Performance of Marine Vehicles at Sea

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Lecture No. # 38

Ship Trials and Maneuvers – II

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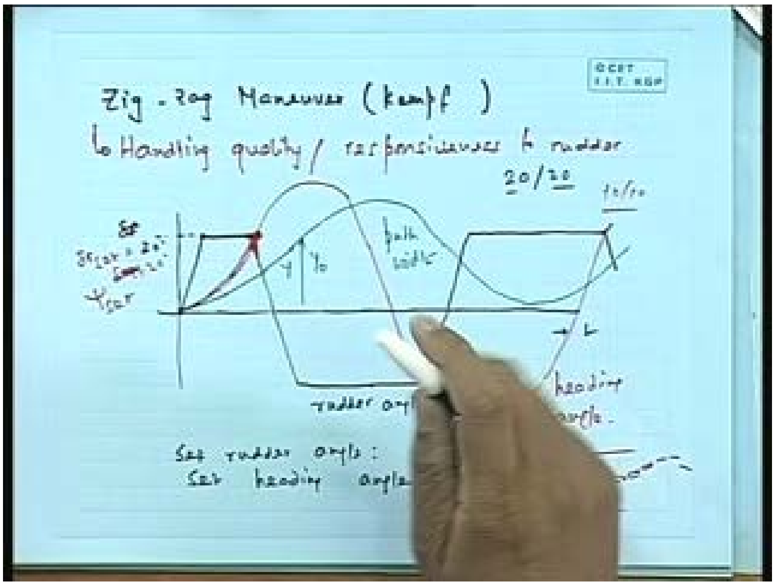

We will start; this part of the lecture also is continuing on ship trials and maneuvers; I will start again from where we ended in last class - zigzag maneuver; now, we understand the maneuver - what we do - we turn the rudder keep on swinging and you measure that; what do you measure? Here at these quantities - this is what I should write down; let me see these terms here or…

This point will be called, first execute; because, that is the time first time that you are executing the rudder - first time that you are actually… at the this time - this is t here, right? This is the point of time where you have made the first execute of rudder - you have given the rudder angle to be plus; this point - this time - is the time for second execute, similarly here - third execute, etcetera; the one two three executes are the time when you have…

Changed the rudder.

Changed the rudder angle.

Important thing that you find out is this - what is called overshoot your angle; how much it overshot - it may overshoot…. there can be a ship which can overshoot for this thing; these measures…this is my first overshoot, this is my second over shoot and like that third over shoot - you understand? Obviously, I had given rudder angle twenty degrees I would expect that the ship would reach twenty degrees or you know… sorry, rudder twenty and my set angle is twenty degreess.

As soon as I set my… heading has reached twenty degrees or that set angle at that time I have actually swung it back; it should have come back immediately - started to change - but it did not change, it started changing in the same direction for some more time and then came back; how much more time it has same… how much more angle it turned is my overshoot yaw angle; for the first execute - first one, second one - second one, like that.

Then, comes a question of time - this is called… I can also call this yaw overshoot; yaw - same thing - my yaw was at this point when I have my execute; say, at this point I change the rudder, my yaw - my ship - would have started to come back on the other side, but it did not; it started going in the same direction for some more time; so, this becomes my overshoot path width; how much it over shoots - think of a canal, if there this is a canal size it has come here and at that point I have given a rudder back; it should have come down, but instead of that it kept on going some more time - distance wise.

Always, overshoot is the maximum that it has reached from the time when the rudder has been reversed; because, we expect that… you know car and all rudder is reverse back they may instantly the ship would turn on the other side it does not happen for a ship; it keeps on going in the same direction for some more time - that is what is called over shoot; this is my first path with the over shoot; then also the question of time is coming; this is the time - this time is known as reach; then there are the time of period it is actually time from this to this - one swing to other; it has become complicated, but I will just show it to you by description - this can be called period.

Let me explain - not go into so much detail, because ultimately the over shoot angle is… what actually is the I M O requirement I will tell; understand that basically what you are measuring is…you keep on changing - turning - the rudder this way and that way; you find out that the moment I change the rudder, after how long - number one, the ships heading turns back and comes to zero; and how much more it kind of keeps over shooting in the same direction.

This over shoot tells me how much it will keep over shooting - heading angle as well as path width and what is the time taken; you will you will find out that if you… it is something like if you want to reduce this time - that means, it should very first turn you will see that the over shoot is more; it is like somebody squeezed this graph from this - like you have a body and you are pushing it.

So, it is either… normally you will find that it turns very fast or it goes like that - you can imagine that; if it responds very fast with rudder - I mean, the moment you give a rudder there is a force there, it would actually go down here and it will want to turn, but it is already gone so much it will go like that and then turn; typically, you will find that if rudder is very effective then overshoot goes up and the time comes down because it is turning very fast, but then you do not want see in reality - you may not want both together, because if overshoot is too much it might reach and the reach the bank.

