Performance of Marine Vehicles at Sea

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Lecture No. # 40

Rudder Hydrodynamics

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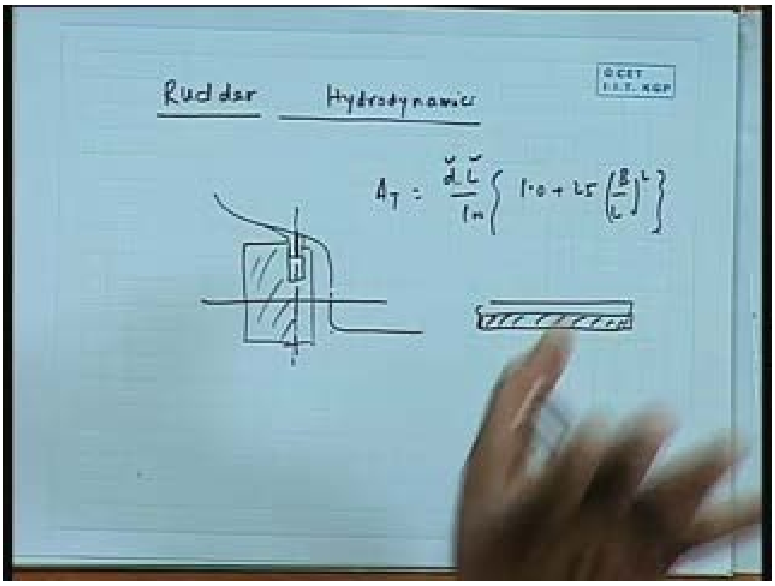

This hour we are going to speak about rudder; but, I call this lecture rudder hydrodynamics, because we will concentrate more on the performance part of it which is because of hydrodynamics; as you know, there are various kinds of rudders - I do not want to go into the detail; there are rudders which are like balance, not balance, having a post… number of types of rudders are there.

Essentially, rudder is a device, which you can rotate about some axis and by rotation it causes - primarily – force in the y direction; this is what you are interested in - you want to generate turning moment and turning force - this is what exactly it is; if you take a rudder here - something like that - it has got a rudder stock; it might have earlier as a rudder post, but as I said I am not getting into detail of the construction part of rudder.

In fact, there is to be empirical formula about the rudder area also - how much it should be; it turns out approximately two percent of the central plane area of the rudder or some other formulas are there - like, some empirical type of formulas d into l by hundred - something like that; one…I will just give you one formula here, etcetera - this and various kinds of formulas; it is obviously - d by d l by hundred gives you the percentage; d l is for a ship - the central plane area more or less this area; A T is some kind of percentage of that - as I say, if you work it out this will turn out to be again around one or so - two percentage - or so.

The purpose of today's talk is - how rudder produces force, what the cross section looks like and some detail regarding its performance; if you take a cross section of the rudder - typical - this is a simple rudder; actually, rudder will have many other shapes - it can be triangular or it can be whatever.

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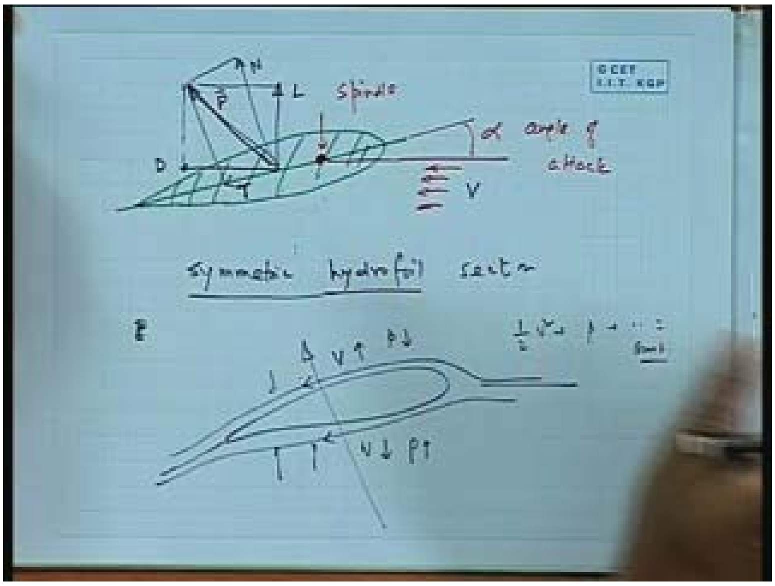

But, if you take a cross section of the rudder invariably this rudder will look like an aerofoil section - a symmetric aerofoil section; it all…from here... the rudder will be looking like a - I will just draw in this way; a turn rudder - it will have a symmetric aerofoil section; this is a typical cross section that you can take and I have assumed that this has been turned little bit; it will be turning about some point here - I can call this may be the rudder stock point or spindle; an axis about which it is turned; now, you have a force coming here I mean - the axis - let us say like this; so, velocity comes this side and I can call this to be angle of attack - alpha.

Let me again say, if you take a cross section of the rudder - first of all, why cross section for hydrodynamics? It is only obvious, because you would except the flow along the rudder to be along this line - not having much vertical motion; any cross section you take you can find out and you can take each cross section, add them up and you will get the total force more or less; therefore, cross section is a very logical approximation and I just want to show or tell you what kind of forces etcetera will be acting on that; you will have a rudder spindle here; of course, this is the symmetric aerofoil section - let us use the word hydrofoil, this is really not much…

It is symmetric, because you want it to have the same performance on both sides - not like an airplane, where you have an unsymmetrical aerofoil, because you want the ship to only - plane to - only go up not down; similarly, propeller - you only want force in one direction mostly, therefore it is not symmetric; but, in this case it is always symmetric because either turn port or starboard you want equal kind of forces.

