Ship Resistance and Propulsion

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Lecture - 7
Air and Wind Resistance Dimensional Analysis I

Coming back to the class, we have already seen about the frictional resistance and wave making resistance. These are the major components of resistance and these resistances are primarily confirming to under water portion of the ship, but above water portion or above the ship also is subject to resistance. Now, here the fluid is air it is not water, where as density of air is about one by eight hundredth of that of water.

So, the importance is not so felt for the above water portion that is air resistance components. If the ship operates at low speed, if the ship operates the high speed that is if it comes under high speed category vessels then the wind effect, or air effect will be more. Mainly the air effect will be more, so here the difference between air and wind is air is a case, where it consist still air and the ship is moving.

So, that means you as good considered the flow of air in the opposite direction of that of the ship with the same velocity of the ship. So, that is what is considered. So, this component become important or considerable when you consider for ships, one aspect and another thing is when you consider the above water portion of the ship is high like in the case of container ship, passenger ships, rorer ships where above water portion of the ship is high, where as when it comes to tanker or bulk carriers above water portion is not so high. And also this tanker and bulk carriers operates in less speed so the speed of air is less. Whereas the wind we consider wind is coming from the nature it is natural wind, which may come from any direction. So, you do not have a control on that, so but physically this can both can be clubbed together treated in the same way air and wind resistance.

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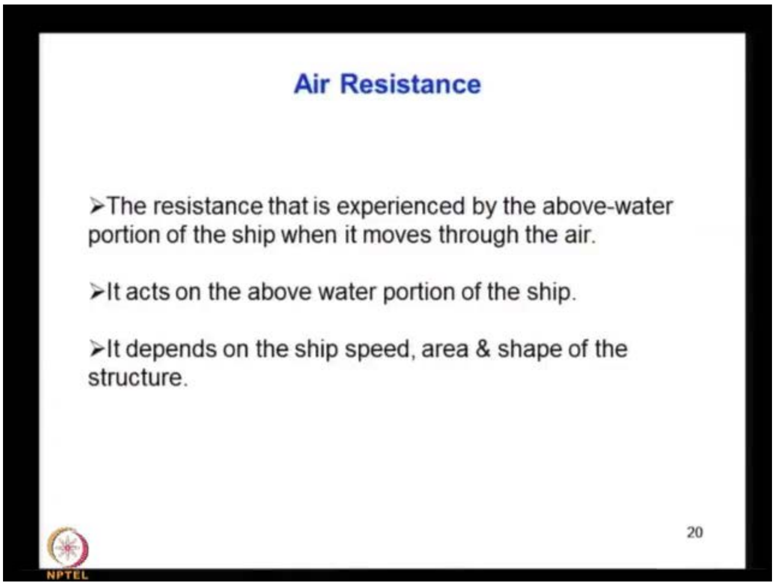

So, that is what we look in to next, so the resistance that is experienced by same what I said above water portion of the ship it moves to air, that is air resistance. It acts on the above water portion of the ships depends on the ships speed, as I said or area and shape of the structure. So, area means what is the exposed area to the direction of the wind and also the shape, where it is having a steam line shape or its having a blunt shape. The blunt shape it will have more resistance more air and the formation track all that will be more. So, this aspects has to consider and so then coming to wind resistance.

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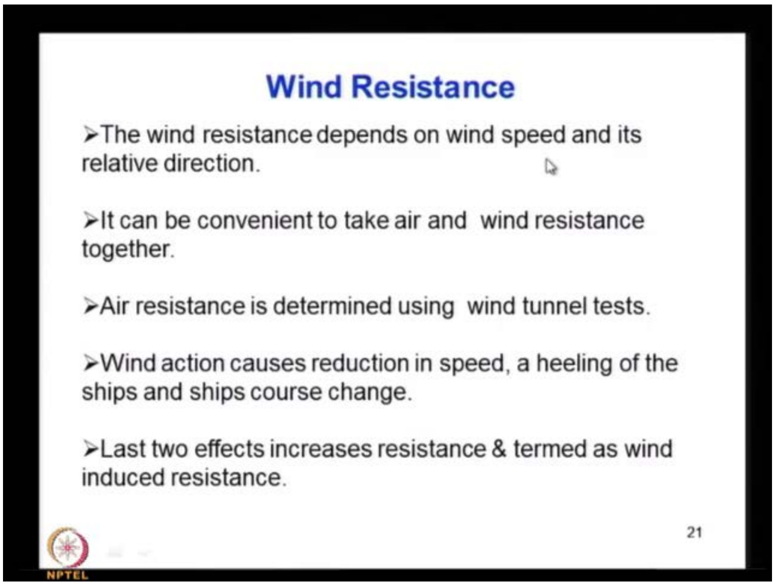

The wind resistance depends on the wind speed it is not coming from the nature and its related direction, where it is coming ahead opposite to the ship or its coming from behind or from coming the side or its oblique. So, depends on the direction of the wind, the effect on the ship resistance changes. So, it can be convenient to take air resistance together as I said both air and it is a air media. So, you should be can be considered to weather, air resistance is usually determined in wind tunnel tests. How do you determine? Because ship you know that above water portion got many type of such as mass are there, winches are there, super such an accommodation spaces there are many items coming on that then above water portion hard part of the ship above water portion all these comes. So, the shapes are different and orientation is different there may be this you know there is a mass a mass behind another mass.

So, when you consider air there is effects called consolidation effect and I think the other one is ((Refer Time:04:31)) subsiding effects consolidation increases chances of increases the wind effect, as other one is called the shielding effect. So, one is behind the other the first one will get the maximum load one is behind the other will less effect, if its closed by so that is called the shielding effect. And the second one is should be the first structure or if they or together, side by side the direction then there will be a buildup of the construction, the flow velocity increases which is called the consolidation effect.

So, depending on the orientation of the structure depending on the shape of the structure and depending on the size, and all these matters in the determination of air resistance. So, it is not easy to analyze it, so what people do is they usually perform a test in the wind tunnel, you put a model of the structure, you flow the air through the wind tunnel at different velocity and you find out what is the ((Refer Time: 05:29)) what is the force coming on that. So, this is how used estimate, so these coefficient for different typical section shapes and structures are available literature, based on the experimental studies carried out by different research groups using the wind tunnel. So, what you can do is you can borrow these values or these coefficients from the literature and use it in your calculation, if you know the shape of the structure.

Wind action causes reduction in speed, that is when a wind is acting that is coming from nature, it causes a reduction speed which is a suppose in the ship is moving forward wind is opposing it and the speed reduces, because it is blocking that, there is an you know blockage due to the wind action. Then the heeling of the ships when wind is from the side, if you have wind is acting from the side ship heals to one side isn't it. So, when you consider a action of wind.

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I just consider, we have a super session accommodation and everything coming here, you may have mass may be crane here depending on the ship hold and all that this is under water portion, this is a water level. So, this area is now exposed to air you have this area, this area exposed to air. So, when the wind acts in this direction, if you look at the other view. So, this is a section view of the shape or different view this is a water level. So, you have this water level then you have such a super such as a contract. The wind acts from this direction that means it will there is a chance of the ship take into one side, the ship will be into one side the hypo dynamic performance of the ship deteriorate.

That means, the resistance of the ship increases then compared when you compared it with a zero heal condition, the ship will have the least resistance when its having a zero heal. So, when it is objective heal the resistance increases that is what it means. So, that is what it means that the healing of the ship, which cause a reduction speed that is the resistance increases speed. Then the third one the ship course change that is if you consider from the planed view, if the wind acts may be in this direction. So, what happens is that it increases the movement in this direction, and then the ship will turn this way, the ship may turn, is it not? The ship will turn.

So, that means there is a drift angle introduced drift angle introduced by the this action. So, due to the action of the wind the ship may drift to one side there is drift angle. So, when the ship moves generates the drift angle then the resistance increases drastically instead of going straight, which is a least resistance orientation of the ship and the ship moves and then it moves then it tilt and moves then the resistance increases. So, due to action of the wind, it will be a blocking effect, which reduce the speed then there is a healing effect can heeling effect which again reduces the speed or increases the resistance. And the third thing is a the ship changes a course that is a drift angle which increases the resistances statistically. So, these are the wind effects.