You always want a kind of balance; that is why to say overshoot is… to say, rudder - huge rudder - I will keep, it immediately turns, but it may turn just hits and turn like that - you do not want it; I M O requirement will actually come up with various kinds of measures; I will tell you again from this diagram - you probably should write this down; reach will improve with rudder effectiveness, means this time - how fast it will come back, how fast it turns and the quickness of turn - obviously will be more if rudder is more effective; will be less if the ship is very stable directionally, because if it is stable directionally as in some book I read - it is like a dogmatic mule - it does not want to change it just wants to go along a straight line.

Therefore, it will take a long time to turn it back; this reach will be… this will come down and it will get stretched this side - the full thing will get stretched this side; yes, like… as if you are holding and stretching this graph; if the ship is directionally stable and rudder effectiveness is less; on the other hand if the ship is directionally less stable and rudder effectiveness is very high - then this gets squeezed back; it will over shoot more, but turn faster; this is what the general feeling is - I am not writing it down, but generally this is the case.

Also, there is a question of speed, obviously; you can expect that if it goes very fast it… over shoot will increase, normally; if the speed is more, it speeds up more so it over shoots more and reach etcetera also will decrease; if speed is fast, it will go up, but reach faster, because it is going fast.

There are all these kinds of qualitative analysis, but what IMO tells is specifically that it must…. some measures that I will mention later on; it says that, in this maneuver the overshoot should not be more than that or should not be less than that, etcetera; it only talks of the first two; you can… simulation you can do it for infinite…it will become a steady state, it will just become like a sine curve, but they will tell about to…. after all, no ship is going to zigzag ten times.

I want to go to this turning circle because we have a time constraint; turning circle is the most interesting and detailed…turning circle maneuver - by the name - is the most simple one; all he does is just steady the ship then give the rudder to some angle and sit quietly - do nothing; the ship will begin to turn on its own, that is all.

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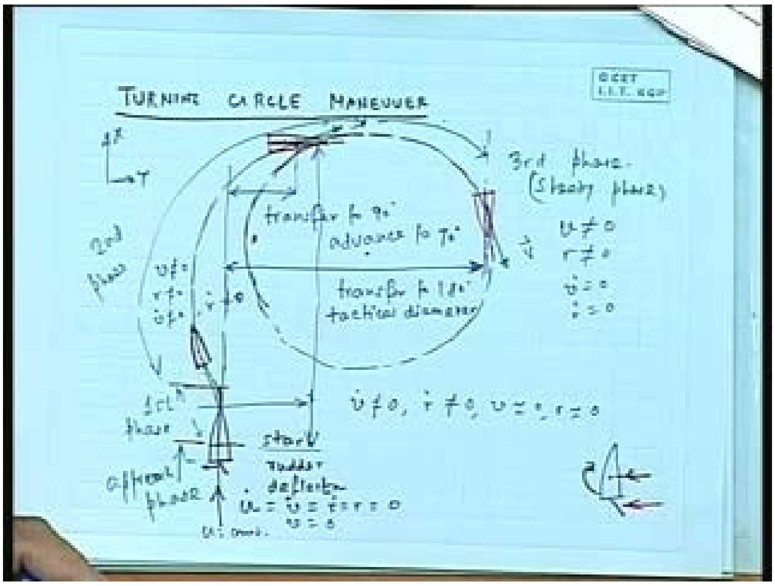

And he measures how much… how…. what circle it took; what you do is that you begin along a straight line; here you have a ship coming - at that time, let us say, you begin to give the rudder - start rudder deflection from here, say, from here; let us see, this was a starting point; the ship is coming steadily; at some point, obviously, it begins to give the rudder deflection - now, what would happen? The ship is basically going to go in a circle, but most ships will look like that - it will go some…this is very interesting actually; first of all, I have to show the path and then it will go like that; may be… I mean if you continue it will reach a steady state circle.

The ship is going to go initially, here; eventually, it will come to a point here; this ship should be drawn by another - probably craft - (No audio from 11:14 to 11:41) like that; what will happen is that you are measuring the ship part….as you give a give a rudder; normally it turns out that there is a…the path that it takes is that the ships slightly swings on this side - you have actually given a rudder in the, let us say, the star board side - that is this side; so, the ship is supposed to turn on this side.

You have given a rudder here - obviously, this way; that is going to turn the ship this side, because you can think of that… the… you know… you can think in a very simple way - water is flowing past this, in this direction; so, it pushes here such that the back side goes this side and comes like that - it simply turns this side.

Yes, that is interesting, of course - I probably…is an exaggeration, I will explain that - many interesting things happen; first of all I will tell you, that we can call this to be the various phases - second phase and third; we can call some phase - small part here - to be… then, up to some point - may be up to some point here - certain point here; then, say… I will explain what these phases are actually, before that can be called approach phase; what we are doing is - it is something like this - your approaching here and there you are giving this angle; as you give the angle here, it takes sometime - the ship basically turns like that; now, we have to…. what have you done? You have simply taken the plot of that - in other words, you have simply measured the location of the ship and its heading angle in instantaneously where it is located; it looks something like that and it will, of course, begin to turn if you keep the rudder steady.

