Seakeeping and Manoeuvring
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Lecture No. # 23
Manoeuvring: Introduction and Basic Equations

Now, we are going to start the second half of this course, which is essentially Manoeuvring.

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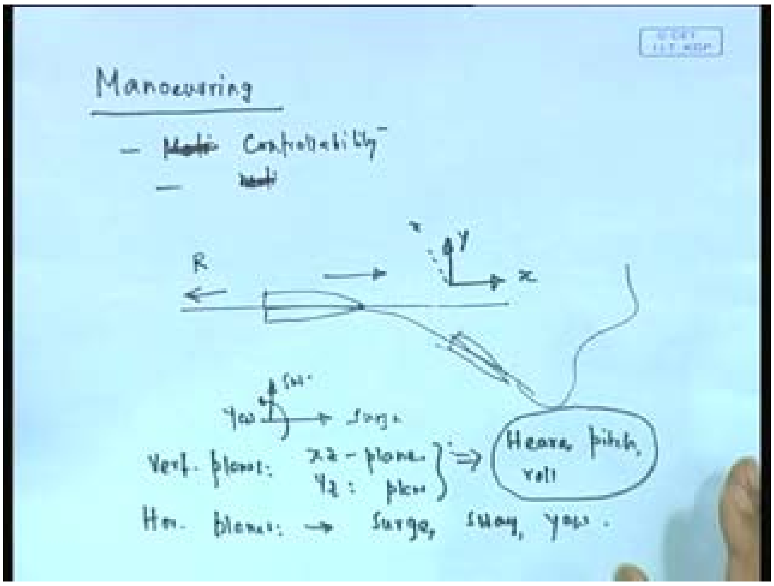

Remember this, this course is Seakeeping and Manoeuvring. So this seakeeping part we have done, now we will begin manoeuvring part. First of all, let me give a brief introduction of what this is about? Some people call this motion control, some people call it control ability.

All these are kind of (No audio from 01:00 to 01:15) actually motion control may not be ,controllability one can say. See (Refer Slide Time: 01:24) assume this piece of paper is the sea surface, calm sea surface. I have the ship here going along a straight line. This we have studied or this is what is the standard wave resistance problem that is, when the ship is moving along the forward line.

The net force that comes from the hull, which direction? In this direction, which is my resistance, ship is symmetric geometrically port and starboard. In fact, all most all vehicular systems are geometrically metric symmetric, simply, because you do not want your pitch motion coming if there is a small one you connect them. But that is what we are looking at.

Now, in manoeuvring what you are, our interest is actually (Refer Slide Time: 02:20), when the ships tries tries to turn or make this various kind of motion in this plane. Now, in seakeeping what we have found out is that motion in this was surge. This was sway, well may be yaw and heave pitch and roll. The of the 6 modes of motion, the vertical plane modes modes of motion, that is, if I were to call this to be x axis, this to be y axis and the vertical is to be the z axis.

In x z plane we you had and y z plane, you can say this two, you know like the central plane and this plane vertical planes you can, I can say vertical planes. It gave rise to the motion heave, pitch, and roll. In the in the horizontal planes I have surge, yaw. Now, these three is the one, we primarily spoke in seakeeping. And if you recall in this 3 modes of motion always, I have a restoration. That is, if I were to heave water pushed up. Pitch, there was a, you know like trimming moment, pitching moment. Roll there was a heeling moment or restoring moment whatever.

But, in the horizontal planes (Refer Slide Time: 04:16), I have no restoration. Effectively therefore, you can say manoeuvring is the study of the motions in the horizontal plane. So, if I were to think why I am trying to make make this, that if I were to think, this 6 modes of motion.

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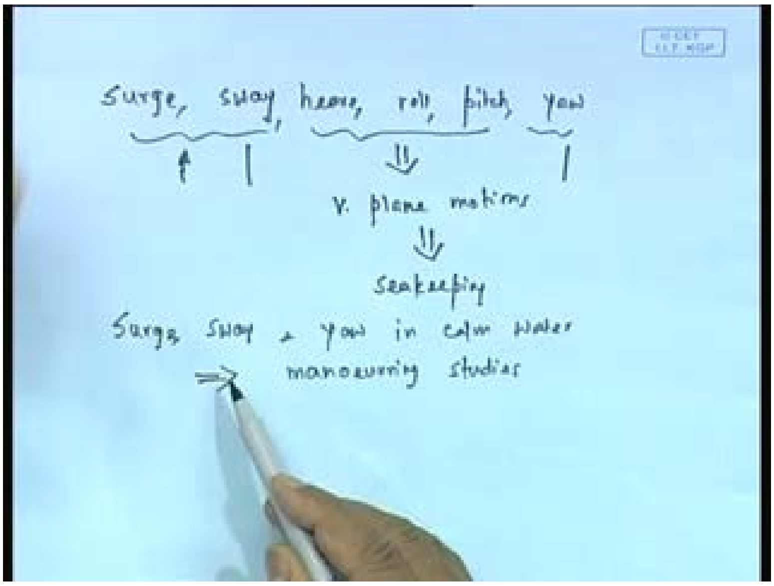

That is once again Surge, what is happening here? I can say that, these 3 vertical plane mostly mostly seakeeping also does wave induced, you know the other parts mostly seakeeping, where as this and this are horizontal plane motion, we will be concerned of them in manoeuvring.

Of course, there is a big difference in not that, I do not have surge, sway and yaws also in manoeuvring, sea keeping. I do have because in sea keeping I had waves in water, existing waves. But in manoeuvring, I do not have existing wave, but I am looking at sway and yaw primarily, not even surge. The reason we are not even surge, so much because remember, in calm water surge is nothing, but forward motion. So, it is resistance problem.