Now, if you have a velocity coming here - v - what happens, as you all know, is that it is going to produce a force in some direction; primarily, there will be a component in this direction which is known as lift force and there is a component in this direction which is called drag force; there will be…therefore, if I combine the two here - this is my net force, sorry, this will be my net force that will come…by definition, in aerofoil there is a force there - we can call it this way, that the net force is this force - say, f; this f is broken in two parts - one is what is called the force component, normal to the direction of the velocity that is known as lift force and along the direction of velocity that is called the drag force.

These two will depend on alpha; these two together is f and you can also find out - resolve them - in terms of the two components which are along the normal and along the tangential part of it - I can call this the normal force and I can call this to be tangential force; all are actually the same part the; reason we are writing that is, because you will find out that if suppose there is a ship here and the ship is along this line - which may not be the case always - then I want to find out what is my force coming along the direction which may be normal to this axis; and we might have to break it in various parts; so, we might want to know various kinds of force components.

This is actually…let me call it p; p... before that, let me say it like this - in all aerofoil theory…in all hydrofoil and aerofoil theory…first of all, these lift and drag forces are well known and I am probably not going to go to this hydrodynamics so much, but I just want to tell you why this force comes - there is a very simple reason; if you have a plate like that here, when the flow comes it basically goes like this and this goes like this and it comes on like this - when the flow comes; now, it turns out that this distance is longer than this distance.

One can show that, if there is a point of fluid then it has got a velocity here which is up and velocity here which is down; because, it must travel the same distance and meet up here at the same time - that is what one can show actually; but, the top one is to travel a longer distance than the bottom one; it turns out that the velocity of the particles on the top is little more than the bottom one; as a result, there is bottom result coefficient says that half into v square plus p plus some g h equal to constant; there is a famous theorem which says that velocity square plus pressure plus some hydrostatic head is this constant; it has a same hydrostatic head, therefore V going up means P coming down - this means P going up; there is a larger fluid pressure here, then there is more pressure there than the pressure this side.

The net thing will give me a pressure on this side; that is why there is a force that comes out ultimately this way; this is a mechanism…this is all aerofoil theory - a whole lot of stuff is there, we need not goes through that.

Is it all for symmetrical point?

No, symmetric unsymmetrical - in fact, even if you have a plate here this is what is called aerofoil theory; this is a different theory, we need not go through all that stuff, but… I mean, it is difficult to tell, but I will tell you one another interesting part - here is that, something like that.

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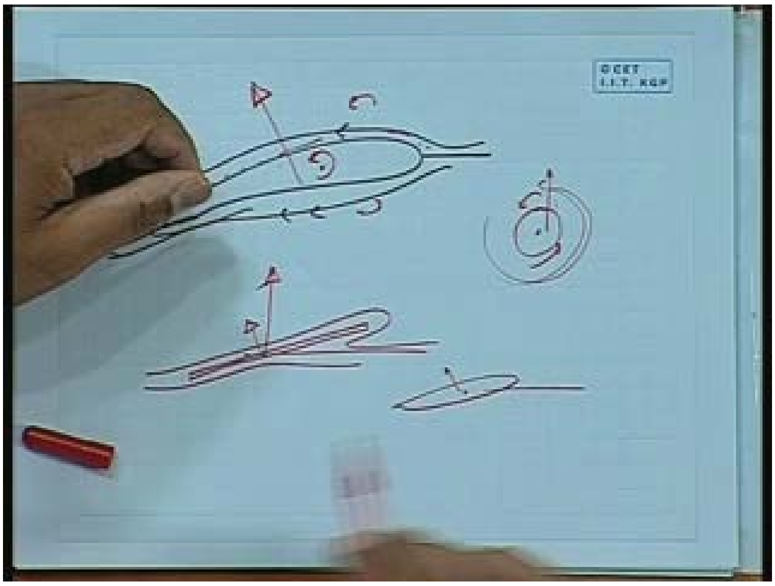

Just spend little time, because we are we are calling the lecturers rudder hydrodynamics - let me tell about this aerofoil theory a little bit; you have this aerofoil or something; I will tell the answer - it turns out that if there was a flow coming here and if it was a stream line, it would have actually come like that and it have come out like this; if you assume some standard flow solution interrupt shown like that - it would have actually gone like that and flow would have come like that; but, it turns out that if this has to happen then - there is a stagnation point; there is a point called stagnation point where pressure is supposed to be zero - velocity is supposed to be zero.

Now, if this was the case then the flow has to come like that - there has to be some stream line like this; but, that is not possible - since this is not possible you might have to… it is… you can think that somebody has to, as if, put a circulation - as if, I am trying to rotate this flow and push this point down to here - as if I have introduce some kind of rotation; this becomes the same as a ball, because I want this separation to be like here, I am introducing a circulation - as if I am trying to induce a motion like this, here.

This is a difficult concept, but it is something like there is a ball there and I am trying to rotate the ball like this in order to induce a motion - like a circular motion; and if you do that to a cricket ball then it you get a lift here; the same way here, if you do that, it turns out that you can get a force there which is in this direction - this is a mechanism; but, you know it is all complicated aerodynamic theory; all you need to know right now is the same principle for its propeller works, aerofoil work etcetera.

The same thing will apply to - answer your question - even for a flat plate; even if there is a flat plate here, the flow comes like that and the flow comes like that - it has a lift; it is simply that the lift here is not as much as you want; if you put an aerofoil its lift is much more; since your objective is to get more force in this direction….