The last two effects that is a healing and a course increases resistance and termed as a wind induced resistance that is actually it is not wind directly blocking it, because of the action of the wind the orientation of the ship changes, and subsequently the resistance increases then the speed comes down. So, that is why it is called wind induced resistance, now how do you estimate this, the wind resistance.

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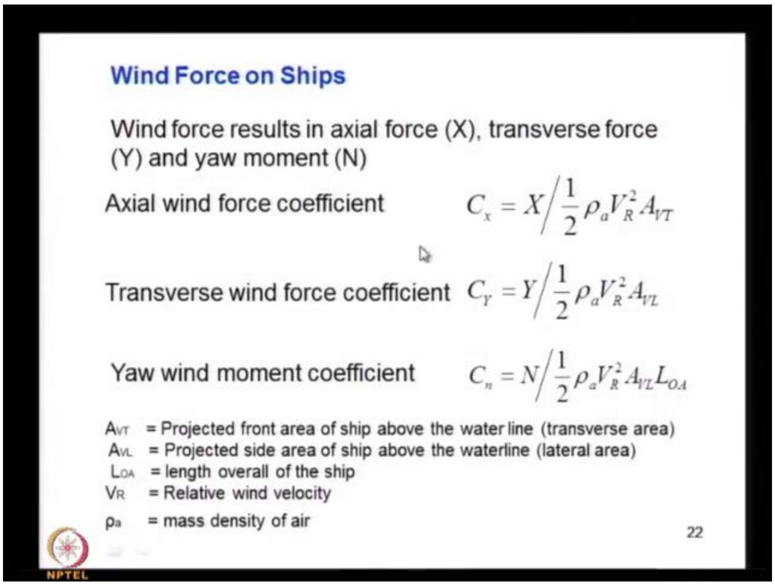

So, what you have is you have all these coefficient known from as I said from the wind tunnel, thus you have you consider wind force results in axial force if it is in x direction there is a component. Then transverse force y direction it can be a component and it gives a moment. So, this all things are considered in horizontal plane, you have the x force y force and momentary moment. So, these are the force combined on the horizontal plane. So, if you want to find out the actual force, the actual force coefficient is represented by axial force divided by half row A V R square into A V T.

So, row A is a density V R is the wind velocity related wind velocity that is related in speed, what is a related wind velocity and A V T is a projected area of the ship above the water lane that is a transverse area so you are consider the x direction. So, what do you consider here is that is the wind is blowing in this direction that is wind velocity. So, you have take the projected area of the above water portion in a plane normal to this in the transverse plane so that means this is a plane.

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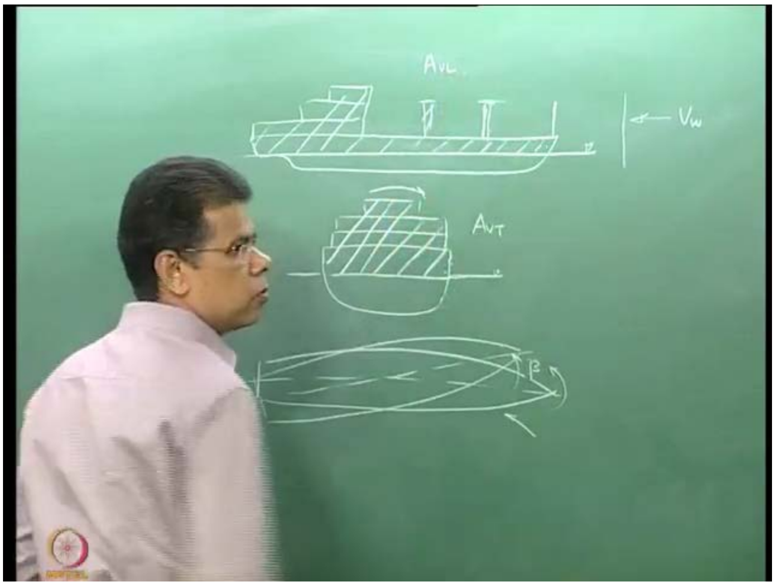

So, this is a area now subject to wind so this A V T is representing this area A V T represents this area, so that is a projected front area projected front area of the ship above the water lane. So, that is the transverse lane, so that is a A V T now you consider transverse wind co efficient that is wind blowing in the transverse direction that is when it blows cross the ship the beam direction. So, the you consider the y force divided by half row a and b half square and A V L here the projected area is usually take the plane the area in a projected to a plane normal to the wind velocity direction.

So, that is what you can say A V L, so here that is how the c y or the transverse wind coefficient is done. So, if this is the case you consider this is the one this is a area now the wind is acting in this direction so this is the area which gives the A V L. So, this area gives A V L and the yaw coefficient yaw wind moment coefficient is given by the total moment, moment divided half row A V R square A V L into L O A which is representing a moment quantity. So, this is a another, so these coefficients are obtained using this relation.

So, what you have is in literature you will be able to get from literature, you will be able to get all these co efficiency C x, C y and C n. So, these things are available in the literature based on the wind tunnel test. So, this co-efficient literature is available so you borrow that appropriate value depending on the shape of the structure a size of the structure or shape and form of the structure you get these quantities from the literature…

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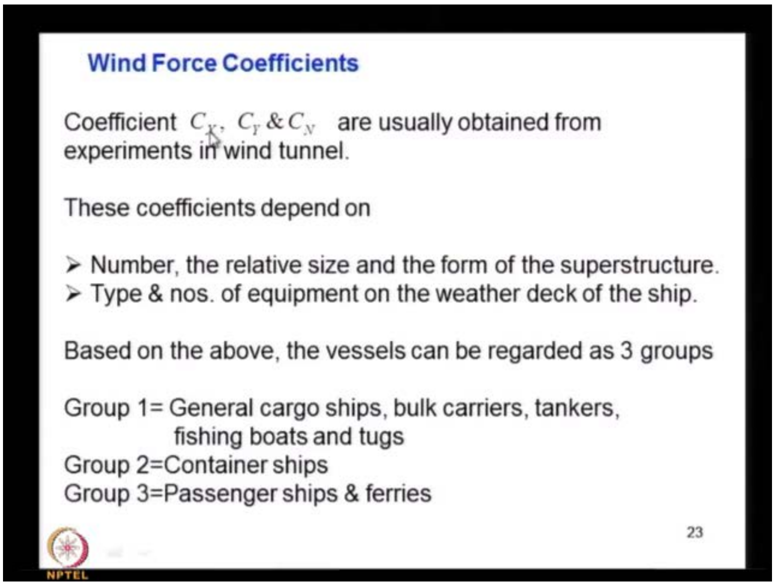

This is a value coefficient C x, Cy and C n are usually obtained from the experiments in wind tunnel or you have to you can perform, if you have wind tunnel facility you can perform it test and get the coefficient. These coefficients depend on number that is number of structure relative size and form of the superstructure. So, if superstructure usually refer into that is a structure coming about the main depth of the ship. So, you have to know how many numbers of structures are there, what is the size latest size of the structure? And what is the form of the structure it is a square cylindrical, or a square shape or it is a small shape may be it is circular cylinder or may be, what is the shape for that?

Then type and number of equipment on the weather deck that is on the top deck you will have number of equipments for various operations including the crane operation, anchor operation, moving lane operation. There are many machinery on the deck. So, these equipments also will have a effects from the bench so you find out that also. Based on all these categories the total generally the vessels are classified into with reference to wind force are classified into three types three groups, group one, group two and group three.

Group one is a general cargo ships bulk carriers tankers fishing boats and tugs, they are free boat less and above water portion also less, this all come under the category of group one. Category two is container ship you might have seen container ship pictures with lot of containers stand on deck. So, the wind blockage is very high for container ships and it is a bad for the ship and you already know the container ship is the stability of the ship is such thick it is to the top loading, and with the wind effects it is going to be worst. So, whenever you design the ship you have to consider the wind effects also to analyze the ships stability. So, that is a another class group two container ship the third group is a passenger ships and passenger ferries. So, that is another class so these are the general classification of the ship because based on which these coefficients are prescribed.

