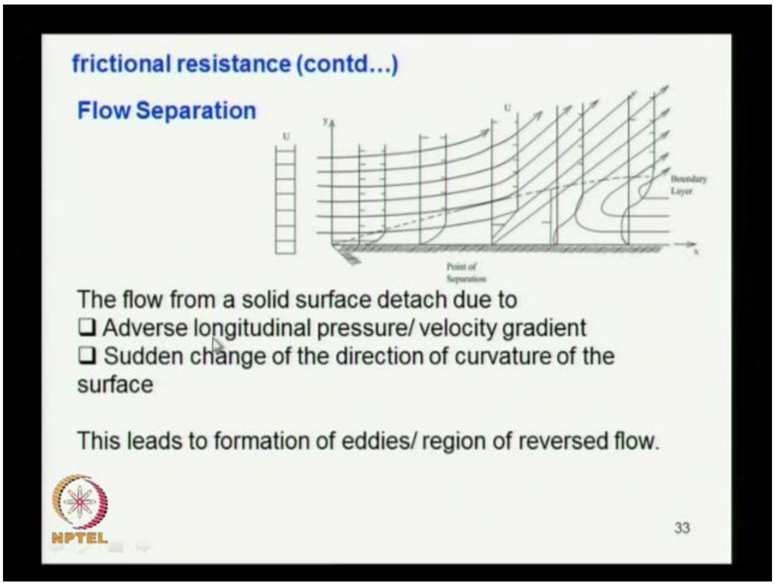

We have already discussed about what is flow separation. The flow separation, you see the boundary layer, the dotted line here is the boundary layer. Here we can say that there is a plate over which there is a flow occurring. The free stream velocity is given by u. So, it is moving like that. So, you can see the velocity profile. So, here this is 99 percent. Here it moves boundary layer build up over the, along the length and boundary layer thickness increases towards the rare end of the plate or the flow. In the case of ship, it is towards its aft, the boundary layer thickness increases. So, the velocity gradient here gives an indication for the point of flow separation.

So, here we can say it is a positive gradient, the velocity gradient. When it comes here, the velocity gradient is almost, it is a zero. It is that it is joining tangentially at the bottom where this is zero. That is actually the point of initiation of flow separation. When it goes further down, it goes further down, you get it is a negative velocity gradient, which gives a clear indication that the flow is already separated. So, this is when the flow gets a vertex. It is so formed during the flows and once the flow separates.

So, here the flow from the solid surface is that adverse longitudinal pressure or velocity gradient. That is you see that there is an adverse flow or velocity gradient. It can occur may be due to a sudden change in the form of the body. If the curvature about the flow is going across the body, all of a sudden, the curvature of the body changes, then the flow separates. There also that is there is the sudden change in the velocity or also there is a sudden change in the pressure. So, the adverse longitudinal pressure velocity gradient results in flow separation.

The sudden change of the direction of curvature of the surface that is what I just explained. So, sudden change in the curvature also results in the flow separation. So, once the flow separates, eddies are formed and you get a reverse flow. That is what we are saying. The flow is getting a reverse flow here. So, that is how eddies are formed. The flow separation in boundary layer remains, the boundary layer remains thin until the flow separates. We have seen that from that here it is usually small and as when the flow separates, the boundary layer thickness jumps up and increases drastically.

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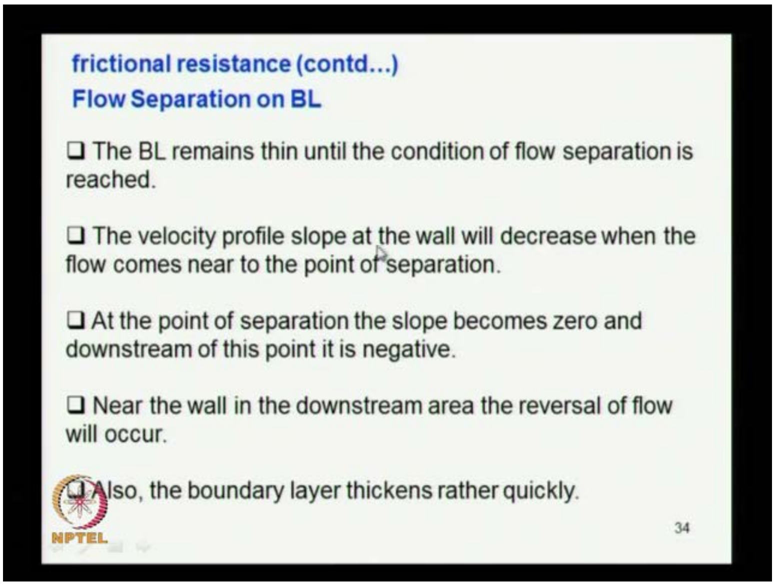

The velocity profile slope at the wall will decrease when the flow comes near to the point of separation. That also we have seen. Then the velocity gradient here, it is more and here, it is reducing. Here, it has become zero. So, at a point, it keeps on reducing towards the point and then it changes to a negative velocity gradient. So, that is what I said. It is that this point, it has become negative when the flow separates. Then near the wall in the downstream area, the reversal of flow occurs. That is you can see that the downstream here, this side the reversal of flow occurs in the boundary layer. Also, the boundary layer thickness increases rather quickly. That also we have seen from that diagram.

