Seakeeping and Manoeuvring

Prof. Dr. Debabrata Sen
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Module No. # 01

Lecture No. # 37

Rudder and Control Surfaces - I

See, today we are going to talk about Rudders and Control Surfaces.

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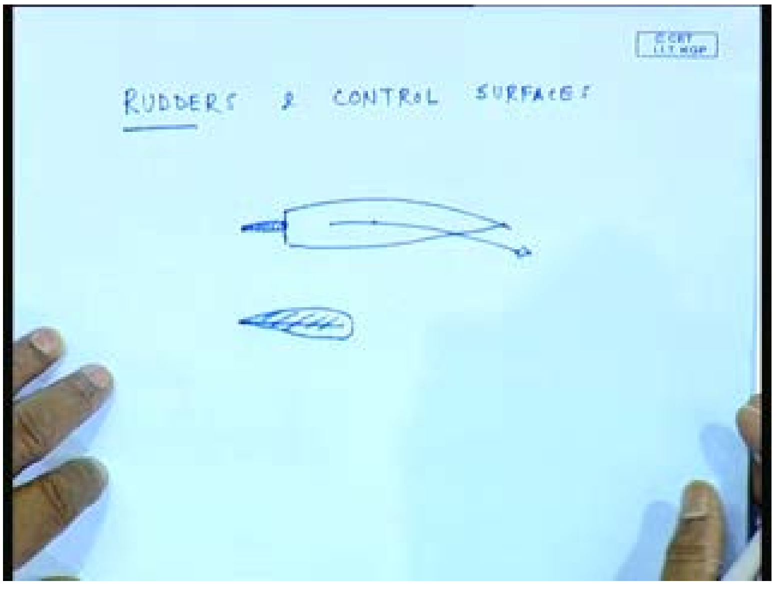

Actually, for a surface ship essentially control surface is the rudder you know. See as I said today we are, our topic is rudder, essentially rudder as you know if I wanted to turn a ship the the the force that I induce is by means of a control surface, which is which it turns out for a typical ship is a essentially rudder; in fact some people think that manoeuvring is essentially rudder design for ships.

Now, as you know rudders are typically aerofoil sections and they are normally symmetric aerofoil, because you would like to make sure that, whether you turn port side or star board side you get the similar force. Before, I go to the the you know hydrodynamics and flow around rudder surface; let me just talk little bit about the various kinds of rudders, that are available you know I plot some pictures for that.

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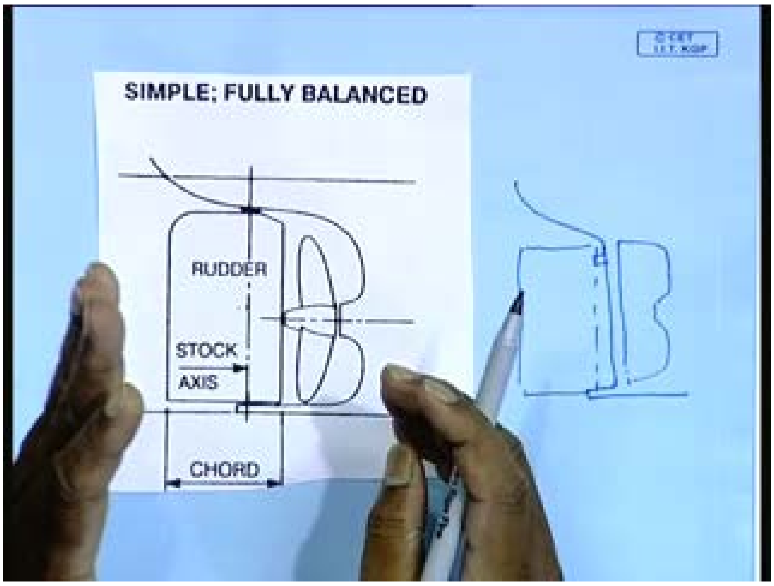

See, this is one ruder type, we call this is a, this is what is call a simple rudder, now if you look at that what is happening here is that, this basically there is a stock here you know this rather rudder post here; that means that this particular design goes like that you know there is support is like that; of course, this goes like the rudder is supported both end; this is this is one of the older type, where the axis was more or less at one end; so it was not very balanced you know weight is more on this other side.

This is a ruder post type, then a simple similar type slight modification instead of the post we have a but, here that is larger plate you know if you see this compare to this one, this one has a smaller this post but, is also supported both side. So, simple rudder on the same topic this is the other kind, which you call more balance, why balance because, see this axis is shifted, somewhere here more forward, what is happen, we will see that afterwards.

The force will act somewhere here through a center of pressure and obviously the stock moment that will come depends on the distance between the two, so if you support it more like where the hydrodynamic center of pressure comes, then it will be more balanced, so this is called balanced rudder.

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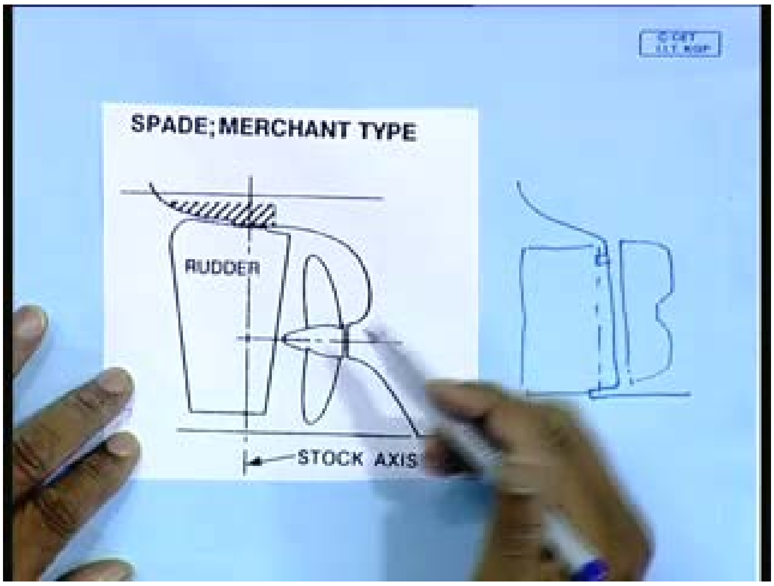

Then, we have got here another type, which is balanced rudder but, with a fix part actually this is if you see this this hatch part is a part of the hull fixed part. So it is almost like as if you have got a fixed part followed by the moveable part something like that if you look at the cross section here but, it is also balanced. Then we have here this is called balanced underhung deep horn, here you know the hull goes like that, underhung some part is hanging below but, you want to have some area this side. So, that the net center of pressure (()) from the rudder stock is not much, that is why this side is because if it was not this side straight, that would have been unbalanced rudder.