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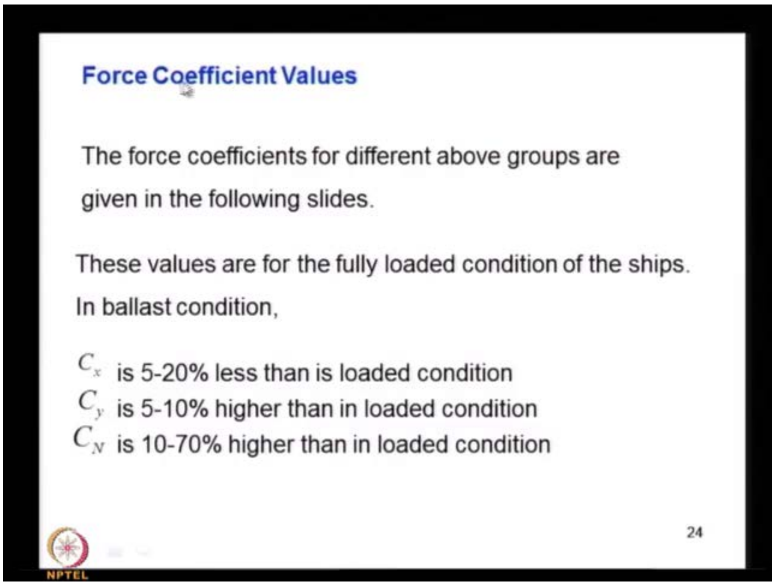

So, the force of coefficient values for C x, C y and C n for different groups as we see below. See this values this values changes depending on the loading condition of the ship the fully normally you consider full loaded condition, but when the ship is not fully loaded, you know that the ship usually has conventional ships, they have a conventional cargo ships they have four operating conditions. One is fully loaded departure condition, fully loaded arrival condition, fully loaded ballast departure condition and ballast arrival these are the four operating condition normally considered in the defense stage.

So, at fully loaded departure condition means that is all the stores of full that is fuel oil is also full and cargo is full. So, the vessel is floating at the different water level, but during the course of its operation when it is moving from one part to another, it consumes lot of oil and also the provisional consumed. So, the displacement reduces marginally, so when it reaches the other side other port we expect the stores or consumables balanced may be around 10 to 20 percent. That is 80 percent 80 to 90 percent consumed, that is that way is called the fully loaded arrival condition that is the difference, but when it is coming the ship may not have cargo. So, it has to come the cargo fold empty, so it has to maintain the water depth and everything for the proper emulsion it go for the ballast.

So, what it does is, it replenish the stores from the port which has arrived. That means stores becomes full hundred percent, but it is in a ballast condition. Ballast condition normally you say it is around 35 to 40 percent of the displacement of the ship, source full. Then there is a velocity departure condition when it comes to the other port during its port of journey it is consumed the stores may be again 80 to 90 percent consumed. So, again displacement changes resistance changes under water portion different, above water portion different. So, that is why these are considered separately.

So, that is what it says that these coefficient values are usually taken of fully loaded condition, if it is a ballast condition this coefficients C x, Cy and C n is some adjustment. So, what we say is that C x is 5 to 10 percent less than the load condition loaded condition, why it is less? 5 to 10 percent less than the loaded condition C x is not the total wind load in x direction it is a C x the coefficient is coming less in the ballast condition. That is ballast condition this quantity is less compared to the fully load condition because the portion which is emerged is most stream line isn’t it, the portion which has come out the ship when it is a ballast condition, the ship will came out. So, but the portion which is come out is more stream line, so the air effects C x in the x direction because of the stream lining the wind effect will be less, for the x portion that is why the C x value comes down.

But the total load will be high because the area will increase so when you consider the area total will be more, C y is going to be more because more exposed area and blockage is more along the length. So, that is not going to calculated the stream lining is not there that longitudinal plane. So, there is 5 to 10 percent more and naturally because of that the C n also goes up it goes up 10 to 70 percent its very high. So, these are the things which occur.

So, you have to make a correction for these values when you consider the ship operating in ballast condition. So, usually you design it for the fully loaded condition, but the ship also operates in ballast condition in such cases, the wind load need to be estimated with these, but the thing here is the total resistance reduces in the ballast condition because the displacement has come down, the weather surface has come down, resistance comes down. So, even if the wind components goes up in some cases the total resistance will be less than that in the case of the fully loaded condition. So, the actual wind force coefficient values with the group one ships…

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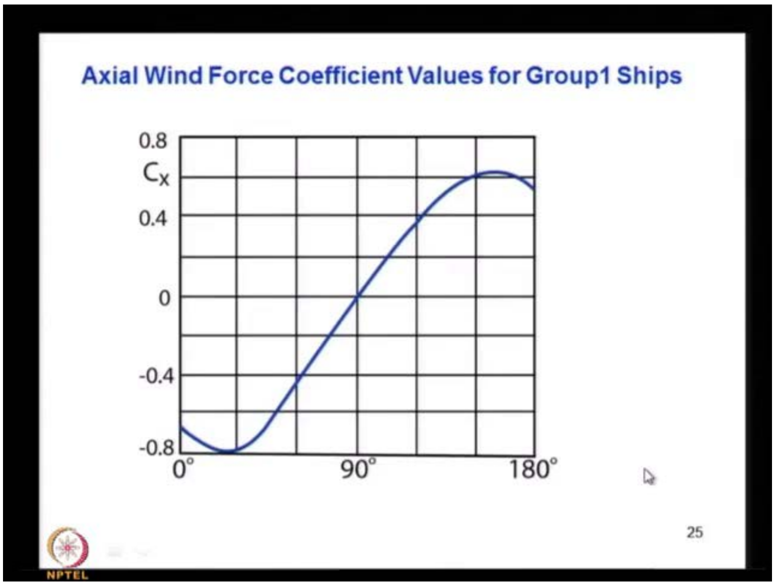

Which you have seen in the cargo ship generally, general cargo tankers all that. So, this is the C x value. So, here you can see water against the direction of wind, so if the winds operates it is positive and negative you can see that its 0 to 90, it is negative 0 to 90 means what? Wind acting in which direction.

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The direction of wind you know that the direction, so when you consider the ship here.

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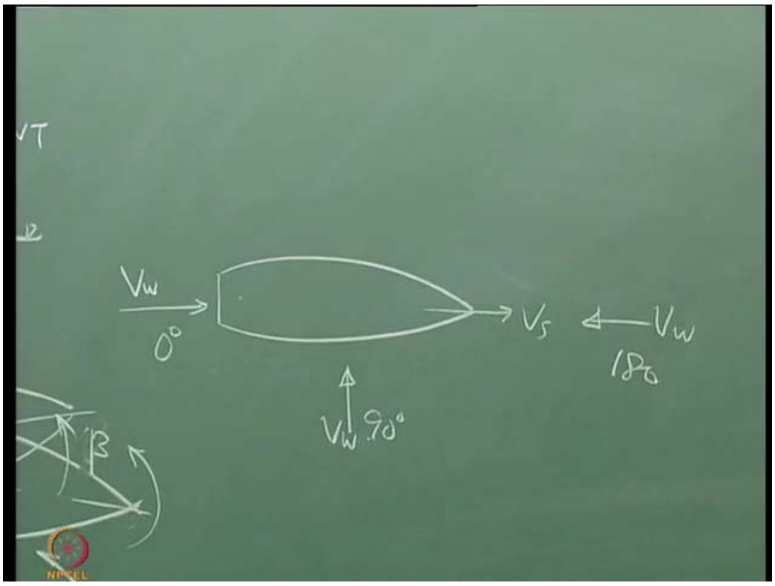

The ship is moving in this direction, if the wind also in this direction it is 0, 0 degree the wind also acts in this direction which is 180 degree, the wind acts in this direction is 90 degree. So, that is a so that means the 0 to 90 means, wind is in the same direction that of the ship same direction means actually is a following the ship. That means is giving a pushing effect for the ship, so that means C x is negative you can see that this region, C x is negative, but when from 90 to 180 degree is going and the other way going to forward side the opposing the motion of the ship.

So, C x value you can see that it is going to be positive at 90 degree, you can see 0 because it is not going to includes any x components force when the wind acts normal to the ship. So, it is not going x how so this is a characteristic representation the value of which you get from the wind tunnel experiment.