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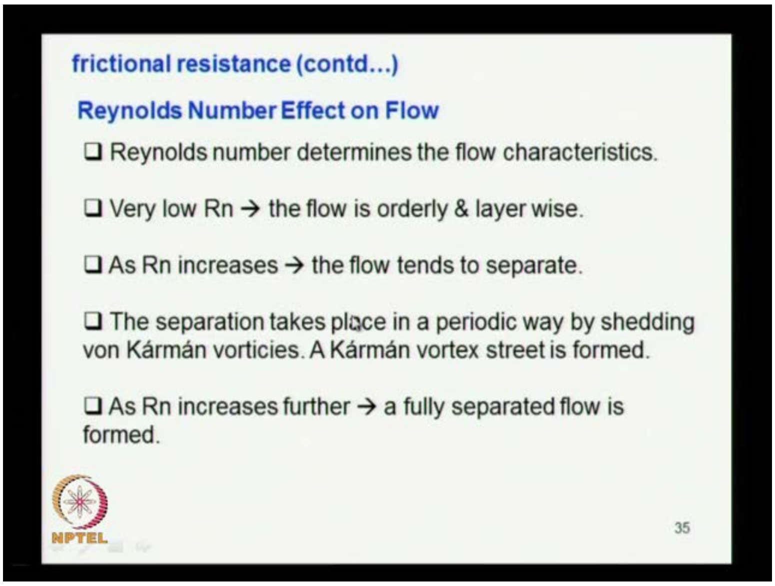

What is the effect of Reynolds's number on flow? Generally, there is a non dimensional number, which has been used for you know that is v l by nu where v is the velocity of the flow l is the characteristic length of the body and nu is the kinematic viscosity of the fluid, which is equal to mu by rho. Mu is the dynamic viscosity and rho is the density. So, that is the definition of the kinematic viscosity. So, here at very rare, low Reynolds's number, the flow is orderly and layer wise. So, it is a laminar flow when the Reynolds's number is low.

As it increases, the flow tends to separate. We have seen that. We can say that when the flow that is even in the previous diagram I said that this is the region, if you look into the local length, this is the region, well up to this, if you consider, the length is small, so Reynolds's number is small. The flow is laminar. When you consider length at this point, the length is large. The Reynolds's number is higher. So, we can interpret the flow pattern also with reference to the place where it occurs and what is the length at that point. Then as the Reynolds's number increases, the flow tends to separate.

So, this becomes that is the flow becomes boundary layer becomes turbulent and flow separates. The separation takes place at a periodic way by way of shedding Karman vortices. So, you see those vortexes are shed from shed when the flow separates. Then if you increase the Reynolds's number further, very high, then naturally, it becomes a complete fully separated flow you get.

So, what is formed is that is the effect of Reynolds's number on that. That is why, when the Reynolds's number is low, the flow is laminar. When the Reynolds's number increases, the flow become turbulent and the boundary layer separates. Usually for ships, if the Reynolds's number is less than 10 power 5, we treat it as a laminar region. If it is more than 10 power 6, it is generally, it is a turbulent region and between 10 power 5 and 6, it is a transition period, so transition region for the flow.

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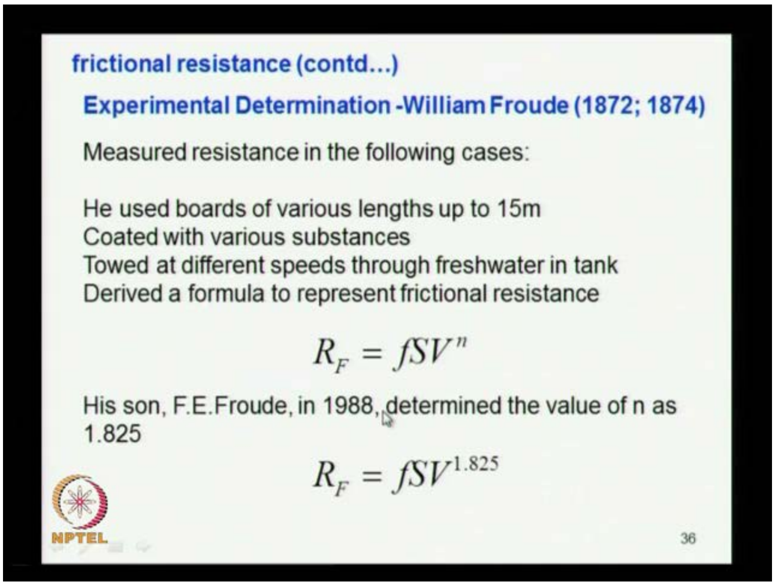