This was a this part was very deep, the next type was where this part was shallower this is what you call under hung but, shallow horn this this is horn this is shallower horn, then the more modern types are the kind that I will we will show. Now this spade rudder what we call now a days most rudders, they do not have the support this side, see or even this hanging like that it is essentially supported from the top, the entire thing is the stock is somewhere here it is supported from the top; so this is what is called a spade rudder.

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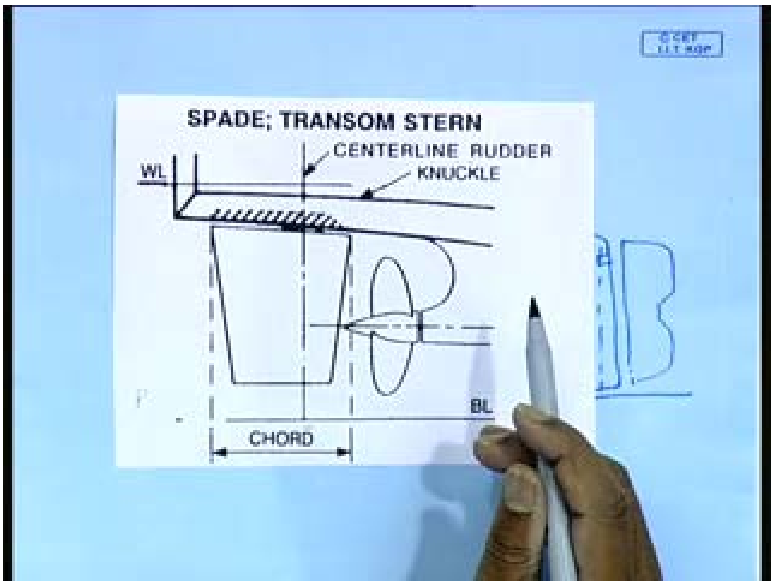

And similar spade rudder this is actually one type of spade rudder and we have this this is the kind that we will discuss more, this most common for now a days transom stern spade rudder. Now transom stern, the difference being this; in this case this turn is cruise stern but, most ships now a days are transom stern you know straight line here, with a straight line part; so this one is like that this is the most common type of rudder that is used now.

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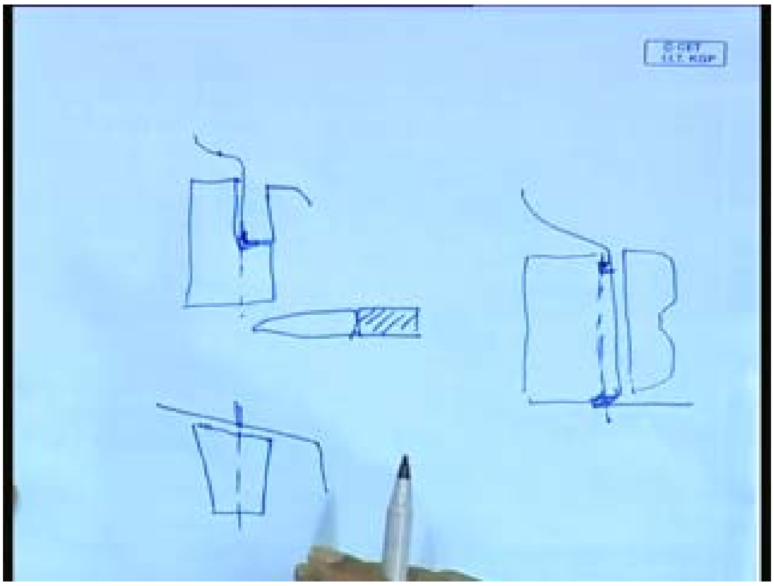

Having said that, so these are various kinds that means what you primarily see is three different type, one was balanced means it was supported by both ends; this end and this end the stock was here, not balanced (( )) the simple type the next type came, that is something like a hanging but, this what we call this horn type, that is the there is a horn here. And the rudder was supported like that there is the deep horn here supported from here and the most modern type is that hull is simply here and it is supported straight from here directly spade type.

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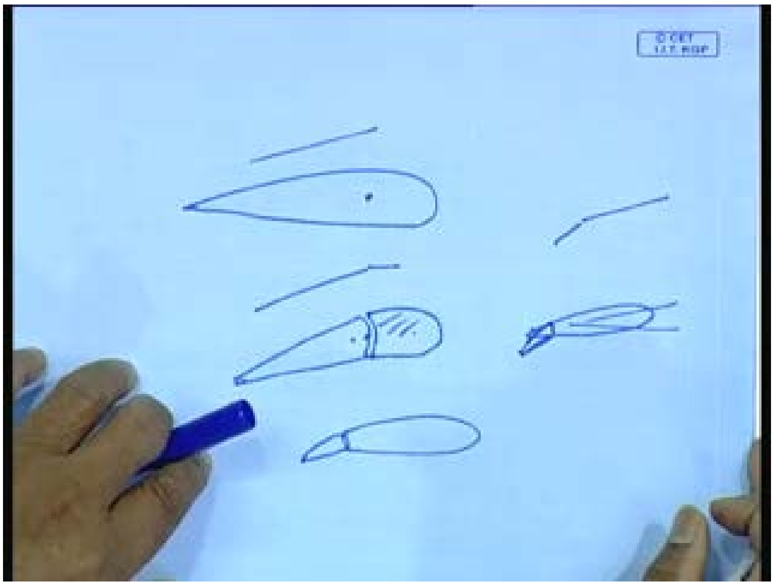

So, you know as far as support is concerned these are various types, now as far as section is concerned, we have all moveable rudder, moving the entire thing you can have a fix part and a part that moves, that is a fixed part, followed by a moveable part and you can have also this flap rudder. Where this and the flap both can move, means the rudder can take a shape like that, with a angle, in other words if you if I want to look at that this will look something like this this.

This will look something like this this and this (Refer slide time: 07:28) is some straight line means the one thing is what I wanted to say is that, one is the entire thing moves one is this part is fixed this moves, other thing is both of them move with a flap like that; that is this also move and another flap here.