Initially, as you give the…let me see, in the approach phase - let me put it this way - in the approach phase what is it that you have got? You have got your velocities - u dot and acceleration v dot - u and v are x and y and r dot as well as r are all zero, also v is zero; because, you are not accelerating you do not have any v dot, you do not have any r dot, you do not have any r and you do not have a v; because, all you have got is u - you only have u equal to constant - that is all we have got.

Now, there is a small part - what happens initially…. this is what we have shown here; there is a small part - what is called first phase - where initially what happens is that this ship begins to turn, but the velocity or….you have just given a rudder; there is…what happens? The rudder gives a force here and as a rudder gives a force here you see that there will be…if you give a rudder here, there is going to be a force here coming like that moment here coming like that. This is the interesting part - when you give a - I will show it here - when you give a rudder here this way, what happens is… this is the c g of the ship - I will get a force this side; this force is going to be equal to this force plus this moment or rather with a color if you draw it.

I am going to give… get a force here - rudder - I am going to get a force this side; this force is equivalent to…as if there is a force through the c g and a turning moment, all right?Yes, exactly. Initially, it always yaws because there is a push here, so what happens is….that part I will come to…this thing - why this swings here - what happens is that because of this force - initially, before it has a chance to change its heading angle this force is dominant initially; so, this things full thing has come slightly on this side; you notice that I give the rudder angle here, immediately there is a force coming this side - so, it first shifts this side then only it gets the turning angle; before it could change a turning heading here - before it could head the ship - it begins to turn here.

This force has caused it to shift this side; that is why it has a slight over shoot on this side for quite some ship; because, the rudder has caused a force on the other side; it is giving a force on this side and turning - this force is more; it has gone slightly this side, then it is going to turn - that is why it has shifted; we call a first phase to be one phase where the… as soon as you give a force - force is mass in to acceleration - you will end up getting some acceleration, but velocity may not have still developed, it is may be very small; there will be an initial phase and moment I give a rudder there is a force I am giving; the moment I give a force there must be an acceleration, because mass into acceleration equal to force; of course, you may say that, that will also give you velocity, but the velocity is still very small; that is why there is a phase where initially -

immediately there is an… acceleration is rate of….remember, that velocity may be small, but acceleration can be still very high because acceleration is rate of change of velocity.

I might have velocity zero to velocity zero point zero two, velocity zero point zero three, but at a short time these changes are occurring; I might have velocities small, but the acceleration high - this is what happened initially for a small time; in other words, the velocity has not yet shifted, actually it is still more or less along this line; it has not yet shifted, but there is an acceleration, in fact, the graph will move be like that; initially, for a while it does not shift; then, it begins to shift here.

Second phase is most complex phase - in second phase you have everything present there; you have got v not 0, r not 0, v dot not 0 and r dot not 0; you have got everything present in second phase; in second phase you have got all transit motion and now it begins to turn; there will be some point, therefore, where it will begin to turn steadily. So, third…what is meant by steady phase? This is called a steady phase or final phase; initially, what happens… will look at it this way - you are giving a force, it was… there was a zero force coming; suddenly, you give a force and as soon as you give a force it will first shift this side; force will introduce some motion - velocity and motion and eventually, because the force is not changing with time you must have zero acceleration; because, mass into acceleration is force, therefore if the force is now constant…after a while the force - you are not changing the force any more - therefore, acceleration must be zero.

In a steady phase, you will have necessarily no acceleration; you will only have v not equal to 0, r not equal to 0, but v dot must be 0 and r dot must be 0; when it reaches a steady phase - when it is going steadily - like a ship along a straight line course, you must have ultimately no acceleration, because acceleration implies you are changing velocity continuously; having acceleration implies having forces, but here the force has reached the balance - no more extra force on the system; like a ship, when it is moving steadily - please, remember - that the net force on the steadily moving ship is 0; t equal to r, r into whatever and the resistance and propulsion just balances the net x force is 0; t minus r is 0; if the t minus r was not 0 the ship would have been continuously accelerating.

Newton's equation says that mass into acceleration is force; if my ship is moving at ten meters per second - it is not changing, it is not having acceleration - which means there is no net x force; that is what is happening; eventually, this vessel will reach a steady turn - it will keep on turning steadily, which means it has got only velocities, but no acceleration; it has reached a velocity of…sway velocity of some meter per second and yaw velocity of some degree per second - it will keep on doing that.

This is my final phase - what we call…now, there is a point where the ship is actually changing its heading to ninety degrees - from the start point; this distance is called advance - this distance is from this reference point and this is called advance; let me still get this…. one second - the diagrams… little bit; some people call it advance for ninety degrees and this distance is called transfer - let me put it this way again, I am having this as my x axis and this is my y axis; along the direction let me call it x axis and this is y axis; that x distance from start point where the ships heading has just change ninety degrees is called advance.

x distance is always called advance and y distance always called transfer; there is a point where the ships heading has changed ninety degrees, because it has just…you are going this side and it has just changed ninety degrees; the x distance where this occurred you are going to call it advance and y distance where it occurred - from the original line - you call it transfer; same thing would, of course, occur to one eighty degrees - this is where it has changed to one eighty degrees - just opposite one eighty degrees; then, you will call, obviously here to here transfer at one eighty degrees.