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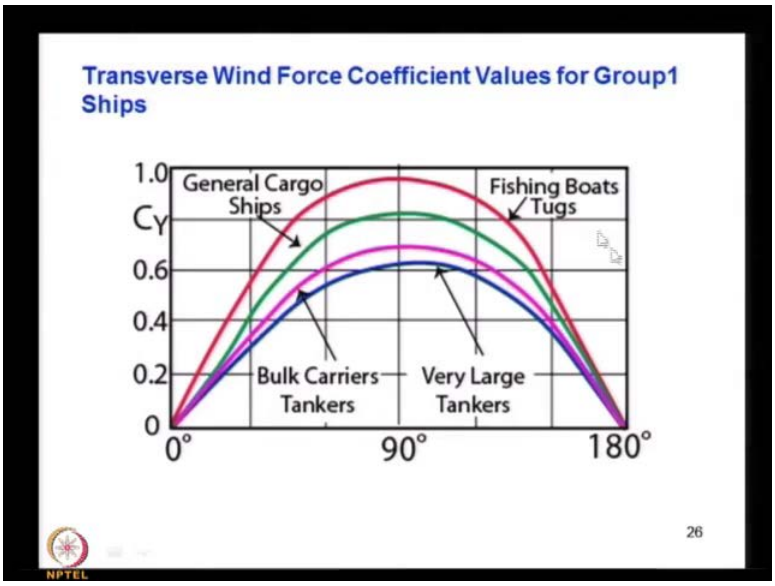

You look at the transverse coefficient group one ships, this is a diagram you can see that C y against the wind. So, the transverse coefficient that is a the beam wind condition, the maximum effect comes at 90 degree isn't it the maximum effect will be 90 degree. Whereas a 0 and 180 degree it will be 0, there is no effect isn't it suppose the wind is I think along the length of the ship it is not going to individual transverse force. So, that is why its 0. So, whether its 0 degree following the ship or acts at 180 degree opposing the ship its effect on the transverse direction itself the maximum effect comes only wind acts at 90 degrees. So, that is how the curves all the curves are shown.

So, here you can see the effect see very large tanks the free board is less bulcarious is so the very large very large tank. So, that means the wind effect is less that is the lowest low tankers is higher sorry higher the boat and the so when it comes to free boat classification, you come to know that the tanker is I think type a ship and the other ship from type b and bulker is a type b six thing. So, that is variation. So, here you can see that this is bulker here and the here the free boat is higher compared to tanker. So, you have more effect.

So, when it comes to general cargo ships and fishing boats is going to be higher and the effect is more, so that is you can see the C y value, how it varies for different types of ships that is for the group one. So, we also similar for the group two and group three.

Group one ships you know is a general cargo bulker ship container ship fishing vessel all these categories.

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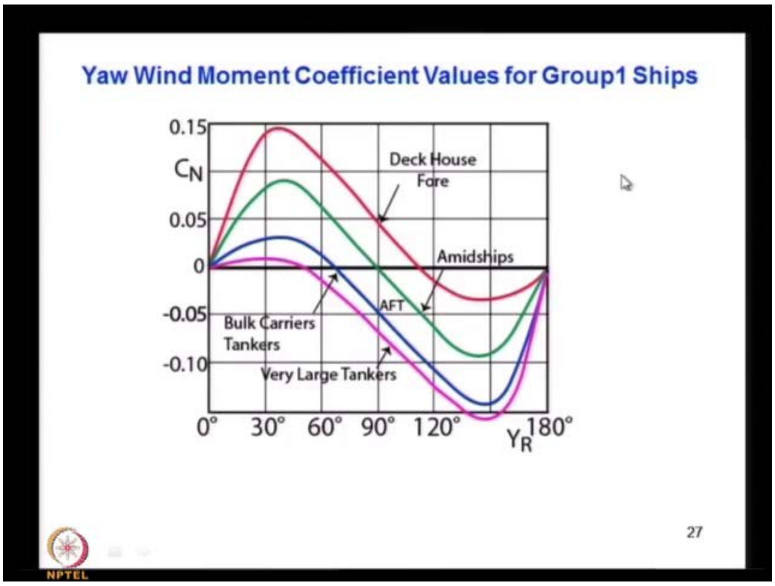

So, again the C n values for group one ship again see that this is a trend, so here the effect is more, where the concentration of the area is so that is why deck house deck house the basically superficial accommodation space, which comes. So, that means the coastal act of the forward. So, here you can see this is a deck house this is a accommodation area.

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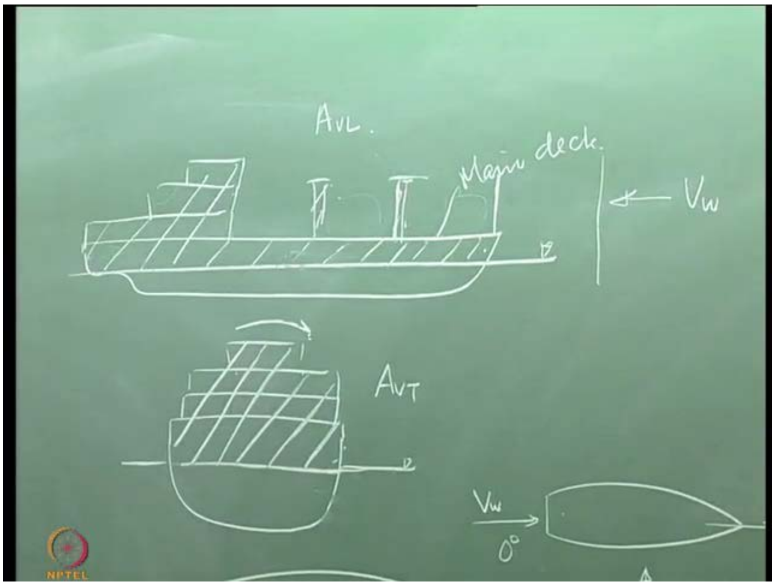

This is a main deck this is a main deck or weather deck called any such which comes above this level is called super structure, here this may be a super structure of the deck house with this is the after the ship and sometimes you get the middle and sometimes you get the forward side. So, depending on that position there will be a change in the movement wind action movement, so that is what is accounted here you can see the deck house forward this is a deck house ship, this is a curve or I think half may be one of this curve. And then you have for the other large tankers and bulk carriers all those. So, this gives an indication one with respect to type of ship, it gives C n value with respect to type of ship gives C n value with respect to location of the deck house of super structure. And also it gives the C n value with effect to the direction of the wind.

So, you can see that 0 to 180, so you have to identify which direction the wind is acting and what is the type what all the things, if you got the value for the respective pick out C n value of the from the respective curve and that will be used in the expression isn't it. Once you get the C x and all these values you put it here C x is not C y is not C n not so you know all these parameters and the denominators air density velocity of wind is known area is known. So, from which you get x y and n so you get what is the force so that what have discussed for the group one ship you can see that C x of group one, C x, C y for group one and C n for group one.

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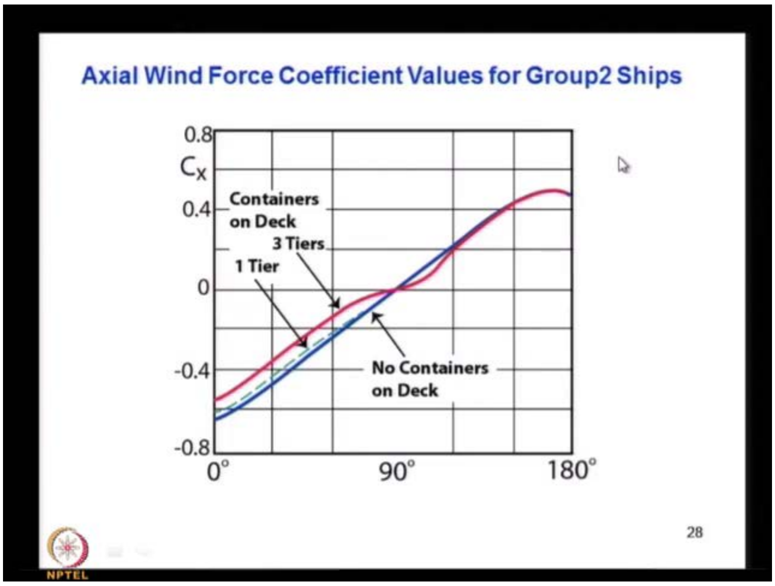

Now you consider the same thing for group two ships, group two ships is container ships where we call that what we defines it is a container ships. So, here the variation you can see the trend is same, but the values differs due to the higher free board and deck possession and all that. So, you can see these values, so if you have one tyre that is here standing only tyre of container above deck or if you have three tyres of containers of the deck. So, if there is variation you just look at this you can see the difference how it is changing here. So, this blue line shows there is no container on deck, but still the container free board is tyre that will have a effect on the this values.

