Seakeeping and Manoeuvring

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Module No. # 01

Lecture No. #40

Theoretical Determination of Hydrodynamics Derivatives- II

See, this this is basically the last lecture for this course you know. Although I termed it continuation of the previous topic, I will actually talk little bit on that and then talk on some special topics very briefly, very briefly whatever possible in time. So, continuing on the hydrodynamic derivative estimates you know, this is another formula for example, I just wanted to mention. See like in in the text book of Fossen there is a there is a well referred book now call, guidance and control of marine vehicles, ocean vehicles I believe, another set of formulas.

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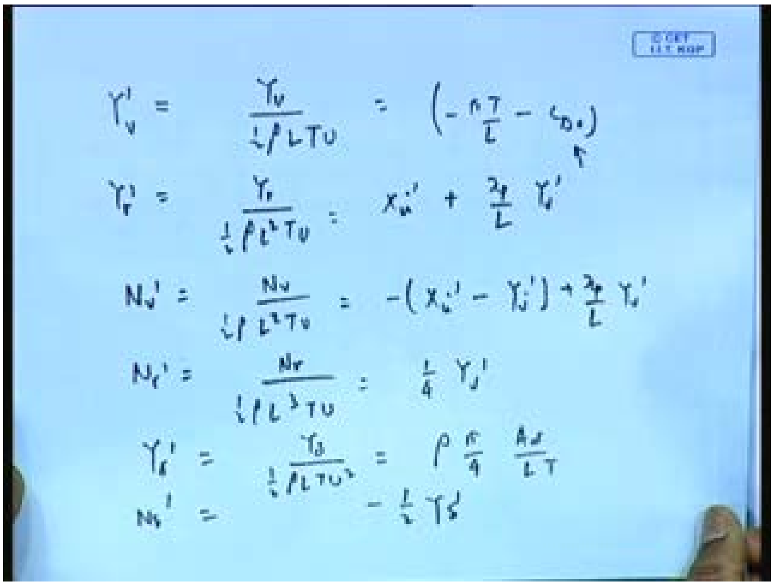

It is, it goes like that, this is all, this is but, here the non-dimensional is done slightly differently, half rho L T U actually here no-dimensional done is with, I I will come back to that it is minus pi T by L minus C D 0, then Y in fact, the added masses are normally not (No audio from 01:14 to 02:10), this rudder derivatives (No audio from 02:12 to 02:21) A rudder by L T A rudder by L T, N delta minus half Y delta. See here, this another set of estimated derivatives given Y of course, here remember that the non-dimensional is not L square, but L T actually, 1 L has been replaced by T you know normally, it was Y v by half rho L square T or L cube T etcetera.

But, here what is happened one of the L is replaced by T there are different non-dimensional variation parameters never mind, but the point is that, this formula here also is same minus pi T by L, if you look at that exactly same as what we have done in last class, based on slender body slender body and stiff theory approximation. But, there is the difference they use this C D 0 term, basically it is modification using this drag part, because you know in slender body also we actually did not take this C D 0 part, actually should be C L cos alpha minus C D sin alpha etcetera etcetera.

Y r dash another thing in this set of formula is that, they use say something call added mass terms correction to that this terms comes in picture here, again comes from theory; now here, this x p, x p is a what is known as a center of pressure point and normally x p is the distance between the central body and central pressure and this x p is approximately, let me write it down on this, so that there is no ambiguity (No audio from 03:55 to 04:04).

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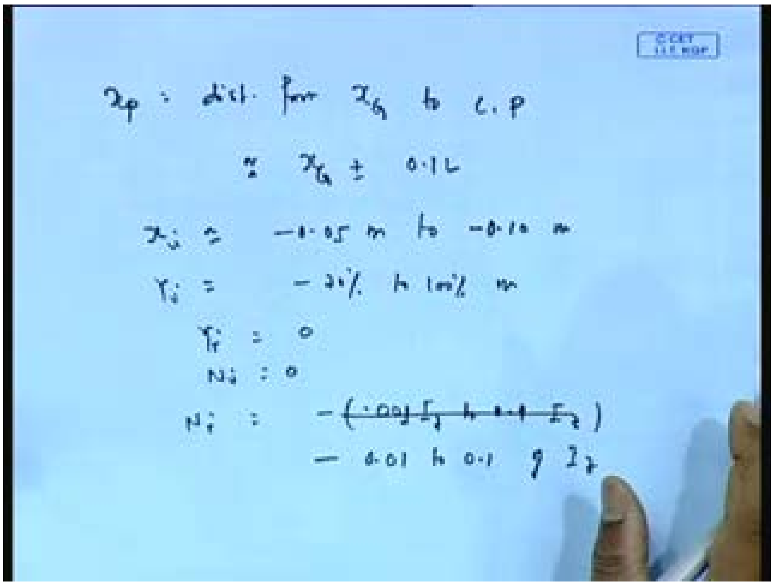

Center of pressure this is approximately x G plus minus 0.1 L, then there are other estimates is given x u dot is approximately minus 0.05 m to minus 0.10 m that is 5 to 10 percent of the mass, Y v dot is approximately minus 70 percent to 100 percent of mass. Y r 0, N v dot 0, N r dot equal to minus 0.01 sorry 0.01 I z to 0.1 I z of course, this is a wide variability you know sorry, let me write it on minus 0.01 to 0.1 of I rigid body inertia, essentially that what it says.

Anyhow, what you will, this is one another set of formula then once again you will notice, the basic form of them remains T by L, but there some more corrections are there, that is another form. And here of course, I have also given this Y Y D it is based on same in fact, it is based on same formula A D by L by T, if you look at that it is same low aspect ratio, assuming the lift produced is given by that you know pi by 2 A.

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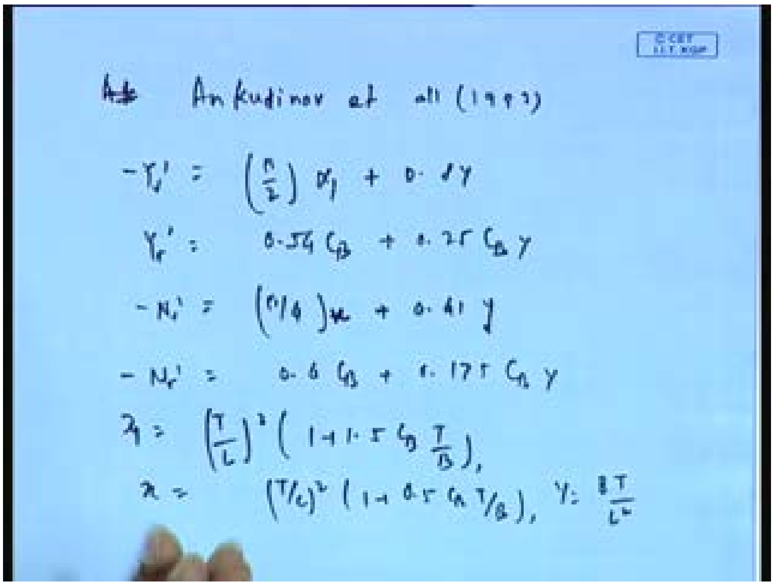

Then just just one I will give you, one another formula by, an (No audio from 05:43 to 05.52) there is the name of the author, it gives you just to show pi by 2 x 1 plus 0.8 y Y r dash, I have to write I have to write fast, x and minus N r dot x 1 is T by L (No audio from 06:34 to 06:46) x there is also same T by L square into 1 plus 0.5 C B T B and y is B T by L square.

