Aircraft Stability and Control

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Lecture-23
Lateral Stability and Control

Dear Friends we will be talking about lateral stability and control so let us see what is the lateral control we have and you know by now it is the aileron that is used for lateral control. Lateral control means this is the wing, if I want to turn and bang towards right, the right wing going down. This is by convention is positive role or positive bang and if I am banking like this it is negative bang.

How do I get that movement so that it can bang like this or bang like this that is the part or role of it lateral control for this airplane we have offer a conventional airplane we use a aileron mostly for banking the airplane. Sometimes radar also we use we will talk later okay. Now see I now show you what is the aileron, you could see this an airplane Sesna 206 which has a high wing, and you know the significance of high wing.

So note down this high wing airplane and the aileron is this if I deflect it down are you able to see this Aileron this part of the wing is going down and going up okay. Are you able to see this or not clear. Now let us see if I put this Aileron down what will happen? the movement I put it down the cambered of this portion which is enclosing the Aileron part that increases positive cambered.

So, there will be a lift additional lift here and that will give a movement about CG and it will try to take the right wing going down okay. Similarly I can do one thing I can use one aileron down and that aileron up so it will give a movement. So, that the wing will go right wing will go down so positive rolling movement. If you define the CL Delta A that is DCL by D Delta A is positive that means the positive Aileron deflection would be left Aileron going down and right Aileron going up you will find.

This definition is being very nonstandard way reported in the different literature but we should know that if I define Delta A positive as left Aileron down and right Aileron up and then the sign of CL Delta A and Delta E is Aileron deflection. So, if left aileron going down right aileron going up, then than the CL Delta sign will be positive okay clear? So, far we have discussed about the longitudinal static stability and what do you understand in that, if the airplane is moving like.

This let see like this airplane is moving like this, let say cruise as an equilibrium if there is an angle of attack disturbance then it should generate a negative pitching movement so that comes back to that trim condition. So it should try to oppose right it should have initial tendency to oppose. Similarly, for vertical stability we have seen, if I take this as a vertical tail and if start side slipping because of the cross wing then the force of this vertical tail will be in this direction.

And that will give a positive Yawing movement, so for a positive Beta there is a positive yawing movement, right wing going back then CN Beta has to be greater than 0 to make a directional stability and to get the CN beta greater than 0 we are putting a vertical tail right and that is why it is called vertical stabilizer.

Another question is the airplane has one motion this, one is directional another could be lateral like this, if the airplane banks like this then it should automatically generate a movement we should try to oppose this motion, that is it is going at a trim like this because of the disturbance it has banked and if it is statically stable, then the airplane should generate a rolling movement opposite to the disturbance and we define rolling movement as moment about.

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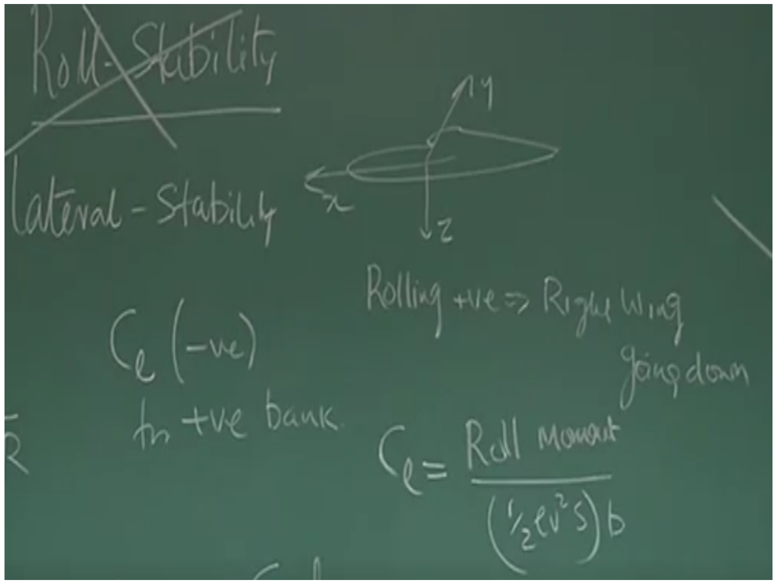

X axis that is, this is the airplane a moving like this a rolling movement is positive is right wing going down clear. Moving like this right wing going down is the rolling movement positive, so rolling movement positive is right wing going down, while I am moving with the airplane right and say for all that examples which we are being discussing, we are discussing in terms, Non-dimensional coefficient.

