Aircraft Stability and Control
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Lecture- 22
Directional Control

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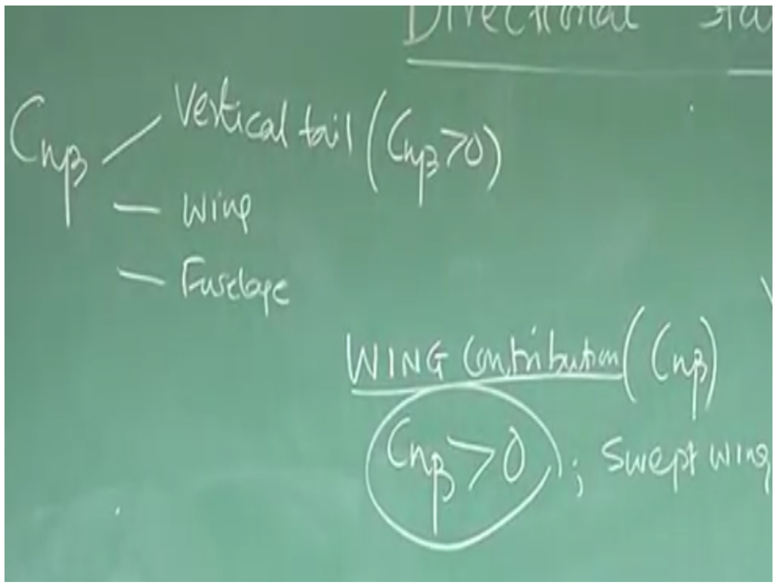

We are discussing the CN Beta effect because of vertical tail for wing and then fuselage. As I have told you for the fuselage we will be discussing all the longitudinal case or directional case in only lecture only because it needs different approach mostly empirical formula we have to use. So I will not be computing CN Beta because of fuselage here. I will not try to module it we will do it in one lecture where longitudinal, lateral direction all will be module. But vertical tail we have seen, say CN Beta greater than 0 you also know how to calculate CN Beta.

Now we are talking about wing, let us say wing contribution right. Wing contribution towards CN Beta, let us understand first the physics, why there should be a CN Beta contribution from the wing, meaning there by if the airplane is going like this if there is a side slip angle introduce because of the disturbance why should wing try to generate the hang movement either this way or that way. We are talking about the wing not the vertical tail.

We are talking about the wing right. Let us take a general wing.

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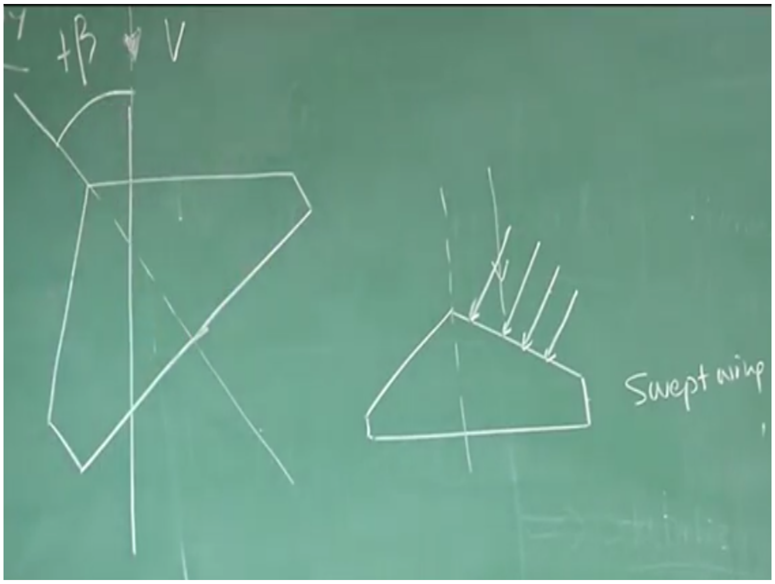

And by now you understand, this is a relative V so, this is positive Beta because relative wind is coming from the right hand side. Now we are flying like this, so now you could see 1 thing very clearly, if you see this diagram if velocity was like this, it is going like this, then the normal component to this leading edge okay because this is a sweep this is a swept wing, and in swept wing you know, you will get the desired effect through installing the aerofoil contouring in a particular fashion.