So, experimental determination of this frictional resistance, just see that the experiments carried out by William Froude, we can see that it is only one half old century old experiments. So, what he did is is that he towed plates of different sizes and different width at different speeds in a towing tank and measured the force coming all over, the towing force required for that. So, if the plate is there and it is sufficiently submerged, the velocity, the wave making effect is negligible. So, the only thing coming is frictional resistance. There is no form. The plate is two d. So, there is no form resistance coming there.

So, only the frictional resistance is coming there. So, you can, when it is towed, you can measure the force coming on the towed rope. That towed rope pulled is equal to the resistance offered by the plate at different speeds. So, collect the data for that and then consolidate that data and analyze the data. He put forward a formula for the experiment for the determination of frictional resistance. So, that is what he said. He used boards of various lengths up to 15 meters coated with various substances.

We have seen that depending on the surface, there will be change in the resistance towed at different speeds through fresh water. I have already explained. So, you know RF, the total frictional resistance is proportional to surface area and also velocity power n. This is taken as a constant. So, later his son, he came up with, I think it is 1888, it is not 1988, so he came up with determined the value of n as 1.825. So, he put the value of n as 1.825. So, this is still like an accepted value for n. It is still used.

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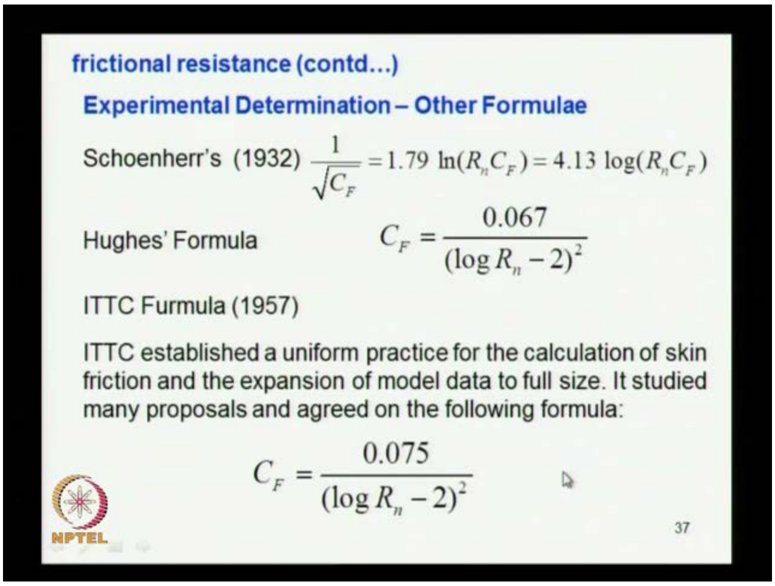

So, various groups performed experiments using plates and mainly two d plates and all that. So, they came up with different expressions for the estimation of frictional resistance coefficient. This is the one we put for the schoenherr. This is the CF is the frictional coefficient, Reynolds's number is a factor here. So, this is the expression given for the frictional resistance Hughes' formula. He came up with the formula CF is equal to 0.067 divided by log Rn minus 2 to the whole power 2. So, this is the expression put forward by Hughes.

So, ITTC you know, it is international towed tank conference that is the organization of people owning towed tanks. They formed a group in the names for standardization basically for the towed tank operation. So, most of the towed tanks, they have to, if they are interested in getting a standardization approval, international approval for the facility, they become a member of ITTC. To become a member of ITTC, they have to undergo different calibration tests and everything for a tank. After that, if it is within the expectable standards of ITTC, they allow the organization to form as a member in ITTC. What we did here is that is appointing the committee to study the frictional resistance and adopt a formula or come out with a formula.

The formula is to find out the frictional resistance. So, a committee that is responsible to, a committee has to look into the experimental activities and also the relations brought out from their activities to estimate the frictional resistance and then suggest which formula should be adopted by ITTC through estimated frictional resistance coefficients. So, this committee went through various formulae and research groups and including Hughes' formula and all that.