So, in calm water sway and yaw is what we are taking a manoeuvring. Why I mention this is because, if you think in terms of ship dynamics, you may al always think the dynamic dynamics of the ship in calm water, in the horizontal plane is manoeuvring. And dynamics of the ship in mostly, in presence of waves in vertical plane is is what we are concerning in seakeeping.

So, in some books, in some texts, from hydrodynamic point of view, do not separate it out. It is only one part of the dynamics from the other part of the dynamics. But from practical point of view, as we know it is a whole lot different. But this is the thing that we should realize that we have, (Refer Slide Time: 06:33) we are looking here now a horizontal plane motions surge, sway and yaw. But, we will initially be talking about and mostly as far as this course is concerned, we will be talking about, this motion in calm water.

If it is calm water you have a question, where is the force coming? Right suppose there is calm water. I say now, I will mention that, so it is surge (No audio from 07:00 to 07:19). So, manoeuvring studies is concerned with vehicle motion in the horizontal plane that is surge, sway and yaw in calm water. Then, eventually there is a question in mind that if it is in calm water, where is the force that is causing? You know the force in yaw direction, in sway direction. Well, surge is a resistance. Now, here I answer this question and this is exactly, the crux of the matter is you see, now think of this.

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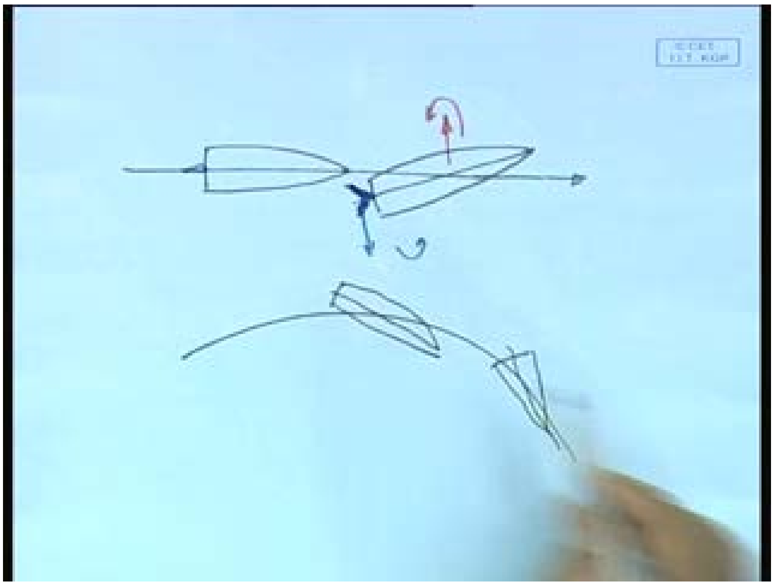

This ship now it wants to turn, so what would happen? Suppose, this ship is moving with an angle of attack, suppose it is moving this side what happens. Because, while turning it has to have some angular of attack moment, now the see here.

Moment, there is an angle of attack, there is the flow is not symmetric both sides. And immediately, it is going to give rise to a force here and a moment here whichever way, so this force and moment, why did it come from? It came, because the hull is not symmetric on this line. Why it is not on this line?

Now, comes the question, I want to turn, so I want to make the head change. How do I do that? I have to get some force from some source. How do I do it, is by putting my rudder see my here I have, now if I were to plot, I had some control surface, see let us say, typically rudder. So, there is no force, but now, what I did? I change the rudder, see I am turning this side, so I am changing the rudder or rather no opposite side.

So, when I give a rudder what happened, rudder is giving me a force this side and a moment this side. So, it is trying to turn, this may not be the actual picture is going to turn. So, now now here is the most important question that I mentioned is basic equation. See, rudder is an outside rudder also of course, is giving the force because of the flow pass did, and it is a control surface.

But, I am somehow causing a y direction force, it transfers force on the rudder, but if you have a transfers force on the rudder that is going to give me a moment of the hull about the c g. So, therefore, I am introducing a force this direction and a moment this direction to try to turn. Now, my ship is turning. As soon as it turns, it is no longer going on a straight line. If, it is not going on a straight line, immediately the flow about the hull gets created, because the hull acts as if is a lifting surface within an angle of attack and as the hull create forces.

There will be hull forces coming and now the therefore, I will have now a yaw force, yaw moment and sway force. So, therefore, I will have now in since I have now a force in the, in a force and moment, in yaw and sway direction. I am going to have yaw and sway velocities.

So, what happens therefore, the ship begins to (Refer Slide Time: 10:33) you see the the it is better to see, this way it turn and what happen as it turns, it will have some kind of a attack. So, then what is happening? Now, I want to study how much it turns the full property. So, you see to study that, the steady state after all when it reaches the steady state whenever or transient stage, my net force should be 0. Because, force is mass into, it should not accelerate.

Now, what is the force consists of, remember I have a rudder force, I have a hull force. So, therefore as I give rudder my hull would have turned and would have balanced at such a location, that my hull force and moment, balances the rudder force and moment.

What therefore, I mean that it is like this. So, if you want to study manoeuvring, it is not like a curve, the manoeuvring of turning is decided fully.

And let me emphatically says excuse me, again entirely by the hull forces, and the rudder forces that get created. Because of the flow pass the hull and that is the crux of the matter that one has to understand.

You are not turning, you are not able to turn just like a car, like a steer and it turns this side, you just does not turn. It turns only, because of the, balance of the forces that get created. So, you have to understand, the the kind of, what are the forces that get created. If I were to turn, what is the steady state etcetera?

So, once again this this, what I said basic equations. You cannot study without establishing certain equations that tells me, that hull force and a rudder force etcetera. All balances and come to certain equation, see this an I like to give this example. Many times I mention that, that when you go to, when anybody goes to a river. When you see, if were to carry. You know like if it is local very experienced, you know fisherman or the, what you call this sailors, country boat the way they change the rudder. And the way they maneuver to bring it up. It just does not follow the standard rule. It is more of experience it is not that you turn it, and it went straight away this side you know.