Less direction is here

And less force in this direction, therefore you want to actually have a design - you want to design a section where you get more and more this l; which means you get more and more this the difference of pressure in the two; but, not so much more that this pressure is less than vapor pressure, then cavitations comes in - that is a different thing; but, this is why even if when a ship is yawing and going it also axis a lifting; when the ship also travels like that - a full ship - it actually gets a force - lift force - in this side; because, whenever the flow goes like that this produces a lift; it becomes what is known as the lifting surface; anyhow, this is a different theory and we are not going to talk so much about that.

But, coming back to this diagram it will turn out that if you have a section here - if there is a flow there - it will always produce a force somewhat in this direction; and you want this direction to be more and more this side because you want more and more lift; in fact, that is what will happen - you want more and more, you want much more l and much more of l than t.

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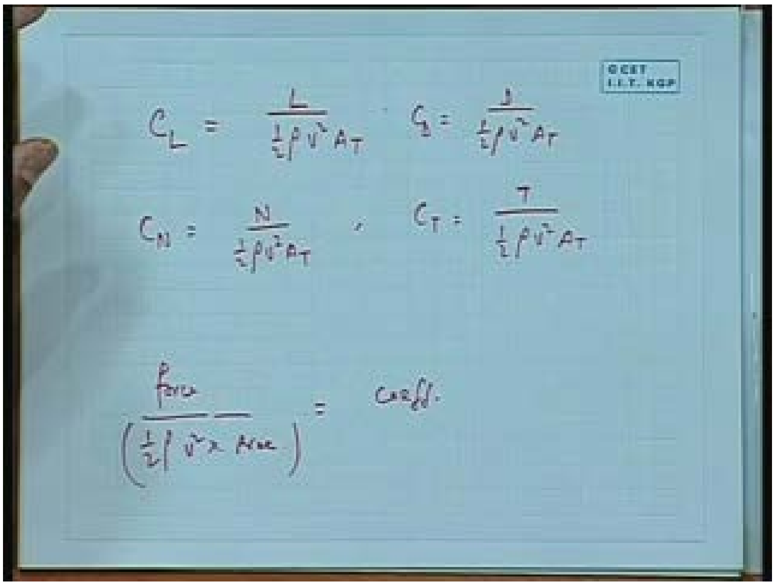

Regardless of that, for all aerofoil theory you get this and it is usual to express these forces in terms of such coefficients - a t being the transverse area and a drag force as d by….you can also call this c n as n force by…it is a common trick, that any force… if you see the unit of force you see that the non dimensional part of force becomes equal to half rho v square into area - this becomes a non dimensionalization part; you always call that to be some coefficient; and it is a fluid dynamics trick that whenever you cannot figure out a force you simply call the force equal to some coefficient into half rho v square into an area.

How are you calling c f? Half rho v square into surface area; how are you calling your total resistance? Half rho v square area; this is nothing but a way of non dimensionalizing the force and you call that unknown thing as a coefficient and that I do not know I have to find out; you find that out.

Similarly here, in terms of instead of getting l and…l and d and n and t you always express them in terms of coefficient and the other best way is to test d y by half rho v l into d square in k t; why in this case this? Because, it is obvious that it will depend on the m b and this velocity - more velocity means you expect more force; it will depend on the area, because more area means more point for pressure to act; if you make it bigger, there are more points where the pressure will act so more difference will come in; it is…so, obviously it is written like that; why I say that is because when you want to finally design you will find out that for any rudder ultimately for a known section c l and c d - mostly c l and c d - are available data banks are therefore various sections; because, it is such an extensive topic, thousands and thousands of experiments have been done for many known sections naka and various data profile and c l c d are available.

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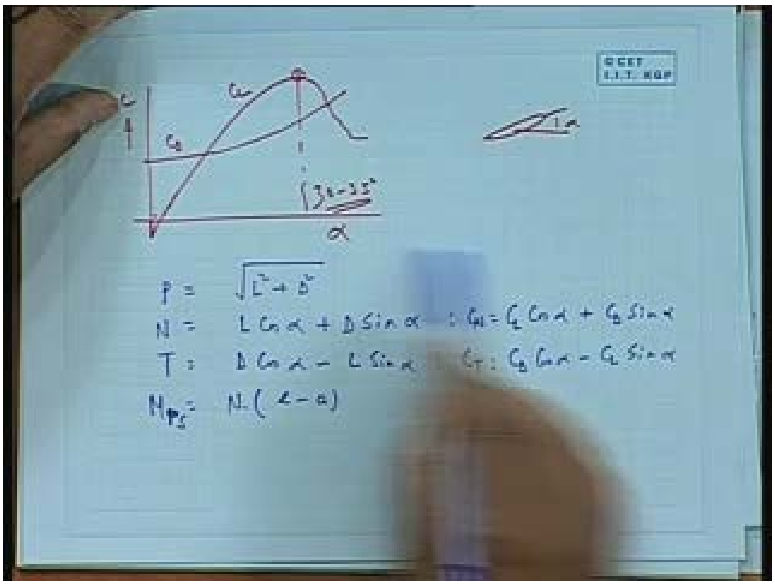

We are not calculating c l c d - we are basically going to use those c l c d part; and it turns out for many sections that typical c l c d part will look something like this - that, is it angle of attack alpha? This is an angle of attack alpha; It turns out that c l and c d… one of them c l… normally, it need not be always zero, but somewhere here, let us say, somewhere here may be; it goes up there and then at some point is stalls - this is up to around thirty to thirty five degree for most of the common sections; and c d initially starts from high - little bit - and then, of course, it still goes up; and there is a c l by c d - this may be c d, this may be c l; this is actually the coefficient any c (s) this is (( )).