So we will define non-dimensional rolling movement coefficient as roll movement or rolling movement divided by half row V square S and as we have discussed earlier. We will be using span as the length to non-dimensionalize the movement right. So what do you understand, from static stability or role stability or sometimes or correctly if I say I should call it lateral stability right?

So I will not use roll stability I will use the top lateral stability because many of the books they talk about role stability but actually correctly it is the lateral stability. So what is lateral stability that I need to know if this is the trim flying like this and let's say this is the wing flying like this and if there is a bang disturbance. The airplane should automatically have initial tendency to generate a movement which will try to bring it back to the equilibrium.

So, now if you see if I am flying like this and right wing is going down so what sort of the rolling movement it is as per the convention right wing going down rolling movement will be positive that is this is the airplane wing if it is banking like this I say rolling movement is positive but to ensure that it has initial tendency what type of rolling movement it should generate it should generate movement like this because it is going down which has to oppose it so it should generate a rolling movement which is left wing going down that means it should generate a negative rolling movement.

So, from static stability point of view what we are seeing is CL has to be negative as a initial tendency the restoring movement for positive bank or role okay? How does it happen? how one has to do this, how you will ensure the aircraft as that sort of capability through its control or through its stabilizers right not control stabilizers.

Unfortunately, we will see that for a longitudinal case there is a horizontal stabilizer for a directional case there is a vertical stabilizer, but for lateral stability they are no special stabilizer for that, but the question is then how does it happen. Let us understand what happens, if an airplane is bank like this, say airplane was going like this and because of some disturbance airplane as gone to a bank angle or role angle like this.

The movement it bangs what will happen? Because initially lift was like thi as it banks the lift vector becomes like this so it will start side slipping is this clear? Again, initially when it is having like this cruise because of some disturbance let's say it has banged bank means the lead vector will also will change so, this one component of the lift vector we will try to side slip the airplane.

So, it will start side slipping like this. Now, the air will come from right hand side, but do not forget you have vertical tail sitting on the top. So because of that force which will be active on the vertical tail it will give the vertical movement. So, you will get that CL beta negative and that is how you make the aircraft laterally stabilizing static case. Let me diagram wise explain this.

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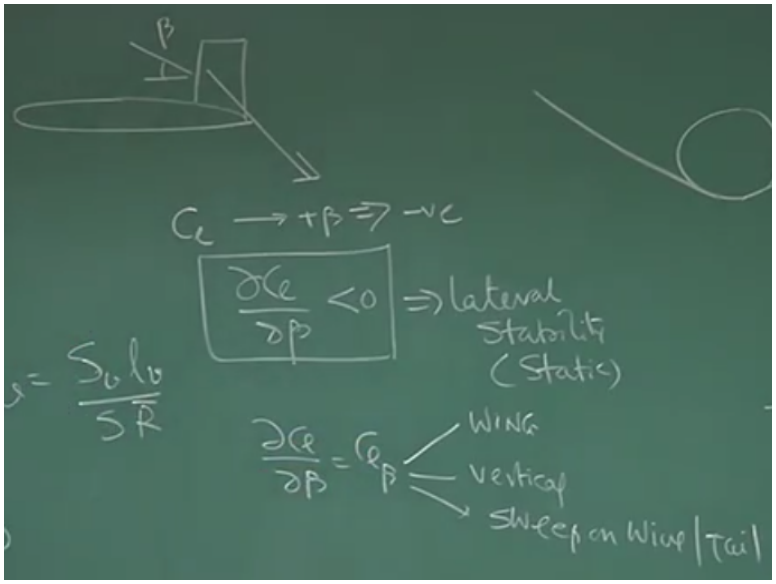

This is the airplane this is the vertical tail and let's say it has banged, it has banged means it is side slipping okay. What type of movement I want if it has banged because of the disturbance I want the movement should be generated which is negative CL should be negative who will generate this movement, this is for the vertical tail because as it banks, it will see starts side slipping so there will be a force active on the vertical tail that is if this is the airplane.