What I am saying you know is that again, see I wrote very quickly you can always look back at that from any book, but the main point I want to tell here you know in this formula since is that, there is no uniform formula, theory tells us based on many approximation that these quantities are in proportion of T by L, reality of course, show that it will be not only T by L, because then there is no (()) on geometric parameter. So, then people started collecting data, making a formula based on regression, when you talk about theoretical determination of maneuvering, it is all based on mostly regression type data, you know most of the companies, who are doing it have proprietary measured data.

So, they you do not know, what is there, what formula they are using probably, but these another set of formula there are more sets here, the important is that even here, there is T by L square that is the important parameter, it is T by L square into some corrections based on B by T, B by L, C b etcetera etcetera. See, there is no end of it, I just want to tell before I close this this part, because I want to discuss some special topics is like this.

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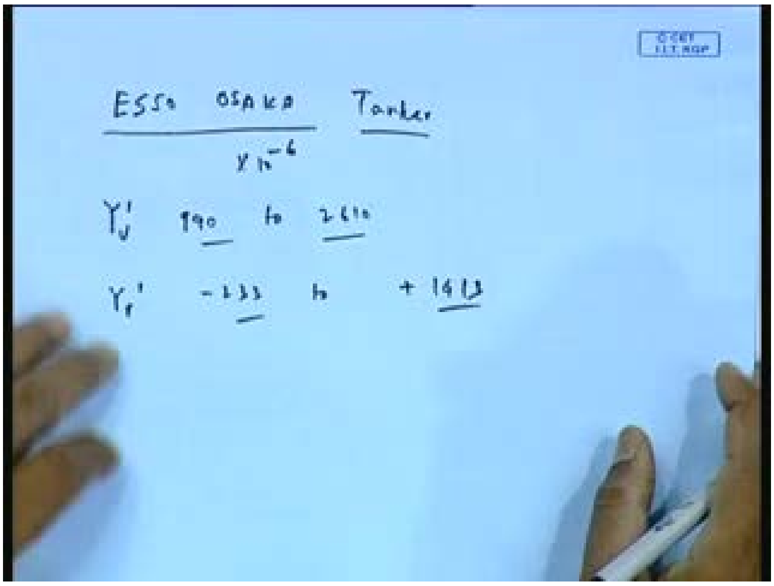

There was a famous famous case of a tanker called Esso Osaka, it is a tanker and in California bay at one time, extends the fill scale test of this tanker was carried out. I think it do not remember to time back, but quite some time back, may be 60’s, may be 70’s like that. As a part of a study many organizations were told, that you come up with theoretical estimates of coefficients and the trajectory, simulated trajectory.

So, there are 17 people who participated, I like to tell you the kind of data that the the the people brought in just two or three example and the model, remember that data is kind of a model, if you use non-linear model of type one you have corresponding data. But if you look at the data of say some of them, say Y v dot I just give an example, it is multiplied 10 power minus 6 this particular 1 or minus 5 may be, anyhow never mind this minus 6 or minus 5, minus 6 I think.

Organization see one like, this is organization it varies from 990 to 2610, this is only one quantity, but some other parameters, let me look at this Y r it varies between in this case minus 233 to well plus 14 13 what I am, this is a kind very wide variability, now look at the forces that I want to tell you this force part also, because of important to understand, see this are the kind of variability they have the people have got.

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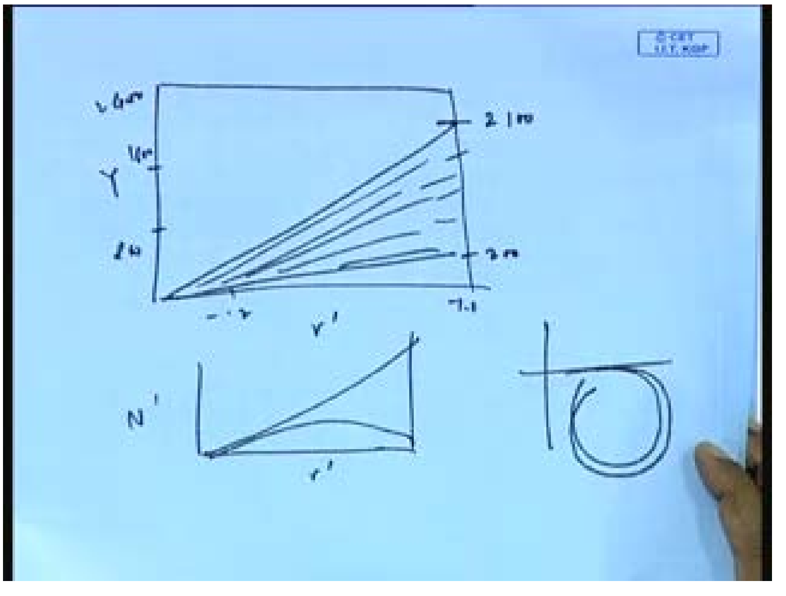

Now, never mind Y v, Y r because, the more important part is to look at this forces, see r verses for example Y, so the the if I have to look at some kind of a approximate scale this is 0.2 like minus 1.0 just to give you some idea 1600. And again we have to multiply them all with this thing, so this scattered become like that almost going at this 0.2 it is 2100 type coming all the way to here, may be this is only 200.

You know what I am saying, see the all these people get a light in between like that, look at that what does it tell me, such a wide variability in the added this coefficient, just see the the scatter another one, if I have to take N, this N part I mean, I just without writing I am trying to show this N part against r dash, N dash here, the result variation of like that, all the way to like this all these you know in between.

So, you know why I I have a purpose of telling you, this the purpose is that however however, now let me also tell you that, however when there is the trajectories are made, the trajectory may differ not that much as you might think, not as this much, because trajectory, so many forces coming together, so many other things interplay, but individual derivatives differ. So, therefore, when somebody tells you you know like in real life that ok, I got this derivative so much, please understand this business of derivatives is a represent of forces, and their can be wide very wide variability, so it is a it is still in my opinion lot of lot of developed knowledge necessary not just formulas.