Typically, it looks like that; this is exactly why… in fact, you do not have the rudder angle and all more than 30 or 35 degree; because, your idea is to get lift, there is no point of not getting lift and getting only drag; you have rudder like that you are getting no lift force, but only drag force - there is no point; you are not bothered, you basically want the lift force more; in fact, you want as much lift as low drag - that is what your ambition is; anyhow, going back to this diagram once more - this diagram - we can easily find out that if I call l and d and if I know this angle alpha I can actually resolve all this p and all.

p becomes, for example, p square is l square plus d square; then you can say that p into cos of this angle is l p into sin of this angle - in terms of this angle, this angle, this angle… we can make all the sort of - we can resolve all of them; this is alpha, this is actually… this part is alpha; I will just write down this expression - that is very simple; because, I am not… the problem of this course is that the space is a problem; p becomes l square plus d square and n becomes (No audio from 17:13 to 17:44) this is very simple, I will just may be go through this with this; this way, I think it can come here now.

n is obviously l cos alpha, because if you look at this n is l cos alpha plus d into sin alpha; this n is l cos alpha plus d sin alpha, because this is my angle alpha; similarly, t is going to be… t … now, t is this side; t is going to be…this is alpha again; d cos alpha minus l sin alpha and, of course, in terms of coefficient it becomes like that.

One more thing is important - there are…probably, I should say; supposing you call this distance to be a, this distance to be - this is my centre, actually this point is my center of pressure where all this you know forces are… having done everything is a center of pressure from where the entire force get to acting.

Let us say, that this is equal to e; what is my… another…. one important point is what is the moment coming on this stock? Remember, this is my stock here on which this force comes here and I want to find out moment coming on that stock; that will n into this distance - the moment coming will be n into e minus a.

E minus a.

So, the moment here I can write - moment of that equal to n into… in fact, moment on the stock - let me call it rudder stock - into e minus a; this is important sometimes because this moment that comes is the moment…. you have got a rudder and you have got a steering gear machine that you have to turn; it has to turn against that kind of moment; you are turning this rudder about this point like this and the moment that you need - if you have turned so much, the moment that is coming on that is so much; therefore, you need to… that moment… because that much of moment you have to apply; this is necessary for your steering gear design - that is why you need that.

Why I am saying that is because in the rudder design we will find out that essentially if you can estimate this l etcetera from every section you can integrate and then get the rudder problem - the entire rudder's performance; the hydrodynamic performance of rudder can be obtained by actually taking section by section the c l c d values and then of course, adding them up all; now, having known for a given section this rudder what we need to know is to kind of define some other quantities of rudder - some of the typical geometric definitions; that I will just try to draw little bit here.

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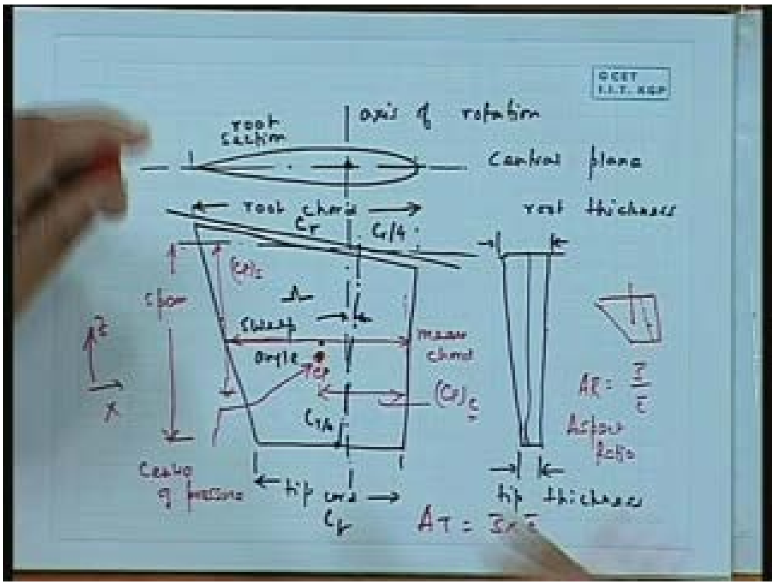

If this is the most general case we are trying to write here; here is the section - the top one looks like that here; this is my stock point here or this is rotating here; first of all, this is my axis of rotation - that is a speed dial; this is my center plane; this is - this can be called root section; this is a tip - some definition; any aerofoil section from which the direction of which the flow comes you call leading edge; this really… you must have been hearing about the leading edge, trailing edge, root section etcetera; may be, let me not go to that - this is tip, this is root, etcetera.

For rudder, this length is what is known as chord length; this is root chord and this is tip chord; this distance is called chord and this distance is called thickness - where the maximum thickness occurs you call it maximum thickness.

Now - actually, I thought that we should draw a line here also - the mean line; if you see here it will look something like… the rudder will be looking something like that; it is…the thickness also comes down as you go down - there is a thickness here; this is my mean root thickness; this will be, of course, my tip thickness and typically what happens is that there is a there is a line defined for a geometry that is what we will be new for that.

If you take a line - one fourth of this - that is, this is a distance here, let me call this c r; this root chord is say c root and this is say c tip; if you take a point here which is c r by four and if you take a point here which is c t by four and if you join this line - this is known as a reference line and this angle….this is...

Sir, taking on the leading edge c r y four and c t y

Yes.

On the leading edge?

Yes, this is known as a sweep angle; and then, of course, you will have some kind of centre of pressure here - let me put this as span; I will… let me write it all down and then I will just tell you; then, this is chord - it is a somewhere here - may be one of these points - will that be same (No audio from 24:25 to 24:42); then you have this c p c n c p n; this is… if this getting all complicated, but anyhow; I will tell you without making it any more complicated - it is something like that.