If this is the vertical tail, if it as banged and starts side slipping so there will be force acting on the vertical tail that will give a rolling movement okay and which direction the rolling moment will come, it will be left wing going down so negative so, this will give negative rolling movement. So, we will CL for positive beta this sign should be negative then it will be statically stable in lateral mode.

What is that? It has been disturbed by a positive bang angle start side slipping which is positive and that should give a negative rolling movement so as to ensure the it has a tendency to come back to its equilibrium so we will say DCL by D beta should be less than zero for lateral stability of course we are talking about static. I hope this part is clear right okay.

So, this is the physics behind the contribution of the vertical tail imagine this is the fuselage and this is the vertical, suppose the vertical tail was not on the top on the underneath the fuselage. Now, see what will be the sign of CL beta and I'm flying like this and because of some disturbance it as gone like this and it starts side slipping as it side slip the force will be acting on this and this will give further rolling movement positive.

So, will it have a tendency to bring it back to its equilibrium no so, that is why but if you put the vertical tail up again you could see as it gets disturbed in bank angle and it starts slide slipping because of force acting on the top and the movement of all the central line, it will try to give a CL negative. So in this case it will have lateral static stability but if I put the vertical tail down like this it will contribute to a destabilizing right it will never try to come back bring back the airplane, after it has banked okay.

So this is very, very important so, the sign is CL beta should be less than 0. Now the question is CL beta or DCL by D beta we say CL beta who are the contributors one is wing, one is vertical tail primary contributor and then also you will see, some sort of a sweep on the wing or tail may help right.

What do we want we want to ensure that the wing and the vertical tail they are placed in a such way, designed in such a way that for any disturbance in positive roll angle, banking like this it should automatically generate a negative rolling movement the mechanism for this is, please understand again and again. if I bank the airplane which some disturbance it starts side slipping because of the lead vector being tilted as it side slips and since the vertical tail is here that will give a force in this direction and that will try to take it opposite direction.

The left wing going back so that is CL is negative so as DCL by D beta will be less than 0 and that is the condition for lateral stability that you understand right. Now, we will be seeing the contribution because of wing vertical tail and sweep. Let us first take the case of vertical tail. Let me explain this again with a help of an aircraft, you could see this is an aircraft, this is the vertical tail.

This is the wing and this is the horizontal tail what I mean by lateral stability longitudinal stability and a directional stability and let us understand. Now for longitudinal stability please understand the airplane is cruising like this and suddenly there is a upward gust right? So, there is a increased angle of attack, it should immediately generate a restoring movement, opposing movement pitch down to ensure that disturbance is zero so we say for a positive Alpha it should have a pitching movement negative.

So CM Alpha is negative. See from here if am cruising like this if there is a positive angle of disturbance it should generate a negative pitching movement right. So, that is called CM Alpha negative or longitudinal static stability. For directional stability suppose the airplane is like this and if it is going like this the beta is zero and if it goes like this could you see what I am saying this is beta 0.

Now if it is going like this, see from here going like this, that means relative air is coming from in this direction. So this will hit this vertical stabilizer, this is will give a force in this direction and this force will give a movement in this direction that will try to reduce the beta or oppose the beta disturbance so we say for a positive beta if there is a positive yawing movement It is directionally stable that is CN beta is greater than zero.

For lateral stability what is the thing that you understand now. For lateral stability we have understood 1 thing. There are no special surfaces design for that so what is done what is the way mechanism work is suppose this is bang angle is 0, now it has banked because of some disturbance as there is a disturbance, the lived vector what was here as it is banked like this the lived vector now gets tilted, say it was initially like this as it gets banked, the lived vector is like this.