For example let me clarify what is the sweep so that you do not. Get confused between sweep and tipper ratio, and this is very, very important understanding, and you must understand.

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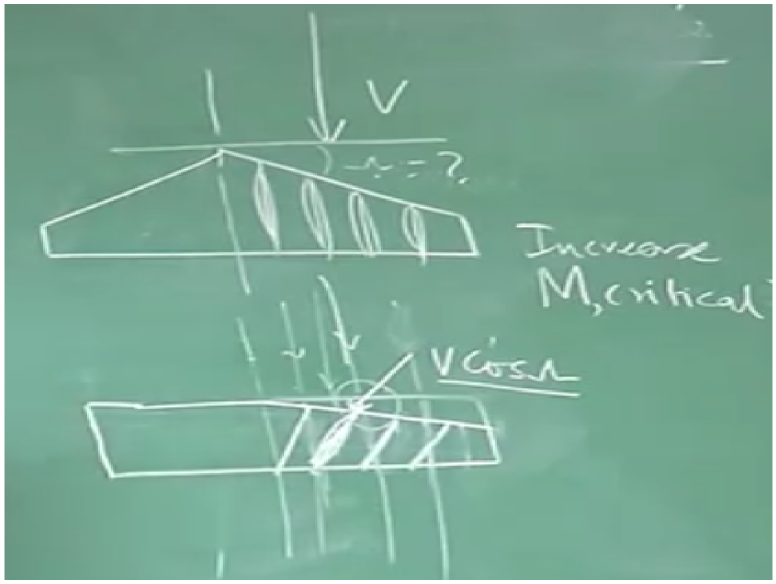

Suppose this is the platform of a wing and these are the way the aerofoil shape has been contoured. And if there is relative air speed V then do I call that this airplane is having a sweep or not? Should I tell this is having a sweep in a literal it says question is yes or no? Let us see what is the physics is behind or philosophy behind the sweep. The understanding was suppose, this is the rectangular wing and this is the free stream relative air speed okay. We understand one thing,

The most of the forces that is generated over an wing is because of the normal component of the velocity, which is on leading start on the leading edge like this okay on the normal component will leading that decide the majority of the forces. So now if I give a shape like this, and still the aerofoils are kept like this, and the normal component is same, and there is no change in normal component right, so what advantage I am getting? What is our aim for a sweep?

We want to increase the critical mark number right, we want to increase I repeat we want to increase critical mark, or M critical means critical mark number. What is the critical mark number? It is that free stream mark number at which for the first time some point on the aircraft that is mark is = 1 okay.

So that is why, if I give a sweep like this, with understanding now the aerofoil are stag like this okay. So what happens, even if the speed is like this, the normal component become V COS of this sweep angle, so now you could see free stream is V but the normal component to leading edge provided the aerofoils are stags like this, that becomes V COS Lambda so the local mark number will be less than the free stream mark number, and that is how increase M critical okay.

So now if that is true, if you understand that this is very important it should refer my first course, introduction to airplane where I think I have clarified these things. Now let us see coming back to this.

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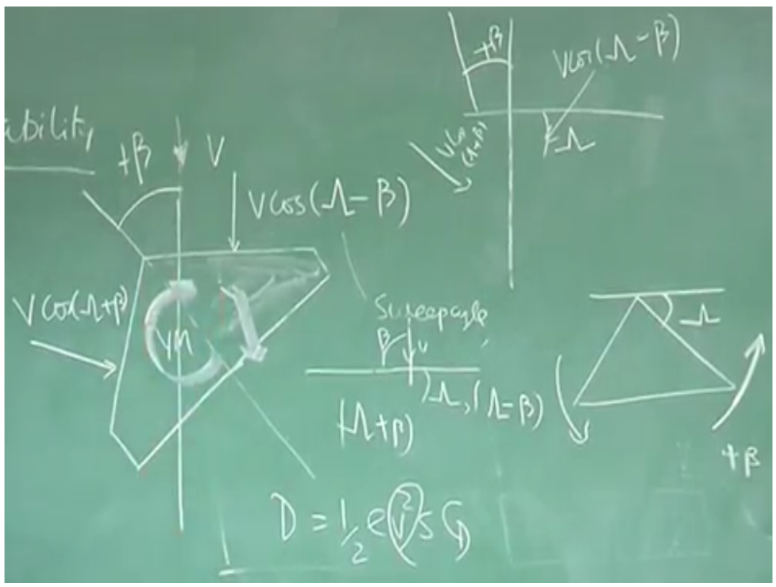