This is actually called - some people call it tactical diameter or study… this is called… some people call it tactical diameter….this is actually…I will tell you… this distance; distance where heading has changed one eighty degrees - where it has changed ninety degrees is transferred; that is this line, where it has changed one eighty degrees - it is also transferred - to one eighty degrees, which is called tactical diameter for a ship.

And this….the….of course, when it was reached a steady turning radius then you have got the steady turning diameter; this distance - the diameter that is reached - this is my steady turning radius, you can call it r - steady turning radius; this distance is maximum transfer; I will tell you....because, we have to squeeze time where I am….

Sir it is maximum transfer and one eighty degrees transfer

No, almost, but not exactly same; I will explain it to you later on that this heading angle is absolutely necessary for a ship to turn; you cannot have a ship turning in this way - like this - it has to turn this way - it is a must; because, if you do not have, then the ship does not turn; there is a so called beta angle - that is, this angle, drift angle - speed vector is here, the heading is here this is my drift angle - beta drift angle; drift angle has to be non zero for a turn; if it is not non zero it cannot turn; it is not like a car that it can turn - it has to turn like a plane or something like this - there has to be a heading angle.

Suppose in the first part of the…

Here, it has not yet changed - there is a heading angle.

(( ))

Yes, little different; actually, I did not show it here because heading angle is…

It will be inward

Yes, it will be inward, it will always be inward here; actually, initially heading angle has not yet developed, because r 0 v 0; eventually, it will begin to develop - heading angle - and ultimately in the steady phase it will have a steady heading angle; in fact, heading angle is connected to v; you will find out that heading angle is actually v - beta equal to v - we will find it out; but, any how, first the measurements and then the other part.

See, what is happening is that, in the first phase as you know - in the approach…let us forget it; first phase we have got just the accelerations that have got set up, velocities have not yet set up and the ship has swung here, because yaw force is pushed it up here heading angle has not yet changed.

Second phase, you will have everything there and now the heading angles slightly begin to change - everything is there; so, there is a continuous change of heading angle up to this point; there will be a point where heading angle has become fixed, the accelerations have become fixed and the ship is just turning steadily; if you leave your rudder and you go to sleep it will keep on turning in a circle; of course, you are not changing the engine; remember, one thing is that once also measure the speeds; because, the upward speed u has changed here - because, of the angle here there is an extra x force that comes; speed also changes - the forward speed - u also changes.

But, of course, it will change and eventually that also will reach a steady state; all of them will reach a steady state, but initially there is a reaction of that; when you give a rudder, you are giving a extra drag force also; so, obviously, the speed also changes because you are not changing the engine setting - engine setting is fixed.

The distances along x axis are called advance and y axis are called transferred - there are two points to note, one is where the heading has changed ninety degrees and one where the heading has changed one eighty degrees; at ninety degrees heading angle you have transferred to ninety degrees - sorry - and advanced to ninety degrees; one eighty degrees heading angle you have got; you do not call advance anymore because advance is lower - here you need to know the advance because you need to know how much it has gone ahead before it turned; you want to know… suppose there is a wall where you are turning you need to know whether it can actually turn before a hitting the wall - you need to know the advance.

Suppose, there is something there and you have to turn; you give an execute here, you need to know how much it has gone maximum; the maximum is not measured, instead of that you measure this ninety degrees heading angle, where normally…; similarly, here when it changes to hundred eighty degrees you see how much it has shifted that side; essentially, you actually take this radius; ultimately, we will see the radius, but these are the measures you actually have.

You have that two point measurement - ninety degrees heading and one eighty degrees heading angle; so, x and y distance of that y distance of that; you measure the speed here and the speed here; you measure of course, this drift angle; finally, you measure the steady turning radius - that is the most important thing that you measure; of course, you also have record of time - at what t this occurred, what time it occurred; that time for heading of ninety degrees change, time for heading of one eighty degrees change and you if you want time for two seventy and all; but, normally people do not go beyond that, because this completes the u turn after that you do not want to keep turning in a real… there is no practical interest beyond that point; you actually do that only to find out the steady turning radius, but then you end the test.

No, you do not turn like that - there is no point; you might at best turn up to this and then go this side, but this is done because you want to know the steady…see, although you do only this much you want to know the radius - to know the radius here to make a full turn for the trial purpose.