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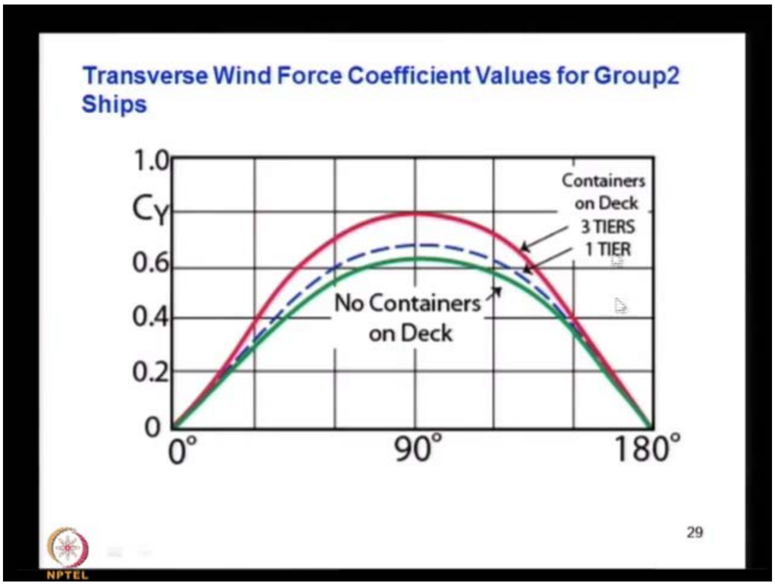

Same container ship group two, what is effect you can see with the one tyre three tyres and no container on deck no container puts on deck. So, this obviously you can see that three tyre will have more effect one tyre will have less and the least effect is with no containers on deck. So, you have less x portions and containers are usually you know blocked it is a rectangular block. So, naturally this the wind effect will be more because of the sharp corners and edges and all that.

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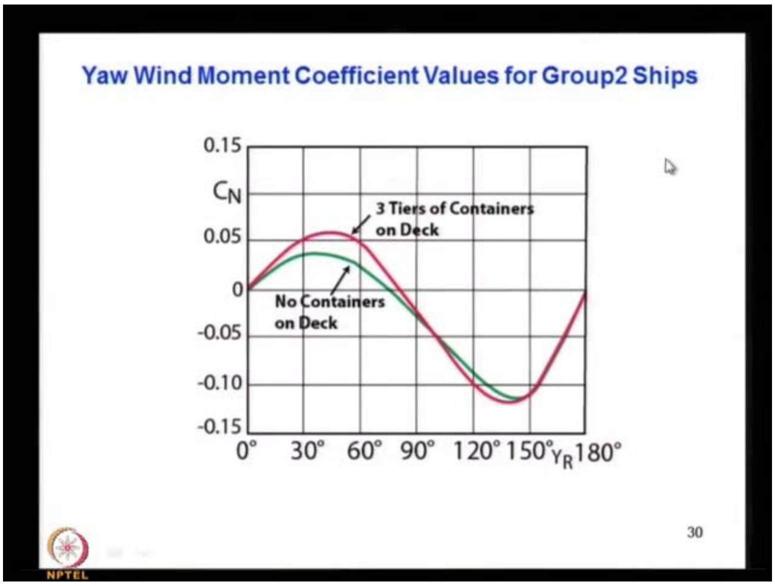

So, this is again container ship group two the C n value is here so strength remains same only the values you see that it is a different and depending on the number of tyres used and number I mean there is used or not.

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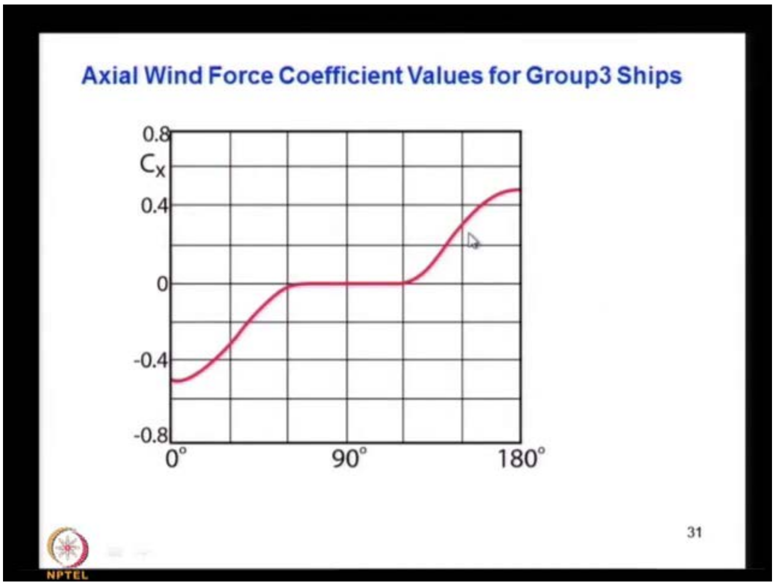

Now, same thing for group three ship group three ship, we have seen it is a passenger ship of passenger ferries. And this is a variation here you can see this is almost flat here and then it goes like that. So, may be wind acting from may be 60 degree to 120 degree its almost the same effect.

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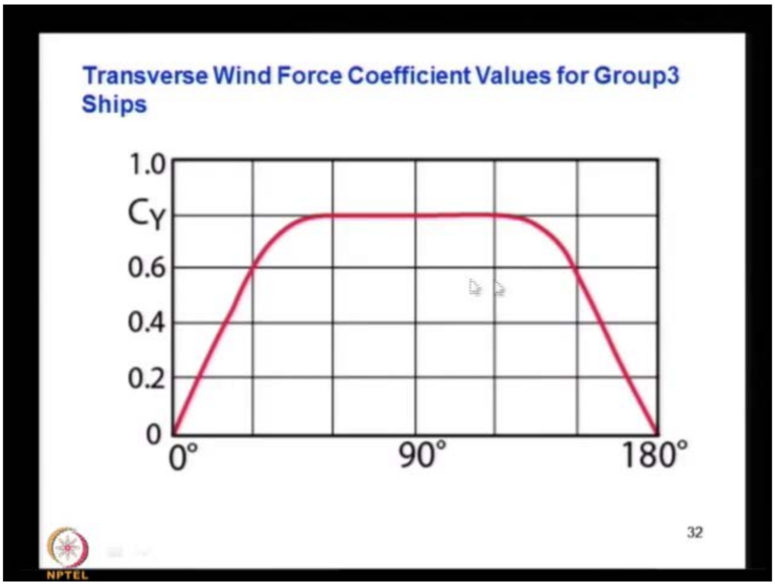

Same thing C y you can see here again the C y values remains same constant over this range that is 60 degree to 120 degree because of this that is shape of the ship, and free boat.

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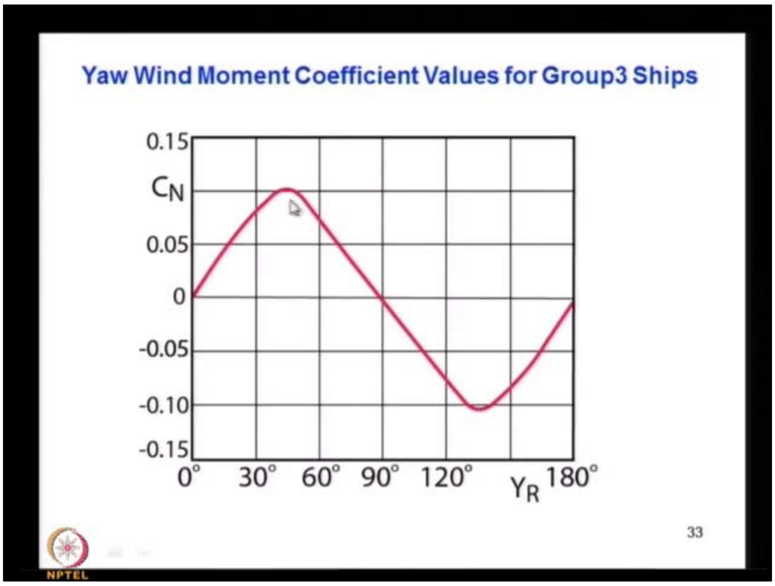

So, this is a trend for the for this moment coefficient yaw moment coefficient. So, what I mean is you get all these coefficient all these are available literature, which has been evolved through the experiments and get these values used to the expression get the wind force, and from the wind force you will you get the component opposing the ship motion.