If this is the Lambda now if I am going for a side sleep that means you have being this goes like this okay it is going like this it was like initial like this now like this okay. So what is happening? How much it is turning? It is turning by Beta okay. So here the normal component will have V COS of whatever Lambda, Lambda is a sweep angle because it has gone into so it has reduced whereas the normal component here, that as increased V COS Lambda + Beta is this clear.

If I do it like this is the airplane, and let us says this is the Lambda sweep angle. Now when am trying to fly, such that there is a positive Beta, that means I will turn like this, so that relative vary speed is this, so this is Beta. So it has turned into by angle Beta, so this effective angle becomes Lambda - Beta whereas here it has increased by Beta so it becomes Lambda + Beta clear.

So the moment there is a difference in the normal component of V you could see easily that this will give more compared to this because of COS function. So what will happen? The Drag experienced by this part will be more compared to drag experience by this part because the velocity here is more drag is half row V square. What is drag? Drag is half row V square SCD so V here is more compared to V here because of COS factor.

So since there will be a larger drag here okay. So this will generate a positive Yawing and movement clear? Larger drag the movement there is a Beta it will generate larger Yawing movement, so Yawing movement positive, it will try to discourage this Beta, it would try to take it to Beta is = 0. And for my definition for positive Beta, it will give positive Yawing moment, because of drag here is more, so you say wing with a sweep, CN Beta will be stabilizing or greater than 0. Is it clear?

I repeat here again, I have understood that if this is the light and the airplane is like this and this is Lambda we are discussing about whether the wing will generate CN Beta because of wing platform whether it will generate stabilizing or destabilizing.We see we have taken a swept wing, and when it is going with the Beta that means configuration should be like this. This is positive Beta and you could see here earlier this angle was COS angle was Lambda so normal component was V COS Lambda so now what was happened as it turned by Beta.

This angle as reduced by Beta, so this become normal component become V COS Lambda - Beta, whether it has increased, so this became V COS Lambda + Beta right. Since you know because of property of COS function this will be speed will be more this speed more means drag on this wing will be more and then that drag will give a Yawing moment positive.

So it will generate Yawing moment positive for a positive Beta, so for a wing the CN Beta greater than 0, which is typically for the swept wing. And if I give you the expression, I will not derive it, or if you want I can write the expression. And you should do it yourself to get the final result.

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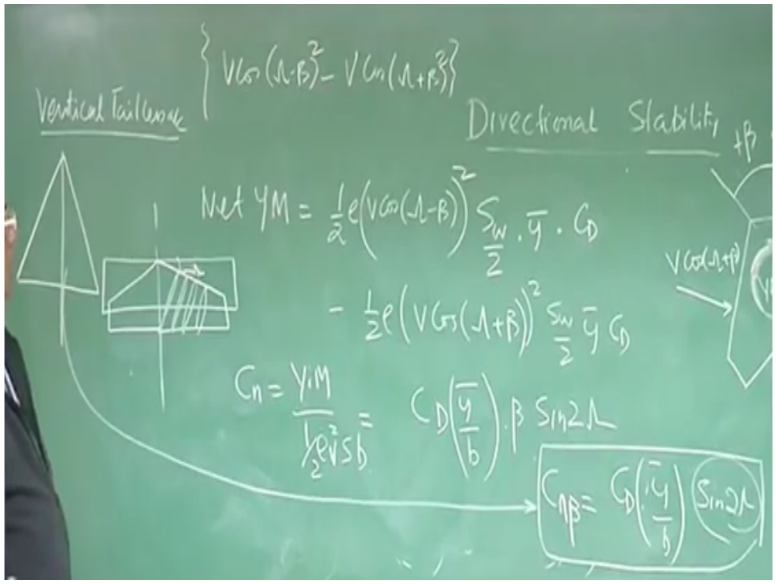