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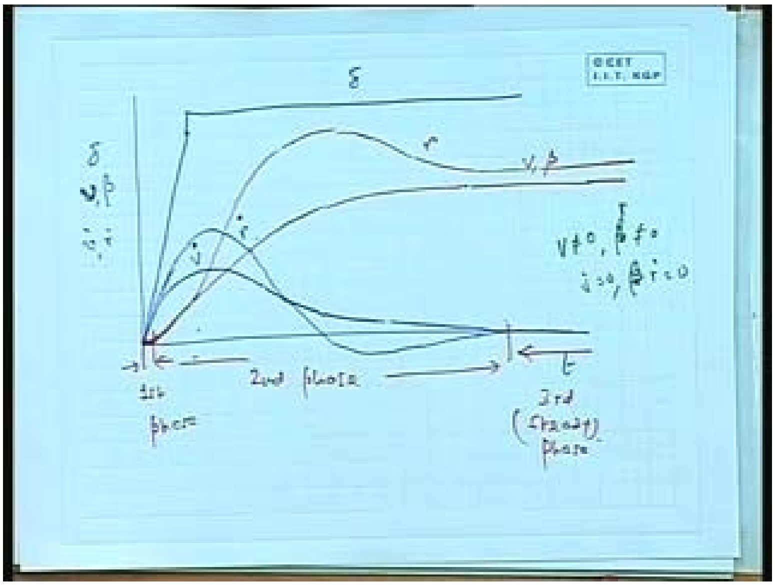

In real maneuver, you may not do it; having done that we will just draw a - do a - quick plot of these values of various things in first and second phase; we have got rudder angle here and you have got v here and drift angle; I will tell you that v and drift angle are actually same with the negative sign - this is small v; then you have got v dot and r dot these are all measured; now, rudder is given like this and rudder is kept fixed - this is my rudder and this is time; rudder is taken and kept fixed.

What happens to this v dot r dot? What would happen is that (No audio from 29:49 to 30:04) the acceleration initially will get set, eventually will come down and eventually will go to zero; similarly, r - r also is going to be something like that; it is actually plotted that way so I am going to plot this way; r may sometime come like that; whatever… it will also go to… this is my r dot; whatever…. it will basically have some value and go to zero; may be you can use other color - this is v and beta and we have got this - this is…this small part is first phase.

What I mean is that, the typical behavior will go like that….the…. as you turn the rudder initially there is….immediately, it will give acceleration v dot r dot, but the increase of v and r - that is velocities - are very less so, there is a small time when we call it first phase; it is not very important really first phase second phase, etcetera; final third phase is the most important one.

Then, everything will be present non zero, but eventually this acceleration will go down to zero and velocities and v and r will become constant; obviously, acceleration zero means v and r constant because d r by d t is r dot d v by d d t is r…this thing; so, when v and r has become steady - fixed, does not change with time - v dot and r dot become zero; at this point onwards you have got a steady turning; in fact, this is what you are measuring - if you remember, for a given rudder angle we wait in these earlier maneuvers till r s reaches steady state; basically, when r has this value I can say now that if I give rudder of so much angle my steady r is so much - that is what we have done earlier; if you recall, earlier, we have actually turn the rudder waited as long as we want till r has become a fixed number, which is this one; it does not change anymore; then, I have changed the rudder again - that is how I have proceeded; it becomes like this.

Now, what happens is that from this we can, of course, analyze the ships behavior and we will go through a little bit of maths - very less amount of maths - to tell you something regarding this phase; this phase is most important because this phase I have got v not 0 beta not 0, but v dot is 0 and v - no - r naught 0 and r dot equal to 0.

So, I can go the equation of motion and try to find out; because, it will be very simple since the equation of motion will have only v and r; there will be two equations - if you recall my earlier equation has something v plus something v dot plus something r plus something r dot equal to something; but, here I simply have something v plus something r is something, something v plus something r is something; I can solve for v and r very simply - I will not solve it, but I want to show you the solution part of this thing.

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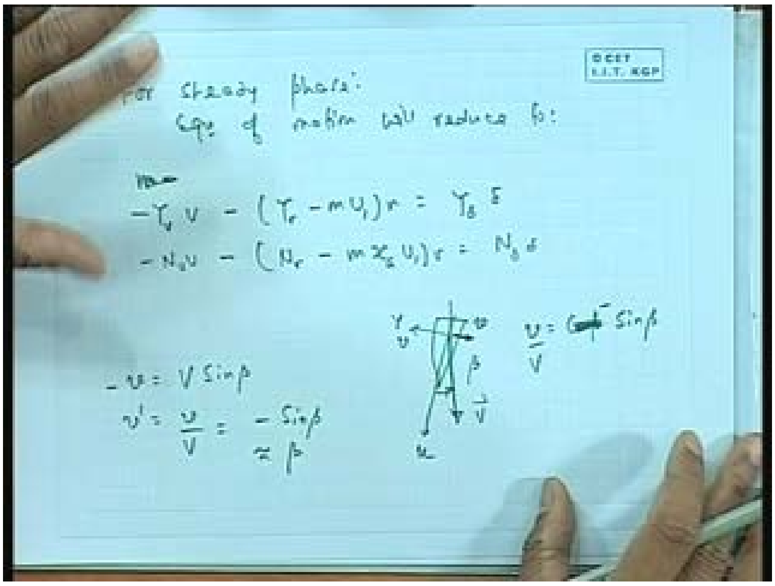

If you look back at our equation of motion….for it will reduce to - I will just write it from here (No audio from 34:08 to 34:30). Let us not get threatened with this equation; I have a reason for writing this equation - may be I will not bother about this; the reason for writing this equation is that…see here, if you went back to my earlier equation you will find that there was something into v plus something into v dot plus something r plus something r dot equal to this; I have got four things v v dot r r dot v v dot r r dot and I had a more complicated solution; but, this is very simple - this is something like a x plus b y equal to c, a 1 x plus b 1 y equal to c 1, a 2 x plus b 2 y will be c 2 - that is all; I have got two by two matrix and I can - without any thinking - solve for this v and r.