So, it as a component in this direction that will start side slipping the machine and there will be a beta introduce this beta will derived force on the vertical tail which will give a moment. Force in this direction, and this force into this distance will give a rolling moment negative please understand rolling moment positive is right wing going down, rolling moment negative is left wing going down.

So, as it bangs it sides slips beta angle is introduced at the vertical tail that gives a force in this direction, and this into this vertical distance gives a moment negative. So for a positive beta, we have CL negative, CL beta negative that ensures that it has lateral static stability clear? Once this is understood we will now try to see how do I model the contribution of vertical tail.

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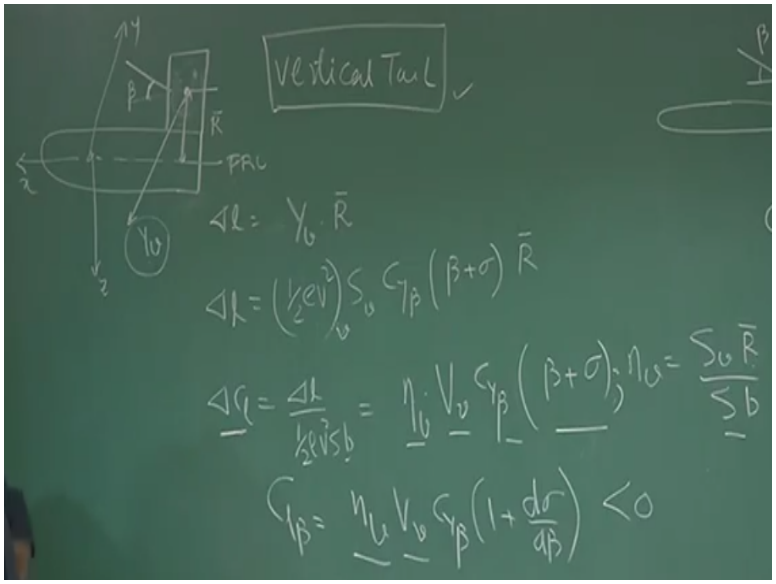

You could see here, this is the vertical tail as we have seen as it banks, it introduces a side slip so, let's say this is the beta, because of beta there is a force YV and that will be half row V square SV CY beta into beta + sigma. This is the first component into R bar, this distance is the rolling moment and thus rolling moment I can non dimensionalize this by dividing it by half row V square free stream S reference area and V.

So then you get this expression Neeta V, V, V, CY beta into beta + sigma, where Neeta V will be SV R bar by S into V and you could easily see this is also something having a nature of some sort of a volume tail, vertical tail volume ratio type okay. Now if I take CL beta, I have to just take a differentiation of this so I get NV VV CY beta + 1 + D sigma by D beta now we have to ask this question what about the contribution what is the sign of this vertical tail? You could see from here the sign will be negative, why it will be negative?

This is positive, this is positive, what about CY beta? We have already seen CY beta SIN is negative, please refer earlier lecture, CY beta is less than 0, why CY beta is less than 0? Again I will repeat you know that this is X and this side is Y and this is Z. So if there is a positive beta, the force will be in the opposite of Y direction okay Y direction is this side that is why we say CY beta is negative.

In my last or last but one lecture I have explained that, what is important here to understand the vertical tail will ensure that CL beta is negative so it will be stabilizing right. Here also please note that R bar is positive if I have taken R bar like this if the vertical tail was here then R bar will become negative and that will make CL beta positive. So it will be destabilizing, for example if it is something like this, suppose vertical tail is like this, instead of up what will happen?

If there is a beta force will act here instead we want to see that it generates a negative rolling moment, see what happens if there is a disturbance moving like this the vertical tail is now downward so what will happen? This will give a force in this direction that will give a moment we will further rotate the airplane. So if the vertical tail is like this CL beta will be positive if vertical tail is like this which is for conventional the CL beta is negative.