So net Yawing movement will be nothing but you see half row V COS of – Beta. This half row V square now V and the right wing is V COS Lambda - Beta so half row fV square and then half of the wing SW by 2 I have to take I am considering for right wing and I am assuming that whole force is effective at a distance let us say, Y bar okay. That typical like centroid the pressure distribution, this is this half row V square S of course you have to multiply with CD of the wing right.

This is from the right wing, from the left wing it will be - half row V COS Lambda + Beta square SW by 2 Y bar CD so this is the net Yawing movement coming because of differentiation drag between this wing and that wing and then I will find CN by dividing Y movement by half row V square SB.

As I told you, you have to derive it Y by B Beta sign to Lambda, what I have done? This V COS square if I just to give a hint, please do yourself don't expect everything will be these are all in the class 10th standard you have to expand it here by taking half row or all this thing common SW by 2 so this can be generalized by using trigonometry relationship.

And you will get an expression of CN like this. So from here you will get CN Beta = CD, Y bar by B and say SIN of 2 Lambda. What is the message here? Message is for a rectangular wing. Which is having wing like this you will not get any contribution towards directional static stability because of wing however if you can introduce sweep to this wing sweep in the right sense please understand sweep means right sense we are talking about some aerofoils also will be something like this track end then only this is the sweep if you introduce a sweep.

Then you can get stabilizing contribution, because of CD right and it will lose depend upon how much sweep angle you have given right. This is extremely important please realize there are now concept goes on vertical tailless aircraft right because the moment there is a vertical tailless you will think.

Who will provide directional of stability? But I say I do not require the vertical tail if I can give sweep to the wing that itself will give me CN Beta stabilizing. So it is nothing very mystic about this, very straight forward from the basic and the standing of life mechanics right.

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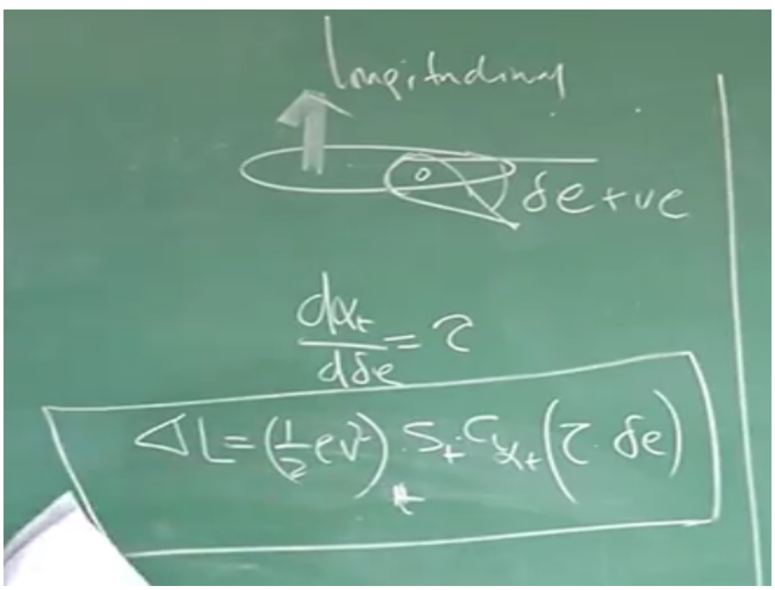

So far you were talking about directional stability now we will talk about directional control. We have seen our aircraft and have demonstrated you that for the directional control primarily we will use a rudder right okay. To take a turn like this we primarily we will use rudder but please understand all this motion can be easily be generated using different combination of control resources.

For example I can use a Ellison and still it will turn all those thing complexity you will understand but at present I am talking about primary directional control, which is nothing but rudder. What was primary control surface for longitudinal control? It was elevator okay and how we found out the control power remember what was the basis, if this is the horizontal tail, this is the elevator will see first we will define.