You just cannot do it, I mean the I will always show this example of course, its quite old but, the only reason is to show that organization that, if you you can all read these paper its here in the (()) proceeding transaction 1993 I believe, very interesting paper. It it shows these results and the scattered of the in model, in coefficient values, in force, in everything, but the final result of trajectory is not that bad, usually I I will just briefly how you can actually get a trajectory simulation you know very quickly.

So, see what happens, this has to be kept in mind, when you talking of a doing a design when you have a you know derivative from formula number one remember, if you use formula number two you might have different state of derivatives. Derivative is something that only a characteristics in my my opinion or my suggestion is that, you should not look at the derivative per sec you should look at the force characteristic mode and a modeling of that.

Get rough idea, there is no nothing sacrosanct at the derivative value, but it is important otherwise, how do you study, so you must keep in mind, this is the reason why you know like somebody ask the question, why we do not have this you know like exercises, problems, the problem of problems are that, if I have to give a problem based on coefficient values, then you can just plug in the in the formula, you get some results.

But, the knowledge of maneuvering comes not in the in the numbers, but in that but more understanding the kind of physics the flow of physics, whether the flow should be more or less, how much the number you have estimated is it right order all this part, which comes slowly. You just cannot do it over night, that that is why giving a problem you can just plug in a, b, c etcetera, then you give a conclusion you know, and you may supposing a, b, c was very wrong as you have show the conclusion is completely opposite, anyhow so this you you keep that in mind.

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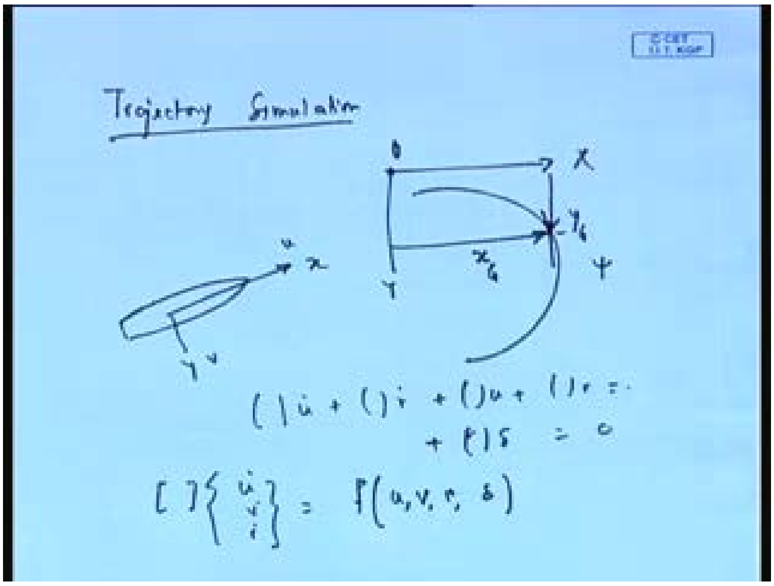

Now, briefly let me talk about something call this this say (()) having said that, let us talk of trajectory simulation, how do you know normally trajectory simulation, because what is happen is that, after you have got this coefficients you need to do a trajectory simulation right. Now, you think is that see here what we do in a trajectory this ship is going like that, I want to find out its, this is my x and Y, I want to find out its x location of G, Y location of G and of course, its orientation that is phi, that is psi, so I am looking at this three.

I am looking at the position with respect to a global coordinate system, then I am looking at its psi that is the heading angle, now I have written the equation of motion with respect to the body system remember, so according to that what I wrote, see I have a body system here, so according to body system I have this as x, this as Y, this as u, this as v. So, what I have got you know, if you remember I have an equation where something into u dot plus something into well r dot plus something into u plus something into r etcetera, plus something into delta that is rudder angle is 0 this how the equation look like right.

In other words, I can cast this to be something into acceleration u dot v dot r dot as function of u, v, r delta I can caste it this way you know one example, I could have given you quickly if I have to keep (()) quickly given yeah x, see here say Y.

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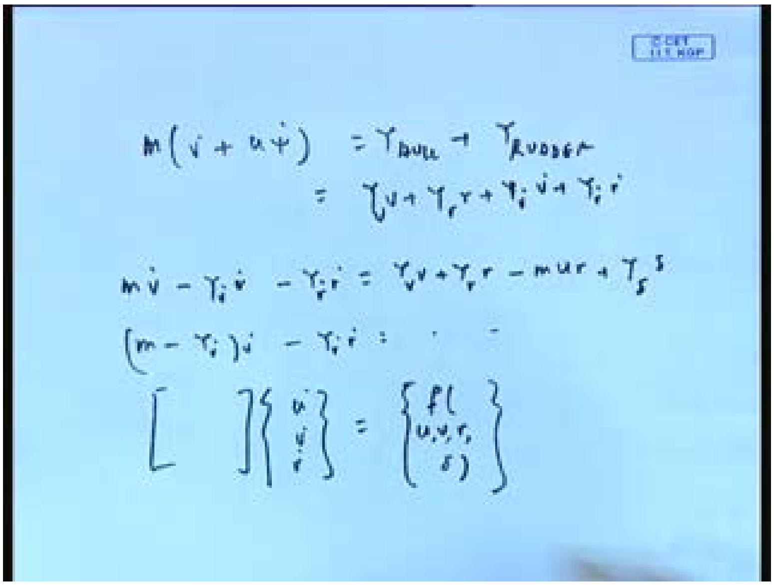

I have for example, m v dot plus u psi dot equal to Y, this is equal to Y v v plus Y r r plus Y v dot v dot plus Y r dot r dot, what I can do see, I can bring this v dot r dot this is, so I can see this m v dot minus Y v dot v dot minus Y r dot r dot actually this is r, this u this is u r equal to Y v v plus Y r r. See, this has been brought this side and brought this side minus m u r of course, I have to have also rudder plus Y delta delta that is the rudder angle you know this hull plus by rudder.

So, what I end up getting you see, m minus Y v dot v dot minus Y r dot r dot equal to this or acceleration terms are there, so this full thing can be written of course, as this side can be written on as function of u, v, r delta; so it is a first order linear differential equation, simple so how you can find out u, very simple.