Finally, they came up with a relation that CF that will be represented by using this formula that is CF is equal to 0.075, whereas we used here 0.067. After they have studied, they have put forward this formula which is appropriate. Then at that time in 1957, they said it is a tentative or it is a temporary suggestion. Subsequently, based on further advancement in the research and the experience, this can be revised, but the thing is the fact is still the formula remains same and still it is being used. So, that is the expression for given formula by ITTC that the CF value can be estimated.

Why the CF value needs to be estimated from the experiment? This is because of frictional resistance qualification. The friction depends on the viscous property of the fluid. If you want to consider viscous property of the fluid, we have to consider the real particle motion. Real fluid particle motion is dealt only with Napier's dock equation. The solution of Napier's dock equation numerically, now also, it is not possible. So, you just imagine that getting a numerical solution for frictional resistance estimation is ruled out. Hence, it will depend on experiment. So, that is why, experiments have been done and frictional resistance coefficient expression has been brought out from these experiments.

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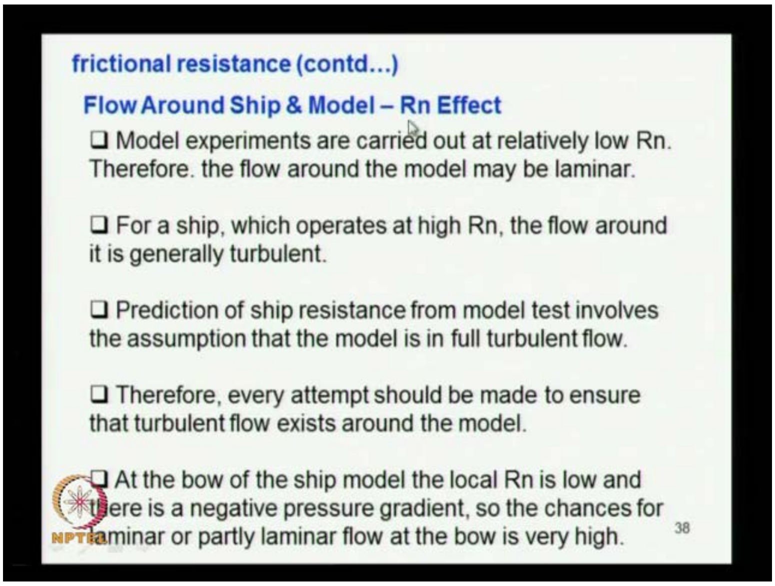

Flow around ship and model, Reynolds ship and model Reynolds number effect, you know that Reynolds number is this equal to vl by nu and here, the speed of model, if you compare this model in shape, the speed of the model is less. We will see later following the Froude condition, Froude hypothesis. That is the speed of model v m is equal to speed of ship divided by square root of the scale. Isn't it? The model length is quite small compared to that of a real ship, maybe a two hundred meter ship is modeled as a four meter. So, you can see the prediction in length.

So, the Reynolds number vl by nu remains the same as because model is done in fresh water and ship operates in the sea water generally. So, what happens? The value of mu remains more or less the same. So, the only difference is coming in the numerator, v and l compared to ship in model. So, the ship Reynolds number is much higher compared to that of the model Reynolds. You know that the flow around the model, around the body, the boundary layer characteristics depends on the Reynolds number.

That means the flow around the model is going to be more than the laminar region, whereas, the flow around the ship is going to be turbulent region. So, if you perform a model test, then you need to have a condition of kinematical similarities with the fluid particle. The kinematic should be similar. It is not achievable between the ship and the model. We will see later how to tackle this problem.

So, the model experiments are carried out at lower Reynolds number. That is the reason I have said now, the flow around the model maybe laminar. So, around the model for a ship, which operates at high Reynolds number, the ship will have a high Reynolds number. So, as I said before that the flow around is generally turbulent. So, there is a mismatch. Here it is laminar and here it is turbulent. The kinematic similarity is not achieved. So, prediction of ship resistance from the model test involves the assumption that the model is in full turbulent flow.

That means to achieve higher dynamics, dynamic similarity, you have to generate the turbulence around the model also. So, every item should be made to ensure that turbulent flow exists around the model. So, we have some techniques how to generate turbulence around the model to give more resemblance to the flow conditions around the ship; then only the prediction of resistance from the model will become acceptable when it expiated to the prototype.

So, you can say that at bow of the ship, the local Reynolds number is because bow is a small length. If you consider maybe 10 percent of the length, there is a small local Reynolds number. The local Reynolds is low, even I mean for the model and all, for the ship also, the local, the front region of the ship, there is a forward region of the ship and also the model will have a laminar flow condition. There is a negative pressure gradient because the velocity increases. So, the chance of laminar flow partly at the bow is verified. So, the bow part usually will have laminar conditions because the local Reynolds number is less and the flow will be laminar in the bow part of the vessel.