What is Delta E positive, this is longitudinal correct and what was the understanding understanding was let us find out how much Alpha of the tail is changed because of elevator deflection and which we denoted by tow and then we see how much Delta L will come because of this deflection that will be half row V square at the horizontal tail.

Or tail into S tail into CL Alpha tail and into whatever this is coming that is tow into Delta E. So that was the change in the lift which was here. I repeat here for longitudinal case, we knew D Alpha T by D Delta E is tow that is how much Alpha tail is changing per unit deflection of tow or deflection of elevator and then what we did for a given elevator deflection Delta E Tow into Delta E the change in the angle of attack at the tail.

So I know half row V square STCL Alpha T into that change in angle of attack will me Delta L and from there I can find out what is the control power or not.

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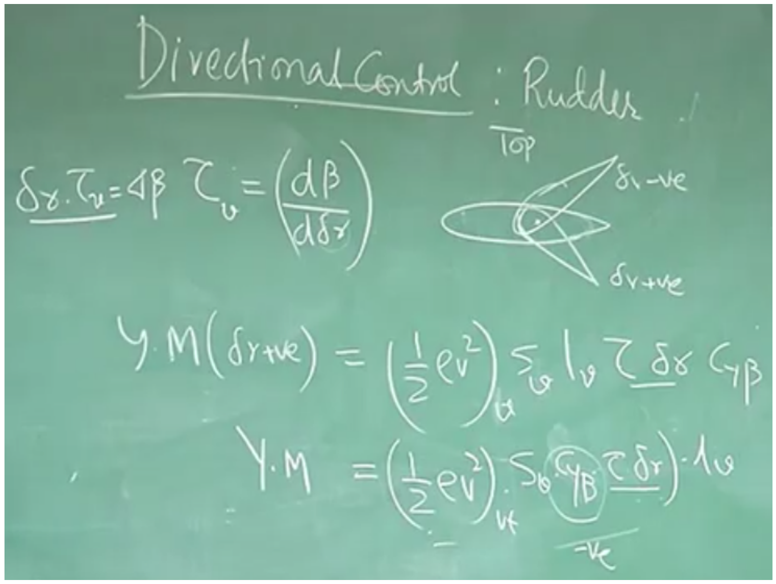

Similar thing we will do for rudder also okay. Similarly we will define tow for vertical tail as D Beta at the tail by D Delta okay. So if I am deflecting say this is the I am looking from the top okay as per the convention this is looking from the top please understand. This is the positive Delta R towards left and this is then negative Delta R let me explain this convention wise if this is the vertical tail or let me more illustrative.

If this is the rudder part okay then towards left this is the positive Delta R and towards right, it is the negative Delta R, is it clear? Towards left positive Delta R towards right it is negative Delta R at the convention. Now see what happens, if I am a giving positive Delta R like this for the force I am going forward of the force on this vertical tail will act which way? I am going like this so force will be in this direction right.

Which is in the right Y direction of positive force will generate. However the Yawing movement will be which way? Force is here CG is there so yawing movement will be lifting going back it is something like this. So, positive Delta R you could see here is generating a negative Yawing movement that you should remember. If this is Delta R positive, then what I will do I am trying to calculate, we are trying to control rudder, control power we are now expert because now we know how to calculate here.

So what will write is Yawing movement because of Delta R positive. What is Delta R positive, Delta R positive means I have shown you that the rudder is going towards left as I am flying like this, this will be = force, force means half row V square at the tail S tail and LV into what is the Beta change because of Delta R we know Tow will be D Beta by D Delta that means per unit change in the rudder deflection, how much Beta the tail is change if I multiply Delta R into tow V that will give me what is the change of Beta in the vertical tail.

So I will multiply this tow into Delta R okay and Beta into CY Beta will be the force and force into this length is moment is it clear or not? If I try to again explain you I can write it like this half the V square the vertical tail is vertical tail. So I will take out SV, LV into I will not write LV here, this is half the V square S, this is into CY Beta okay into Beta is nothing but tow into Delta R so this whole become the force into LV, that becomes the movement is it clear now. What I have done?