So this is stabilizing configuration okay as per lateral stability is concerned and we know the expression now. Do not get mixed up, just understand the physics behind it we will be solving few numerical to make you very handy about this expressions right. Now you want to come for wing.

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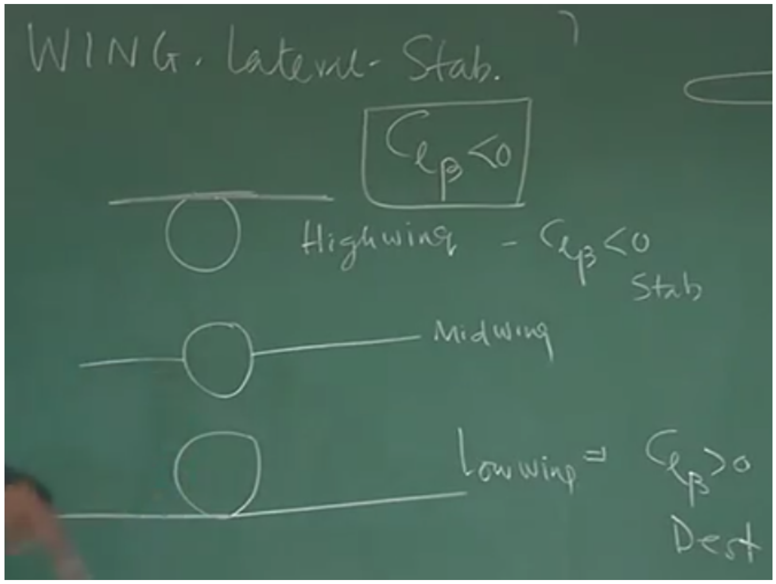

What is the wing contribution for lateral stability? You might be seeing a wing which are having led on the top of the fuselage, these are called high wing. We will have wing set at the middle they are called mid wing configuration and there are wing could be like this these are called low wing. Which one do you think will generate CL beta less than 0? What is our aim?

To have lateral stability, I repeat to have lateral stability we have seen CL beta should be negative that is the airplane is moving like this, if there is a positive disturbance in the roll or bank it should it will automatically generate beta, because it starts side slipping and it should generate a negative CL. So that is what CL beta should be less than zero to ensure that it has a initial tendency to come back to its equilibrium once it is disturbed from the equilibrium in bank.

Now from this diagram, you could see what will happen, I will just try to explain you through some sort of a illustration what generally happen, let's assume the pen is the fuselage, okay it is like this the high wing on the top of the fuselage you could see right? The high wing, now as it banks and as it starts side slipping, this because it is high wing, the air will gust in here and that will give a force which will try to bring it back to the bank angle zero clear.

Again I repeat, if it is flying like this as it banks it starts side slipping, but because this is a high wing the air will gust in and will give a force here which will try to take it towards the equilibrium or it will generate a negative rolling moment, So, this will give CL beta less than 0 and this obviously you could see, if this is the low wing, this is low wing as it bang starts side slipping the force will act on this wing if further rotate it.

So this is CL beta greater than 0 or destabilizing and this is stabilizing right. So, typically for lateral stability we put high wing so that we have adequate lateral stability but you could understand whole combination of lateral stability will be appropriately designed because you know the vertical stabilizer also gives CL beta negative this gives CL beta negative and you have to really proportionately design

Your aircraft sometimes there are maintenance issues, sometimes there maneuver ability issues so, one needs to choose between this, this and this right. Now if we have to choose a low wing, than what happens? Low wing you know, it is having CL beta greater than 0 or it is destabilizing, But say for some reason you need to have a low wing.