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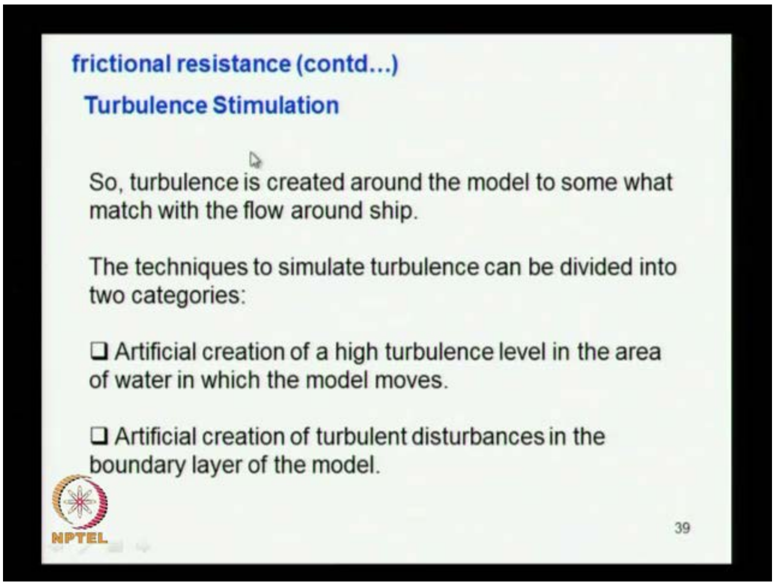

So, what do you do in resistance is that to get some resemblance between the ship and model flow condition, you try to stimulate turbulence using some technique. So, turbulence is created around the model to somewhat match with the ship. It may not be matching exactly with the ship, but this method may have some turbulence, may be having low turbulence. So, you just induce the turbulence there. The techniques to stimulate turbulence can be divided into two categories. One is you create turbulence. The whole flow coming to the model is turbinated or you create turbulence fully in the boundary layer.

So, there are two options. So, you disturb the flow, create the turbulence just before the flow reaches the model or you came only from the boundary line of the model which gets the turbulence. Both of these are acceptable. So, that is what the artificial creation of higher turbulence in the area of water. The water in the model itself is in turbulence or artificial turbulence disturbances in the boundary layer. So, these are the two options you have.

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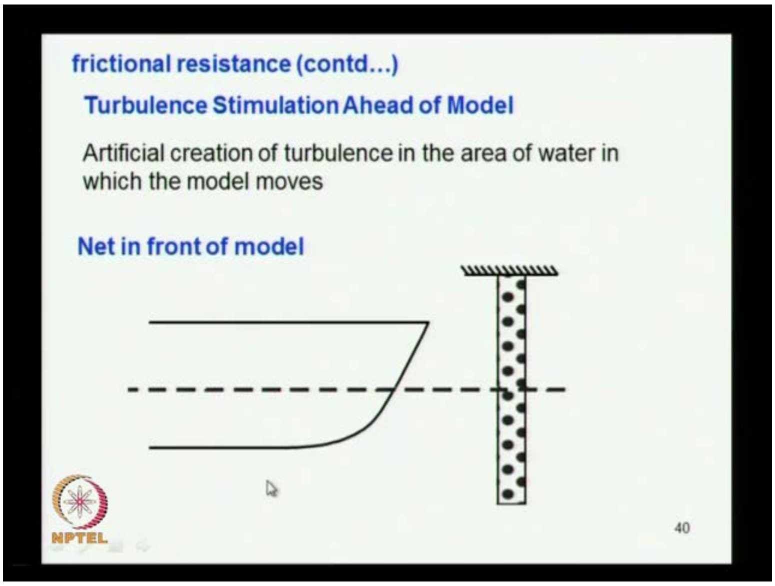

So, here we see what happens. We disturb the flow ahead, turbulence stimulation ahead of the model. So, what are the options you have? So, you have a carriage. In the carriage, you can fix. You can fix something like this. This net you put when the flow passes the net. So, that did not use that turbulence. So, the whole flow around the model will be under turbulence. So, that is one of the techniques here. So, you have a net which will form a part carriage. So, when it moves forward, the flow is coming from here to here. So, when it passes through the net, it becomes turbulent and turbulence is simulated.