So, when you for example, go for this paddle paddle boats and all any any lake, you you realize how tough it is to actually. You know come to a dock. You just, you know, you learn soon from experience. That if I do that, it will go here. So, the response of the vehicle is not one to one. It is not that, I just turn that, it just shot shot this side not like a car or a scooter or a cycle, that I just changed the handle it went this side.

It is because, the entire mechanism of which side the hull turns is nothing but, balance of force and moments. Where did the force come from? Force come from primarily by the flow going pass the asymmetric hull.

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Symmetric hull means only resistance force. So, you see, this is that is why it is extremely crucial for us to understand. This part, this is why I am spending time on on on, you know like on this this part of manoeuvring, and we have to understand. Think of the example of Titanic, the captain has seen the iceberg; you have also going a rudder. But, yet the ship actually went very much on that side, and then hit, and this thing. Suppose, it was a car you would have immediately deflected. But he could not deflect here.

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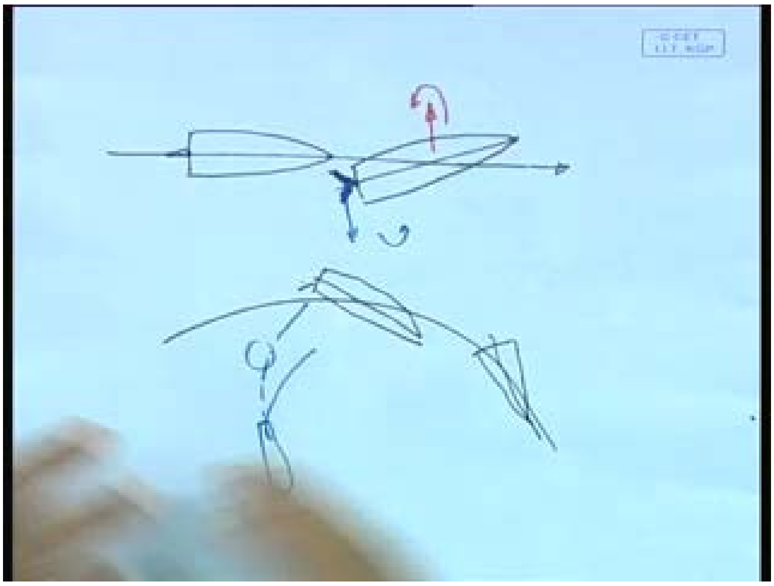

Even though, you saw the object here and you are coming here and you give a rudder. You actually went more like that, you did not go straight like this. So, the ship did not respond, because if I give a rudder like a car, if I give a large thing immediately you would have turned, but it did not. All these, tells me that unless turning manoeuvring as little more complex, because it is nothing, but interplay of forces.

And the hull force becomes very very very important. Because it is the very large hull, that is there and you know very large mass, it has to be turn. So, I will contribute to this this entire equation etcetera. And therefore, the today's lectures we have turned know basic equation. You cannot avoid writing equations to study manoeuvring, for ultimately the characteristic of manoeuvring will turn out to be the characterization of the hull forces. Because of the flow passed it, which has to be written in terms of expressions.

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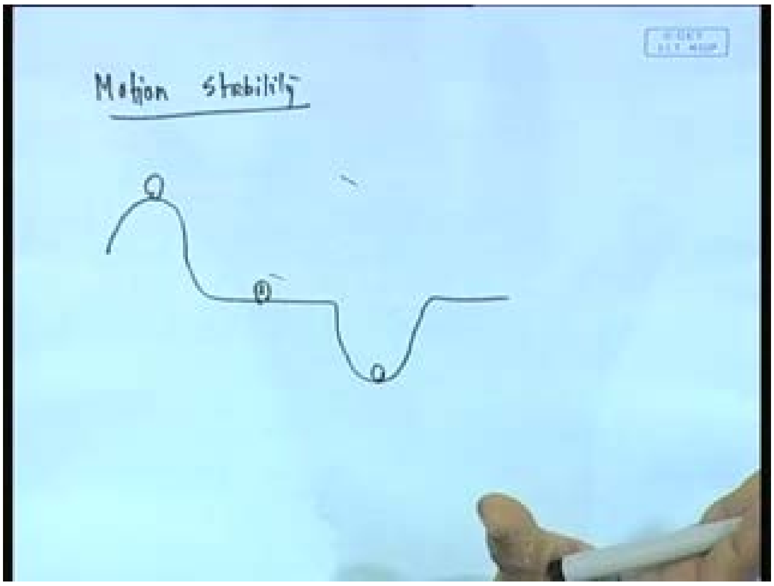

Now, having said that let me first talk about certain basic ideas regarding directional stability. What what we are looking for or motion stability. You can say directional. Now, you see, excuse me again sorry. This stability is a concept, that all of us know. We have all known that you know this classical example of a ball here, a ball here and a ball here. Everybody knows this know that, if I were to displace the ball here from it is initial position. It comes back to that stable this I shifted it stays here. Neutrally, stable this I shift it displaces from there it is unstable.

In other words, what we say a stable equilibrium means, if I were to change the system from the initial stage by some small amount. It comes back to the system etcetera etcetera. This we talked in terms of static stability, now the same thing will apply similar kind of concept for motion or directional stability. But remember ship is neutrally stable in horizontal plane. So, there are actually 4 kinds of this stability, course stability possible, something like that.

