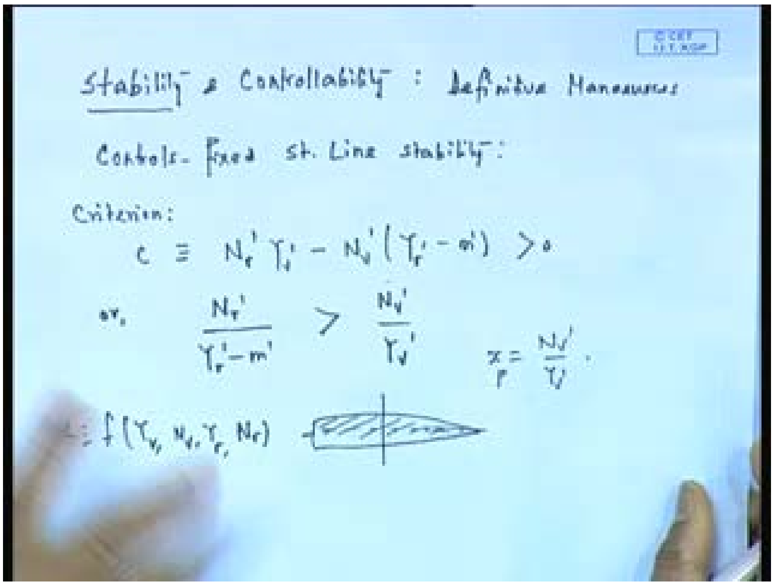
Seakeeping and Manoeuvring
Prof. Dr. Debabrata Sen
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Lecture No. # 28
Stability and Controllability: Definitive Manoeuvres

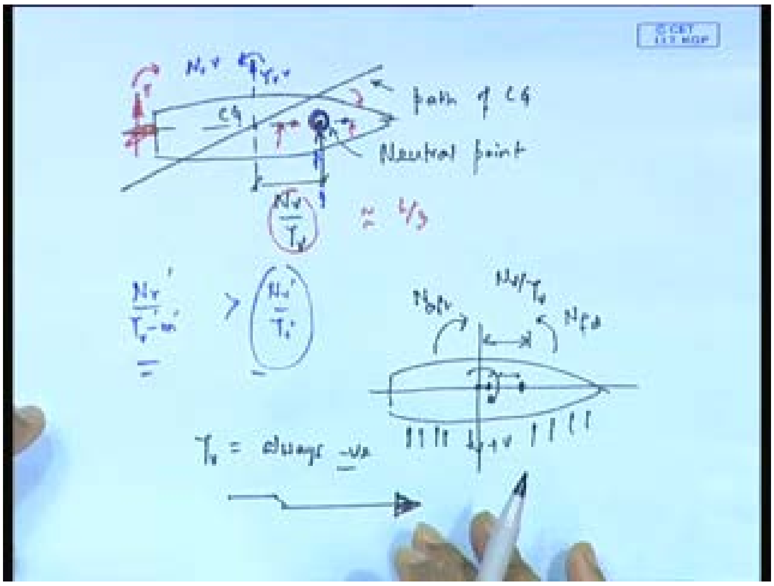
Today's lecture is termed as the….

(Refer Slide Time: 00:27)



Actually, although I am saying this, in the last class, we were talking about straight line stability and we derived a criteria. And, I will like to talk about that little more in this lecture at the first part of the lecture (Refer Slide Time: 01:05). This was the criterion that we established in the past lectures, which should be the property for a hull to possess, what is known as controlled-fixed straight line stability; which basically means that supposing I do not apply any rudder; rudder is fixed; then, this hull must produce forces in such a way that its force is characterized by this coefficients N r, Y r, N v, Y v, must satisfy this equation. In fact, we also went to say, which I will; that this – a distance x equal to N v dash by Y v dash is known as the distance of a neutral point or n p – x of n p – I will come to that. But, let us realize this first of all. What are these terms? These are hydrodynamic derivatives. What you find here is that the stability criteria therefore, depends on linear velocity derivatives; there is no acceleration derivatives involved; it is depending on Y r and N r. So, this is extremely important and we will do some kind of problem to tell the physical importance of that.

(Refer Slide Time: 03:49)



Now, let me look at this again once more this point little bit. This point – this distance N v by Y v is known as neutral point. What it means? That this I also explained in the last class that a force created here and a moment created here is equivalent to a force created here after all. A Y v created here into v and N v into v is same as a force of Y v v created here, because that force will obviously give you this much of moment; that is very simple. So, this point is known as neutral point actually. What it means? That here an interesting point that comes in. Now, what we have the criterion? We have the criteria is that N r by Y r minus m with a dash if you want must be N v by Y v dash. Now, this is the force acting purely out of v.

Suppose I have only v; means I have only a sway velocity; then, I have got a force acting (Refer Slide Time: 05:43) N v v and Y v v; which means I have a force acting here. So, you can also call this to be a point of action of the total force acting due to sway velocity due to v; whereas, this N r into r and Y r minus m dash into r would be the forces, etcetera acting, because of rotational motion – yaw velocity; r is yaw velocity. And, one can also find out this to be the distance of the point, where this net forces acting, because of pure yaw motion. What this tells me is that this point of action must be ahead of this point of action for stability; that is, the center of pressure… You can call this also… This can also be called center of pressure. After all, it is nothing but something like what you call resultant – the point of action of the resultant force. This is the point of action of the resultant force or pure sway; and, this will be the point of action of the resultant force from pure yaw. So, this one must be ahead of this one. That is what it says.