I can… I have just like that solved for this v and r, which I will show you without going to the solution - I will show you; but, before that I want to tell you that supposing there is a ship here - well this heading angle part; I have got here the ship normally going like this - this is my x axis, this is my v and this is my heading angle beta; this is my x axis this is my y axis; small v equal to…supposed to be the your cos beta - no, sorry, not per cos beta, sin beta with minus sign.

Let me explain that to you - what is happening is that this is my small v here; small v is supposed to be in this direction - ninety degrees to the….to this - no this is my u this is my v; actually, in this case what happens is that my v happens to be…if my beta is positive v happens to be big V into sin beta - see, my v is big V into sin beta with minus sign; why minus? Because, when beta is positive v is negative; I do not want to go to the detail part of it part, but my definition of v dash equal to v by V; therefore, it becomes minus sin beta; this becomes equal to beta, because beta is small; what happens is that drift angle is nothing but non dimensional save velocity.

Because, this diagram may not have been clear, but I…if this is my v axis - if this is my v axis, this is my u here - my small v is this one, because you can draw a rectangle; if this is my v here, then this is my small v and this is my u - the two reservations; this small v is nothing but v into sin beta; v is sin beta, but v is negative for positive beta, therefore it is like this; therefore, v dash is minus beta; why I am saying this is that when I make this…. there is only reason without mathematics; when I make it non dimensional, when I like it all this way - like make it all non dimensional; this non dimensional… actually this u will go away because this will become one this will become one.

I make it non dimensional; this is, of course, not necessary - this delta part; then what happens is v dash becomes equal to beta; what happens is that v have an equation in terms of beta and r rather than v and r; I have now got an equation - something into beta plus something into r dash equal to something; something into beta plus something into r dash equal to something because this is nothing but v dash - that is all I want to tell you.

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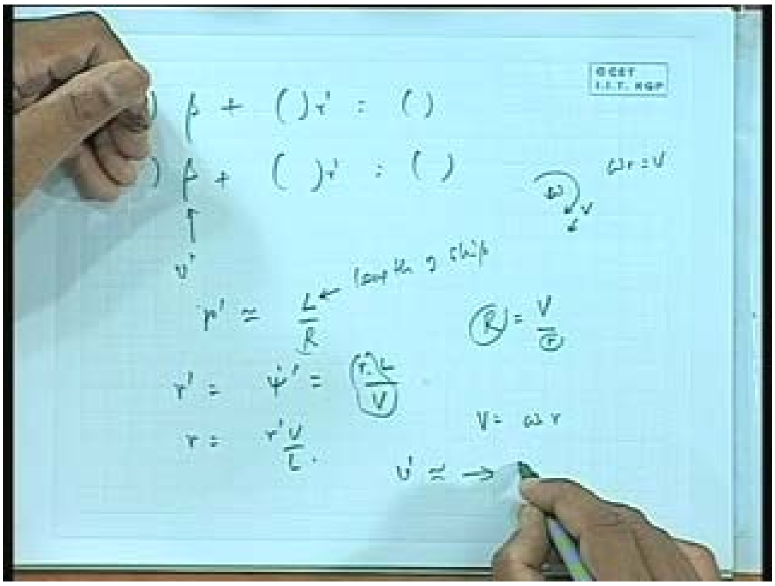

If you do that you will find out that…also, there is one more thing there - r dash, we can show is equal to l by r, if l is the length of the ship - I am not proving that…in fact, we can also prove that; r dash by definition is equal to psi dot dash is equal to r into l by v - that was my…if you look back at the non dimensional relation it was like this - I had r dash defined as r l by v; that means, r equals to r dash v by l; r by definition is v by r; the radius - steady turning radius - into by definition v equal to r into r.

This is…I do not know how to say that actually, it is something like v equal to omega into r - from this formula; you see omega equal to v by… if something is moving at a… there is a linear velocity is v and angular velocity is supposed to be omega, then omega r equal to v - that is the formula; if the rotational velocity is omega, radius is r then omega into r equal to v.

Here, my rotational velocity is r and radius is r, so r is v by r; this is only very simple algebra - all I want to tell you is that if you use this kind of thing you will find out that r dash, which is by definition r l by v - r l by v will turn out to be l by r; in other words, basically this r term comes in; this non dimensional yaw velocity is l by r; l is the length of the ship, r is turning radius.

If it is confusing to you, right now, my purpose of this - just this slide - was to tell you that as v dash can be written in terms of beta, similarly r dash - without derivation, let me tell you - r dash can be written in terms of capital R, which is the steady turning radius because; r dash is non dimensional heading yaw velocity which is velocity into l by v, because v and r are connected - these two are connected to each other through the radius r; therefore, r dash can be related to capital r- that is all I am trying to tell; because, the direct velocity - tangential velocity - and the rotational velocity are connected by the radius.