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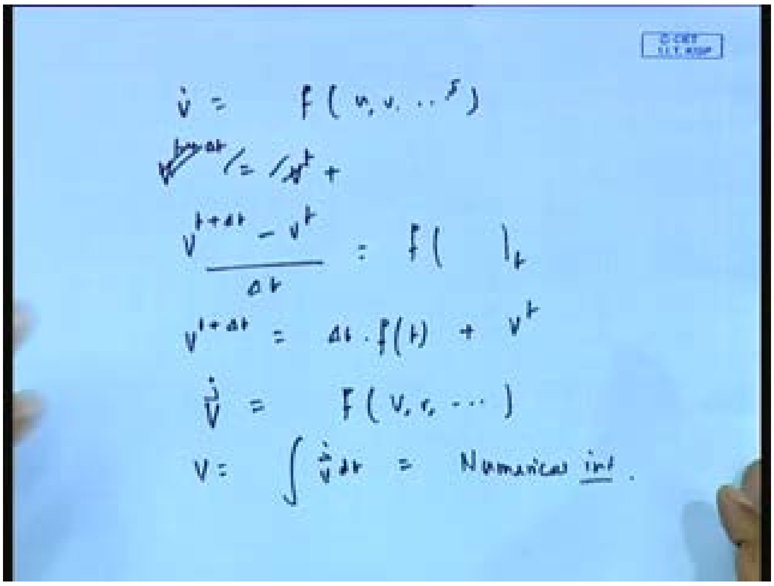

It is something like I have an equation like v dot equal to some function of u, v etcetera, so I I will estimate simply say T plus delta T using a numerical thing is V of t plus, basically what I will I will write in this way, you know let me write in this way, this one I estimate as V t plus delta T minus V of t by delta t equal to this values at time t.

So, therefore, V at t plus delta t becomes delta t into f at t plus V at t a what I am trying to say you know no going to this, but basically you are using a simple linear, simple numerical integration of this equations, because I can write this is integration of that, because what I have got a expression is a vector velocity equal to a function of v, r etcetera. Therefore, V is given by integration of v dot d t and this integration I do numerically, but this will give you u and v and psi, what about x remember I need to find out x I need to find out x Y, so the next step will be very simple, because I also write this this you know like coordinate system.

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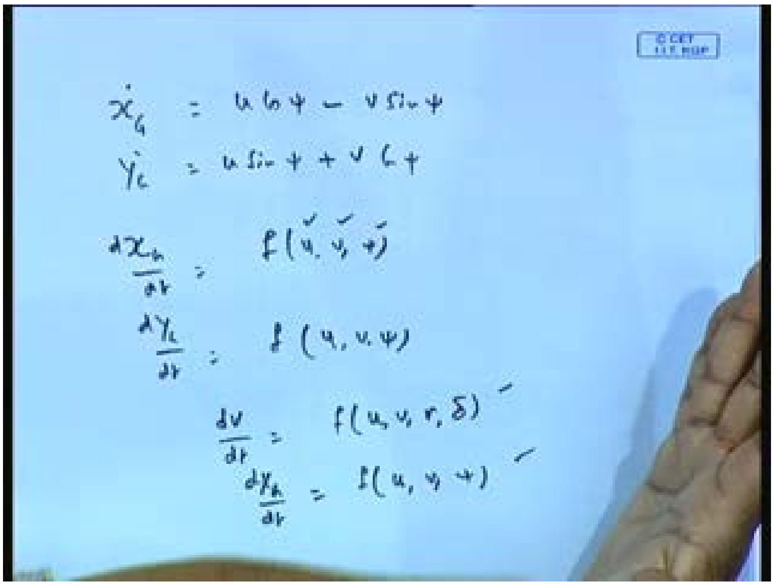

I know that (()) just 1 second, x G dot equal to u cos psi minus v sin psi and Y G dot equal to u plus v cos psi, so same thing, so ones I determine u, v then I can go to this to find out x G and Y G exactly what you find here D x G by d t is a function of u, v and psi d Y G by d t. So, what you do I have found out now, u and v and psi therefore, I apply to that and find out x G at T plus delta, that means what I am saying that two short thing, see Y have a set of equation look like that d v by d t equal to function of u, v, r delta then I have got d x G by d t function of u, v, psi.

So, I progressively integrate that twice to get this, it a very simple and that is how we do it, so I just want to show you that, now a day many of this software like mat lab and here and their etcetera. Many of this you know like its all embedded, you give a differential equation form, its after all these are all differential equation d x by d t is function of this d y by d t function of this it directly integrates (()) does it all the time.

So, really there is nothing much, but it is being done, but what is important of course, that you have to fit this correct values here, this will be all function of hydrodynamic derivatives, rudder derivatives you will start with the t 0 for example, the initiation is that at t 0 my delta is given some small angle, you know you just given a small angle.

We have to also understand that in the equation of motion, I have to for surge equation, I have to also thrust and resistance to be to be model properly etcetera etcetera, additional of things to be model properly, when you do that, we can end up getting a trajectory simulation, its very simple. So, this is only just very brief read you know like mentioning, I believe that you would only learn this when you actually do it and when you do it, you find it trivial, very easily do even.

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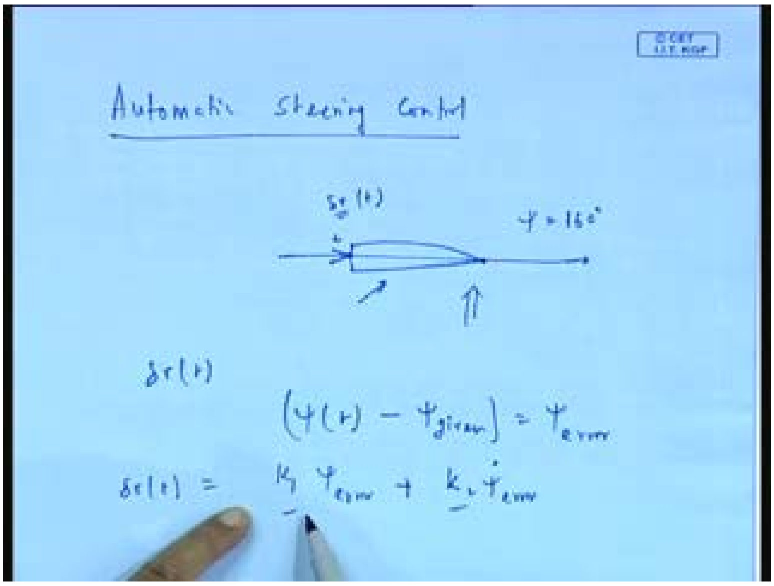

The the other thing that I want to talk about is, automatic steering control (No audio from 23:00 to 23:12), see now a days almost all ships would have an auto control at in place; now your idea is to go on a straight line mostly, now there are all winds and waves and all coming to deviate it. So, what you have to do is to keep on giving this delta r as a function of time continuously, so that it maintains a certain psi.

See, you are heading along this line say this psi equal you say just for example, say 160 degree with respect to some reference normally they will all measure with respect to true (()) you know all like you have 45 degrees etcetera etcetera, you want to go that, you are going to (()) have straight line.