The interesting point here is that actually, this (Refer Slide Time: 07:02) point – why it is important? In many ways, is because if you actually apply a force here, there will be no change in the heading angle; the heading angle will not change if you apply a force here. Now, if you apply force after that – this side, after that – this side, then what would happen? The heading will change; the ship will turn this side. And, if you apply the force this side, then the ship will turn on that side. And actually, if you apply the force here, then the net moment that comes out, the balance will be this force into this distance. Why I am saying this is because that is the reason why rudders are actually kept with the aft, because if you keep the aft after rudder, if I put a force here, I get a large moment about this point. And therefore, effectiveness of rudder; if I put a kind of a port rudder – a starboard rudder or a port rudder whatever, it turns the starboard side, because here if I turn this side, force comes this way; if I turn the rudder this side, force comes this way. This force will cause, because this force must balance with this force.

At equilibrium position, the force and moment created by this (Refer Slide Time: 08:22) must balance with the force and moment created by this side, because the net force and moment should be 0. And obviously, here you end up getting a much more leverage of the point. That is one of the reasons why you actually have rudder at aft, which is more effective. Before that, I should say typically, for ship N v by Y v typically is approximately l by 3; approximately. So, it is normally forward. Then, you get more rudder (( ))

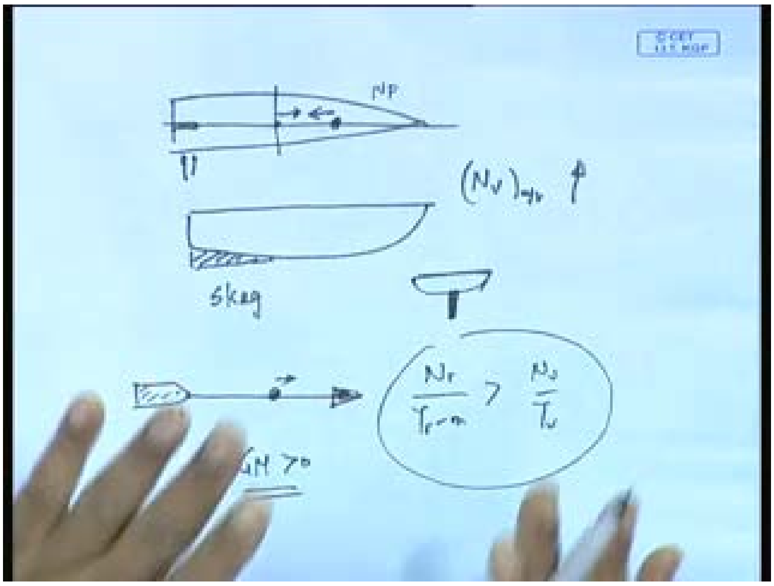
Now, I will tell you an interesting story. Suppose I want to make the ship more stable; what I should do? Suppose this point happens to be aft somewhere (Refer Slide Time: 09:06) here; then what happen? If I want to make it, then the ship is unstable. Suppose this particular location is somewhere here; this is not satisfied; which means this location is somewhere here. How should I make it stable? By bringing this point back. Say if I bring this point back here, how do I do it? I normally do that by… I will come to this by… Y v is always negative remember; N v here of course, is also negative in this diagram. So, I should make N v less negative probably going towards positive. Remember, if N v was positive, this point would go actually aft.

But, now, that means if I want stability, I should bring this (Refer Slide Time: 09:48) point back. But, if I make this back, the rudder effectiveness is reduced. That also makes sense. If a ship, which is very stable, we will not want to turn. That makes sense. I am only trying to tell you from a physical point of view, because it is important for understanding point. If I were to bring it back, if I were to bring the neutral point backwards, that would cause more stability; more stability – I am using a relative term. And, if I were to do that, then the effectiveness of the rudder to turn reduces; that means, controllability and stability has kind of like opposite side. If you make it very stable, it does not want to turn; you want to go on a straight line. So, we will see later on that for design, we have to have a balance; it should be stable, but not too much stable; too much stable means it does not want to turn. And, this is evident from there.

Now, I come to another point here regarding this stability point again looking at that. I will draw it here again another diagram, so it will be easier. Now, we have said this; this (Refer Slide Time: 11:05) distance is N v by Y v. Now, Y v is always negative, remember. N v – we said can be positive or negative; of course, for typical ships, what we are finding out? It is negative; otherwise, it would not be forwarded. Now, if I bring the CG… Now, what is N v? If you recall, in our previous classes, you will find out if stern is dominating, effect of stern is more, then N v becomes positive; if stern side was… Actually, what is happening, if I were to give like a… Very quickly, this is plus v, if I were to give a velocity this side. Then, the fluid force is acting on this side, because I am trying to push that hull. So, the fluid will act. So, this gives me a moment this side; this gives me a moment this side. So, if this one is more than that one… I can call this to be N aft and N forward.

If this was more than (Refer Slide Time: 12:08) that, I end up getting a net positive N; whereas, if this is more than that, I end up getting net negative n; which means if stern was dominating, you make it bigger and bigger, then of course, it will tend to become of course, more positive N. But, in reality, what is happening? We are finding out here that N v is negative by some amount. So, if I now shift the CG forward, what I am doing? I am basically making the aft more important; that means, I am basically reducing this distance obviously or bringing this neutral point aft – towards aft; that means, I am trying to make it more stable. So, one of the things to make hull direction straight line stability is to bring the CG forward. That is of course why you may find you have mass here; you have a feather here; mass here; let us say the mass part here.