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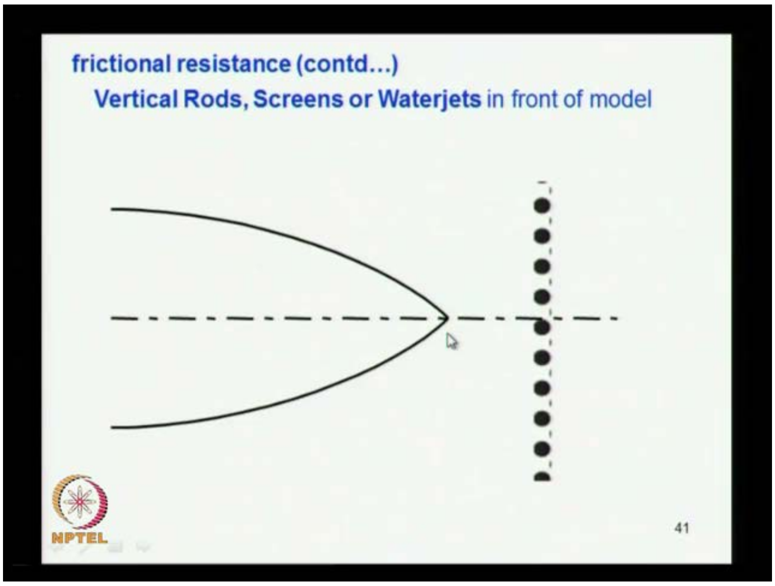

Next is say to put an array of the rods, small rods. Again, when the flow passes through that, there will be a flow separation turbulence created or maybe screen of water jet. You just put a small water jet screen in front, so which also induces the turbulence. So, the whole model will be under the turbulence region.

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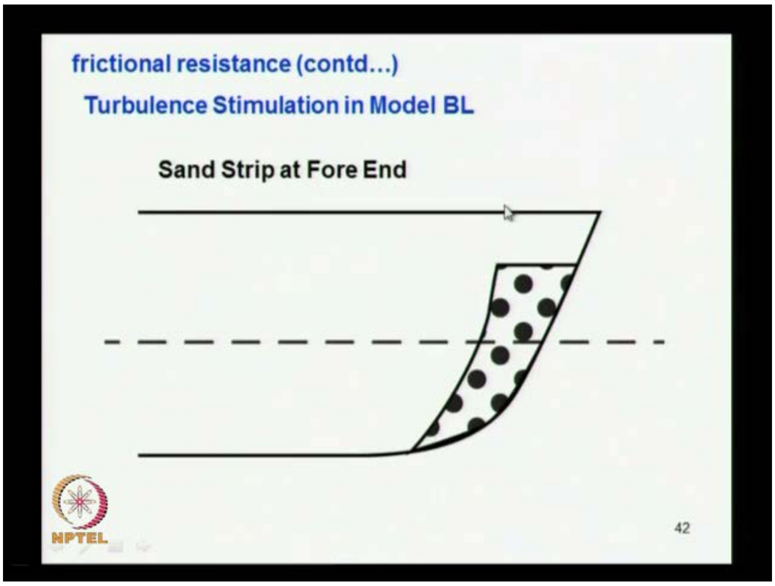

Another thing is now, look into the boundary layer. How do you induce the turbulence in that? That is the second option. So, what do you do is you put a sand paper strip over here. So, it is rough. When the flow passes over this, there is a turbulence created. So, this turbulence will extend in the boundary line. So, the boundary layer becomes turbulent.

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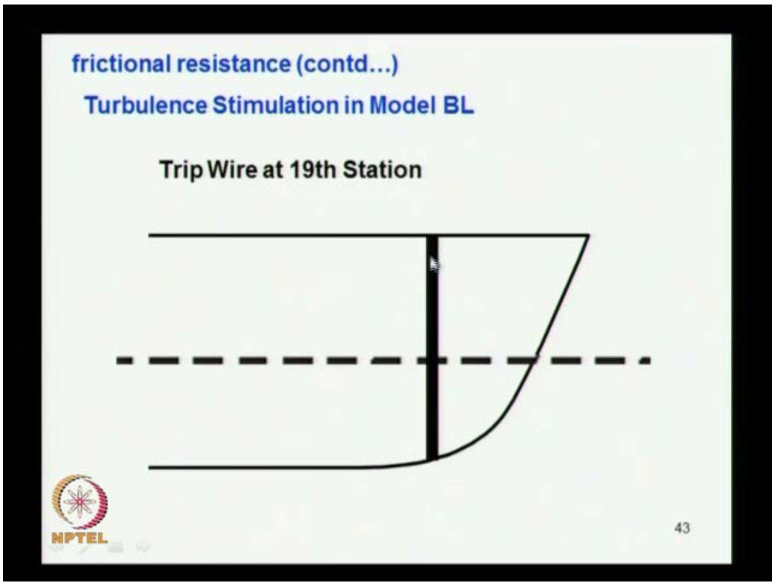

The next option is putting the trip wire. A trip wire is placed usually at the 19th station. When the flow passes the trip wire, the flow separates and you get the turbulence in the boundary layer. You know that this is the method we are adopting here. Usually, it is put to 19 that is 5 percent away from the perpendicular side that is order line in the section point. Why this region, why this is put to 5 percent is we have already seen that the local Reynolds number is less. So, in the ship and also the model, the local Reynolds is less. So, even for the ship, I think we have seen before one of the diagram, it is going to be laminar. Isn't it? I will just see that we had a picture.