So, from that you will be able to find out what is the resistance isn't it, the ship is moving forward the wind may be coming in this direction this direction or may be this direction. Take the component x component of that and then you put it along with that and then you find out that it is a resistance offered that is one aspects.

Second aspects is we have seen before what all the aspects only the speed rotation due to the resistance, other two are heal and coastal or the drift tanker. So, if the wind is coming in the y force will give you the information about the healing isn't it, if you have y force you know where it is acting and you know what is the healing movement due to wind? And you will be able to find out what is a heal angle due to the action of wind which usually taken as from the transverse components. So, due to the heal then you will be able to judge, what is the increase the resistance due to the healed orientation of the ship. And the third one there is a movement yaw movement when the yaw movement you know you know how much the ship is going to drift. So, in that drift position what is going to be the wind resistance, so you have to give all these three information help in finding you the effect due to various aspects.

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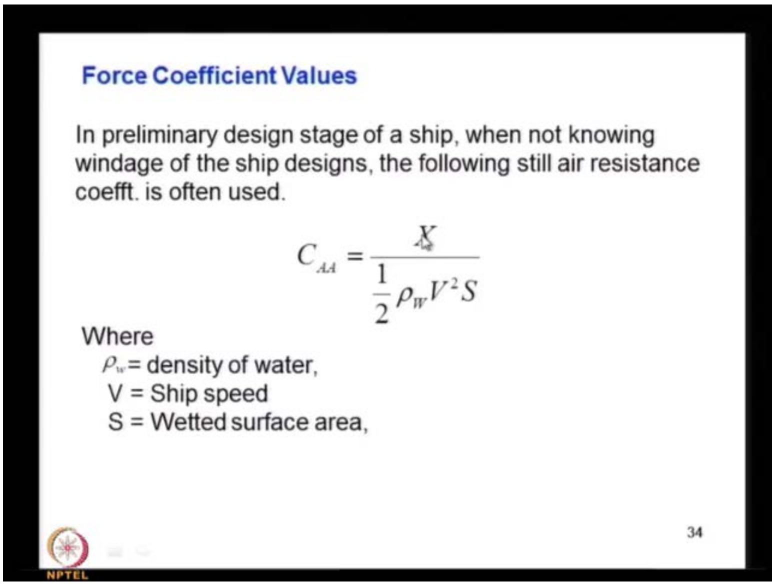

So, here the preliminary distance of the ship when not knowing the wind age of the ship designs because the preliminary stages you do not know, what is the exact shape formed and everything is not known. So, do not have an idea about the actual super structure super structure size, super structure shape and the orientation and everything you do not know.

So, what you do is you go by some standard empirical relations, so its again observed through studies. So, use that values C AA is for the still layer resistance square it is not due to the wind its due to the air, air resistance. So, this C double A represents that and so it is given by you use one A, why use two A here because already you have used one C A, C A used in resistance C A represents the ship model correlation relevant C A is already used for that. So, that is why you put double A for the air resistance ship module correlation allowance is due to account for the may be we will see it later because the change in the reference between the model and ship. So, that is accounted by the ship model correlation elements.

So, here the whole thing even though you talk about the air resistance, this parameters are given for the underwater thing that is here water density speed remains same and also the weather surface these are the quantities you see here. So, this is based on this because these quantities are better known even at the preliminary stages. You know what is a surface area at these two empirical relations, you know that dimensions and coefficient, you can find out the wages of this area from the distance. But you are not clear about the above water portion, so that is why these parameters are selected for the non diversion relationship.

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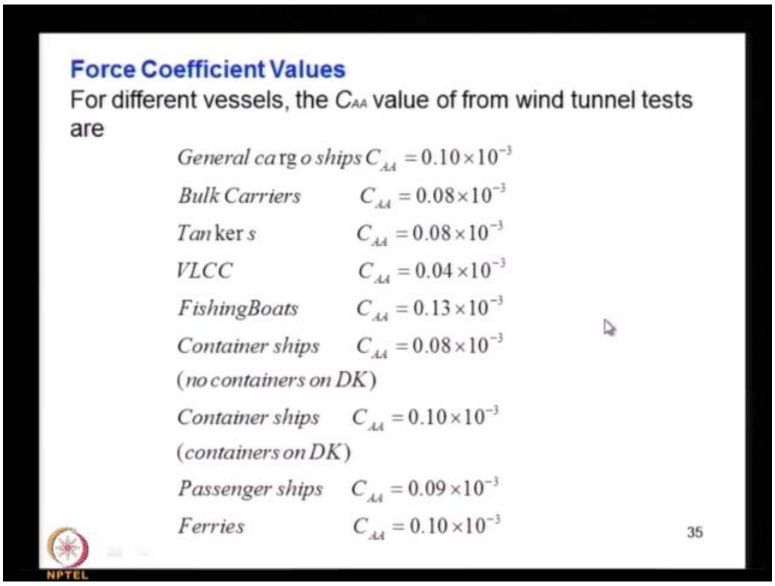

The force coefficient values are given like this let is general cargo ship you just give a allowance, you get frictional resistance C f coefficient, we have wave making or resistance coefficients here. So, you are adding that from the module test now you put another relevant C AA is equals to 0.1 into 10 power minus 3 for the air resistance. So, you just add it if it is a bulk cargo ship it is a bulk cargo it is a value tanker this the value you can see that the change in value also, if it is a V L C C very large crude oil career this is a value, you can see the values less fishing boats the value has gone up.

And the container ships value is not so high for that no containers on deck values only small, but if the containers on deck the value has gone up passenger ships, this is the value ferries. So, these are the values we select and just put it along with the other resistance coefficients to get the total resistance coefficient which will help you in predicting the getting the total coefficient, and predicting the proto type resistance because in when you perform the model test, in a lab condition you are not measuring the wind resistance or air resistance.

So, these are completes almost all the components of a resistance there are some other small components all that which usually, like you know the wave breaking resistance in a small components also present this is a major component, this are the major component that is a frictional resistance wave making resistance and air resistance air resistance compared to a very small compared to the other two components. So, once you get this you can find out then you have other relevant that we see later, and we put along with that you find out the total resistance of coefficient.

Now, we move on to the next topic this is a dimensional analysis you know dimensional analysis are carried out on equations and physical quantities basically to predict to give non dimensional parameters, this can be applied to geometrically similar body at different scales. So, basically this is done to predict the proto type resistance value or parameters, psychodynamic parameters from the model test.

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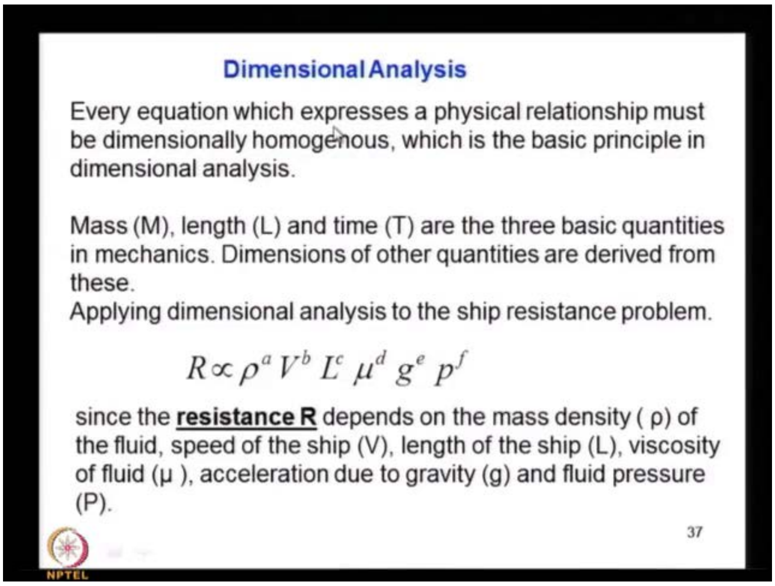

So, you can see there every equation which expresses a physical relation must be dimensionally homogenous, is it not? When you write in equation of motion or any equation all the terms should have the same dimension in case of, if it is a linear equation of motion, you will get all the terms in Newton's unit. If it is a rotational motion equation then all the terms will be moment will be Newton meter. So, similarly, any equation when you write even other physical problems you have to see that when you write that when you write the equations all the terms it is a homogeneity of the dimensional should be there in the equation. So, when you represent the fundamental, when you represent any term any physical term it can be derived or presented from the basic quantities in mechanics, which is mass length and time.