Tangential velocity is rotational velocity into the radius; all that I want to tell you is that v dash is connected to beta and r dash is connected to r; I can write this now as something into beta plus something into r; something into beta plus something into R is something so that I can solve for beta and r; two equations - two unknowns - I can solve for what is beta and what is R - that is as simple as that, there is nothing complicated.

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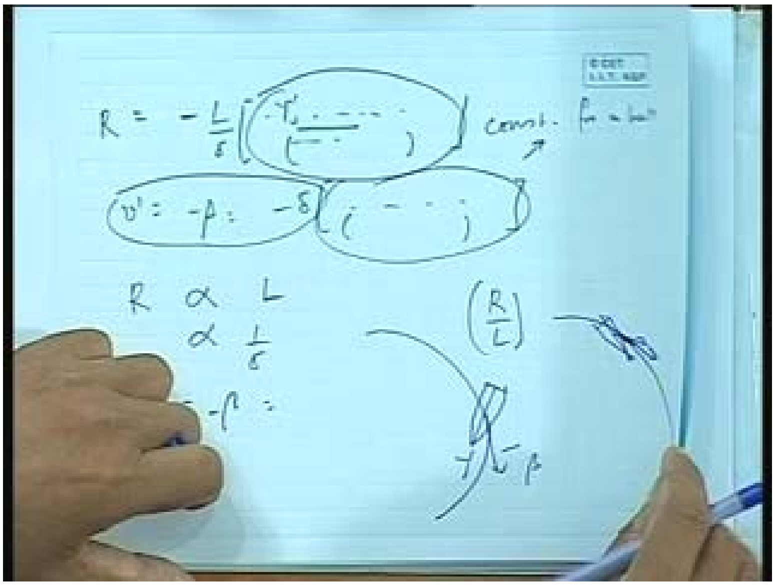

If you do that, you will find out that that R will become something like minus l by delta into - there is a term there - all this term will come in y dash v etcetera - like that it will come; and v dash, which is minus beta will come to minus delta into something - it will come like that; I am not proving that if you put that, but why I am trying to say is that you will basically find out that in one of this bottom part - in fact, let me see that from here… forget it.

We will find out that here there will be a part - I think that it is this bottom part that we will find out that one of them are related to the stability criteria; you will find out that if there is a stability there - this positive - then only this relation will hold; never mind this part, what is important is that R becomes minus l by delta into some term; let us look at this carefully and see what the physically the meaning is; this part is all a function of non dimensional derivative for the hull, so, there is a constant for a particular hull; similarly, this is a constant for a particular hull, because this term if you write down will be y dash v m dash g whatever, whatever, whatever - this is a for a hull

What does it show? That r, therefore, varies with respect to l and r varies with respect to one by delta, which means - number one, longer the ship larger the radius of (( )); that is why we actually have this as a criteria; you will find out that the IMO criteria is connected to R by l not R; also R is inversely proportional to delta, which means more the rudder angles smaller the radius of turn.

V dash equal to b minus beta is…if you see this part - v dash and delta are related; more delta….more v dash means more drift angle; in fact, without proving I can tell you from this sign - minus and plus - also one can tell you that the ship is always….if you give a port rudder it will turn on the other side; this basically means that if the ship is turning like that - if it is turning fast it is going to have a very large angle; the v is like that, this is the beta angle; and if beta… if you give rudder very strong then it will have very large this angle and turn.

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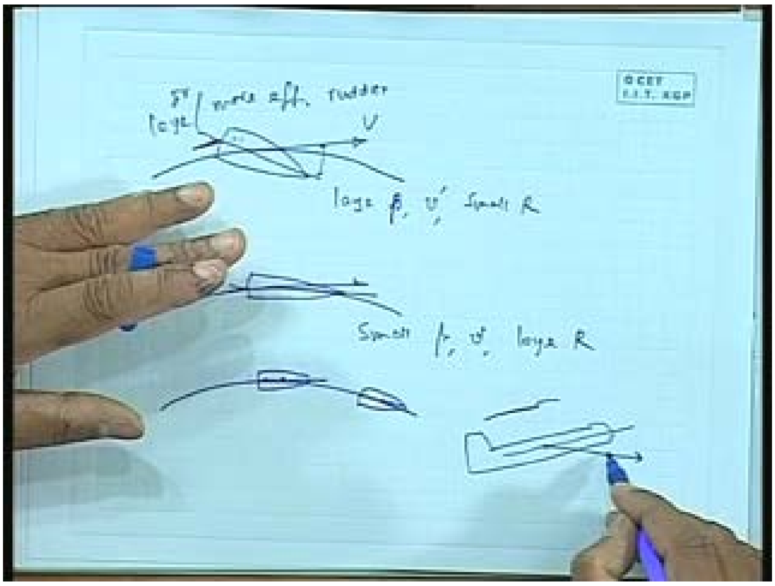

Rudder effectiveness is smaller then it will be like turning with a smaller angle - sorry, oh may be another one I will show; this is very interesting from the observation point of view that….let us see from this side turning - this is better may be for me to draw also; v here, ship is going to turn very fast; large beta and v v dash, large rudder or you can say large rudder angle .