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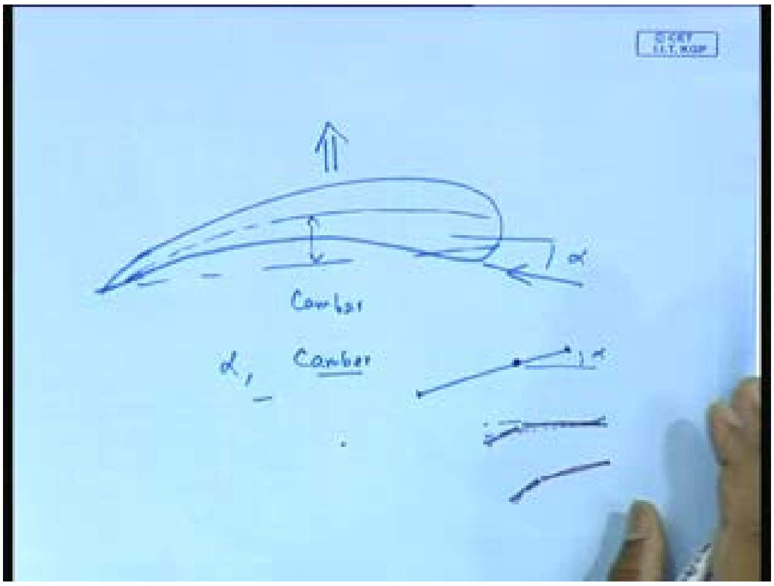

See, the reason for this of course, various types there are more complicated types simply you know if you look at a control surface, asymmetric you actually have something like that and you have what is called a camber curvature. Now the lift that comes has normally two effects one is angle of attack what we call alpha and one is because of camber, in other words you see in aircraft, you always have this camber why because, you are primarily looking at lift only one side you are not looking at both sides but, here we want to have look at both sides.

Now, this three different rudder way it is suppose I have straight one rudder, so I can only make the angle like that about this point, means with an alpha; so the the lift comes only because of angle of attack. The fixed rudder if I have kept it fixed on angle it here now it it has an effective camber type, because this full thing is almost like you can approximate this by something like camber.

And if you have a flap type, both this thing so it has got both camber and angle of attack factors, what I am trying to say you know essentially this modifications are, so as to get extra lift that is all. Additional lift but, most rudders are of course, simple type because these are more complex and they are used not for ship's rudder, large rudder, they are used more for control surfaces in you know in submarine, torpadoes and you know such such body which require very high manoeuvring.

Having said this, let me now just plot the geometry of a rudder, typical geometry of a rudder is important to kind of understand that, so that will take little time.

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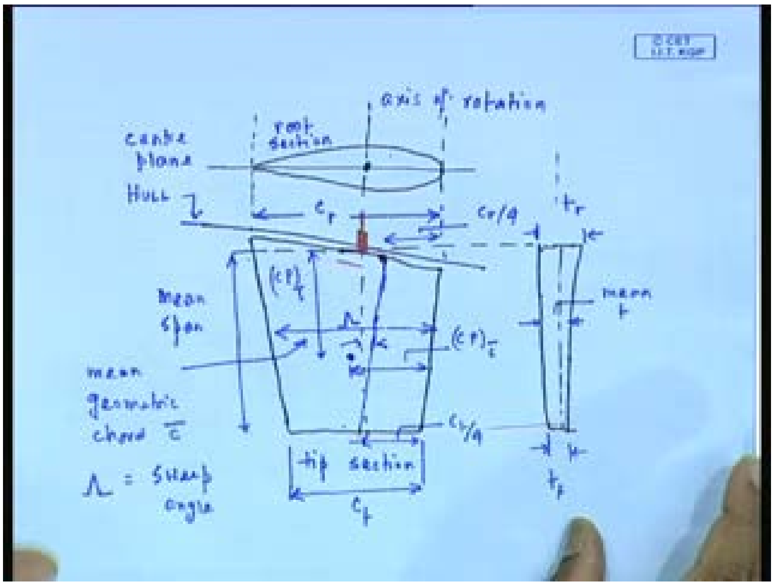

So, we have let us say hull surface here, because we need to have this definition various, these are all mostly done this spade rudder, typical rudders will have some kind of a cross section like that this. And then if I look at this outside, cross section it will look this may be the axis of rotation here; so this is bit too far if I take some kind of a central line here, if I were to draw here, let me just draw it then I will tell you, what this taper down normally here.

Then there is a one fourth coordinate, now let us draw this thing here (No audio from 11:37 to 13:01) let me just draw it then, I will tell you this (No audio from 13:05 to 14:25) see what I do is like this, essentially I will tell you, if you take a rudder this black line typically a rudder, any measurement this side you call cord right so this is let me [FL] put one another one here, let put this as (No audio from 14:49 to 15:09) let me, let lets go go through a slowly.

See, this outline is my rudder measurements along this say x axis if I call it, is what is called cord; now if you take at the, so the top one is the root section, this is the tip section so this one is the cross section for the root section, here as you see from the top if you measure. Now if you this is a bit taper right, so if I take an average mean, let me the tell the other way round the this length here of the root section is what we will call c r, cord at root section this of course, you will call cord at tip section and the geometry I have which is geometric mean cord.

Similarly this side, we did not say that this side both, because since normally this is a flat the reason, you see the reason I will tell you another reason, why this is flat here, this is like this normally what happen that you your objective is to get as much lift as possible; now for that, you want to increase the rudder area as much as possible. So, if you actually the hull line is like that and if you make it straight line, you will lose lot of area there is no point of losing lot of area, besides there can be flow separation and (()). So you want to make it as parallel to the hull line and hull line, normally goes up; so you make a parallel here but, this one on the other hand, you want to go close to the bottom, so that it you know you get a maximum benefit, so it was a plain line.

So, there is a normally a this is a plain line this slightly taper if you take the mean of that and take this height this is my what is called mean span, so these directions are span, so always remember this is cord this is span. Root section tip section tip section thickness typically, the it is thicker here and thinner here, so this is the, that is also why it is so? For such spade rudder is because remember, rudder stock is coming here and when the force comes you have a bending moment.

So, the bending moment is high on this point, so you would like to because of the force is see there is a plat here and forces coming here, supported here see, the plate is being supported here, from one side this is a stock here on which supporting here. And if your force comes there obviously bending moment will come here, so that is why normally you will have always the thickness is more thick here you know this how the design goes.

Now, in order to geometrically understand this you know the tapper, what normally done is this this psi I should write there is call sweep angle, you have to have a measure of the taper, how much is the tapering. So, this is normally done by taking quarter cord line, that means if you take a point here, which is one fourth of the c here, another one one fourth of the c here and draw a line there the inclination of that with respect to the vertical.