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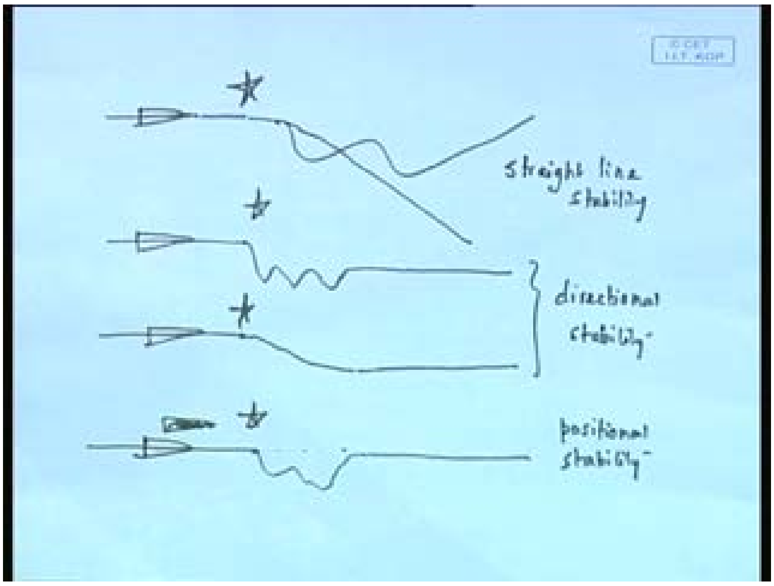

There is a ship coming here. So, I here I give a disturbance, large disturbance I gave. You know ship, let us say I give a push. Now, what happen then of course, I give a push and left my hand just like our roll know, I just rolled it to a 5 degree and left my hand. What would happen, there are various possibility the ship can actually no no no rudder. Remember there is no rudder, it can actually then take a straight line course. It can also go halyard halyard. I do not have this; I mean this is one of the behaviors that are possible. If a ship behaves that way, we call this this this particular property, the studying these properties known as straight line stability.

Now, the second one, my original path is here, I give a disturbance here, the disturbance that would have something like that. But ultimately, again it goes to straight line or I was coming here. It gave a disturbance here, this is a disturbance, but it actually just deflected. But in ultimately came to just here this two, what we call a behavior, if the ship behaves this way or it posses this characteristic. We will call them directionally stable, because the directions are same (No audio from 18:32 to 18:42).

Now, another one that here, what is this this ship here and this is here disturbance. But it ultimately come back to this same line, we call it positional stability. Now, let me again look back at this and take little time. See, what I have shown here four diagrams, depicting certain behavior of the vessel. Initially, consider a vessel is coming on a straight line; I disturbed it by some disturbance. You know push it or whatever left my hand, just like in a roll case. I just give it a roll and left my hand.

Now, what happen the ship can there can be two possibilities, the ship can go along along a straight line fine. But it will not be the same straight line, because there is nothing to restore it back. Remember, because it has got some change in heading you have a propeller thrust. So, it cannot come back to it is line. So, it comes on this, but that is one. But it may also actually completely go in a halyard manner.

So, if it actually goes in this line, if it possesses a characteristic of this line going after disturbance following another straight line, we call that the particular vessel possesses or has straight line stability. Consider the other case, these two cases where similar disturbance is given and the final path has become parallel to the initial path that is having the same direction.

If supposing a vessel behaves that way or is able to behave that way, we call it that it is directionally stable or it possesses directional stability. Final one is that I give a disturbance the ship is coming here. And after the disturbance it finally, when the disturbance removed it finally, resumes its original direction and position means same line. So, we call it has got positional stability.

Now, the interesting point is that, none of these three are ever possible without acting an external force like rudder action. In fact, this is not even possible without having a controlled rudder action. You know, you must have an appropriate controller, as far as only hull is concerned. That is you do not apply the rudder, you can only have this characteristic. Now, you see therefore, now the point is that you can have both the characteristic, either this or this which one would you prefer.

Obviously, you would like to find out whether the hull has an intrinsic. So, this becomes an intrinsic characteristic of the hull, because intrinsically you have designed the hull. So, that if there is a disturbance, there it takes the straight line, know I give many examples for that, you take a pen or any any object, you through on the on the, you throw on an ear, what happens I will come back to this diagram.

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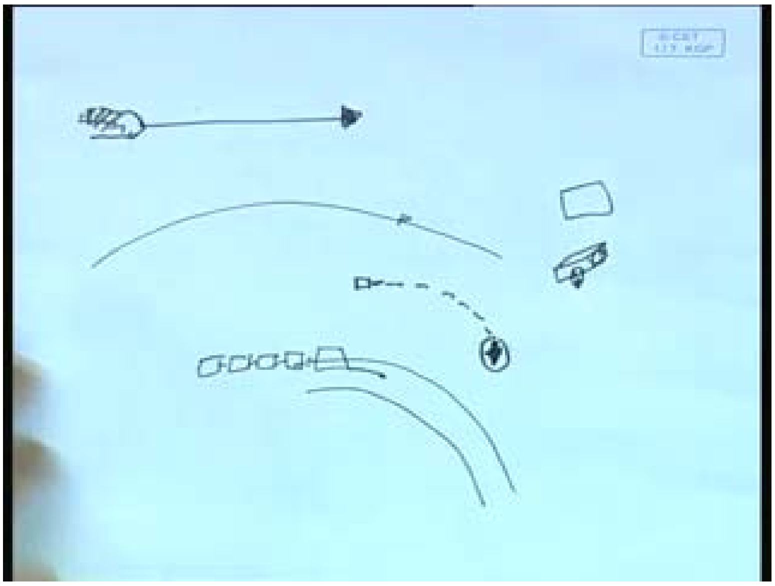

So, I have this something object I throw on the ear. What is the trajectory text, you can throw and find out it may actually go like that. It does not follow a straight line right. See, if I just take a stick, I just some small some pencil and throw it in ear does it follow a perfect path like that. No, but now you put a mass here, and you put a feather here, like in an arrow. What happens, it goes exactly in a perfect line, and you understand that.