This tail I make it vertical tail dynamic pressure at the vertical tail no objections S vertical no objection, CY Beta into Beta should be the force so like CL Alpha into Alpha tail so CY Beta into Beta, Beta is what? Tow into Delta R was the additional Beta because of Delta deflection so this becomes the force into LV is the moment so this gives Yawing movement. What you have to check? You have seen that Delta R is positive it should give Yawing movement negative because of the force is in the direction.

Yawing movement will be negative so I have to check whether it is giving Yawing movement negative or not these are positive yes CY Beta is negative you know that, so it is indeed consistent in sign from here the Yawing movement expression I go to CN how do I get go to CN I divide by Yawing movement by.

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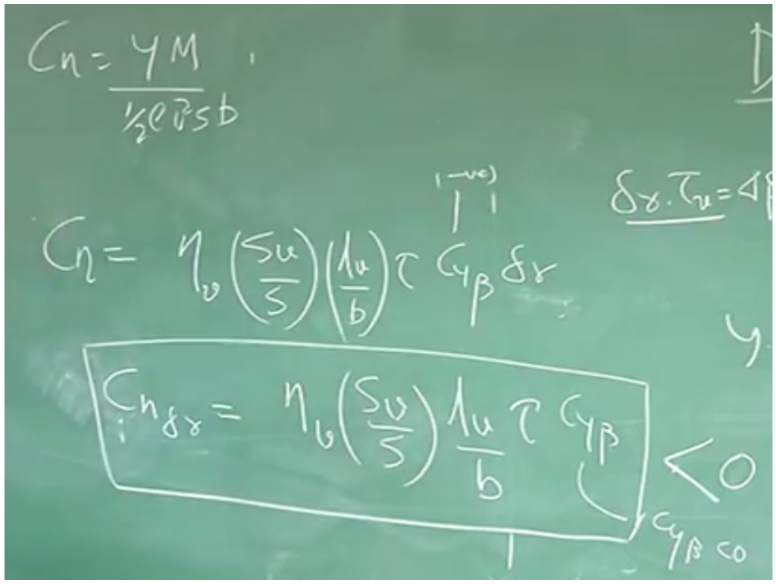

Half row V square, so CN I write as Yawing movement divided by half row V square S into B so CN I will get as Nita vertical tail then SV by S, LV by V no problem then Tow CY Beta Delta R. Let me check everything is there, half row V square so divided by half row V square free stream so it will becomes Nita SV by S, LV by V Tow okay. And I am again checking that if Delta R is positive this Yawing movement should be negative.

That we have seen physically and since CY Beta sign is negative so this is taken here we are talking about control so what is CN Delta R that will be Nita V, SV by S, LV by B Tow into CY Beta, and what is the sign of CM Delta R? This is less than because CY Beta is less than 0 now recall. Now let us go back to longitudinal case, and directional case let us make one comparison.

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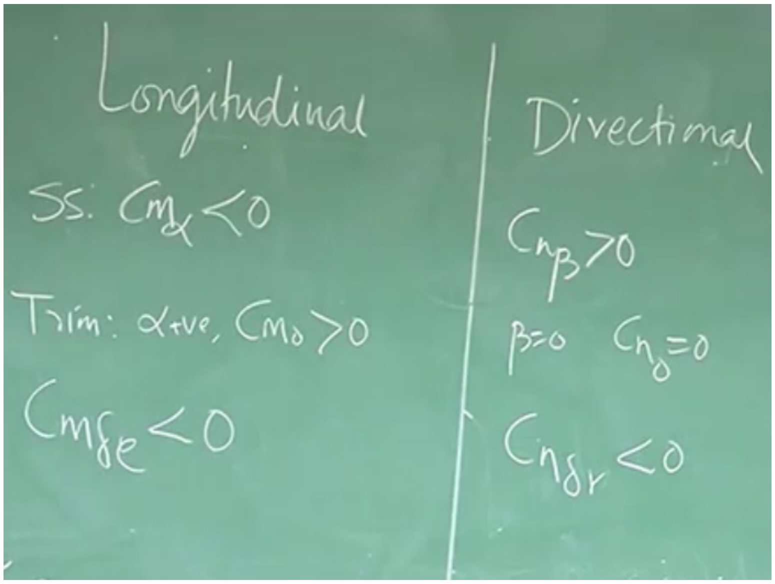