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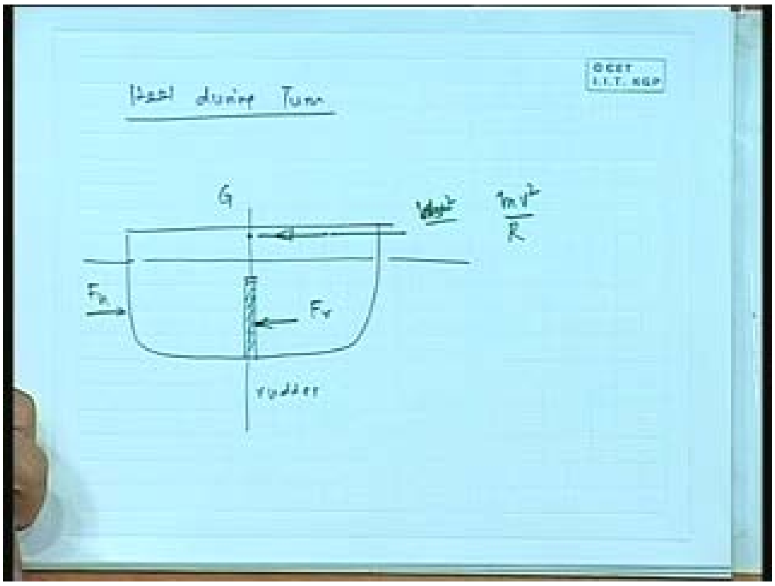

Small v dash b - if the rudder is turn small; that makes sense if…and small r; this small beta of v dash large r - this large or more effective rudder; large delta r or more effective rudder small delta r or less effective rudder; if the rudder is very effective it will turn fast - smaller radius, but of course, larger drift angle; and obviously, it will slow down more because there is a large angle you are giving; this is what is the typical characteristic, in fact, IMO requirement stipulates something connected to the turning ability, etcetera; this is essentially the part…we have to talk about IMO so I have to sort of - let me see if there is time there otherwise next class we will do.

This is very interesting - interesting from many points of view; because, first of all it tells you that you cannot have….if you look back at this equation, you cannot have in this relation…we will find out any R; in fact, we can we can prove that if you take r and delta - if there is no beta; beta is an essential part for turning - you have to have a beta for turn which means that you cannot have a ship turning which is actually following the same line - it cannot go like that; it simply cannot go like that, rather it has to have a drift angle; if it did not have a drift angle…you can do that, provided - as you do in a maneuver test - because you are holding by something and turning it.

On its own, by rudder it cannot turn if it does not have a drift angle which is not like a car; that means, when it is turning its x axis and the direction of velocity are not same;

this is the point which is not same in the in the case of a car or something; we are turning to that (( )) and the car follows that line - here it is not so.

In fact, aircraft also it is not so; it has to be…. when it comes down plane sometimes it comes down like that - there is an angle here, velocity is this side, but the x axis… like the plane is - I cannot draw the plane, because I do not know let me see; but, velocity is coming down like that and a plane is coming down slowly like that, but it has an angle; it comes down like this for example; this is an interesting observation - there is one thing that may be I have time to do - that is even more interesting; it is heal during turn - this part let us quickly… very elementary one I am going to tell here; say, there is a ship here and here you have got here a rudder; draw all this stuff - this has become like a tanker with a big thing; no rudder here, this is the rudder here.

A centre of gravity, say, g is here and it is turning on one side; as it turns, as you know… very quick time there; as you know, as it turns you have to have a centrifugal force here and this force is delta v square - delta is actually weight, in fact, I would like to write weight or what m v square by g? In fact, yes, m v square by r - m being the mass of it; this is a sort of this thing and you have here a rudder force f r, because it is….see, it is turning this side in this direction and a reaction for f h.

As it turns, rudder gives a force here; this is now here, basically we are looking at it this way; the ship is turning in this direction - I do not think I have time… this thing… you have given a rudder, so there is a rudder force here; this is my f r; as it turns here there is a centrifugal force - centrifugal fugal or pital - we have to see and there is a reaction force to the hull.

I think I am going to not have time for this, but we will start from here; but, what happens interestingly is that the interplay of this force will cause the ship to actually heal and it turns out that the ship heals on the outward direction, which we will discuss; in fact, there can be a problem on that that - how much it will heal during steady turning; and the most interesting part is that when you are turning outward direction and we will show later on that if then you suddenly bring the rudder to zero degree you are in very much danger to actually suddenly increase the heal and even capsize.

The ship is going to heal on this side as you are turning; some captain decides to bring the rudder to zero at that time - all of a suddenly; then it will actually at an instant it can actually be turn more - this we will discuss - how much it turns and why it turns little more; it is dangerous for the navigation person - you should not you know quickly turn the rudder to zero, you should do it slowly.

I will end it here; unfortunately this class time ran out, otherwise I would have finished it; but we will discuss that in the next class - this, as well as the IMO requirement and then follow with a rudder. Thank you.