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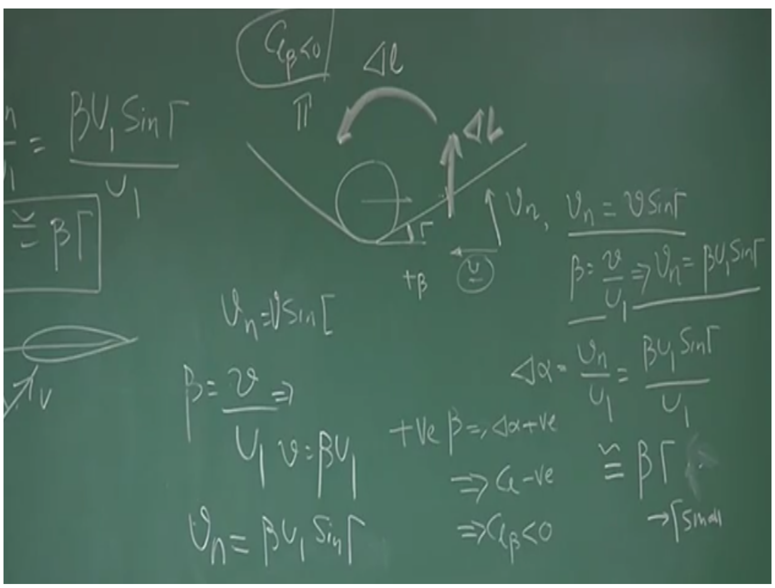

Then what we can do is, instead of putting low wing like this we can give some sort of a dihedral, this angle is called dihedral angle, it will give a positive dihedral maybe 2 to 3 degrees, and this immediately will generate CL beta less than zero right. How that will happen? Let us try to formulate that, we will do that formulation, so what is the understanding? Although the low wing was giving CL beta greater than 0 which is destabilizing, but if you give a dihedral, then that will make CL beta less than zero.

If we appropriately give the dihedral angle, how that happens? Let us derive some formulation for that, you could see this diagram I will just tell the mechanism we may not derive the expression here. Mechanism is very simple, say this is say dihedral angle Gamma and let's say it is side slipping like this. So this is a relative wing side slip velocity, that is if the airplane is side slipping like this, I can write relative speed of air is coming the opposite direction this is this.

So this I can write as this is the side slip velocity. Now please understand as far the wing is concerned, what is the angle of attack of the wing, it is the normal component divided by the horizontal velocity that is the angle of attack remember? If I am saying this is the airplane and this is the V so what was Alpha? Alpha was the normal component divided by this component. So here I will try to see what is the normal component so normal component is VN SIN of Gamma to V this is the term.

So, this component is V the side velocity in that side slip velocity into SIN of Gamma which is a dihedral angle okay. You could see that if dihedral angle is 0 than, if the airplane side slip there will be any normal component to the wing which is very clear, if it is, if the airplane is like this and there are no dihedral, if it side slips there will not be any normal component you could see from here also that if the airplane is just side slipping like this.

It is going like this, there will not be any angle of attack induced, but if it has a dihedral, then from this diagram. You could make out there will be a normal component V = SIN of gamma. So, this means you know beta is nothing but V by U1, U1 is the horizontal velocity and V is the side slip velocity. So, this if I use in this equation, I get V = beta U 1 so V N the normal velocity will be beta U 1 SIN of gamma, right okay.

Which is given here, you see here so what is Delta Alpha? How much Delta Alpha is change in the angle of attack will happen or increase in the angle of attack will happen? That will be VN divided by U 1 so beta U 1 SIN gamma by U 1 or from here you could see is Delta Alpha which is coming now if I say Delta Alpha will be = VN by U 1 this will be = beta U 1 SIN of gamma by U 1.

So this is approximately = because if gamma is small, I can write SIN gamma = gamma so what we have seen? We have seen Delta Alpha is approximately = beta into gamma the dihedral angle. What is the message? Message is if this airplane is side slipping and it has a dihedral then there is an increase in the angle of attack by this much on the right wing which is going into the wind and this Delta Alpha will give Delta lift and that will give Delta rolling moment.

So what is happening? If the airplane is side slipping because of this gamma dihedral angle it will generate an additional angle which is given by beta into gamma. Please note if gamma is zero there will not be any increase in the angle of attack it is only possible when there is a dihedral angle. So this increase in the angle of attack will give increase in lift which will give opposing moment in terms of rolling moment.