So, you see immediately you understand. Now, remember there is no rudder and all action here. You are just trying to find out intrinsic characteristic of this. So, this one has therefore, a directional straight line stability means it is following a straight trajectory. But this does not have, what does it tell, it tells us, obviously there is something happening. There is some characteristic, that defines or that kind of characterizes the straight line stability of an object.

Another example, you know that not a train. But in our younger days, there used to municipal cars which would have a small car (Refer Slide Time: 23:10), attached with the link number of small things. Now, you see you are going on a road remember it is not a train line. Now, you will always find that, when this goes they all follow like, you know this this this this are following. Why should it follow, remember the engine can be actually pulling it here this way. The the the motor and the last bogie is still like that, but it is still following this line.

You know what I am saying that, the municipal car that engines that fellow is going this side, he his his the motor is here, the last bogie is here, but it is still following this line, should it have followed. It is not necessarily mandatory, that it should follow, I mean in it is not necessarily true. Unless and until you have ensure it has certain properties. Remember it is not an it is not a train line. You know all of them might be having just 2 wheels, just a in a bogie with with. So, called bogie with a with a 2 wheels, 1 wheel and another wheel.

So, you know the even here, this concept of the stability comes in directional stability or possession of stability. Because, until and unless this is different dynamics of course, but the concept is similar. That there is something, some mechanism forces which should be in such a way that, if I pull this side they just follow in the same line. So, this property what I was trying to say is what is called that straight line stability (Refer Slide Time: 24:43).And a ship can only of the straight line stability or lack of it.

So, naturally what when we are starting initially, what we are going to be talking about is to develop an equation of motion. To try to find out, when the ship is disturbed what kind of forces get created on it. This is similar to what we have talked, in roll for example, because we said that as soon as I heel the ship by theta degree. What are the, what are the moments that got created, because of hydrostatic pressure.

You see the difference is that in a ship (Refer Slide Time: 25:23) in a in a static roll case. I have rolled it by a small angle. Moment I did small angle the only force acting on the hull is what hydrostatic pressure. So, what I essentially did, that this hydrostatic pressures on that new weighted line. I added them up to find, what is the net moment acting on that hull. Only thing we called it hydrostatic is because, the moment I calculated arise, arose, because of hydrostatic pressure only.

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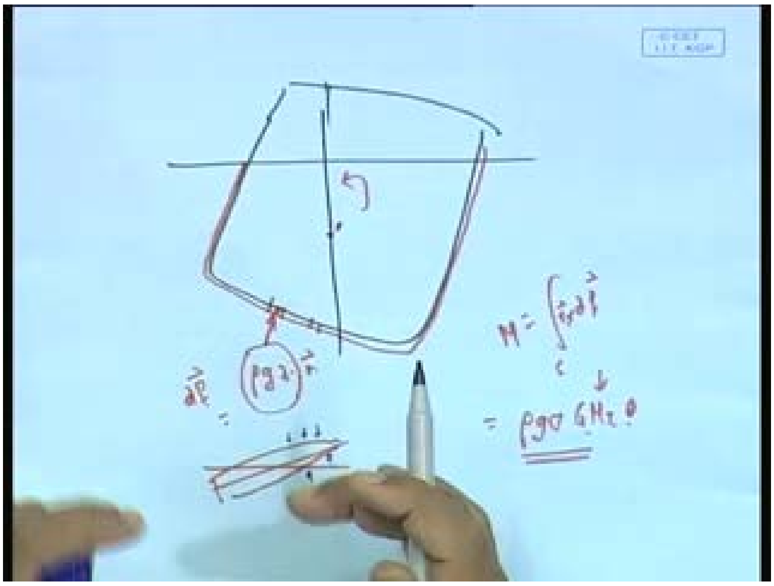

I I think, I want to explain to this because this things are important from see here. Remember I will draw it this way, I I made the hull like that, what has happened? Now, remember see these are all important conceptually important, I have this, my weighted surface. Each point, I have got this pressure acting rho g z into n. This is my hydrostatic pressure. What I did I I take this hydrostatic force, if I call it say f d f. So, I found out moment about that that about whatever the c g point some point, if I call r.

So, I found out moment equal to integration of d f r cross d f, that is what I have done over weighted surface. This is what I found out is the restoring moment or why I found out this moment. Then I found out that -this moment is this direction, it will tend to reduce theta.

See, we have never talked about this line, but essentially that is what we have done I have displaced the hull. Then I found out if I displaced it, what is the external fluid pressure acting on it. The fluid pressure acting on it happens to be rho g z into g m t. That is what the, that net result of that comes out to be rho g v into g m t into theta or g z whatever.

This is what actually the result was, and then we found out that, obviously, the direction of that depends on this quantity, because others are actually constant. You know what for the given theta rho g v, does not have any any kind of sign attached to it. It is not a directional quantity this two may be, but I am always taking theta positive. So, we find out that, if this is opposite to that, basically it restores. So, this was a concept we used.

Here the same concept we have to use it, because here what happen, my ship has now become like that, so, now I have to find out that. Because, it is going the difference being here, the pressure that is acting on the hull is now dynamic pressure not hydrostatic pressure. Because of, the flow around it and now this ever we integrate them I get the net force on the hull, and net moment on the hull.

And that must balance in some sense or that plus the rudder forces, the control forces must come to a 0 or in in other words, in this case the static stability case, what I am doing,? Is the, see here we we we we we (Refer Slide Time: 28:41) the ship was going like that and certainly at one point I disturbed it. I kind of made it like that, you know at one point, it was there was no rudder, I somehow pushed it. Eventually, what happen, forces got created on that, because that flow is not anymore straight line.

Now, what I want to know does the force created and the moment created is such that, it will tend to make this theta this angle 0. This angle 0 meaning, it will try to align itself in the direction of motion. This is what we the question that, we want to ask. Of course, it cannot go back to the same position, because there is no restoring force. But, it can come back to the same straight line.