One has to understand that these are only a certain standard, all you need is some measure of how much it is tapered, now this taper and this taper is not usually same, so there is an mean line taper. So, instead of taking mean normally it is taken as quarter cord, that means from here take a point c r by 4 here a point c t by 4 draw this line, that angle is called mean sweep angle. So this is kind of a you know cross section, etcetera for your rudder.

Now, we will now look at the you know like lift and drag and such things for that we need to know this to first of all, so this this picture is clear right; so the reason of drawing this is because, we will see afterwards. That ultimately, what I need is a lift force coming on that lift and drag, because this control surface means lift and drag the net force that comes on control surface is always lift and drag you know propeller surface also we have said, rudder is a same thing; all the forces are, because of this lift and drag just like for propeller the way the propeller force is we are getting the the reason the aircraft flies same reason.

So, there with this later on there will be some empirical formula and the empirical formula will of course, depend on the cross section shape and certain geometric parameter, that is why this parameters are necessary, because the formula will be evolved based on such geometric characterization, means in terms of span, mean span, mean cords sweep angle etcetera, etcetera that is why this terms becomes essential for us to understand.

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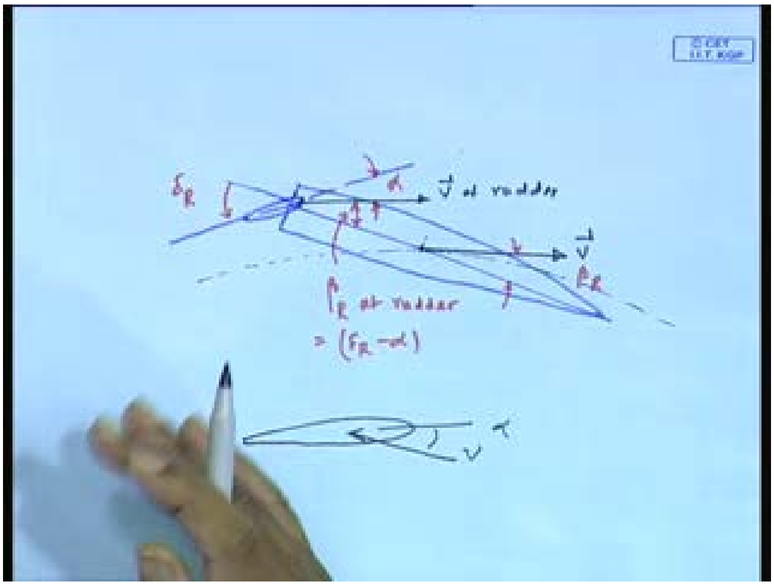

Now let us look at the lift and drag part you know for before that we need to have this two kind of diagrams you know, let us look at this ship part first, suppose now this picture we should see, say this is my ship here and the rudder is here (No audio from 20:56 to 21:31), this a rudder angle (No audio from 21:33 to 22:06) see, these angles are important for us to understand, first before we proceed to that, what we have drawn is see, this ship is turning right that means it has got a path line. So it is velocity is this side remember it must have a drift angle, we have talked about that, when we are doing turning circle manoeuvr, means when it is turning it has got this is my x axis it has got an beta r which is, what is it (()) beta r drift angle of the ship.

Now, not exactly same but, if you look at this rudder also, the velocity also here, you would expect to be more or less parallel slight difference but, for the velocity at this the water, this rudder movement if you see will be along this line, v at rudder which means flow is coming this way to the rudder, you see here this is my rudder, it is moving this along this line, when oriented this way what is this angle alpha.

Alpha is the angle to which the flow comes to it, I will draw that picture later on or rather if i draw this way this is this is way the v comes this is my alpha, angle of attack; alpha is essentially angle of attack, delta R is the rudder angle, the angle that by which you turn. Now, this angle that is delta minus alpha that is is the drift angle at rudder, why this is important? I will tell you in a minute; you see remember one thing, what is the lift force for a control plane, which direction is a lift force up means what, up can be any direction is normal to which direction is it normal to this x axis or normal to the velocity axis.

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Normal to the normal to velocity.

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Right.

So therefore, that is the that is the point therefore, if this is my v here my lift is normal to the velocity right, so lift will be along this line, drag will be along the v, v axis now, rudder forces when we say y force, which side is y force it is normal to this axis. Remember it is normal to central line of the ship; so what we have to do is to resolve all the forces in the proper direction, that is why I do this diagram here, we need to resolve the forces in proper direction. Now we will we will come back to this diagram but, let me now draw this diagram of the you know like the rudder section itself.

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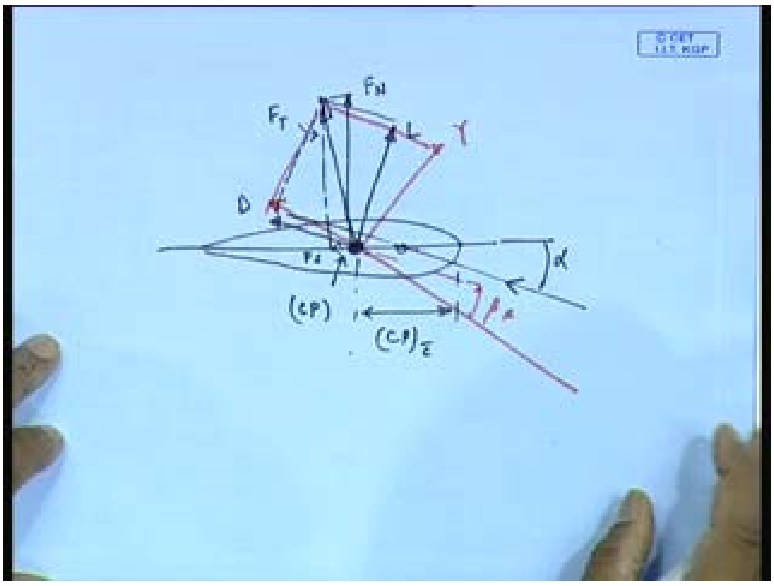

So, the rudder section will look like that, I will just draw a bigger one, so the here (No audio from 25:23 to 25:37) the this is C P, let me call it C P, see flow comes with an angle alpha just like here that we are seeing, flow is coming with an angle alpha to the rudder this is a rudder this blue line and the flow is coming this way; so the flow comes at an angle of angle alpha that is angle of attack.