So that will give negative CL. So, we are seeing now for a positive beta again the dihedral will give us a negative CL so this will ensure CL beta less than zero so by giving dihedral angle we have seen that it helps in increasing the lateral stability or static stability okay. The derivation of exact terms I am not covering in this lecture, you can refer in your book, the basic idea is that you should understand the physics.

What is happening you can always find out what is the expression for Delta L and all by taking the total the lift and integrate using the strip (()) (27:26) theory, which are matter of details I will not be talking about this, those are interested they can check for the assignments. We will give you assignments, we will give you derivations and those things will be solved there okay?

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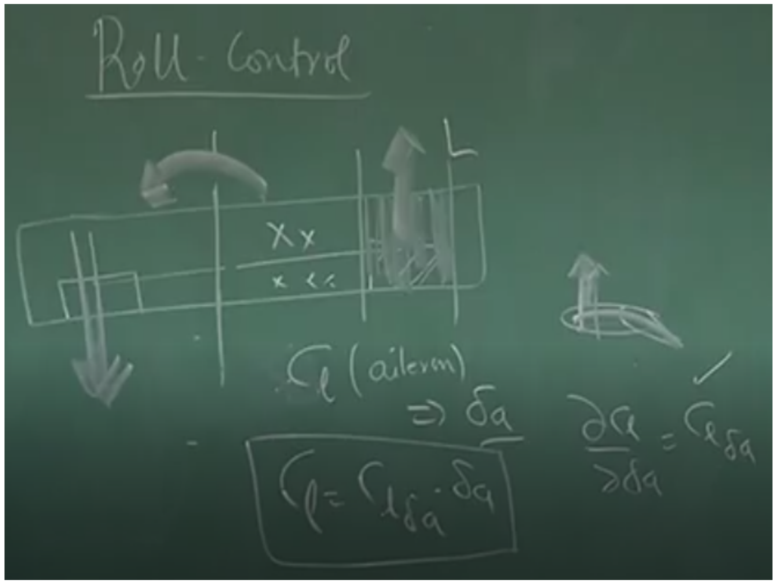

To conclude this part we will now finish our lecture by talking about roll control. We know what was pitch control, pitch control was using elevator. What was yaw control? Yaw control was through rudder, Now we are talking about roll control, that is if you want to bend the airplane right or left, which control surface I will be primarily using, Please understand rolling moment convention is right wing going back is positive, left wing going down is negative right?

So, what are the roll control for an airplane? Primary control is aileron okay. What happens if I deflect this aileron here downwards let's say this is like this, I deflect it downward so what will happen? If I deflect it downward then locally what will happen? There will be change in the cambered because this elevator has gone down correct. As it goes down it will increase there will be increase in the lift, isn't it?

Because the camber has changed similarly if I put it down it will be in the opposite direction so that this L and this L from, and if I take the moment about the center line we will generate a rolling moment that means which we will try to bang the airplane. So, what is the understanding? That if I put the aileron down here and aileron up here. Aileron down here means force will increase here, lift will increase here so that will give a rolling moment negative right.

So, again CL I know because of aileron I can generate through Delta A, Delta A is the aileron deflection and the derivative is CL Delta A and if I write CL because of aileron deflection after model it like this CL Delta A into Delta A or DCL by D Delta A is what is CL Delta A. The sign of CL Delta will be decided by what sort of sign we have given for Delta A, For CL the sign is very clear, right wing going down is positive, left wing going down is negative.

So many people define Delta A differently so depending upon what sort of positive Delta A you have define you can pick the SIN of Delta A keeping in mind that right wing going down is positive, left wing going down is negative. So, this is typically role control derivative we will be sending you some expressions for this derivatives in our block but as an understanding.

You should know that when I am deflecting the aileron here this portion of the wing aerofoil is getting or this portion of the wing is now having a different aerofoil, that is loosely saying they have become more cambered, however nothing is happening here in a isolated manner. So, when we try to find out what is the affect of differential lift here and here we have to take care of this and I will give this expression in pme of our block right okay? But you understand this. Thank you very much.