(Refer Slide Time: 13:20)

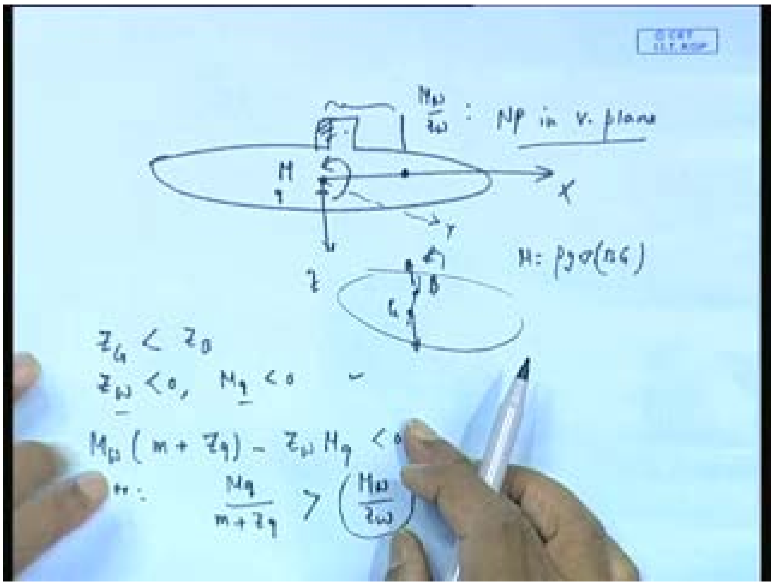


Now, I want to do another alternative. I put some kind of a fixed structure here; that means, if I were to look at a ship… Maybe I should draw another diagram here. These typical ships will have… If I put a skeg – it is called skeg; or, simply you put some vertical plates, let us say. Skeg is in small boats, you will find that between this hull if you take a cross section – that there is a cross section here with a bar here; in a sail boat and all, you will find that; that center plane skeg one part goes flat, surface goes… It is called skeg, which is essentially like the feather. What I am doing? I am making aft more dominating because there more fluid forces can act on that. If I am adding, additionally, a more force will act on that. What it means? N v aft – I am increasing. What it means? The center of neutral point – I am moving towards this side; that means, the N v, which was negative, I am making it less negative; maybe going towards the positive; that means, neutral point I am shifting backward. So, this is explained to you why for a arrow to be directionally stable, I have weight forward, which has caused the center of gravity move forward; and, I put a feather aft, which is like a skeg, the aft side from the fluid dynamics resistance, becomes more dominating. This is what kind of explains that fact.

This is very important, because ultimately what is happening therefore, I am giving a physical explanation on right. But, what is happening? We have ended up getting… Again, if I write (Refer Slide Time: 15:18) N r by Y r minus m more than N v by Y v… So, we will be doing little later some problems. We have to actually estimate these numbers and see just like the GM must be more than 0 – the criterion for static stability. Similarly, this is the criterion that I should have. But, here I have a problem; there it is also in a sense analogical. If you make GM very high, then it becomes uncomfortable, because there is stiffness. If you make this very high, it becomes very stiff and does not want to turn; it is like a dogmatic kind of… Like somebody wants be on a straight line only; does not want to turn; not good. So, the controllability becomes less. So, these two are opposing sides – stability and controllability. So, what happens in a design, we will actually require this to be satisfied, but just satisfied.

In fact, in some designs, this need not be even satisfied, because all these studies with controls fixed – means no rudder action. It is possible to design a ship, where you want a very quick turn. For example, if a petrol vessel has to turn very fast, which is deliberately designed to have negative stability, because it becomes very fast turn; but, it should be able to be turned with a rudder action. I mentioned this last class with respect to a cycle; that if it is like kind of when you try to ride it with your hands off like (Refer Slide Time: 16:53) this thing, the stability is not there; it tend to fall; but then, those can be very easily quickly turned. But, the one that is very steady, it takes more force to turn. Exactly, the analogy is very similar here. So, this is the stability part.

(Refer Slide Time: 17:16)

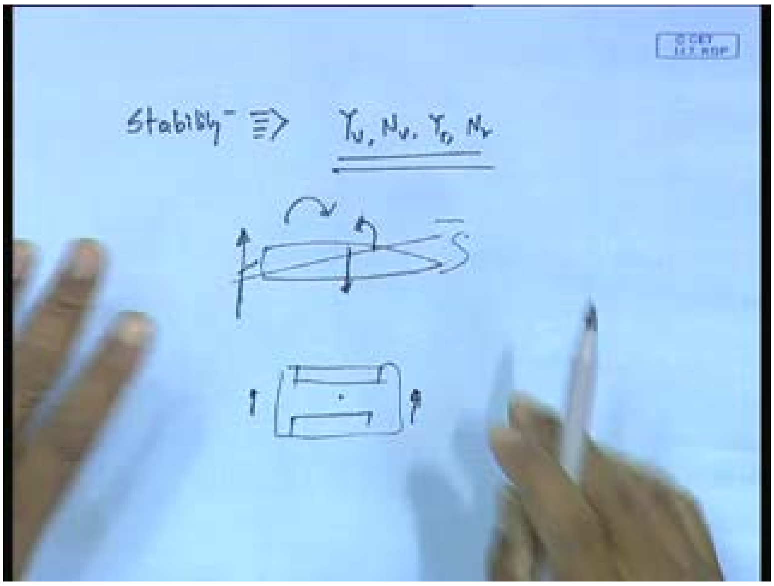


Now, let me just mention little bit before I go this problem and then the next part is that in a submarine, in a submerged body, where the planes are now X and remember this I call it Z; and, this is Y; and, I think this side is M – that is positive aft; and q. There is also a criterion in the vertical plane of stability. Remember, this is the vertical plane; this plane is vertical – water depth. So, we need what? In a ship, we have talked about is a stability in the horizontal plane. For submerged body, I have to talk stability in the horizontal plane, which will be exactly same, but also in the vertical plane. Obviously, in the vertical plane as it goes vertically moving up, it (( )) go deep and then become a straight line. So, you have to talk about stability in the vertical plane also.