Right now, where I am trying to tell - introduce - some geometric terms to define the rudder geometry; why? We will find out that for each section, as we have seen earlier, that the forces that come on that section can be expressed in terms of c l and c d - for that particular section; let us say, you have forward the c l and c d - then, you can resolve them into any direction that you want; you are doing this for a section, but if you want to do for the entire rudder then you have to do for each section and add them up - you can integrate them along the section; therefore, you need to have some kind of idea regarding the geometry of the rudder; what are the parameters that are basically used based on which you normally have this rudder force estimation, etcetera - that is what I am trying to say; in any aerofoil or hydrofoil section, this length is known as the chord length this is the thickness.

Therefore, here this is my chord length - any measurement along this width is a chord length - this top one is known as a root, this is a tip so there is obviously a tip chord length and there is a root chord length; and if you take the average of that you have got a mean chord length somewhere; because, I am just showing in these two ways; now, this rudder is shown to be having some kind of a angle - it is not a straight line - it is having some angle; I need to have some kind of numerical measure to know how much the angle is; it is not straight line - this having an angle this having an angle and this diagram; we need to have some parameter trying to say how much it is inclined and that is turned by taking one fourth of this from this edge, one fourth of this from this edge and drawing this line and finding out how much this line is inclined with respect to the vertical.

This is known as the sweep angle, which tells me approximately what is the orientation and what is the taper - that is all; if just… you have to think of it this way - these things are…if you think intellectually or from your mind it is simply one measure of trying to find out how much it is tapered.

Sir, the central access in the dotted line of…

This one is the line about which it is….

Sir, point of intersection - does it have any (( ))

This is the same - no, there is no relevance at all; it may not be here, it may actually be on this line only - it is just to show for my ease that it is here; it need not be at…it can be… suppose if there is a rudder here - something like this, this, this and this; this sweep angle is going to look something like and the stock may be here; it is just to show how much is the angle; see there are two lines there so the standard has become that you take one fourth of that from each and take that line and find out how much that line is inclined with respect to vertical - that is all.

Then you have got a point here where the enter force will act - we can call it center of pressure, center of force; and now you measure the center of pressure's chord length and you have to know… define where it is located - how do you know? For any point, location is x and y coordinate; here, the coordinates are measured - how much it is from that line here, how much it is from one edge and how much it is down from the top; you can call this length to be c p c - chord length you can call this c p s - that is the length along span; this side is called chord and this is known as span.

There is, obviously aspect ratio - there is a thing called s mean by chord mean; once again the dimension of the rudder - in this how high the rudder is - the measurement of heights…

Span.

Is called span; measurement of width you can call it chord; obviously, it is varying, therefore, you have a mean chord and a mean span and the chord by a span by chord is aspect ratio, as you know for a rectangle; you get an idea.

Here is the…

Aspect ratio - it is a typical word for aspect ratio; any measurement along the…if I call this to be… if I call this to be, say, z direction and this to be, say, x direction - any measurement along x direction is called the chord; center of pressure points have got x coordinate with respect to this mean edge at the end - we call that c p c; this is called c p s, etcetera; essentially, we do not have to worry about all this stuff - it is simply to tell you that the typical feature associated with this has to be some kind of measure of geometry - some kind of width and some kind of height; so, the width and height are all the span and chord.

The aspect ratio they are taking z by x.

Yes, this by that - this by that, z by x aspect ratio; if you…. this is again a question of standard - if you take this by that then also aspect ratio one can say as it is a rectangle; you can take long side by short side or on the other hand you can make this side short and that side long; it does not matter and the area of that rudder, which is very important - a t - a rudder area is, of course, the mean chord length into mean this thing length - because, it is a rectangle…that area… this area becomes very important.

Why we are introducing all that is because we will find out that later on there can be many empirical formulas available where you can find out the total force based on these parameters; we have seen earlier that for individual section c l c d can be found out; so, what one can do of, course, is to go to a long n and try to find out for each one c l c d and then resolve the forces and integrate them -the procedure is long.

On the other hand, there are some empirical formulas that have been found out…when you have these parameters known - length, breadth, mean chord, mean point, etcetera - you can estimate what is the total force coming out or total c l for this - overall c l - not for individual sections; the c l meaning the net force coming on that if you have turned the rudder, because, after all, the turning…the angle of attack is going to be same; because, this section or that section or this section - any angle of section you take angle of attack is same.

So, those directions are same; these directions are going to be the same; instead of getting this c l c d for individual section you can actually find out the total c l and total c d in terms of the entire propeller by means of empirical formulas; which is nothing but integration of… that is why I introduced these sort of things here; in fact, if you look back at that we will find out that - where is this formula, again? l cos n - this n is the force coming along this direction; this is normal force coming - normal to this, which is equal to l cos alpha plus d sin alpha.

As we have shown here - let me let me do it again, separately; it is all getting confusing - what I wanted to say is that - separately, again - what we have done is that we expressed rudder forces in terms of y delta r into delta r - that is what we said; here, the rudder angle - if you think that the ship is here, going straight line and you have turned it; therefore, alpha becomes the rudder angle - approximately; in reality it may be more complicated than this, but approximately rudder - alpha is the rudder angle.

Obviously, the…I want to find out what is y - the rudder force in the y direction; it turns out that you can find them out by resolving this l and d type of thing; the flow comes this side, the ship is along this side - we can find it out - you can actually find out - resolve them - in terms of l and d; I need to see this picture here - just one second - I will show this in little more detail.