So, and this is my let us say center of pressure, which means what is center of pressure actually, I in the previous diagram also I should have mentioned here that ultimately you know what is happening this entire force will act as, well if you take the net force, it will act as some result in point i am we are calling it this point center of pressure C P. And this C P will have coordinates this side I will call it C P c that is C P of that basically x of C P that is C P c bar, that cord length of the C P and this we are calling it C P s bar, that is span of the C P; essentially the there is a it has a two coordinate know x and y, if I call this x, if I call it y, then x this basically span wise.

So, why I mention that is that here, supposing this this thing, so my this distance is essentially C P c here, my forces act which which direction the force act lift will act, this direction, normal to this, drag will act take it from here. So, the net force will act where this is the total resultant force, again this will have a component which is normal to the x axis of rudder and tangential to the x axis of rudder F T, I can call it no not F T here, if n means F S, we can call it well F N.

So, you can resolve see, the point is like this you can resolve, these forces in any direction that you want, whichever way you are basically looking you want it you can resolve it. Once again the flow comes this side, you we always call this force as drift force, this force as drag force, right; now net force of course, is lift and drag F T in some direction and if you again resolve it you can resolve it to F N and in this direction.

But the point is that, now this is one side but, if you look at this this diagram you will find out that here what we have done, you see if I look at this carefully this was my v, so my lift force was normal to that, this was my lift force right and this was my drag force see, along this line this drag force. But, what is my y force? My y force is going to be well, this will have resultant this force but, my y force y rudder is actually force in this direction, normal to this line and x rudder is going to be this one.

You see what we are trying to do here, that means here if I drew it see this is now the ship axis here, we look at that ship axis is actually at an angle, beta with respect to v that means if this is v here, this line is so ship axis actually along this line with a beta r. So my y force is going to be here, that is y force is going to be this one and x force is going to be this one; once again let me, tell you it is a question of resolving the forces, you see this probably let let me draw it in another one.

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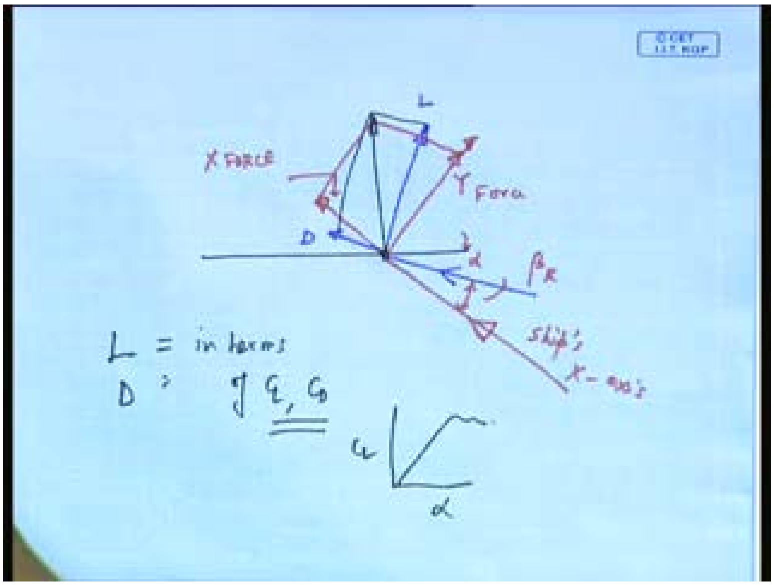

We just draw with respect to a line then, will be easier because I have this my rudder, let us draw various colour flow comes this side, so my lift force is there drag is here, right which total this is my net total force ship axis is here, so y direction is 90 degree to this that is my direction y. So this dissolve in this direction (No audio from 31:44 to 31:54), what is this angle, this diagram should be kind of clear in your mind you know the reason is, because I will tell you, as far as control surface is concerned by itself you always look at lift and drag and you write them as you know c l, c d, etcetera half rho c l d u square etcetera right.

So, these are written in terms of lift coefficient and drag coefficient, no remember that you always plot c l versus angle of attack most control surface you would have seen this hundreds of time this kind of diagram, c l versus angle of attack, because for control surface by itself, when you look at people only want to find out, what is the lift and what is the drag any naca or any control surface. But, our interest here would be also to find out what is y d r, that is y force because, of the rudder and your x force because, of the rudder.

So, I am looking at this y force here, I am looking at the force which is the, which rudder is producing normal to this, this side which is not same as normal to the velocity, because of this beta, that is why we are trying to make this resolution etcetera. So, now having done this you know this diagram see, so what is this angle this angle therefore, is beta, this is.

So you see I can straight forward get Y in terms of L and D by taking beta, because basically L and D are you know like further angle beta R, beta R, beta R, if I call it gives you Y see, I have got L and D. My Y is beta R to L therefore, all I have to do is to find out this way, then then the things become very simple.

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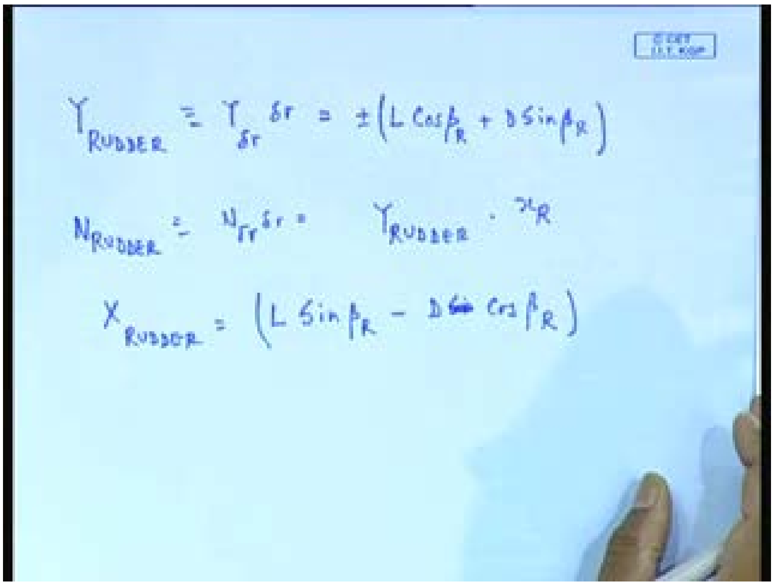

So I end up getting resolution like this you know that, my Y rudder that is given by Y delta r into delta r that is that is how I the definition of that, if delta is rudder angle Y delta is d y by d delta R and this is given by plus minus L cos beta R plus D plus minus; because, it can be both sides, you can see that from here, because this L is translated to beta r. So, in D of course, it will be always, so L cos beta plus minus D you know like sin beta in this case plus both sides and N R, N rudder, what is X R, X R basically the distance of this c g to the center of this pressure, this distance straight forward, which would be approximately L by 2. approximately l by two.