Then, the similar criterion comes out. But, in (Refer Slide Time: 18:20) here, there is only one difference; I will only very generically say is that in this case, an additional force will act even with the control not there, which is hydrostatic force, because here remember, that there is the CG and CB. As you know, CG must be below CB. And therefore, as it turns… If it turns for example, there will be hydrostatic force. If this is turned here, that center of gravity force will come, buoyancy force will come; this is B; this is G. Suppose a vessel is turned like that, it will have a turning moment rho gv g mt or g m z or v g. Now, you will have a turning moment of M – rho gv into B to G. That is now BG – center of gravity. So, what happened, why I am saying this? Because the criterion comes out to be similar, but there is an additional criterion comes in. I just mentioned this that the criterion comes out to be 3 – Z G more than Z B. In fact, this is by… Remember, this is positive Z. This says that G should be below B. That is obvious. You have studied this in statics; it has only two orientations: either this or just opposite. So, if G was not below B, then G will be below B by just turning upside down; turning turtle so-called.

The other one is that Z w less than 0 and (Refer Slide Time: 19:47) M q less than 0. This is of course, a criterion that is always satisfied, because that I have discussed that in the previous class diagonal terms always are negative, because if you give a W here, Z will be opposite. If you give a q this side, M will be opposite always. Like if you give a positive q, it will give to negative M; if you give a positive w, it will give a negative M. But, the important one is this one; that is, equivalent to one that we have mentioned; or, this is same as saying this is less than 0 here; means this minus that is more than 0. This (( )) And, this term is again the same neutral point in vertical plane. What I am saying that there is a similar criterion that comes. This is actually known as high speed criterion, because this applies only at a higher speed below a minimum speed for vertical plane. And, only thing you will find that the difference was there; it was Y r. M w is equal to N v, because M is N; w is v if you say analogy. Only thing is, there the sign comes minus; that is because here you will see X to Z – this side is plus M; and, there X to Y – this side will be plus N. In the other this (Refer Slide Time: 21:21) thing, X, this is Y horizontal plane and this is plus N. That is why the sign becomes minus; that is the only difference. We will discuss about this some other time, but I thought in the same line, let me also show you the form of the equation. So, what we find out is importantly…

(Refer Slide Time: 21:46)

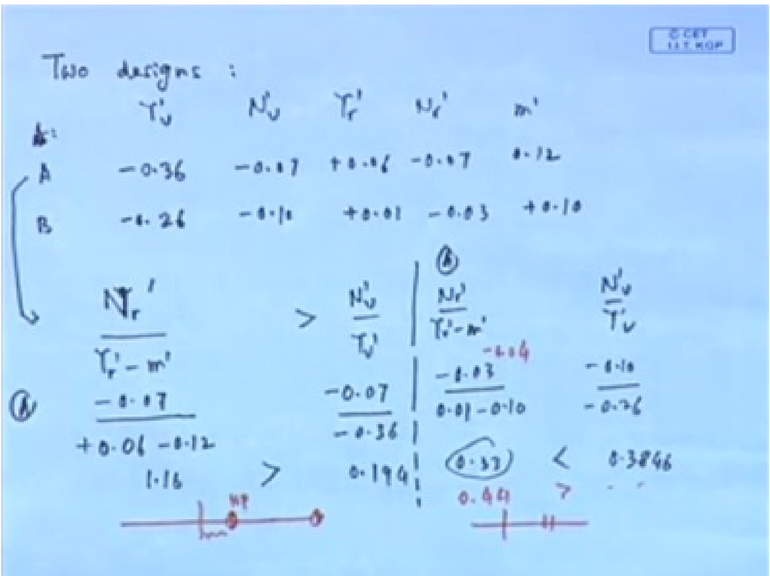


And, we will discuss that linear stability depends on hydrodynamic derivatives without the control and we will definitely have to therefore, discuss how do I find it out, how do I determine them, etcetera; that means, these characterizes the hull behavior. The important point for us to recognize is that maneuvering is necessarily – which I said repeatedly and I will repeat again – balance of hydrodynamic forces acting on the hull and the control surface; control surface rather gives a moment. This will turn, but when it is turning steadily, the net force and net moment must remain balanced; otherwise, there will be acceleration continuously. So, the net force should be 0; net moment should be 0. So, I have one force coming here.

Obviously, I must have force coming from the hull. How the force does come from the hull? Because it was turned and because of the flow coming on that. So, it is very complex. And, these forces are what I have represented by means of hydrodynamic derivatives. What are the forces? And, this balance must be achieved depending on the geometry. Why I am saying is that you have seen that when this blocky kind of shapes are there, that I remember of these tests for these models. Here there is very less controllability no matter what you are doing, because when you turn the hull forces are, it is behaving very erratically, because you really do not know what is happening. So, it is hit and trial kind of situation, because when you get a blocky kind of body, you are trying to turn.