Because, you see what it means that (Refer Slide Time: 29:28), again I mean this is only for discussion purpose purpose here. Look at this vectorially this is my direction u and this is my v. Actual, as if it is going this side, see it was going this side and I just give a push. So, it became like that, now what I want to know that this angle must diminish. Because, when see basically this v means, I have a small velocity here, because no, not that small not this side u here. I have a small velocity here. Because vectorially this is my u, this is my small v, this is my vector v.

So, I have a small v created sway velocity. And I want to know that sway velocity must come to 0, because only then small u and vector v will align itself to each other. So, these are the kind of the questions, I am asking and these are the answers of that I am trying to find out. And, if I want to do that, as I repeatedly said and I will just now come to this, you know that expressions expressions basic coordinate system.

We need to understand and write equation of motion. Equation of motion, obviously, would say mass into acceleration equal to force the standard form. We have to come to up to that equation. Then, find out the property of the kind of hull forces that gets created. Then I will also find out what is it that it takes. For me, to make sure the hull is, you know like stable or and the related studies studies.

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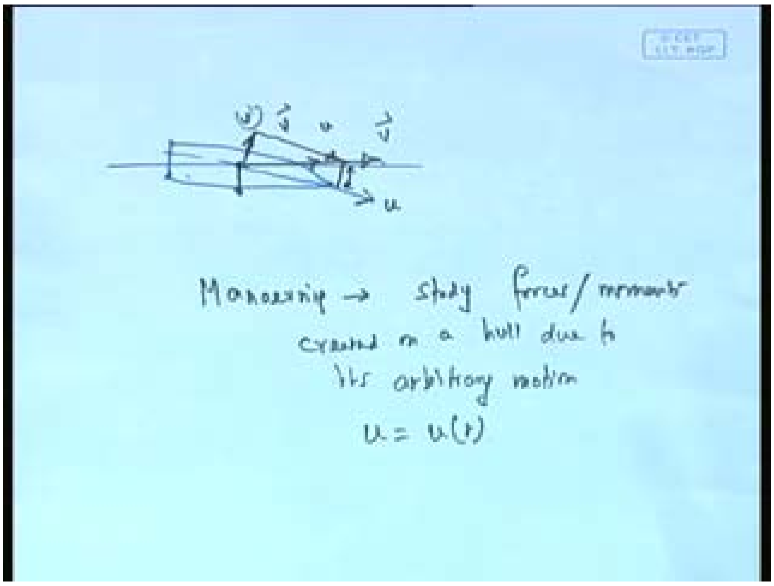


In other words the entire manoeuvring therefore, I need to study forces, moments created on a hull making a non straight line, making a motion which is not along it is own x axis for arbitrary motion. I can create on a hull due to it is arbitrary (No audio from 31:40 to 31:50), I can call this way in a general sense. So, this is very important, that is why I keep repeating that one has to have an idea regarding this force. And it is it is all interplay of ocean.

I can give many reasons for that. You know, you see for example, this you can think I will not tell you the answer. If you say a falling leaf, this is a typical question ask in Newman’s book also. You will see a falling leaf will always align itself in this direction and fall this way. It will not fall in this direction.

Again, there it is related to somewhat stability concept. I will not answer that you you think about it, what kind of, what what are the fluid forces acting, and which is trying to stabilize. This side slight moment it makes it like that. But on this side, if it is tried to do it remains stable.

So, now I am going to having now established that, I have no choice in starting manoeuvring, but to establish an equation of motion. First thing, I have to do is to write down a frame, coordinate frame etcetera, define various parameters. So, that I can write equation of motion, so that is what we will do today the rest of this this time see here. Remember we are talking at a lower level, now I am talking of only a ship manoeuvring in calm water. Therefore, I am concerned only at z equal to 0 planes. This piece of paper z equal to 0, this this piece of paper, if my sea surface.

So, I have here (Refer Slide Time: 33:27), now I want to track the position. So, what I should do, first of all let me just draw this properly. Then, we will know arbitrary motion of the ship is there. We need to draw obviously, actually somewhere here (No audio from 33:53 to 34:07). Let us say, let me first draw this see here. We I need to define various parameters.

Now, in order to track the ship, how do I know its position where it is located, I must have some coordinate system. So, I am going to have an, what is called an inertial coordinate system, initially O here X 0, Y 0 or small X 0, we can call it small, because there too many symbols will come. So, this is small X 0, small Y 0 inertial coordinates system. Now, I must fix a point on the hull.

Now, you you know, just like in in seakeeping the position of that is fully fixed, but with respect to a fixed point on the hull and the rotation of that. So, first of all we here just like in seakeeping, we will define another, so called body coordinate system. Let us see this body coordinate system will look like, will call it this way and this way in this case.

And this point is we call this say some point. Typically, centre of gravity the trace of the central gravity actually it need not be central gravity. But we are taking here central gravity the trace of that, this this this line, this blue line is the trace of the central gravity. That means, this is what the path it is taking, say this this line is the path at g is following this. That is my path.

So, obviously, the two coordinate that is X 0 G and Y 0 G tells me, the location of that. So, it I know the location of the G and also I need to know the orientation of that. So, you see here what would happen is that, I have a spaced fixed coordinate system o X 0 Y 0. So, it is inertial coordinate system I may call (No audio from 36:18 to 36:39). Now, I will have G X Y a body, this is my vector v, the fluid velocity vector v (No audio from 37:00 to 37:15).

What is, what what is this angle? Before before, I come to this angle or rather we can call them also. This angle, what is this angle this is angle of attack of the of the hull, because you remember the at this point the vessel is moving this side. This is my v, whereas this is my direction of the longitude of axis. So, that means, this is my angle of attack because fluid is coming this way. If I sit here on the hull fluid comes this way.