So, this is the you know this is the Y and this rudder and of course, sometime you want to know the additional drag coming, because of rudder D cos this will be the X force of the rudder. Obviously there is also X force coming you know like as you do this way there is a drag coming along this side; in fact you will be surprise that the drag, because of large rudder angle is significantly large and it is used as a breaking device for a ships.

And in fact for submarines during emergency rescue the most effective, means to reduce speed to actually put a rudder they call a rudder hard (()) hard you know like maximum angle rudder it acts as a break. You will of course, see that planes also when they come down they actually put up as a kind of breaking device.

Now this is about the rudder forces that, we need for manoeuvring purposes, what about rudder stock when I want to design, what also do I want to know see, I also want to know this is a rudder stock here, right I want to know how much of moment I have to give it on the rudder stock, because after all I have a stirring gear device, because I have to turn it. So, I need to know how much of torque I have to give it, you see the force will come on the plat here and that plat is going to give a torque on that or I have to give; so much of torque, because if I want to turn I have to give a torque like that.

So, I have to design the rudder stirring gear compartment for that power, so I also need to know, what is the torque coming for turning it and what is also the bending moment coming on this point, because here I have a force coming; so this supported here, this may break, because the rudder stock should have enough strength to withstand that stress.

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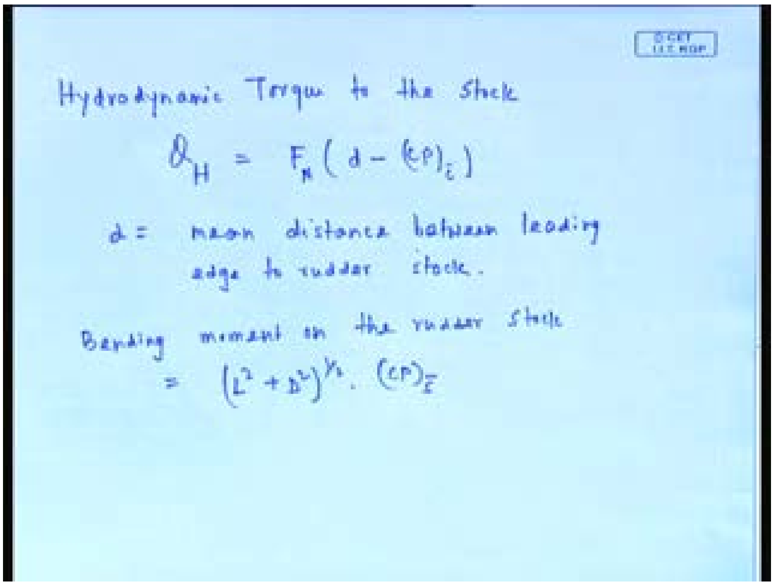

So, for that purpose you see here (No audio from 37:46 to 38:23), this will be given by net force F, F is the net force, actually F is the normal here, this is the I will tell you, let me tell you this F is this where is the diagram; actually here F N, we call it F N here, this F force c here.

See, this picture F N is my normal force which of course, is calling here it is written as F the same as I will just call write this F N; anyhow I call it F N only, now this this is my stock where I have my rudder this is my force normal to it. So, what is the moment coming obviously F N into this distance right, so herefore what I get is this F N into d minus c p c bar, when d of course, is the mean distance of leading edge to the rudder to the center of stock, that is basically d is this distance, mean distance of this, this is d.

Or rather let me write down, leading edge we we we remember, we always call this edge the leading edge, right the forward edge you know this from propeller; c p c of course, we do not know. Now bending moment (No audio from 40:24 to 40:44), now what is the bending moment is going to come here; let us look at this, see here on this two diagram, so on this c p c I have a net force coming, what is the net force? Is F T what is see, the net force is normal, remember net force is coming of this point, normal to it.

This force is how much that is F T remember F T because this way the force is coming what is F T is L square plus D square square root right therefore, what is the bending moment of this point, this force into this distance straight forward right and this distance is c p s. So, I end up getting this as (No audio from 41:40 to 41:52), so this is basically then what we have done is interestingly that all that you need is L and D if you know L and D, then you can figure out almost all quantities of interest.

So, now question is how do I represent L and D, now normally what what you will do we will do is that we always will represent L and D in terms of c l and c d for example, this is a common thing, no that now, let us put this non dimensional term, then we will.

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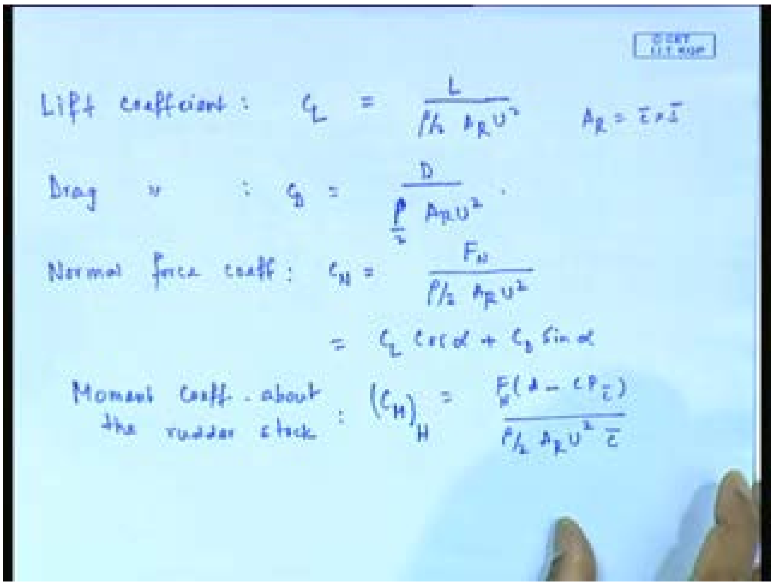

Now, lift you define for lift a coefficient, we will talk about this, how to get this thing later on C L you define that as L by rho by 2 A R into U square, A R being the effective area of the A R you can call to be the span into you know like mean cord into mean span essentially, the area rectangular that area, plan form plan form area you can call.

Drag coefficient, let us first write this then we have all kind of thing normal force coefficient (No audio from 43:29 to 44:00), see normal coefficient is always like that because, that we can see in terms of alpha, this normal this one is of course, this angle is alpha. So, F N is L cos alpha and D sin alpha, right I did not write it before but, it is very easy because F N is normal this is L this is normal and this angle is angle of attack alpha, (No audio from 44:27 to 45:06), let us call this is F see here moment. So, there is a, this c note that this c will come here; because this moment here is half rho a square u into a distance some length coordinate will come here.