Yes, there is a turning moment from (Refer Slide Time: 23:43) external sources, but the hull forces that must balance must be adequate balance there, because suppose I give a very large force here and enough hull force not get created, it will simply keep turning like that, because there is nothing to balance it. So, you have no controllability. You may just go somewhere here, there, etcetera. So, if you have to study controllability and maneuvered, we have to necessarily have an understanding of this the forces that get created. And, we are always thinking many times erroneously that it is the rudder force that is important. Yes, rudder force is important to start the turn, but hull forces are equally important, probably more important in order to make sure that the behavior is OK.

(Refer Slide Time: 24:37)



Now, let me just quickly go through say two small problems before I go to this – the definitive manoeuvres part. There is a small problem; there it says – design A – it has its values Y v, N v dash, Y r dash, N r dash; A and B – minus 0.36, minus 0.07, plus 0.06, minus 0.07, 0.12; and, this one is having minus 0.26, 0.10, plus 0.01, minus 0.03, plus 0.10. I also tell that this… The unfortunate part is that this coefficient values – non-dimensional – even M dash – they are not usually nicely like 1, half, etcetera; they will always normally become 2-3 decimal places from the… – like 0.00598 – like that. There this number that you work with, they will not turn out to be round numbers close to 1. Why I am saying, in many cases, you will find in fluid mechanics, you actually non-dimensionalize with a constant factor such a way that the numbers are nice to work with

– 1, 0.5, 0.2, like that; M for example – added mass; added mass is non-dimensionally added mass by mass in CKP. But, here it is not done so; it is always done by half rho l square or half rho l cube. When you do M, half rho l… If you (( )) you divide by M, it will be 1. But, M dash is M dash by half rho l square. Depending on the size and all, you will end up having completely different number 0.002, etcetera; anyhow. So, why I am saying? Because you have to understand.

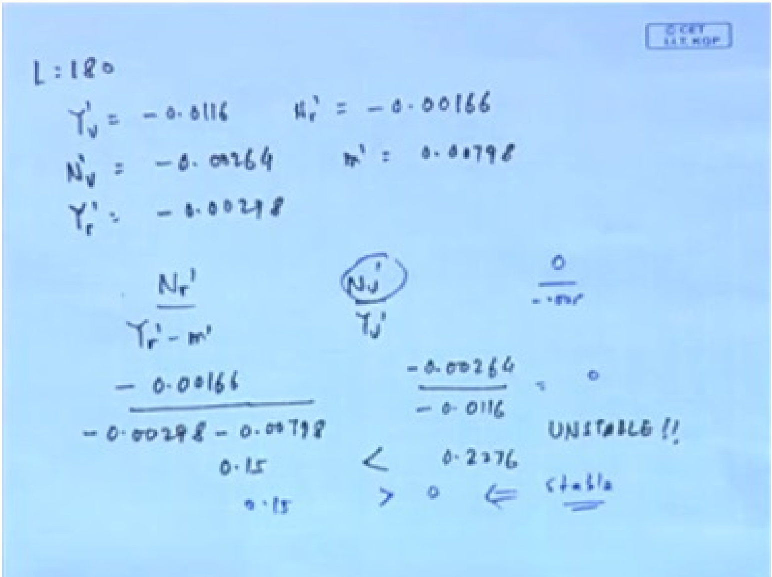
Do not try to round up the numbers because it is 0.000358. So, I will take up to second decimal place; it will become 0. So, you cannot do that in this thing. Most of the numbers will be third, fourth, fifth; you must take up to five decimal places. But, this is of course different. We have to comment… they have two designs. The question is that comment on the directional stability of the two and the neutral point position of the two; very simple directional stability requirement. We will go back to this. Let me look in terms of the neutral point only. Say design A – we will just work it out. I must make sure that N r dash by Y r dash minus m dash – this must be greater than N dash v by Y v dash, which is a neutral point. So, let us see for the design A. What is this (Refer Slide Time: 27:30) value? This value is minus 0.07 divided by Y r dash is plus 0.06 minus 0.12. And, this side is – let me work it out first – minus 0.07 and Y v is 0.36. So, this side is divided by 0.36. That is equal to 0.194. And, this side becomes… Let me see; how much this becomes? 1.16. So, this is satisfied. But, the point is that this satisfies all right. But, you have to comment on the 2. Let me see the other one; then, I will tell you how you end up commenting. This for design A.

Design B – this is the first term (Refer Slide Time: 28:39). Let us see; this comes out to be N r dash is minus 0.03; Y r dash is 0.01; m dash is 0.10. And, this N v dash is… What is this N v dash? minus 0.10 divided by this is Y v dash – minus 0.26. So, let me put it this one – this number. It comes to 0.38. And, this comes to… How much it comes to? Tell me? 0.1 minus 0.01 – 0.098; 0.03 divided by 0.09; that is now 0.33. So, this is becoming this. First of all, you will find out that this is unstable and this is stable. So, the question of commenting does not arise; I thought this is more unstable. But, what I was trying to say, I will tell you this – see this is… Of course, here the conclusion is very simple; this ship is unstable; this is stable. Now, if I want to make it stable, I have to make sure that I am trying to satisfy this. There are many techniques of doing that; I have to increase N r for example. So, N r can be increased; I have to decrease N v or make it more it more positive like minus 0.01; I can even make it 0, etcetera. So, there are techniques there.

But, other thing I wanted to tell you. Supposing this turn out to be… Suppose in a problem, the way the number was, instead of 0.03, let us say it was 0.04; then, what would have happened? 11.44. Say it was 0.4; suppose it was 0.4. Then, it would have been 0.44. So, this would have been more than this. Now, you comment on the two. The comment is that yes, both are stable, but this is much more stable than this (Refer Slide Time: 30:54) because you have to see this distance; or, rather c-coefficient; c-coefficient would be actually measure of the distance, because it is this minus that. So, what would have happened, c for this would have been much more than c for this, because here what you are finding out is that this point is 0.194 and this is 1.16; whereas, here this point is this neutral point and this is a point for the yaw.