Just think, as far as we are concerned for the class all we need to know - all we need to find out - is that for each section I know for specifically that there is a force which is normal to the direction of velocity which is called l and along the direction of velocity which is called d; once I know two - four - two components, I have known the total force; after all, remember that the fluid gives a net force vector and then I can resolve that in any direction that I want and some of the directions of the force will become y some of them will become x - drag force; this is the essential point that I wanted to make here.

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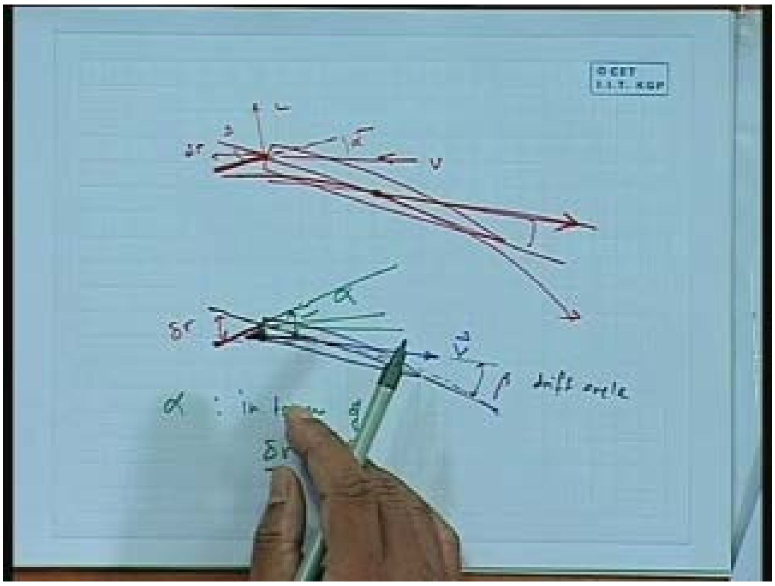

There are more complicated diagrams that one can actually tell; for example, a ship can be moving in this direction in a tangential fashion here or other ship is moving in this direction with a heading angle here; the ship might be moving in this direction - velocity vector; when you are turning, the ship is moving in this direction - this is my trajectory; the ship is turning like that, but…and the velocity is in this direction; the rudder is, of course, here - along say this direction; my rudder is like this - angle is my rudder angle; but, the flow comes to it along this direction, parallel to that along this direction the flow comes - v comes here; this is my angle of attack.

Therefore, I can find out now from there the force is (( )); this v is coming here, therefore force in the normal direction to that - normal to v - let me see, I will draw it here; this and this becomes lift and drag etcetera; I am not getting into the detail - all that I want to tell you…this becomes a little more complex for you to see; I will explain to you just this diagram in a very brief thing.

Maybe, I should draw it here - just think of that; this is my ship - in which direction is the ship is moving? When it is turning, we have shown that the ship is turning with… where is a blue one… a velocity this side; that is why the trajectory looks something like that - it is turning; this is my longitudinal axis of the ship; as far as the ship is concerned, we are calling this to be actually the drift angle beta; see one by one this point; now, this was turning because the rudder was in this direction; the rudder - what is rudder angle? Rudder angle is, obviously the angle it makes with respect to the ship - that is, this angle is my rudder angle; think of that - rudder is like that and the velocity is like that; that means, the force that the ship is moving this side, which means the flow is coming along this direction; that means, on this you can say the flow is acting to this - green one I can put here - along this direction to the rudder.

What is the angle of attack? It is this angle - this is the angle of attack alpha for the rudder; what is alpha therefore? Now you can make out alpha in terms of delta and beta, because you can easily make out because this v goes here and this angle goes here; along this angle… you can make out - you can express alpha in terms of….so, the angle of attack as we have found out here - this alpha - is not the rudder angle exactly; this can be… in fact, we can find out this to be…. I am not doing it here, but I think I can find out this to be simply beta r plus this - let me see this and this - where the diagram is here; this is delta r here and this is this angle - delta r is actually this angle; here the alpha v is this way and this angle is the beta angle; in fact, you will find alpha becomes - sorry - the… what is alpha? v is this one so v can be as this one.

We can make it out - beta r plus x… let me try to find out; beta r rudder - geometry and all that - let me not get into this right now, but I am saying - trying to say - is that you could easily find out that alpha is…in fact, this velocity is this side - that is, this velocity alpha is this one; this is my angle of attack alpha and this probably is the other angle - you can express that in terms of delta and beta; therefore, what happens is that....you know now that for a section what my effective angle of attack in terms of the rudder angle beta r and the drift angle - rudder angle delta r and drift angle beta - is; you will know the angle of attack.

Once you know the angle of attack, obviously you can find out c l and c d; once you know c l and c d you can find out what are the total forces coming on that; and once you know the forces coming on that you can find out what is my net y force, because ultimately I want to find out… this is my x axis here I want to find out what is my force coming along y direction - that is, what is my y rudder.

This you can find out in terms of c l c d, etcetera; and this y rudder is y delta into delta r, therefore from there you can find out y delta r; the essential point is that you can effect… ultimately find out what is the rudder force that is coming in the direction y and in the direction x by simply taking a geometrical consideration and trying to find out geometrically what is my actual angle of attack and then resolving the forces along the desired direction; there are some simple - very simple - algebraic expressions for that.

What you need to know, as far as the class is concerned, is the principle - the principle is that for any section if there was an angle of attack known you can find the force coming on that in terms of c l c d; once you know the forces coming on certain directions you can resolve them in any direction that you want; for a rudder behind a ship, you can find out what is the angle of attack in terms of the rudder angle and the drift angle of the vessel; once you know the angle of attack you can find out the c l and c d and the lift and draft forces in terms of c l and c d.