So, this angle, it is the angle of attack with from aerodynamicist nomenclature. Here, we normally call this a drift angle. (No audio from 38:14 to 38:22) This is actually same as angle of attack (No audio from 38:25 to 38:34). Why I am saying is that if you think this ship to be a lifting surface, which of course, how it behaves eventually at a low. You know very low efficiency lifting surface, then this becomes my angle of attack, but typically in in our nomenclature. It is referred to as drift angle.

Now, if I measured this angle also with respect to this line. How do I put this line again, Say no, I think I will put another (No audio from 39:13 to 39:36). Say here drift angle is the angle between the velocity vector and X axis that makes sense. Let us take it slowly the drift angle is the angle between the velocity vector and X axis. Whereas, heading angle or yaw angle is the angle that it is making from it is original heading to this. That is, what the the heading it make with respect to X axis, the X 0 axis.

See heading or yaw, see initially it is coming this side. Now, you are measuring the yaw angle or heading angle with respect to that. See for example, if I say it is going a 0 degree. Now, it is yawing 40 means, basically instead of going along this line is it it is heading with 40 angle. So, this is what we call basically the in the ship's heading angle or yaw angle.

See, yaw angle, once again is measure of the ship's heading with respect to a fixed reference line. See, when I say the ship is heading 180 degree with respect to some line which means with respect to line it is head is 180 degree or 10 degree or whatever. So, heading is always measured with respect to a fixed reference line. In this case the reference line is an inertial O X 0 line.

So, but heading is not really important from dynamics point of view. It is only important from the point of view our actually wanting the, you know like navigation point of view. You might say, now having said that, this is the two axes, now we will be introducing certain kind of quantities. Number one is that, let us this this distance, what is this distance it is going to be y 0 G and this distance is x 0 G.

Now, I want to find out, remember I have to establish equation of motion, what is equation of motion? Equation of motion tells me mass into acceleration is equal to force, that is it. Now, suppose I take this to be the axis. Now, I have to take this axis because this is inertial axis. Now, this line along this this line, let me call this force, let us see what force we have written along the line parallel to inertial axis. Let us say the force coming on the hull is X, let me see what 0 and Y 0. Once again let us understand that.

See, I have to have an equation of motion that tells me mass into acceleration is equal to force. Now, this side my acceleration is Y double dot O G, this side my acceleration is X double dot O G. So, mass m into that acceleration should be equal to force in this direction. So, let me call, let me define here for the sake of definition force in this direction is X 0. And force in this direction is Y 0; that means, X 0 and Y 0 are forces along the inertial coordinate system (No audio from 43:33 to 43:56).

But now, I want to also define the forces coming along this direction, X direction. You see, that is body small x direction to be big X and force in this direction to be big Y. That means, I am defining x and y to be the forces when I measured along the body coordinate access.

Moment of course, n you know here moment is going to be X to Y this direction. That is we call it n that does not that is same. Whether, you call body coordinate or X, because the z axis is same. In both the cases that are z O and small z are same, because they are both in in this case downward to the piece piece of paper.

The question, now that is asked that we are going to ask is that see from point of view of our well well the two more thing, let us also put. Now, velocities see here this side my velocity is Y dot O G, this side my velocity along this side is X dot O G. But normally, what happen I want the instant of velocity along this line along this line, this is going to be u, and I call it u. And this is going to be small v.

Because, you see when you are on a ship, you are only seeing, what is the velocity along it is own x axis and how much it is swaying. Sway is basically v, how much is a swaying with respect to itself itself. So, here comes the question know that, we are going to do it probably next class. I need to write an equation of motion.

Now, remember I cannot write in equation of motion with respect to this straight forward sailing that, this X force equal to mass into this velocity acceleration. That is, this X is equal to m into u dot. I cannot say that, because remember this body is rotating also. It is a rotating frame of reference.

So, what is of course, you probably know this of of from kinematics. Essentially I have to write this equation of motion in this frame of reference. Because, in this frame of reference there is no rotation, so if I write rather I can, I just write this in a second here and then we will go the next part.(Refer Slide Time: 46:31) I can say x 0 force equal to mass into X O G dot dot. This I can say.

Similarly, Y 0 this Newton's equation of motion and n Of course, I will come to that n. But the problem is that see, that I do not like this. The reason is because I want to write them in terms of body frame of reference. Otherwise, what is happening, see here tomorrow the body may be oriented this this way.

Then my drift angle everything changes; then next time it may be on this way. So, you know this angle drift angle or whatever not drift angle the heading angle etcetera. All that keeps changing and therefore, I really cannot tell what is that at some point for example, the ship is here my actually, the X inertial force is actually Y force sway force on the hull. When it is opposite, it will be again the opposite direction.

So, what is essential is for us, initially, to make sure that we are writing this equation of motion (Refer Slide Time: 47:40) with a frame of reference on the body. And that will require some kind of transformation to carry out.

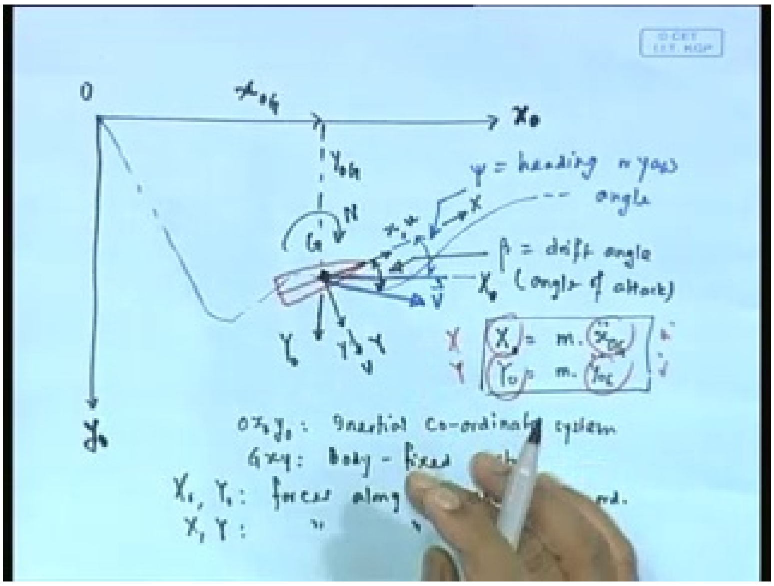
And this is actually fairly standard this transform, but the the the main question is, when I have a rotating body. A body, which is undergoing rotation along a translation rocket, aircraft, missile, torpedo, submarine anybody that undergoes a motion in a space you want to sit on the body. And you want to write the equation of motion on the body frame of reference. Because, you want to know along my X axis, I am going and how much from that I am going y axis, how much I am swaying.