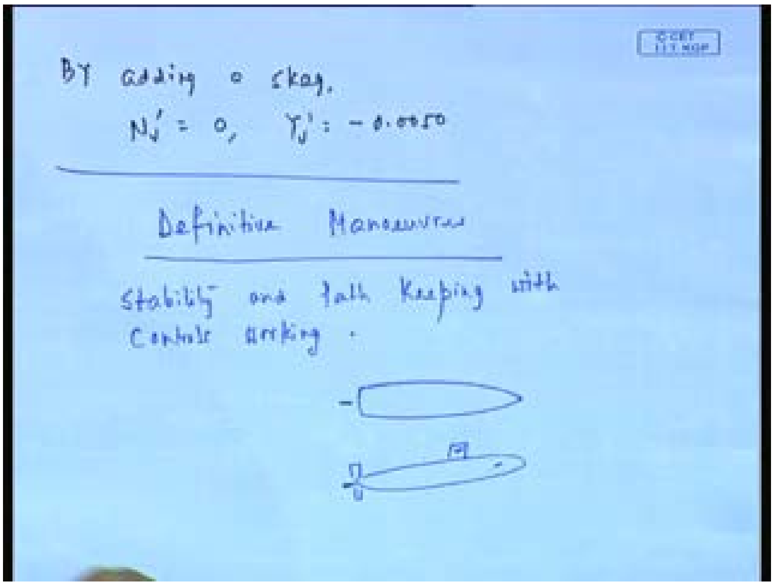
Here, this point is here (Refer Slide Time: 31:23) and the other point is just here; you understand that no? That what I am saying that if I have to comment, then I will find out that both are stable, but it is something like this one is having much higher metacentric height equivalent GM, because the c value, which is N r Y v minus this is much more than the c… Both of them positive, but this c might be something like 1; this c might be 0.1. Therefore, this is much more stable. And then, we will find out afterwards that as a consequence, it will have much less deviation to turn; it will actually take larger circle to turn. This was how the one problem. Let me go to the second problem.

(Refer Slide Time: 32:21)



Particular ship, which is 180 meter long, has these values. This problem has two parts. Firstly, the part one says that find out that this ship stability – it shows that it is unstable; then, after that, I will go the next part. The next part will say that – you know what is skeg; by adding a skeg, N v and Y v has got changed; they have given a modified value. And then, you say that with the skeg, with these values it will become stable. So, first let us find out this whether it is unstable or stable. So, here again, I always remember this formula more – N r dash by Y r dash minus m dash and N v dash by Y v dash. So, this value is how much? N r dash is minus 0.00166 divided by Y r dash – 0.00298 minus m dash is 0.00798. And, this let me write this – of course, this value becomes… It is easier to do this side value first – 0.00264 divided by 0.0116 – 0.227. Something like that; this side became 0.15; is it? Something like that. So, obviously, this is less than this. So, unstable. I mean if you see, this criterion is not being satisfied; c is basically less than 0. Now, it says they have added a skeg; it says by… I will just write in the next page.

(Refer Slide Time: 35:18)



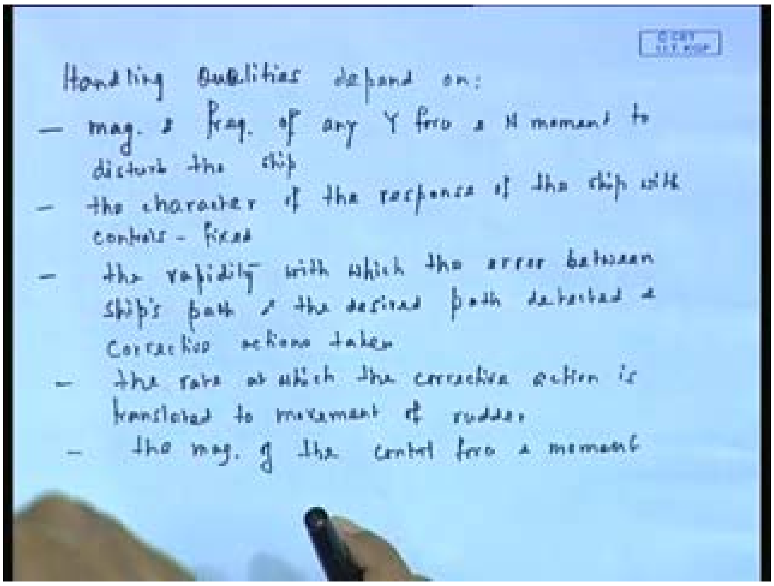
Now, it says show that the vehicle becomes stable. Now, I will work on this (Refer Slide Time: 35:43); basically, it will be easier; this side remains unchanged; this side – this value has become 0; and, this value has become whatever. So, this has become 0. So, now, 0.15 is more than 0. So, becomes stable. This tells us the kind of problems. But, obviously, now, I will go to the other kind of part. Obviously, the question comes; all that is very nice. Therefore, I will have to determine or find out the coefficients, hydrodynamic derivatives; first, when I do a design, I will actually have to estimate those values and try to find out how the vessel behaves.