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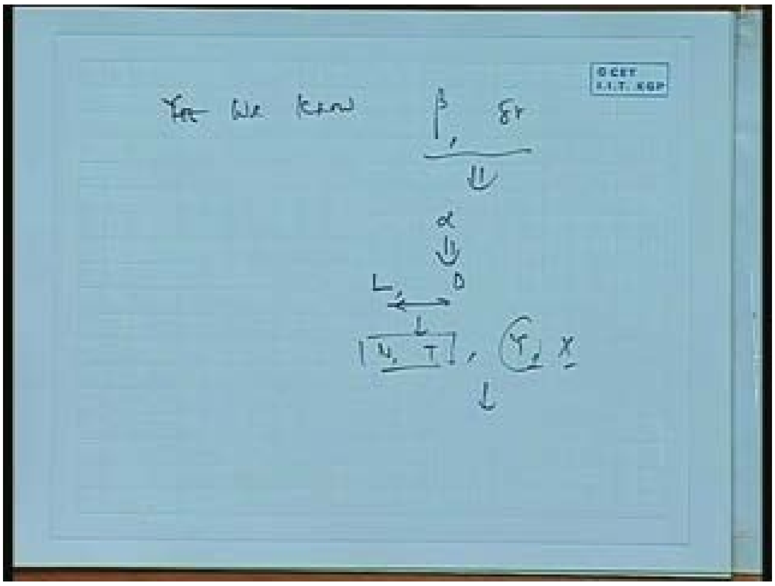

c l and c d will be known from tables of standard sections for which you have used the rudder; you would have use the rudder design based on some section, so you know c l c d; from c l c d… let me let me write the steps here; you will know - you know or we know - lift angle beta, rudder angle alpha and from these two we will know angle of attack alpha; we know beta we know delta r so we will know angle of attack; once you know the angle of attack we will find out for that angle of attack what is my lift force and what is my drag force, because we know c l and c d; once you know these two we can find out what is my n force, what is my t force, etcetera; and from there we can find out what is my y force and what is my x force - simply by resolving; once you know what is my y force and what is my x force - the y force is my y delta r and r delta r; so, I can find out y delta r; in fact, I can find out what force comes out of the rudder, how much of that force is causing it to turn; and if you look at this diagram you will that the y force ultimately comes this side; and if this is a ship's c g this y force into this distance will be the one turning moment

Ultimately, you have got a ship here, there is a force coming this side - y force; there is a force coming this side - rudder x force and this force is going to cause a moment of n - you can find it out all out; it all comes down to simply trying to take some kind of resolution of this rudder to various angles, etcetera; therefore, I just want to tell you very quickly what can be the can be the rudder force formulas in terms of c l c d, which will follow from this definition.

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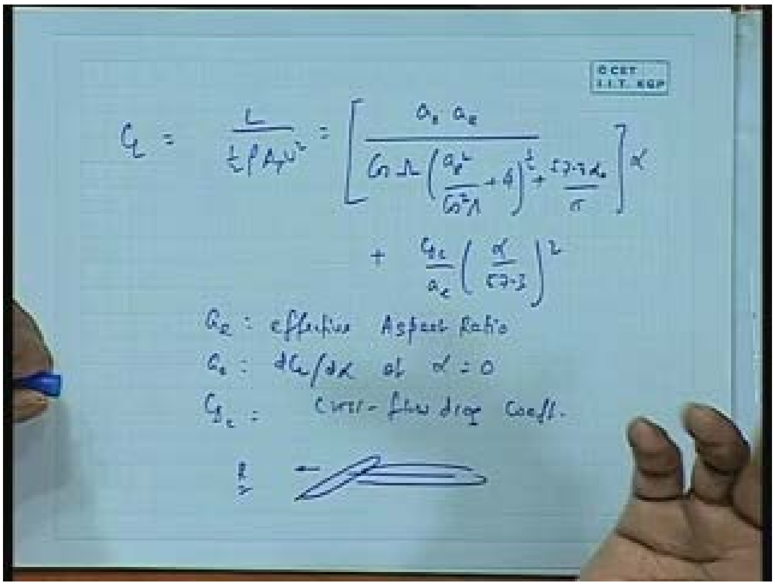

If you have this definition, you can have some kind of formula; we will not write the full formula - all I wanted to mention to you is that empirical formulae have been derived where you can find out the force coming on that in terms of the combined c l of this, which is written for example, as c l - is, of course, lift by half rho into area t into v square; people write that a formula looking like something like this - one of the formulas; cos… this thing… a e square by (No audio from 43:58 to 45:02) etcetera; all I … let me not go to so much detail.

The question that remains is something like this - you will be knowing…you are interested for the rudder - at the beginning - to find out what is my….let me see from the end - I have a rudder here and I want to find out - if I give the rudder angle of delta r - what y force will I get, because the formula of turning in my…all the turning - it is y r delta r was the rudder force; to know y force I have to find out what is my lift and drag on the rudder; conversely, if I know lift and drag I can work out y force; to know lift and drag I must find out what is the velocity magnitude and from which angle the flow is coming - that is the angle of attack alpha.

Supposing, I find…. I said that before, that you can find out angle of attack in terms of heading angle, lift angle and in terms of your rudder angle - these two will give you angle of attack, fine; you know the velocity of the turn. Fine; so, I can find out lift and drag - I could find out for a section; now that I have this kind of complicated section, somebody has suggested a formula that you can use - this formula; why this formula? Because, this formula takes care of the fact of aspect ratio - is there somewhere an aspect ratio there? It takes care of the factor of skew angle; in other words, it is an empirical formula for getting lift in terms of those parameters; normally, you would have used a particular - I should say section shape - may be naka one zero five four whatever.