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It is obvious from that. That we can see here. This is the shape say the forward side and after that say here is almost very smooth flow is there. There is a laminar flow in this region, the forward region. Then it takes off and become turbulent towards the aft because it happen while the forward region is, its local Reynolds somebody is less. So, the flow becomes laminar. So, when you perform the model test also, you create a situation where the forward side will have a laminar flow turbulence is created only after that. So, that is why, this trip wire is placed at the 19th station that is 5 percent after the forward perpendicular.

Another option for turbulence simulation in model is studs at the forward. You put some studs small projecting out and finally, out and again same as sand paper. So, it passes and creates turbulence. One more option which is rarely tried is the internal vibrator that is outside the hull, the vibrator is a high frequency vibrator. You vibrate it. Then due to vibration, the flow gets disturbed and turbulence is created. Usually, this is not tried because it is dangerous. So, high voltage is required for that and generally this is not tried. Another factor in the frictional resistance is roughness. So far, we have considered generally smooth surfaces.

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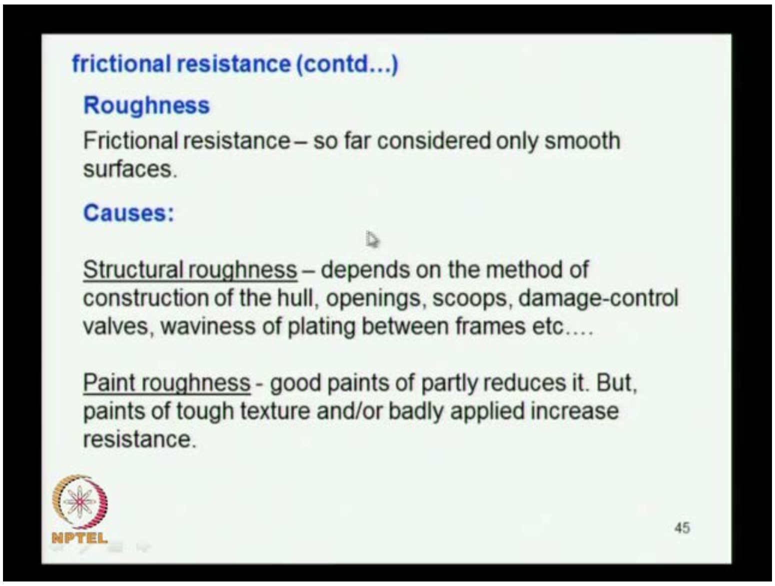

The causes of the roughness, structural roughness is coming to the actual ship case, not the model. The model is usually smooth, wax model or maybe fiber glass model or the surface is soft and smooth. The resistance predicted from such a smooth surface model does not match actually with the prototype because prototype is not going to be as smooth as a model surface. So, prototype will be rougher due to various reasons.

So, some of the reasons are it depends on method of construction of the hull, whether you are going to have a welded ship or whether you are going to have a molded like fiberglass or whether you are going to have a riveted joint. So, all these methods are there. In the rivet, the roughness is more than the resistance pressure. The resistance will be more.

Depending on the type of the weld, how many joints and everything, again there is a roughness factor, which differs from ship to ship, then opening. There are on the hull, you know, you may have different openings underwater. That is you have to get sea water for various purposes, like sea water for cooling of main engine, then for cleaning purpose, for various operations. Then you have openings on the surface, which will naturally give more roughness to the hull, the resistance.

Then, there are scoops damage control item controls and valves control and all that. This obviously have some tension to the more surface to the ship and which act to the resistance, but compared to the ship size, it is only a small quantity, but we better not ignore it. Then we will see waviness of plate between frames. So, we will see that the ship construction is a stiffened plate. It is a plate which is stiffened inside. So, between two stiff nesses, it is unsupported.

So, this plate, during its construction or during the operation can be subject to deformation, it maybe the temperature reason or maybe imperfection in the construction. Various reasons contribute to that and compare to the model, there is a change. There is a dip and hump on the surface of the ship resulting in more roughness for the surface and hence it increases the frictional resistance. So, this one comes under circle reference. So, this is the reason of roughness of the prototype, which is not envisaged in the model.