Now, usually in our design, as of now, sea keeping as well as maneuvering was not being checked or seen as a design part. You do a design and eventually evaluate to find out whether the vehicle has adequate maneuvering standards, rather than design it for having a maneuvering standard. Nobody is doing it basically. So, it becomes kind of in a loop, kind of a check. Now, having said that, what is happening, we will have to find out how do we assess a vehicle's maneuvering and controllability qualities. It becomes a qualitative thing. If you have a kind of a vehicle, you will say that this car handles nice; then, you will say this car does not handle nice. So, many of the decisions are somewhat subjective. Now, like some of these boats that you see, it does not turn properly or some of them turn nicely. So, it becomes very subjective. So, here comes this issue of what we call definitive maneuvers; I will mention to this today only this.

This is related to from practical point, stability and path keeping with controls working. By controls – I mean rudder; by controls traditionally for ship, it means rudder; controls are this. Remember for a submarine, it is more than that, because you have to have a control for both for vertical plane, which is given by the aft plane and also forward plane – bow plane or a sail plane. In a ship, it is the rudder; in a submarine type of body, you have stern plane as well as either a plane here or a plane here (Refer Slide Time: 39:06) depending on that. This is a sail on a plane – bow plane they call or on the bow itself. And of course, you have a rudder. Rudder is normally on the aft only. But, the vertical is very important, because there is a neutral buoyancy; if you cannot keep it, it will hit the bottom if you cannot come up. But, these are my controls. With the controls working, you want to find out, because that is the final handling quality. So, what we are going to talk about little bit of that before going back to that. What we have so far talked…

Once again, if I were to repeat, we talked about a ship's intrinsic quality of whether it will be straight line stable or not. But, in reality, what happens, as I mentioned, even if the vehicle does not have a straight line stability, you can still control it if you have a rudder, because if you apply additional force to absorb the instability, it will get absorbed. So, ultimately how it handles depends on with the rudder working. So, this is what we are talking here before we get back to that (Refer Slide Time: 40:20). Obviously, what we will find out is that hull – if the hull was just stable, then even if I apply a small rudder force, it will turn. But, if it is very stable, I need to apply very large rudder force. What do I want? I obviously want vehicle to be stable, because otherwise, even if I want to go on a straight line, I have to continuously keep on applying rudder, because when it goes on a straight line, you have a waves, currents; things are not straight. So, always a disturbance is coming. So, you would always want to control. But, if it is too much stable, then I cannot turn in a port and all. So, these handling qualities are what we will be discussing now and what we call on…

(Refer Slide Time: 41:07)



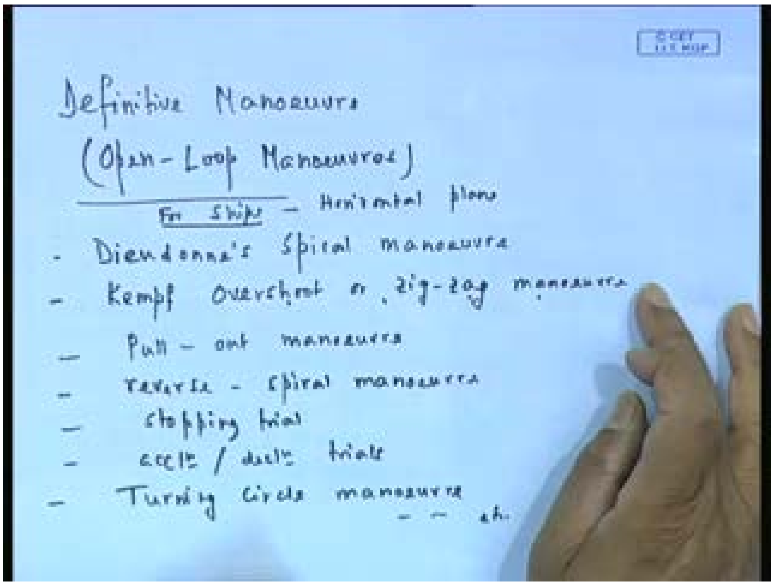
Let me write down the points the handling qualities. Now, let me write down this. Number 1 – it depends on magnitude and frequency of any Y for v and N moment to disturb the ship. I will first write it down. The character of the response of the ship with controls – fixed; the rapidity with which the error between ship's path and the desired path detected and corrective actions taken. Let me write it in a minute and then we will… The rate at which the corrective action is translated to movement of rudder; the magnitude of the control for v and moment. What I mentioned is something like that. There may be more points.

Number 1 – when you talk about the ship, finally, the handling qualities as designed and as it is working in ocean, obviously, it will depend on the environmental disturbance outside; magnitude of any sway force and y moment. Of course, I wrote that way; but, what it means – the point number 1 is essentially the environmental disturbance, which is always acting; of which, you have no choice. Obviously, if you are going on a lake – calm lake, you are better off, because disturbances are much less than if you are going on open ocean, where there can be much more disturbance. This is external factor we have no control on. It of course depends on the straight line stability of the hull. This is what is the character of the response of the ship with controls fixed, which is nothing but what we spoke so far – the straight line stability. It will depend on the characteristic of that way. It means whether very stable or unstable or not. For example, if it is extremely stable, small waves, it will not go on a straight line.

Now, the other part is like this – suppose you have to go on to this heading and you find that you have swayed it; obviously, you have to make a corrective action. So, the rapidity with which this action has been detected – this is again a factor basically depends on the measurement system, etcetera and not on the ship response itself, because somebody is there; you have to continuously get a feed of what is its position; what you wanted; the difference should get feedback. Nowadays, it is much instantaneous; earlier, it was much more difficult, because you have to get a tracking or a platform outside sources.