Some section, for which you would have had a graph, where the c l c d for that particular section is known; now, if you have a geometry with all kinds of combinations, you can actually use these formulas - something like that - where if somebody walked out it looks like good a fit; in which you can find out for the entire section what would be the total c l - effective c l - which means I can get the l - lift force.

Not only can I can get the lift force, but there are also actually similar empirical formulas by which you can find out where is my location of centre of pressure; there are same formulas given where the location of center of pressure….once I know this location of center of pressure, I can find out what is the net moment coming on the rudder stock; which is… I mentioned there that it is something like n into this distance - this is what we can do initially, because by doing this you have a quick estimate about the rudder's working.

I am not sure if I am kind of making it clear because as I said there are too many things to be squeezed into too short a time so that it becomes a little problem; but, the essential features that I wanted to mention go like this - that you need to find out the force coming on the rudder, because more the force better it is; you can use this and the force comes for lift and drag - there is a drag also coming when you turn the rudder here, there is a… behind the ship here; then it increases my resistance - that is the reason why actually my ship slows down.

You want you wanted to slow down less, but you want to turn more so you have the c l c d phenomena; this is why you have not put a…we have gone from a plate to an aerofoil section - there was a long time you see in boats we have got simply a plate, because a plate also is an aerofoil section with an angle of attack; if you simply take a flat plate also - like that - it will also produce a lift and drag.

This will be less.

Much less and the…so it is less effective; that is why we use aerofoil section, but this ordinary plate is very common - you can you can find it in your country boats; just put a plate there.

Once you have this lift and drag for each section, then you can add them up; but, a better thing that has been done here is that for a typical rudder section the…combine the integrated lift and drag could be expressed by means of some empirical formula, which takes into account geometric features such as aspect ratio, such as various other that - sweep angle - etcetera.

This is only a question of applying a simple formula to a rudder for designing purpose; this is the reason why I do not want to go term by term, because going term by term the class gets an impression that there is nothing better; but, the point here to tell you is that as of now we have an empirical formula - somebody suggested; tomorrow you may suggest a different formula - it is simply that the empirical formula empirically corrects the lift and drag or gives you a lift and drag based on a various geometric features; in fact, earlier days - even before that - there was a much simpler formula given where the rudder force could be simply said to be something like some constant into a r into v square into delta r.

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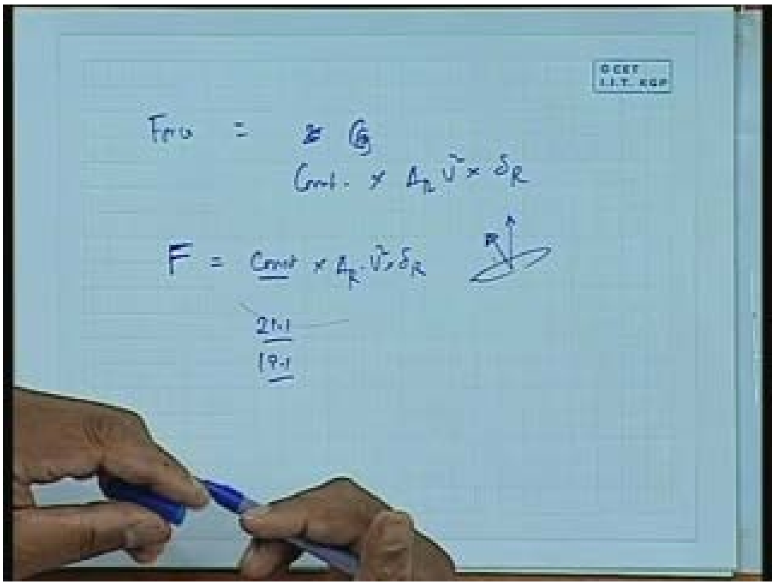

Long back, people were using some standard formula - again, the rudder force will be equal to… rudder force - the net force that comes on the rudder angle with knowing the direction; that rudder force will come on the - basically, it was a normal force here or x force; one of this, does not matter, depending on the constant; it was estimated to be as some kind of constant - that is, a coefficient - into area of the rudder into v square into an angle delta r - like that it was done.

If you see that this will turn out to be same thing as c d and this constant was suggested s something like twenty one point one; people have given various suggestions - nineteen point one; from that on wards people have actually improved and the this formula is an improved formula.

To sum it up - last sentence - to sum it all up, the rudder produces force because of its aerofoil action; so, the force is lift and drag; traditionally, lift and drag for aerofoil sections are always expressed in terms of c l and c d, which you know for known sections - we do not have to calculate ourselves; although, it can be done today using sophisticated fluid mechanics calculation procedures, but you do not do it.

Once you now know c l and c d you can find the lift and drag on a rudder section; once you know that you can find out what are the forces coming in any direction that you want; to know that you have to know angle of attack; to know angle of attack you have to know rudder angle and the drift angle and there can be some other angle also - just geometric correction; with all that you can easily find out rudder forces coming; to make it even better - if there is a rudder where the cross sections… where the length and the dimensions change - there are geometric features like top is wider bottom is narrower etcetera; you can find the combined c l and c d in terms of some empirical formula which corrects on those sectional c ls by using geometric features - aspect ratio, sweep angle, etcetera.

Once you get that, you have this diagram - you get c l c d, you get l d, you find n t, you find y - that is it; and that is how you can estimate this rudder; if you want to - do not want to - spend that much of effort you can go even lower down and have an even simpler estimation; but, as you know, simpler the estimation it is more approximate; as you go up more you have more sophistication; in fact, today you can analyze the rudder by using far more sophisticated fluid dynamics theory.

That is where I will end, because in an one hour class you cannot do any more than that on rudder. Thank you very much.