For static stability what was the condition? CM Alpha should be less than 0. So what is the condition for a static stability for directional? CN Beta greater than 0. So for trim what is the condition? Some Alpha positive or we say CM0 greater than 0. For most of the directional case trim is Beta = 0, so CN zero is zero right. What about the control CM Delta E was less than zero and here also CN Delta R is less than zero.

That sort of mapping you must have okay. Let us ask a question why you were getting involve into so many expressions, directional stability, directional control, please understand when we are discussing about the longitudinal stability, and longitudinal control we got this insight in a exhausting manner that I may like to fly at different different CL, or different different space I may take to turn, I may go for maneuver I have to go for takeoff and landing so all this things are to be appropriately understood for that we need to elaborate study on static stability.

Static margin, elevator control, power neutral point etc.,. Why we are doing all these directional stability and directional control? Because primarily we understand, we are rudder the specific role powerful enough to handle adverse yaw I will explain what is adverse yaw. Then it should be able to a symmetric power, I will explain what it is. Third is crosswind then fourth spinning and many will come what is the adverse yaw? As I told you.

If I want to go for a bank roll like this okay. let us say positive roll I have to roll like this. Roll positive by convention is right wing going back, what is happening if it is going like this we could see that this person relative wind will come upward as it is going left will come upward. So, here the angle of attack will increase compared to this which is going up and angle of attack means lift will increase lift increase means induce drag will increase.

As the induce drag increased here it will try to turn like this. So if you want to go for a roll, it will automatically turn like this. So that is called adverse yaw, and we do not want to do that when you are going for the banking. So this adverse yaw has to be controlled neutralize by using appropriate rudder deflection.

Because rudder can give Yawing movement in either direction depending upon where you have deflected. So this is one of the primary purpose of rudder. We will also see, what is purpose is on asymmetric power, that is suppose for a twin engine airplane one engine here, one engine here and one engine fails then what will happen? The moment one engine fails this will generate Yawing moment because of this thrust being alive.

So I have to neutralize this, how do I do that? So, because this thrust will be generating yawing moment in this direction I have to generate a yawing moment in this direction, who will generate this yawing moment? This is through a rudder by appropriately deflecting it okay? Which way I should deflect? I should deflect the rudder you know by now deflect like this.

This is rudder positive, if I deflect like this it will generate a force in this direction so that will give this moment which is required to nullify this moment, So rudder is extremely important so rudder control power should be assist.

It should be enough control power, so that it will be handle this sort of asymmetric power if there is a failure of engine right? Similarly for cross wind, you know what happens in cross wind? And I want to land like this and because of cross wind there is a Beta introduced so how do I land holding this cross wind effect that also we will be explaining as we will be going forward.

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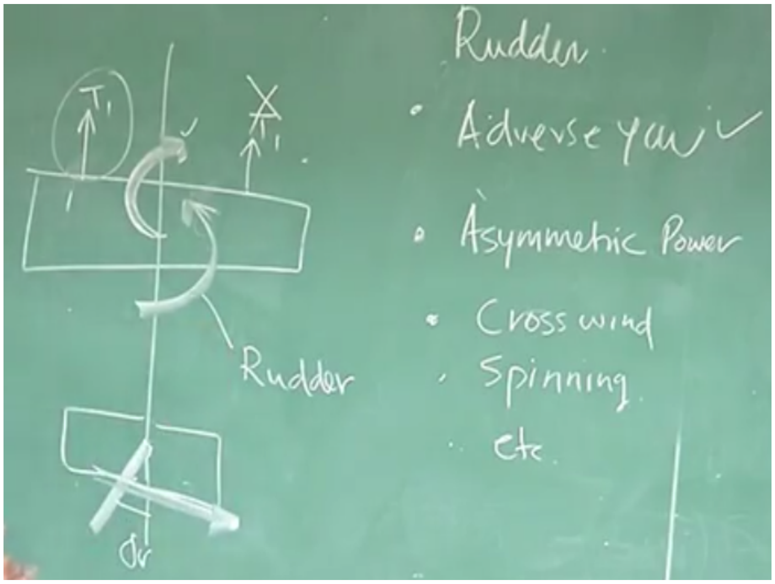