So, what what we need that we have this definition that we have worked out, but we basically require to, write an equation of motion starting with this because, this is by fundamental equation of motion. I have to start with this and rewrite them change all these things in terms of this. And establish my equation of motion in body frame of reference. That is my first job.

This of course, will not have completed my story at all, because I have established my equation of motion. But my most important point that I have to ask myself was what is this X 0 and Y 0. Because this is the fluid force that is coming and in in that again I am much better asking myself, what is my X and Y, because X and Y would tell me this X is nothing, but my resistance force Y is my sway force.

See, if I were to call, what is my force in X direction and Y direction the X 0 direction Y 0 direction. It is much more confusing, because the ship can be oriented, you know on that. So, as far as hull is concerned you always want to know what is the force coming on the hull along it is X axis, and along along it is Y axis.

(Refer Slide Time: 49:46)



And that is another reason, why I have to rewrite them in terms of X Y and in terms of u v. That means, I need to rewrite these by changing this X 0 Y 0 to X and Y and changing this 2 u dot and v dot. We have to do that, we will be doing it, you know eventually, but we will have do that by using coordinate transformation.

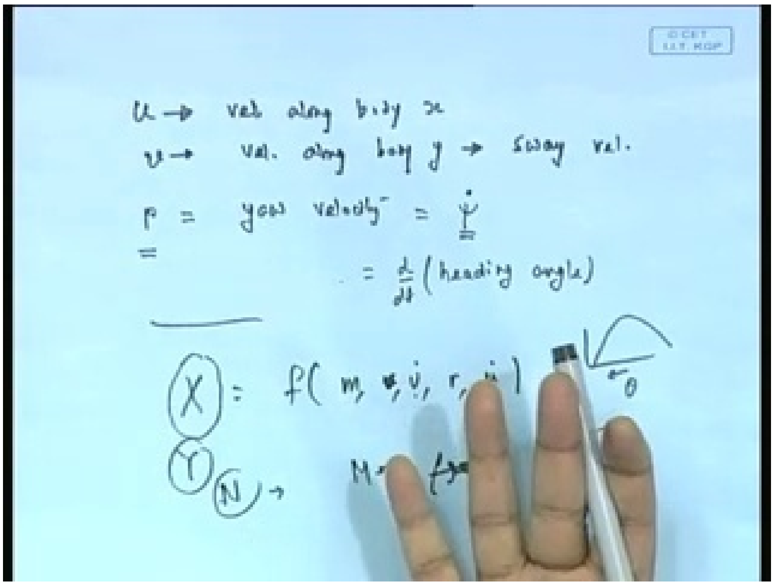
So, this remember that one one more thing, I did not write, I write it down. See, rotation we normally, do not tell this is u, this is v, rotation motion is always known as r. The velocity like u v and you call it r. In far, I should write it down, because it is this thing body access (Refer Slide Time: 50:33), u is always velocity along body x, v is this is what we call sway velocity this what is called sway velocity. Remember sway velocity is always, when I am sitting on the body, how much it is transferring transferring and this one r r is known as yaw velocity.

Actually, you will see from here (Refer Slide Time: 51:12), that r is psi dot. Remember that when you are doing dot. You it is always the rate of change of heading. Remember psi dot psi dot not drift dot. It is not beta beta dot. So, r is actually (No audio from 51:25 to 51:39), but for unfortunately, no fortunately r and psi is not sensitive on the axis system that we have chosen.

Simply because my z axis is downward to the piece of paper for both, but I can tell you that, this is not necessarily true for (Refer Slide Time: 51:58) a general 60 of body. If I were to take a submarine or a rocket or a torpedo or a missile, anybody then I would have actually much more complex equations. Then what I am going to have, because there r also will have change.

In in any case, what we will be doing then next class is that, we are going to their first write the equation of motion. That is very important, but as I kept telling equation of motion is going to tell me something like this.

(Refer Slide Time: 50:32)



You know force equal to function of some, you know mass v v dot r all that, you know u actually v dot v dot like like. It will tell me that. So, what that does not going is not going to tell me the full story. Because I am going to have to find out what is this X, what is this Y? How much does it change does the Y come down with v.

You see, remember this is a same thing what we have done in restoring force, you know see this you you just compare, I just want to tell you this and end it this n in a in a with with respect to our, you know like roll. This n was nothing, but my m which was nothing, but my rho g v into g m t into or rather G, z we may call rho g v into G z. Remember that this G z graph, if you plot as theta came down G z G z came down. Theta, as theta came down G z could not have gone up because then there would have been a violation.

So, similarly, here I have to find out, if v comes down does Y come down or Y go up. See, it is a necessary condition that, it must come down in order for, it to come to the position. Because as I am bringing back theta to 0 my restoring moment must come to 0 at theta 0, my restoring moment must be 0. Similarly, here when my v becomes 0, my y must be 0. If it was not 0 then it would continue to shift and these are the kind of questions, we will be asking and finding out there is a very…