Then, it is not over. Then, the rate at which the corrective action is translated into movement of rudder – now, you get this in the helms; then, you immediately have to act the rudder; there is a time gap; there is a phase gap. What you have found out now, after a while, you will correct to the rudder. Then, of course, I will write (Refer Slide Time: 46:44) – ship response to rudder force. Then, of course, what happens, you apply the rudder; so, rudder is going to give a corrective force. Obviously, it will depend on the amount of corrective force; larger rudder means more corrective force; smaller rudder means less corrective force. Then, of course, how the ship would respond to the corrective force? The point I am making therefore, is that this (Refer Slide Time: 47:14) entire thing becomes a part of ship's handling qualities with controls working. So far, what we talked about is this and this is of course, environmental disturbance. Now, I need or we need to study or assess in some sense these quantities. For that purpose, what is happened, we have devised what is known as certain definitive manoeuvres; the word called definitive maneuvers.

(Refer Slide Time: 47:49)



Some people will call this as open-loop maneuvers. In controlled engineer, we will call this as open loop. What it means is that, definitive means there are certain tests designed for a ship, for submarine also, for ship also, which would actually try to establish the handling qualities. So, that is what we are going to talk. What it means is that in briefly, you are going to give certain control actions; means turn the rudder to 5 degree; then, do nothing; just find out how the ship respond to it. Then, you will know; just like in say automobile and all, everybody has a turning radius given; maximum turning radius you can get. How do you do that? There are test there; that you just turn it and see; you know how much (( )) Then, there are test of what is called a (( )) test. There are points here; you take curve like that. How fast you can go? And, see that during that, it does not topple over. So, these are called definitive tests; means you are having a definitive action. Do this to the rudder for these cases and find out how the ship behaves to it. And, this gives you a qualitative estimate and also, some form of quantitative estimate of how the ship handles.

If you give a rudder, suppose it quickly turns; then, I know it is very responsive to the rudder. But, if it turns very slowly, very sluggish I will call. So, these there is a set series of tests done, which we will discuss eventually; some of them we will discuss. Set trials done, which would actually characterize a ship’s handling behavior with the controls working. And, ultimately, that is what it matters. So, these are called definitive maneuvers. We have number of them in horizontal plane; also, quite a few of them in vertical plane for submerged bodies. Submerged bodies – for example, it is diving down; how fast you can bring it up? Does it come up at all? Etcetera, Etcetera. For example, let me just write down a few of the points here. We will discuss this (Refer Slide Time: 50:32) later on.

Some of that definitive manoeuvres – one is called (Refer Slide Time: 50:37) Dieudonna's spiral maneuver; some of these – these are some ships – some maneuvers for ships here – actually in horizontal plane rather I should call. These are also called direct spiral. Then, I have got – I did not write the most important one –. See here I just mentioned this and we are going to be discussing; and, there are more also here. There is… The important trials are actually a spiral maneuver; there is a trial called spiral maneuver; we will discuss that. This manoeuvre is done essentially to determine whether the vessel has instability in it or not – straight line instability. Basically, the purpose of that I will write this at length later on.

Kemp overshoot or zig-zag maneuver – this is (Refer Slide Time: 52:58) actually the other thing to find out how quickly it respond to the rudder; going zig zag, you can tell. Pull-out maneuver – it is to find out very important test whether the ship has straight line stability or not; means whether c is negative or positive. Reverse-spiral maneuver is part of again finding out whether there is instability. Stopping trial; actually, before that, I should tell turning circle maneuver – very important – most ships, you must have a turning radius. So, this is only to find out turning radius; this is very common in car; everywhere, you say minimum turning radius 7 meters, etcetera. Stopping trial – also important – anywhere when the ship comes, there is a trial called stopping; you want to stop the ships; the ship does not get stopped; it is simply because of inertia, it keeps going. So, the trial will tell within what distance you can stop a ship. There are some requirements. Then, there are acceleration/deceleration trials there. So, there is now set means of doing these trials; from the output of which, you will be able to characterize or find out how the ship handles. This is what is called definitive manoeuvres.

Normally, these (Refer Slide Time: 54:16) are done for a ship after it is launched and it is ready; before delivery, these trials are done. And now, I will also tell you and end today's class by saying that there are IMO requirements, which says in order for a ship to be certified, it must satisfy or meet certain criteria just like our stability criteria – GM should be less than this, etcetera. So, there is nothing like good or bad, but it must for example, zig-zag if it is overshooting too much. People may think… Just very quickly, I will give an example. You may think that I will make it actually very (( )) just stable. Therefore, it can respond very fast; just go very fast. But, the point is that the one that goes very fast, it also zig-zags much within over… It also overshoots a lot. So, that we are going in a canal. Say Japan – you are going to a port in a canal. Now, if you want to do zig-zag, it may actually hit the bank. So, you cannot afford to be overly maneuverable also; you cannot afford to be overly stable also; then, you cannot turn. So, there is a limit. You can neither do this more nor do that more, because if you want to turn very fast, it will simply… Like a small road, you want to turn it; just goes under and hit the bank. Therefore, there are standards, which we will discuss.

We will discuss from tomorrow's class onwards for 2-3 classes this trial in detail; what you want to measure; and, what it characterizes of the hull, etcetera. These are what is called definitive manoeuvres. They are done for a full ship. But, also, this can be done in a model scale; you can also do this by simulation using those derivatives, which is what we keep on doing many times during the design time. Like you can numerically simulate the trajectory and find out. These are open loop, because closed loop means you must control it. Like I want to go straight line; so, if it goes there, I will correct it. But, here no; I just give a rudder and see how it goes; I do not want to control back. That is why it is called open loop. So, with that, I am ending today's class we will see tomorrow this.