Now of course, continuously there is a deviation and suppose a ship is unstable, then it will continuously try to deviate, so you need to continuously control this d r, so what we do I need to have a controller where I have to give this d r as a function of t automatically to make sure, the the heading is you know 0. What of course, is done is that it is a feedback loop no, there is a sensor that will measure, what is the exact psi t, with respect to what is psi t given.

So, I can call this to be psi error, depending on the psi error it will get feedback to this activator, it will automatically control the rudder, supposing it is going on this side and rudder will try to minimize on the other side. So, you know you can have a very simple control r rather I want to mension, it will be obviously function of this error, so you can have something like k 1 psi error with the k 1 can be some tuning factor you know you can choose it.

In other words, supposing it is going on say you know like right hand side you turn, the rudder to make it 0, but this is actually a very simple kind of concept I mention, but normally this never works. So, what happen you have to actually add a term called this, this is kind of of a when k 1, k 2 are what is called, you know you can say the gained functions or some coefficients are you are you understanding what I am saying here.

See, that when I have a ship moving in a desired direction, I want to make it go in a desired direction, I want to head straight, I have no control on the environment will disturbance that is coming, a large waves are coming beams are coming etcetera etcetera, so there is always a tendency for my ship to be deviating from the root.

Now, I cannot if you go to a boat builder he is continuously correcting this rudder right by hand like you would be continuously correcting a cycle trying to make a direction, but here of course, now a days the concept is pore auto controller you automatically set the controller; so that it automatically keep on in fact, I have seen myself on ship the rudder continuously dance small.

So, but the question is that, I must have a signal to the rudder, how much it should turn to correct the error, obviously I have to correct the error, so I have to turn it, I show this turn should be proportional to the error that is one thing. So, I can always this I can determine from simulation, this I can determine from many control I call become, control system is now become very sophisticated, this is what I showed here, that if I just kept normally what would happen you know, if I just keep that I I show it to you.

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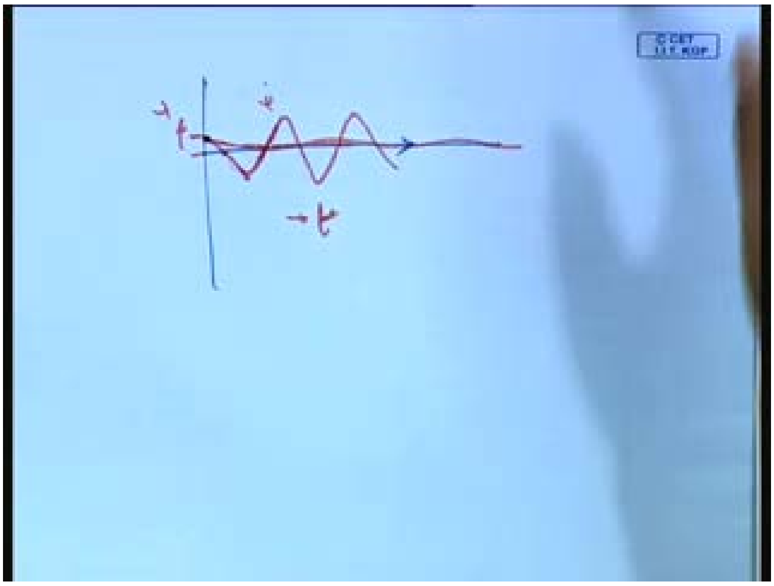

Normally what would happen suppose, I want to go to this is my heading angle say desired, I have gone to somewhere say at at some instant I am heading is somewhere here, this is my desired trajectory my heading is that, so I give that try to overshoot and then, I correct it go overshoot. Then try to, so basically it tends to have a like that, because what would happen see here lets say, I am having an error of plus 2 degree, so immediately I give a rudder on the other side. So, the rudder make it go on the other side, but then as I by the time I come here, I want to turn it, but it have overshot somewhere here, then again I turn it, so it tends to have some kind of a behavior.

So, what you what normal people will do that you have to add another term call like this another, you also want to make sure psi psi dot error is 0, remember you do not want to your another purpose is to make sure psi dot that d psi by d t, that is the rate of the error is 0. Because, naturally there should be no no velocity, because you see the rate amplitude is overshooting is psi dot, the rate amplitude is my psi curve its t, so you want to make it 0.

So, then one, actually as one more term like this, so this is what is call the typical p d controller, this is known as a proportional term, this is known as a derivative term you know this is this now, some people can have an integral term in a P I D controller, that is going to be something like that k 3 into psi d t, that the integral error should be 0. But, I am not putting that this is a typical P I D actually P D controller, why I mention this is because, automatic control of ship is now or auto controller is almost a universally applied phenomenon, to all ships. They do not use this they may use much more sophisticated control system, then just the P D controller P I D controller, because in P I D controller the problem is that one has to decide, the tuning factors and depend there is no unique solution you have to optimize it.

You know it is the question of how you approach that, and example is that in this case you could approach this way another another control controller fellow it goes much nicer, another person goes like that it depends on which one you want to choose etcetera etcetera. But, this is the basic concept regarding controlling heading there are similar controller in submerge body for depth etcetera, which is more important you know depth control.

So, this is now finally, I actually now in fact, now I brought (()) logic of depth control, I want to just mention briefly, very briefly and that is very interesting you will find, some typical aspects of a submarine control, a submarine behavior, submerged, but a behavior. As I said I will, because this is very interesting you know, I am in and this I I will, you you should pay little attention to this, let me bring this (()) my own writings here.

See how do I put that, we have talked all this while and this last 20 minutes of this class I want to talk about this two very interesting phenomena, which is contradictory to your intuitive thinking for a submarine behavior take a submerged body.

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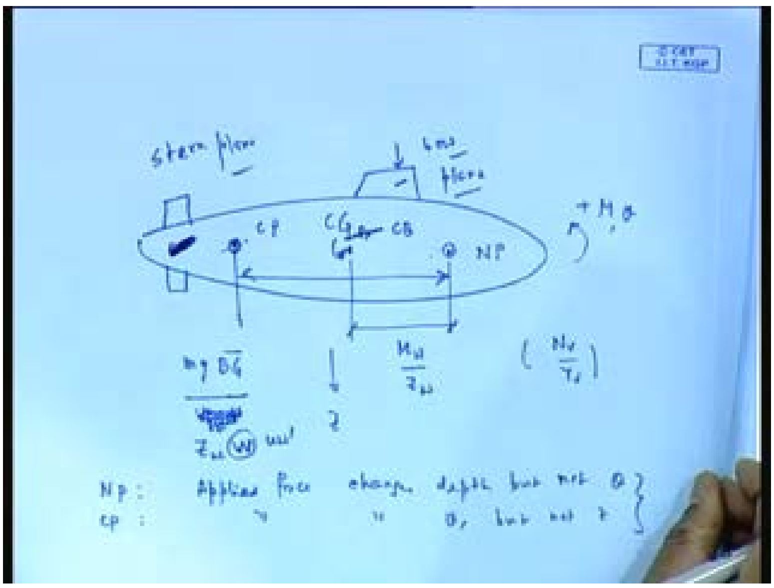

There is also fin here now in submarine you know, there are two point that is extremely important, there is a point call neutral point, this is my C G and this distance, let me first tell you this is given by M w by z w this is actually similar to N v by Y v in the case of. Because, here we are talking of you know like this is my z direction, remember and up is my, because x Y, so this is my plus M direction and plus theta pitching, this is the actually x z plane x z plane.