So, if you know M, L and T you can derive other quantities units of other quantities. So, applying dimensional, now we are discussing ship resistance, you know ship resistance depends on density of fluid, water or air depends on the speed if already seen the resistance, frictional resistance proportional to v power 1.825 and the z refigure resistance proportional to v power 6. So, its depending on the depends on L we have seen that it depends Reynolds number, it depends on fluid number zoe, we know that it is L is a parameter on all these things, it depends on the length, it depends on the viscosity friction mainly it depends on the viscosity, depends on G gravitational acceleration due to gravitation, so that is one which determines the size of the wave.

So, if it is a less gravity there will be size of the view and so G is the factor there and the pressure which again depends changes determines the pressure related to resistance you know, we make a resistance pressure related. Viscous personal resistance is again personal resistance, so all this type of components we will have a influence on the pressure. So, since resistance are depends on that is what I said it depends on density speed and everything this is we have just mentioned wave pressure.

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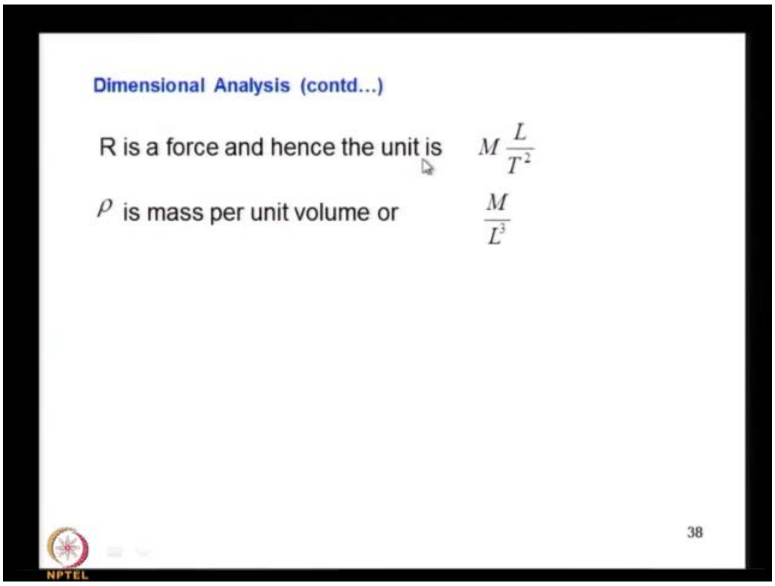

Resistance is a force and hence we can say mass into acceleration mass into L by T square, there is a resistance of force, row is a density is mass per L cube, meter kilogram per meter cube or this is mass per L cube is a representation of that.

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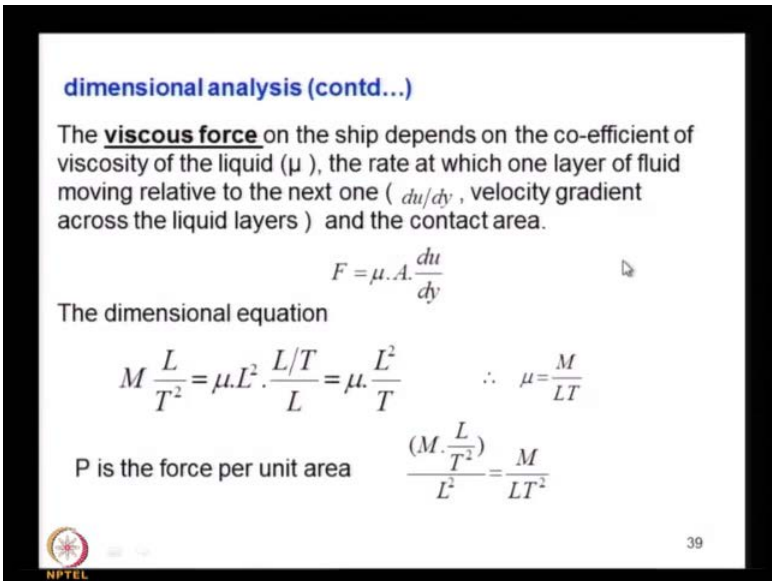

So, when you come to viscous force, what is a you just find out what is a unit of mu, what is a unit of dynamic viscosity? We know the relation from the Newtonian relation tau is equal to mu into doe u d u by d y, that is a relation given for Newtonian. So, that into area that gives a viscuss force tow is a air force, so if the body moving there is a sharing effect shear stress is proportional to velocity gradiant for any neutron in fluid or water is a Newtonian in fluid.

So, if you integrate the tau, tau is the shear stress, so if you integrate the shear stress then you get the shear force over the weather surface isn't it. So, that is what is done the shear force is given F equals to mu into A into the velocity gradiant. So, this is a physical relation now using this physical relation how you derive the unit for mu, using the fundamental units of mechanics that is mass, length and time.

So, here they you can see that F is equal mass into acceleration M into L by T square that is equal to mu you do not know what is the unit, A, A is L square mu is L by T, y is L. Now, you simplify it so you get mu into L square by T, so that means you then you get mu is equal to M by L T. That means mu is the unit of mu is what is it kilogram per meter per second isn't it. So, that is the unit of dynamic viscosity that is how you derive the units this coming from the basic you have to derive the unit. So, P is a pressure which is forced by unit area and force is M into L by T square divided area L square and that is equal to M by L T square. So, that is a unit so that means kilogram divided by you can put you can just see that if you work it out. Finally, work out will be Newton per meter square it will come.

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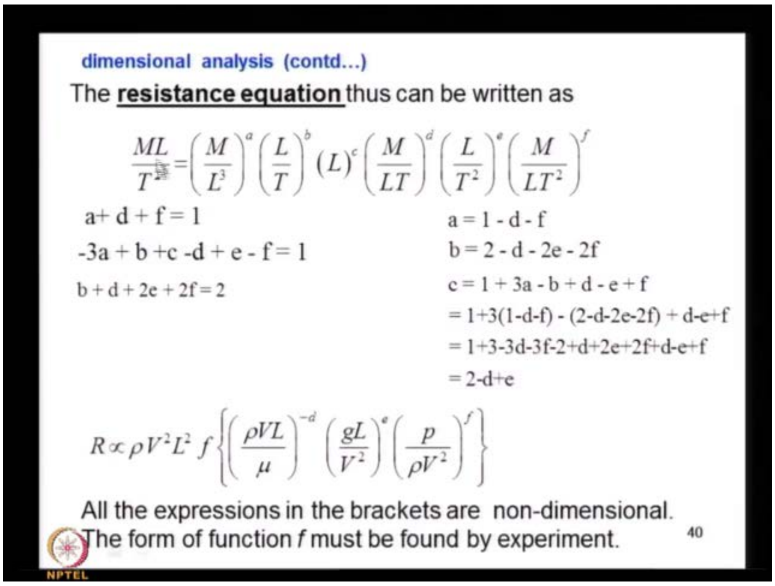

So, from the resistance expression, what you have put here from this relation I just put I, can write the same dimensional thing M by L T is equal to I put row raise A. So, row is M by L q and b rays to b, b is L by T rays to b. Then length as said then M by L T this is the viscosity, which we have derived now and L by T square that is a g, and the final one is the pressure that also we derived now. So, we derived this just now and get back to the resistance relation and we said see that this is the relation, normally put now you know you just compare the co efficient on either side M, if you say M is equal to 1 for a M is equal to a here for it is a a M d, d is here M f. So, a plus d plus f is equal to 1, the comparing the power on either side of the equation.