But you understand rudder is required here spinning, sometime the airplane during spinning may go to stall, stall is as the angle of attack may increase very high, your aileron etc., may not be that effective because the wing has stall but rudder can be very effective and that rudder can be used to stop this rolling motion or it can help us in taking out the aircraft from stall. So these are the things that we will be discussing, but you should know that rudder has specific purpose.

For handling adverse yaw situation, asymmetric power, cross wind, spinning to bring out the aircraft from stall and there are many such will come. So as I will be completing the lateral then we address them in appropriate sense in a appropriate time okay. We are trying to give an example of importance of rudder control. Why you should know this?

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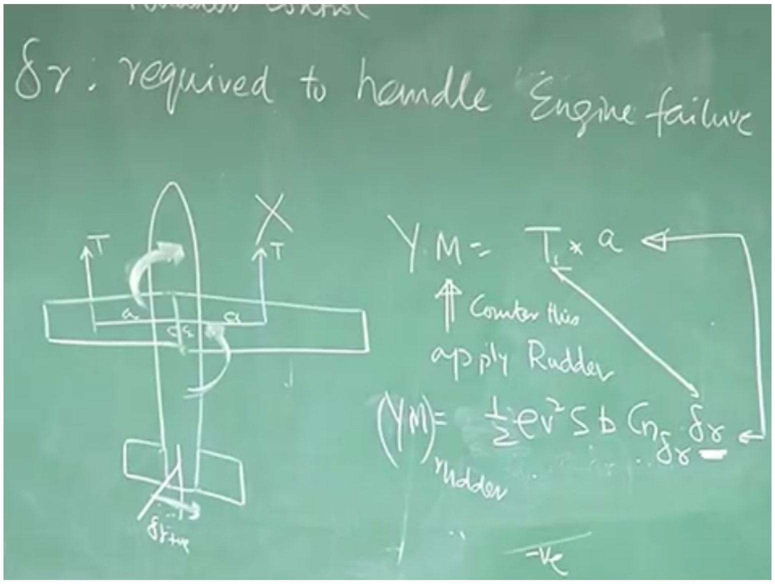

Why should not only know how it works, but you should know how to design an appropriate rudder, For a specific case, suppose this is a twin engine airplane, and one engine has failed, let us say this engine has failed in flight what will happen? The moment this engine fails this thrust is there so about CG it will give a yawing moment.

What sort of yawing moment sign will be positive or negative? You could see, it will turn like this so this right wing going back so it will be positive yawing moment. So how much yawing moment it will give? It will give T 1 into A this is the force into distance this is the yawing moment it will give.

Now what is happening? I need to correct this yawing moment, otherwise the airplane will rotate, so what I have to do? I have to give a rudder deflection to counter this to counter this I have to apply rudder. So this is giving moment in this direction so I want a moment in the opposite direction like this how can I get that moment? I get the moment if I deflect the rudder in a positive sense Delta R positive.

The moment Delta R is positive I know this force this will get this moment and how much moment rudder will give? Which is yawing moment rudder will give is will be given by this expression half row V square SB into CN Delta R into Delta R right.

We know the expression of CN Delta R by now, so these two should be equal in magnitude right. By equating this two I can easily find out, how much Delta R is required for a given T 1 is it clear? I will equate, this is the disturbing moment, this I equate with this so I can easily find out how much Delta R is required for given T 1 and then I should also know the limitation of Delta R how much Delta I can deflect for it to remain effective, right.

So, for a particular value of CN Delta R this Delta is very high so I will increase CN Delta R so that the Delta value remains within the limit so this is a very simple but very interesting and very useful approach to ensure that you can still control the airplane when one engine has failed as per directional motion is concerned right. Thank you very much.