This point is called neutral the the most important thing is this this the critical point, this point is distance, this distance from neutral point is given by m g B G divided by V z w like that, actually V v into z w we can call, w into (No audio from 32:52 to 33:04) actually I will not I call it not that way, I am going to call this as call it like that, no no sorry.

See, let me let me put it this way (No audio 33:28 to 34:01), now we are in a point to discuss, see there is a submarine here, there is a center of gravity somewhere here, there is a call neutral which is same as what we said neutral point in for a ship. The distance of that neutral point from here is M w by z w, M there is the two coefficients, what is the neutral point, neutral point is point where if you apply a force here, it will change depth, but not trim angle.

If you actually apply a force here, that means suppose suppose here I will come back to this here, that supposing I have here a you know like control plane, suppose I have a control plane here, if I apply the control plane up and down it will change depth, but not theta, so it will just go up and down like that. So, if I were to put some kind of an fin here, at this neutral point a fin, some kind of a fin what would happen it will simply go up and down, but not change trim angle.

Now, critical point is a point, which is defined to be a point, where if I apply a force then it will change the trim angle, but not depth, so it turns out see what happens now, nownow here the is the question, this point is located at a distance of m g B G by z w w, actually z w w. In fact, here this this this W is u w dash you can call it, so the point is that see basically this bottom this this bottom is connected to the forward speed in fact, actually I we can yeah this is u w dash.

Now, the question is that see, as you go higher speed see what is B G, B G is the met centric height for a submarine, center of (()) gravity you know be be will be somewhere

here, C G is somewhere here. This is a C B, C G is this as you go high speed u becomes larger, this becomes smaller therefore, this shift but, when you got a low speed happen this c p keeps going aft. Now, is a interesting, see here supposing I have a stern plane located here, what would happen suppose my aft plane the one that I used for changing depth is located at this point, what would happen, if I were to give a stern plane angle I would change the trim angle, but I am not going to change depth, but my purpose of stern plane angle is to change depth.

Remember, what do I do with a stern plane, this is what is called stern plane angle, there is a, see rudder is here for turning a horizontal direction, you can say turning a vertical direction is basically your aft or stern plane, in a typical submarine there two planes you know this is call stern plane, this is call a bow plane.

Now, the point is that see, if this is aft of c p, so when I turn it to go down what would happen this applied force here, it see at at this there is no change in depth, but if you make it aft, one can show that if this point aft of this. Then there is a change in depth in one direction goes down, but if this becomes forward of c p, then it goes up I will show you this this diagrams, in critical diagram here very very nicely, see here (No audio from 38:23 to 38:32).

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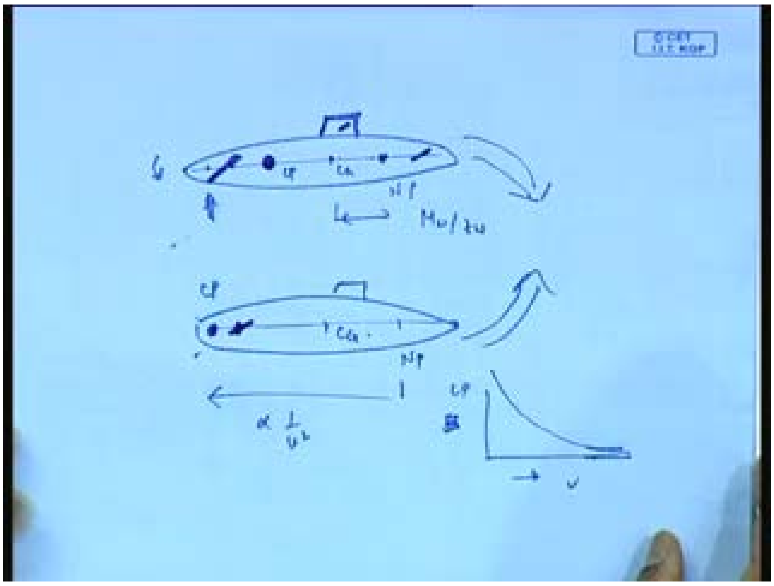

See here, I give delta is like that stern plane my c p is here, C G is here and neutral point is here, then this cause the vehicle to turn, but if (No audio from 38:48 to 38:57) c p is here, this would cause vehicle to go up. Now you see this the the the the point of interest here, this is just just realize this again my neutral point is fixed, given some mean neutral point is fixed because, neutral point distance we have seen that is M w by z w, but we have seen that this distance is actually given by, it is in inversely proportional to u square.

So, naturally what is happening at higher speed my c p is somewhere here, but as I go to lower speed my c p actually keep shifting back backbackback, now there is, now what is happening at c p itself, as I mentioned in earlier one. If I keep a stern plane and if I turn it it is essentially not changing depth only angle remember what happen, I will come to that again later, now you see here, if I were to keep it.

So, at high speed when I turn it say this way I turn it, stern plane it is call by you know like you are giving turn, so naturally force come this side and therefore, the ship turn downwards, but now let us say you are man and your dive depth is suppose to be like you know like you know bringing the stern plane down is dive. But, at lower speed, now you are going at three knots c p is turn out to be here, now I gave dive down vehicle begin to move up, this is what is called reversal phenomena, very interesting phenomena reversal phenomena.

That means, you cannot tell for stern plane that, if I give a down it will always go down at a very low speed, that means what is happening see there is a speed at which the c p has just exceeded this, so at the when c p has just come to the see, as long as c p is in front of that at high speed as I give dive it is just dived down. Now, I am slowing down it is still diving down, but a lower rate I come to a where I I basically give a angle, but it does not dive it is simply giving a trim angle, that is what we said know, that is that is a characteristic of the point, it is simply changing the trim angle, but not diving anymore.

Now, I go further slow the go beyond that, now I give a dive angle go opposite side goes up, so what is happening is that, if you give delta s versus you know like this you know a speed, critical speed will basically come down to be like that. Typically you know like a critical speed tell you this part just 1 second, need to tell you this, x by no, this is v and this is this is actually the location of the c p location.

As the speed goes up you know this this distance keeps shifting up, so why it is important you know is that in any submarine typically, it turns out typically it turns out that there is a critical speed, it is around three to four knots. And therefore, you should not go beyond that, because at those things become very very awkward that is one thing, second thing is that I tell you this other think connected with this.