Similarly, for T, T is equal to we will go by L, L is equal to 1 that is the 1 here L raise to b L rays to minus a this is minus a L rays to b then L rays c, c here then you have L here minus d, L here e then L denominator minus l. So, this is equal to 1 similarly, you have the expression for the comparing the power of T, there is T is equal to 2 if you consider here T rise to two here it is minus b its all taken denominator negative of a two, and here its b and here its d and here its 2 e and here its 2 f, so that is what you get this relation. Now, you have how many unknowns 6, 1, 2, 3, 4, 5, 6, but only three equations.

So, what you do is see you re arrange it and you put in this form a, b, c and others in terms of a, b, c in terms of d, e and f. Now, get back to this relation resistance equation you can write resistance proportional to bow into v square f square into L square into function of these parameters you can rearrange in that. So, here you have the function of row into v into L by mu that is mu by row is equal to mu is a dynamic viscosity by density is equals to kinematic viscosity.

So, V L by mu is representing what? So, Reynolds number and here you have g L by V square or v square by g L and this minus e. So, which is representing the fluid number? So, here you have P by row V square which represents the all less number, so you have all these things all these parameters here I think you discussed this before. And so what it means resistance depends on Reynolds number fluid number and Euler's number. So, that what missed all the expressions in the brackets are non dimensional if you say that this are all non dimensional quantities and the function f is all these square if you find this from experiment you can evaluate the resistance equation.

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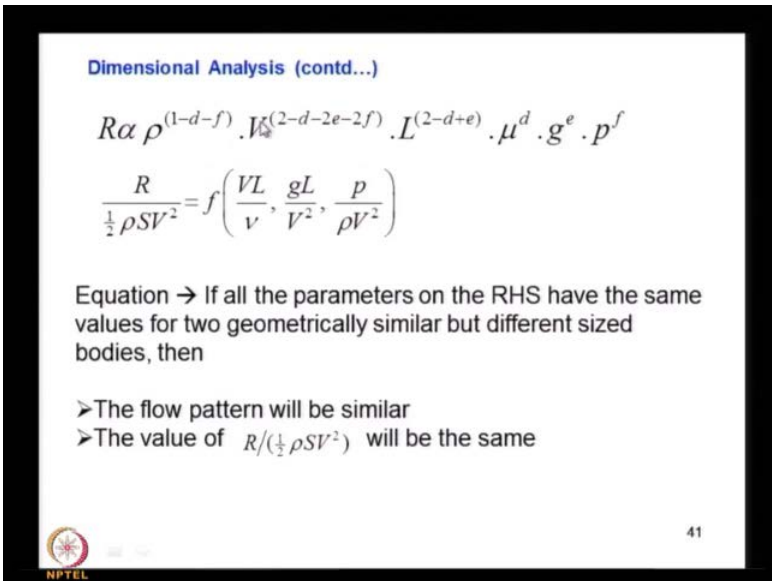

So, R is now proportional to you can just using that previous relation these relations over here you right in this form over here. And finally, you right R by half P S V square is equal to function of these three numbers. So, if all the parameters on the right hand side this parameters are the same valve for two geometrically similar, but different sized bodies like this you have to just indicating one model and other one is a actual same. So, this quantities can be or remains same then this quantity also remain same, like the co ordinances that this is a non dimensional resistance also resistance coefficient.

So, resistance coefficient will be same provided these parameters also remain same for model and proto type. So, we will see subsequently whether this is possible, so the sized then the flow if that is the case the flow pattern will be similar, around the model line ship and the value of this value also will be same through the same if these valves are same, for model and shape the flow pattern will also be same. And subsequently this value also resistance coefficient also remains same for ship and model.

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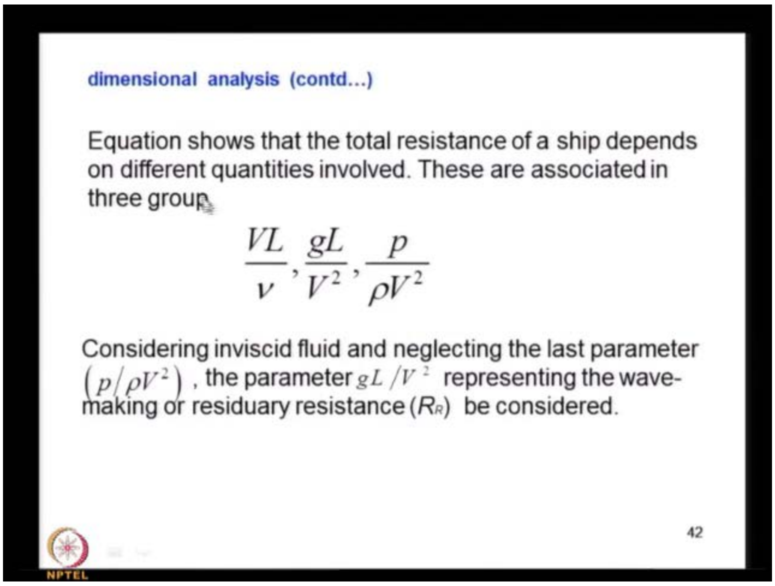

Equation shows that the total resistance of ship depends on different quantities involved these are associated with these ok we have already discussed, this it depends on this. Considering in viscid fluid, consider no viscosity that means this time not cancelled, so final somebody has not there and neglecting the last parameter you see that if you do not consider this, then the resistance will be depending only on this parameter that is a Froude number.

So, if you consider an in viscid fluid and this pressure variation is not cancelled, we will see later how it's going to change it. So, then the resistance will depends only on the Froude number. So, if the fluid is in viscid you will not have frictional resistance so but you we have the wave making resistance. So, if that is in case if you satisfy this only the Froude number alone you will be able to predict only the wave making resistance, or in general residuary resistance. So, that is what is concluding so the parameter g L by V square representing the wave making or residuary resistance can be considered. So, the resistance component will be the resistance components, if the Froude number is only satisfied then the resistance, which you can predict from the model is only the frictional resistance or if you can satisfy the Reynolds number you can predict the frictional components also.

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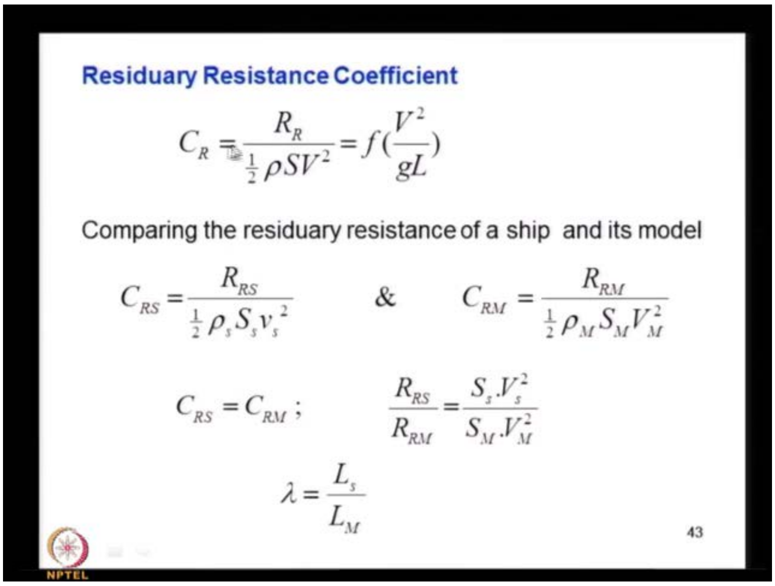

So, the residuary resistance coefficient C R is now put as residuary resistance R valued divided by half P S V representation, which depends on Froude number that is what we discussed. If you satisfy only the Froude number what you get is only the residuary resistance and if you non dimensional you get the C R, that is the residuary resistance coefficient. Comparing the residuary resistance of ship and it is model is a C RS that of the ship is given by this quantity that is residuary resistance of the ship divided by half row S that is the sea water density, that is the S S better surface are of the ship and this is should be v s, not v s, v s is the ship velocity.

And that for the model you use the model parameters R R M is the residuary resistance set for the some model divided by half row M, M is the fresh water density that is a lab condition. S M is the surface area of the model and V M is the model speed. So, from these relations, if we take you find that since it is satisfying this one C R S is equal to C R M. So, that is what it ((Refer Time: 49:31)) for inside for this one. So, when you take ratio of these two quantities you see that assuming the density what case is being water same being to get this relations that is R R S is equal to this quantity. And I think we will continue next class.