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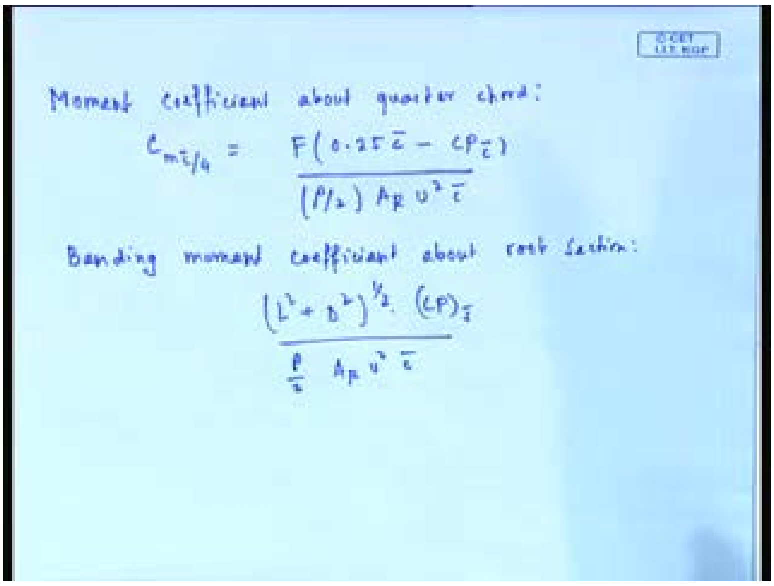

Then two more thing I will do (No audio from 45:29 to 46:04), this is also defined the cord is like that, this is important from design point of view this (No audio: 46:16 to 47:10) you know these are all sort of coefficient. Now I so this is only a non dimensionalization of the part, now let us let us look at one one one thing about this this part is Y rudder X rudder part you know this this diagram along with this beta R part, beta r beta r r part delta just one second, let me see this this diagram of the ship.

See here, what happen see, quite often you want to estimate this, one of our purpose is to basically be able to estimate Y D R, now N D R is Y R into X R and X R is almost like L by 2 you will find out; therefore, in non dimensional form that N D R is Y D R into L by 2 into L by 2 will give you N D R right. So if you get one of them you get the other one nicely, so the the question therefore, is that how do I estimate Y D R.

Now, what is happening here see this beta R, if you look at this beta R beta r is a drift angle, now sometime quite often beta R actually, how much do you think a ship ship normally drifts when it is turning, when you give about 30 degree of rudder, the it may be drifting with only about 3, 4 degrees drifting see, when the the drift angle is this angle you know, that when the ship is turning like that it is, this angle that is my beta R.

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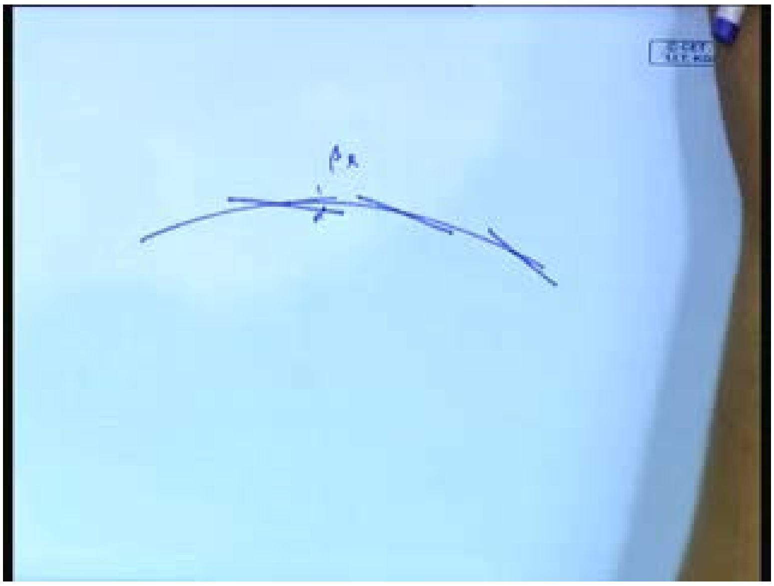

Now, if you look at this diagram here you will see that delta R is alpha plus beta R from this relation, now if beta R is small then delta and alpha becomes some what similar, so what, why I am saying this is, because in such cases, what is happening for a given rudder here; actually by this approximation you can get you can get a relation of Y D R in terms of C D and C L and actually what happen if beta r was very small then Y D R D R is approximately equal to L, now see suppose Y D R D R is approximately to L.

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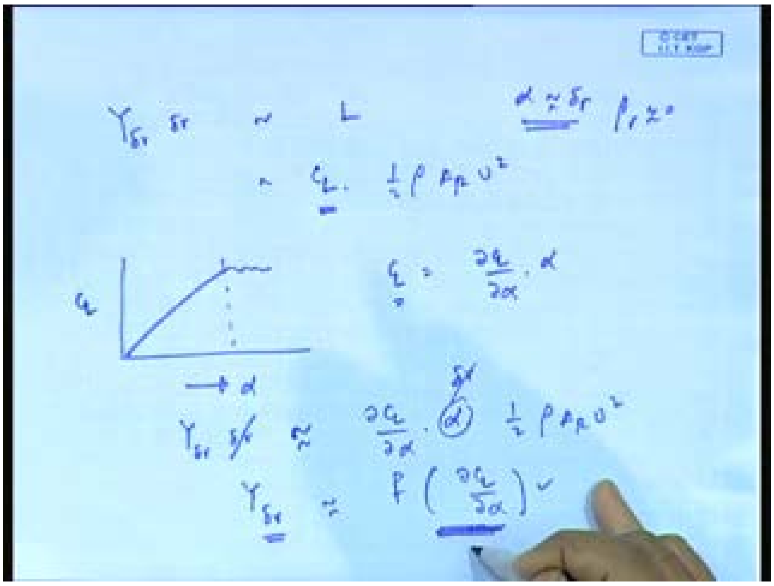

Now what is L? L is now you see, let me get back to that, now what is happening Y D R is approximately say L but, what is L? L is what we just did L know, L is C L into half rho A R into U square but, normally you know you do not write C L, what you do that alpha versus C L is plotted here. Actually what happen alpha approximately equal to delta R according to our if if you are making a approximation, beta R very small, then alpha equal to this thing when beta R is actually 0 right; when beta R is small you see here this is small, then this angle angle of attack and D R becomes almost close by.