Before that what about the bow plane, bow plane is either here or here, now typically what happen bow plane is in actually forward even neutral, it is in quite in forward side, normally, it is forward of neutral plane like if you go to, if you have gone to (()) any of you have gone to (()) and see there submarine you would see that, it has got a plane at the very front, but that is a very old design.

Now a days many of this planes are on the sail, see this is called a sail and instead of bow it used a sail, so it is not that much forward, it is somewhere here, so the thing the difference is here this is slightly back. But, the question is that c p is normally aft of this, for it to go actually forward of that, it will have to go at such a speed which is in practical, so normally never c p goes forward of the bow plane.

So, far as bow plane is concerned there is never reversal that is an important point, so bow plane we do not worry, but stern plane there is a big to worry, now the is which is more effective to bring it down, now we have seen this earlier also in a rudder.

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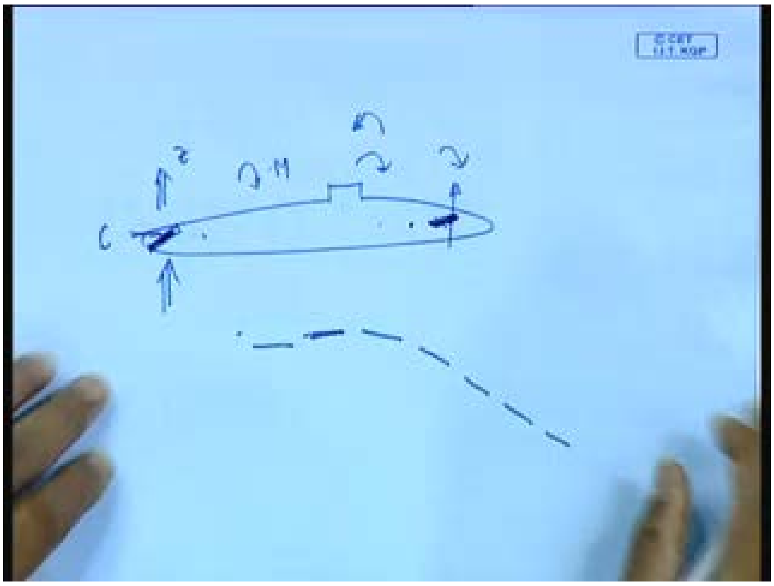

See, if I have this neutral here and rudder here this a leverage I get is much more, if I keep it further off see, if I keep it here number one is that, see if I had to bring it down this way what would happen, I get a force this side right, so I gave a moment this side of course, I get a moment this side only if it is assuming c p is somewhere here. So, there is a remember there is a there is an reversal this thing is trying to push it up, this angle is trying to push it down, so what may you may expect this go little up no, up then then come down.

So, the heave force is created here is trying to push it up z, but the pitch moment is trying to nose down it, so there is an reversal problem you know opposite, but if you take a bow plane here, so for bow plane number one, I am bringing it this way, now for bow plane supposing I want to come down say my bow plane is here somewhere here, what do I do.

Remember, that if I do this way, then I am getting a force here and moment there, what it trying to do, they are in the same direction, both of same direction up and nose up for for down opposite, so bow plane there is the heave force and pitch moment are in the same direction, so there is no control problem as such, but in the stern plane you have you want to go down but, essentially you are giving up force.

Upward force do you see that, see here you give an upward force here, but downward moment, so it actually it goes like that, but here you give upward force and upward moment goes like that, see there is a there is a see here, I given an upward force and upward moment, so it goes like that and here I give an upward force, but downward moment, so it tries to go down eventually like that.

So, the this is you know kind of phenomena one has to kind of then why do you keep it up, because obviously for a same small angle the leverage you get is more the same reason why, rudders are kept at the aft and of a ship, you get much higher leverage to you know kind of effectiveness to bring it down. So, normally in submarines is two planes are used for various purposes one is to maintain depth, sometime you know supposing here, you want to go down without a trim, just go down like that you can never do that with one plane.

Because, any one plane would always necessary produce theta and z, what you do you have to use both the planes, this will try to nose down and this will try to make sure that have adequate moment up to make sure, that it is in the same level up. So, you know that is why normally in submarines you have always two, submarines you have got two, now look at vehicles like torpedoes a u v other vehicles you do not have two, why you do not have two, because normally what happens see take a u v there is a sitting there. So, even if it goes down with 60 degree, you do not care, it can go down 60 degree, but in a submarine you have to control the trimming angle, you cannot go down order form 50 meter to 300 meter, at 40 degree nose dive, and then everybody is going to fall. So, therefore, you always have to control trim and that you do with this of course, there other controller you can design controller, where you can go down at that particular trim only that is all possible with only one also.

But, this is all like you know sort of a kind of what I should say this, the controllability issues why the bow bow fins are also use for simultaneously most of the time, see now the other thing I want to tell you for a submarine is that, in order for you to maintain a level depth.

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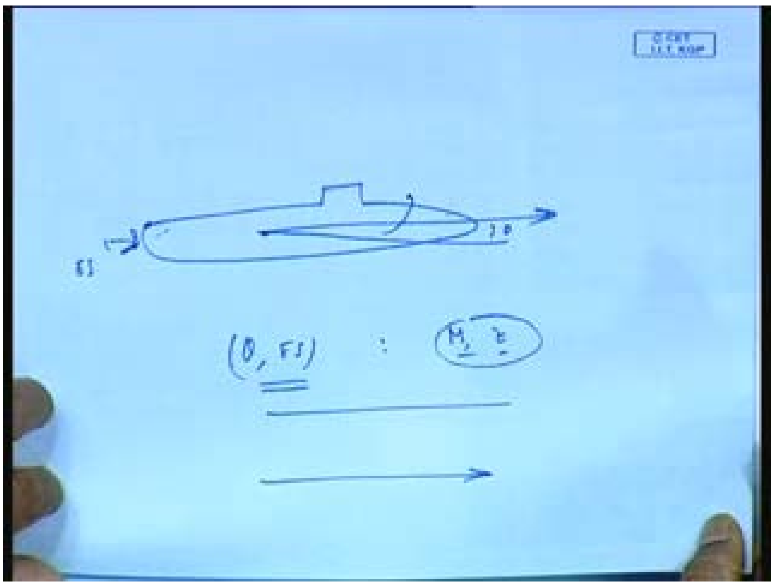

You want to go a straight line you will see that you can never achieve a straight line suppose I have no controller, it will always with a go up or go down why, because obviously one can tell there is no symmetry here, so there is am asymmetric moment that comes. Normally, it is designed to go up, so what you should do to maintain level depth this is called neutral angle, what you have to do tell me you have to make sure that, there is a small theta and small stern plane angle delta s, it turns out there is a this combination this combination necessary to maintain level depth, a stern plane angle and a corresponding trim angle. That means it cannot go straight line, it has to go with a small very half a degree trim angle with a small angle, this is my 0 setting, that means my 0 setting is not exactly 0, unlike in a ship in a ship my rudder is at 0, so the suppose I am in a calm water there is no disturbance, my my rudder is 0 I am going on a straight line.