Then, plain roughness is there. There are a lot of paints under the different layers of the paints, primer you know, then anti corrosive paints, anti poly paints. There are different layer of paints applied to the underwater portion of the vessel. The texture of the paint and application manual, you know efficiency, everything matters in getting a smooth surface. So, depending on these factors, there will be a change in roughness which will not apply to the model.

So, that is what it says that good paints partly reduces it, but paints of tough texture, depending on the texture paint or badly applied, manual labor is not as very skilled, so there is a problem. So, all these things matters in increasing the roughness. So, that is the one due to the paint roughness.

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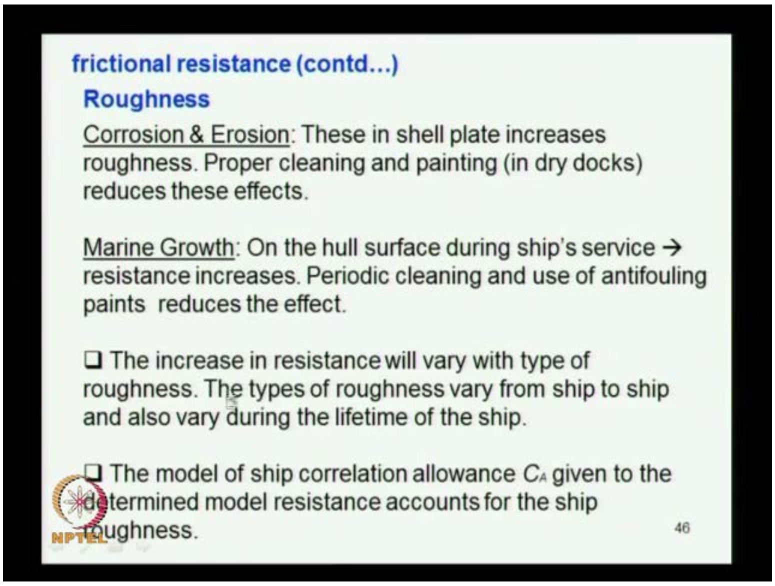

Other causes are corrosion and erosion. Why the roughness increases compared to that of a model? Sea water, shell plate is very sensitive to sea water, which results in the corrosion. Due to the corrosion, there will be a surface roughness increase. So, that is why, proper cleaning and dry docking of the ship is mandatory once in two years. That is we have to take the ship to dry space. Then you ship the surface and repaint it and put it back to the operation. This is mandatory for all ships, otherwise you know corrosion if there for a longer period, it will eat away the plate. Then the ship sinks and comes down and the ship may collapse.

So, it should not occur for the safety aspect also and for the life of the ship, it should be done. Then another is the marine growth. This is underwater surface of the ship, which is put into operation. It has been there for many months. Over the period, you know that there will be sea living beings, they start living on the surface of the body of the ship and you see accumulation of sea weeds and all that on the surface. This obviously increases the roughness drastically and thus the frictional resistance, so which should be avoided.

When this continuity will be there, there will be a lot of fuel consumption cost increase. So, in all respects, it is not a good thing. So, you have to see that these weeds are all removed periodically and cleaned and paint put to operation. So, the surface radius resistance increases. Periodic cleaning and use of antifouling paints reduces the effect. So, you put antifouling paints. It will become, it will reject or it will reduce a chance of fouling. So, the increase in resistance will vary with the type of roughness. It is obvious. The type of roughness varies from ship to ship and also varies with the lifetime of the operation of the ship. Isn't it?

In the beginning of new ship to the operation, initially there is no growth and everything is les. So, roughness is less. Over the course of time, the accommodation of biological growth increases and roughness increases and resistance increases. So, it should be periodically cleaned and repainted, then the model of the ship correlation allowance, CA given to the determined model resistance accounts for the ship roughness. So, in the model resistance, this roughness is not there.

So, what you do is when you extrapolate the model resistance into ship resistance, you have to give an allowance for this roughness, which is called the model ship co relational allowance to account for the change in roughness between the model and the ship. So, that is what you call the co relational allowance.

So, by now, we have covered what is frictional resistance. We have seen. We started with what are different of resistances. We have seen the two major components are frictional resistance and wave making resistance. We have seen how the frictional resistance is represented, how it is estimated using finally we have said the ITTC formula that is 0.075 by log Rn minus 2 to the whole square.

That is the formula, which is used to find out the frictional resistance coefficients of a ship and the reason also I have mentioned why this is depending on experimental data as getting it numerically, it is difficult. Getting it even from experimentally model test also, it is not possible because there is no kinematical similarity between ship and model. Reynolds’s operates with different Reynolds’s number. Hence, it is not possible to get the frictional resistance obtained from model extrapolated to the prototype. So, these are the aspects related to the frictional resistance.