Now, the there is the point I was trying to make, now you write Y D R D R as this right but, C L is not written as if you plot the C L graph it will look like that, some slope so C L is written as d C L by D alpha into alpha. Because normally it is a straight line, initial part and you design it for the straight line part, so you call C L as d C L by d alpha alpha therefore, if I look at that then what did I get Y delta r, delta r is approximately d C L by d alpha into alpha into half of rho A R into U square.

But alpha is delta R therefore, what would happen that you end up getting Y delta r approximately in terms of function of d C L by d alpha so you know this is why i mention this is because you can make an estimate of d C L by d alpha sorry Y delta r in terms of this in most control surfaces this what this is known as slope of the lift curve this d C L by d alpha d C L by d alpha will be known to you mostly this graph.

And what happen is that, this d C L by d alpha turns out to be also there empirical formulas for that, several empirical formulas for that it is normally seen to be you know like like inverse of a aspect ratio, aspect ratio being b y s, etcetera, etcetera. So, if I have an estimate for d C L by d alpha then I can get Y d r; now we will be talking later on, I think tomorrow’s class about various formulas for getting C L and d C L by d alpha empirical formula for a given rudder.

So when I when i look back at all this part, what you find out here, in all this, that we have found out all this forces, that everything comes out in proportion to L and D L and D are written in terms of C L and C D. C L and C D can be written in terms of d C L by d alpha into alpha for a given rudder section.

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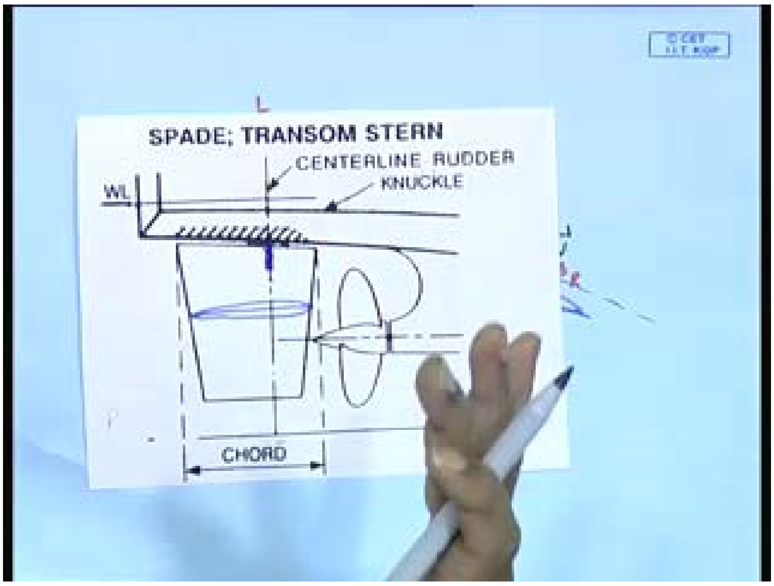

Therefore, what happen when I have a rudder section chosen, say take any any any rudder like this, so I have this cross section here, so I will be knowing this it will be based on some naca or some section.

So, I go to the literature find out what is my d C L by d alpha then I can find out c l then i can find out l and once i find l and d then i can find out all other quantities that is how much is y d r, n d r as well as more importantly what is my moment torque coming on the rudder, moment coming on the rudder. The torque coming on this rudder is important for me to design my stirring gear that is, that much of force I need to turn it and the bending moment, here is important for me to make the size of the stock, otherwise it will you know break up.

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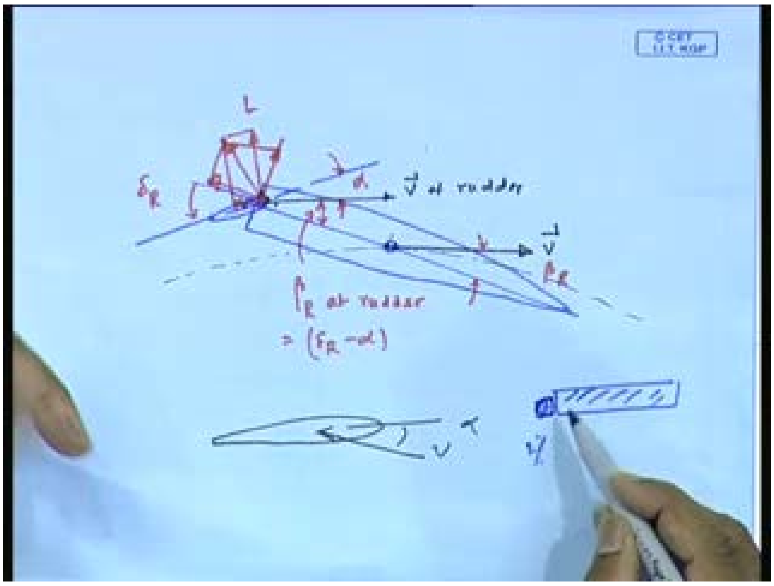

So therefore, what it turns out that for controls surface hydrodynamics, when we talk essentially it turns out to be nothing but, lift and drag; of course, there are correction because of drift angle but, as I mentioned many a times the drift angle is small, typically for a small you know, when you go only at a very large slow speed, then drift angle may be large therefore, you can make good estimate and that is what is done.

For preliminary design, what would happen you need to find out a net force is coming on the rudder, force coming on the stock, torque coming on the stock, etcetera. Now, you can make an estimate of them and also we will see that the the the thumb rule of rudder is that you pick a rudder area, if you if I took a cross section of a ship, hull profile view rudder area is approximately 2 percent of this area that is the rule of thumb.

See in all this C L C D just last thing, let me just tell you you know it is a very simple rule you increase a r you have more C L, L C L is constant let us say therefore, the thumb rule is very simple a ship is not behaving well it is very sluggish; the the the thing that people do later on is simply increase rudder, just make rudder larger. Now rudder larger also has another effect, because when you add rudder larger at the end and if you do not turn it, then it acts as a skeg and it increases c, because it it makes the stern dominant and it makes direction will be stable like a skeg, like you are adding some part.

So, this has two effect it try to make the rudder ship, go on a straight line also it is larger turn of course, naturally you need larger force, because of that but, anyhow, so this is about this rudder, we will talk tomorrow about the various empirical formula and may be work out one or two problem type thing`of the rudder force on a typical rudder, so with that I end today.