But, for a submarine, if I want to go on a straight depth you know you can actually think it upside down like as if in a deep water going in the other direction, I want to maintain depth I want to go this water line and I want to go exactly this depth. I cannot achieve that without setting a small trim angle and a small stern plane angle that means there is a combination of theta delta is necessary to ensure that I have no M moment, no z force that is what I am looking at.

Now, there should be no turning moment, no z force and in order to get this 0, it turns out I have a setting of delta and theta s, and this is what is known as neural angle setting, neutral plane setting, and this again if you plot will turn out to be something like this typically. A neutral plane setting theta as you go to speed this is speed, it goes like that and may be small these are very small angle or rather may be say delta may go like that because depending on the way you tell.

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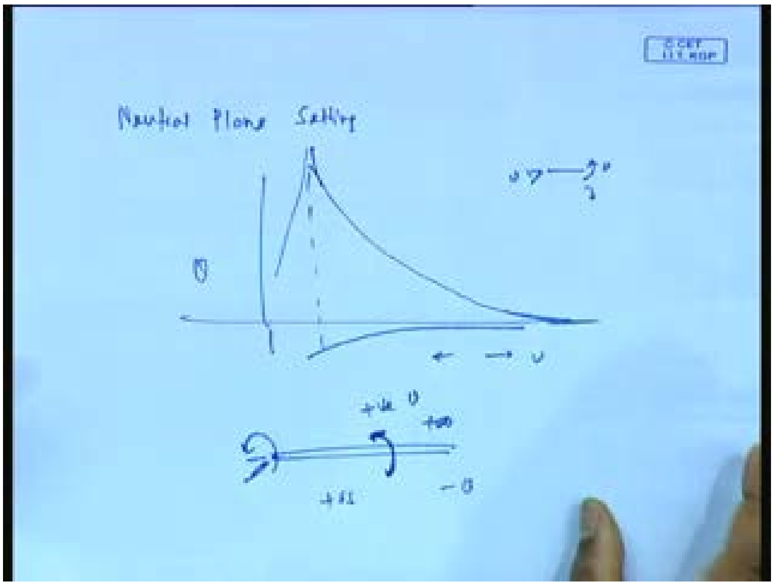

See, if you take this to be positive theta, then positive one gives you negative theta you know like that what I mean is that see here, if this is my turning this side is positive theta, now if I turn this stern plane no this is negative, this is positive. So, for nose up is positive I have to rather nose down, if I want to nose down for negative theta I need to give positive delta s, delta s is this one positive delta s. So, what I mean is that if I this is delta s rather may be call it theta, now the problem is here the the reversal I said at this it goes to singularity and then there is a reversal there actually at this no, I think I should draw another diagram to do this.

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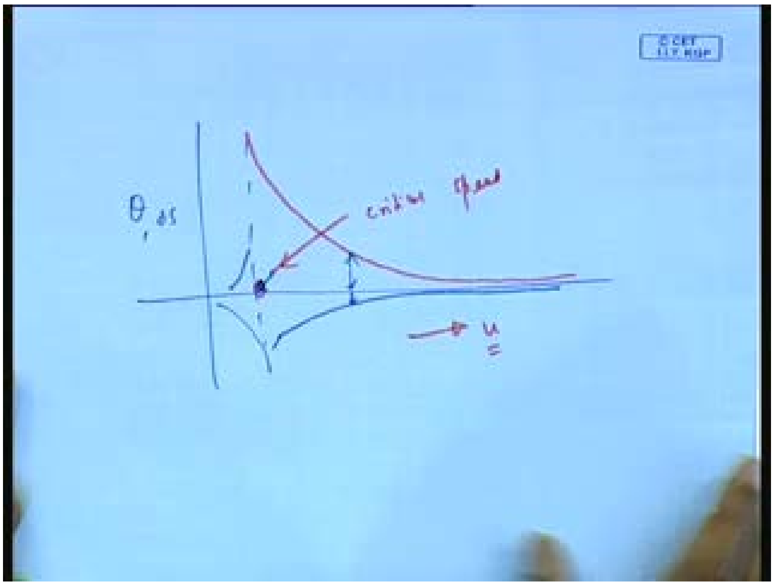

This is I just want to show you this say theta delta s, so let us look at theta theta will look like that, let us say and delta s may look, which means what it means, it means I must have this much of delta s and and this much of theta to maintain something like that, to maintain level level height.

Now, at this speed suddenly it changes to opposite direction, what is that this speed, this is that critical speed, the speed where the reversal happens at this things become actually singular type, very large rudder angle you need to do that. So, this this is this point is what is called, this is my critical speed anyhow, so I will just close it you know eventually I mean on the submarine part.

So, what we I I wanted to mention is certain (()) of this behavior, that in a in a submerged body hydrodynamics, the reason why this happens this reversal etcetera happens, if can you guess why it it should happen this reversal or this what is extra here, in this plane compare to in a horizontal plane manoeuvr. Horizontal plane manoeuvr there is nothing like a rudder angle, if I turn on the opposite side stable ship it will go in the opposite direction, see it is not there a t e, knots it goes, if I give star board rudder go star board and at at two knots it goes port it will never happen. But, in a submarine we are finding for stern plane it is happening, remember rudder is like a stern plane at the aft end of the hull, what is the difference, the main difference is you should notice there is an existence of the hydrostatic force, you are going to ask me there should be hydrostatic force in ship also, what is the answer of course, it is not in rudder, because in this plane where we are doing there is no hydrostatic restoring force, but here in this plane you have an hydrostatic restoring force.

So, it is a question of competition between hydrostatic force and the dynamic force, hydrostatic force does not depend on speed it remains same dynamic force depends on speed, so usually dynamic forces much more important than hydrostatic force when it goes on a speed, at a very low speed hydrostatic force dominate and that is where the reversal happen.

So, in a submarine you want dynamics to be dominant not hydrostatic, because after all it is you know like C G, C D is not much also anyhow, with that I am ending and this this is where we are formally ending the course, so I do not have time otherwise we would say that what we covered in maneuvering. Of course, is that basic equation, stability part then we talked about definite manoeuvrs, we talked about how to determine derivatives by experiments and then we talked about theoretically how we can you know and also rudder little bit of rudder. So, with that more or less it is just a small part of manoeuvring, and with that we are going to close this course here.