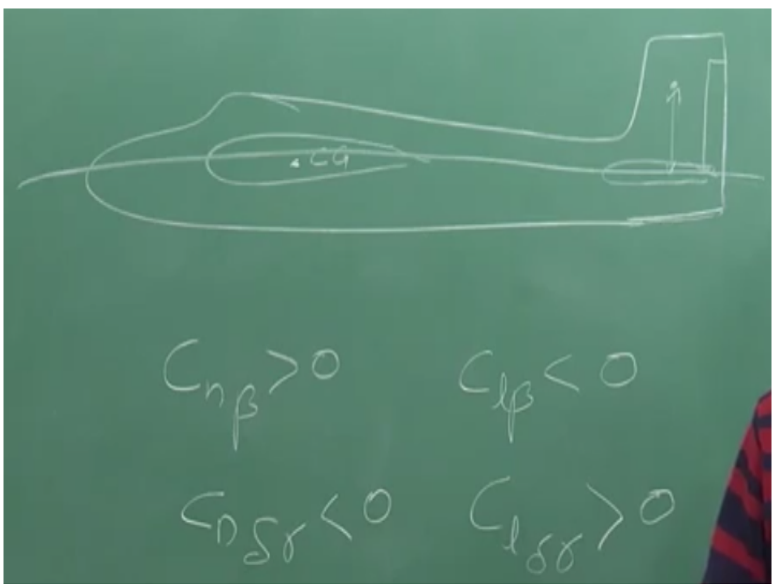
Aircraft Stability and Control
Prof. A.K. Ghosh
Department of Aerospace Engineering
Indian Institute of Technology-Kanpur

Lecture- 24
Directional, Lateral Stability and control

Hello friends, I am Vijayashankar Dwivedi, TA in this course. In this week in previous lectures, you have studied about the directional stability, direction control, lateral stability and the lateral control. You have studied the stability derivatives, CL BETA and CN BETA and the control derivatives CN DELTA R, CN DELTA A and CL DELTA R and CL DELTA A, we have seen for the stability, we need the positive value of CN BETA and negative value of CL BETA, if we see in a conventional design.

(Refer Slide Time: 01:02)

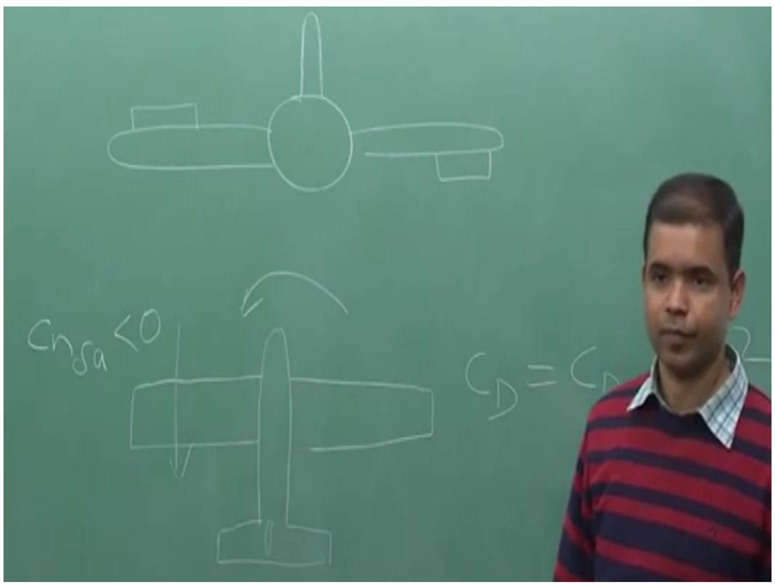


This is our aircraft for the positive value of BETA, we can see this surface will feel a force outward in this board and this will give a positive yawing moment so the CN BETA will be positive or the contribution of this vertical tail is positive towards the CN BETA. And if you see for the CL BETA when we are the positive value of BETA, this there will be a force outward this board and suppose is the aerodynamic center of this vertical stabilizer, and this the body X axis. So there will be a rolling moment because of this arm.

For the positive value of the BETA, this roll will be negative so we can say the contribution of this vertical tail is negative towards CL BETA and for the control derivatives suppose this is our rudder if we deflect this rudder will some positive value, there will be a force in what this board and this will give a negative yawing moment. So CN DELTA R will be negative and for the positive deflection of the radar the roll generated due to this extra force will be positive.

So the value of CL DELTA R is greater than 0 and when we deflect the aileron with positive value means right aileron up and left aileron down.

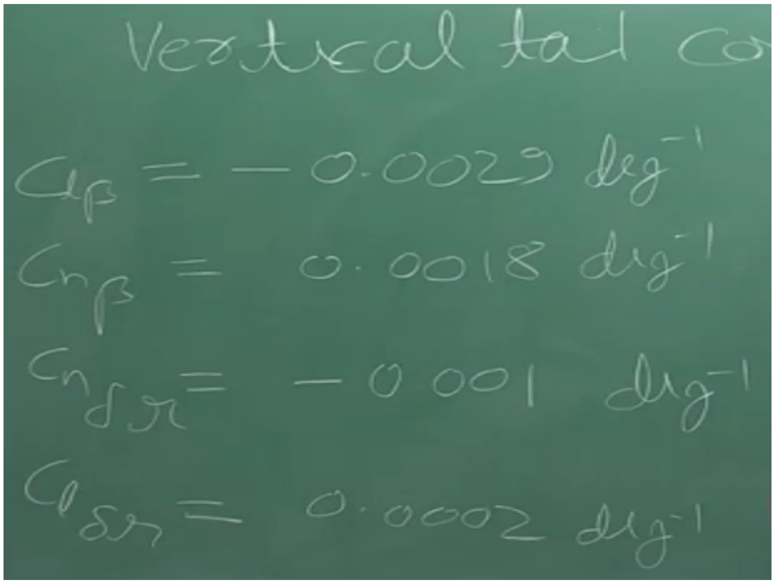
(Refer Slide Time: 03:40)



There will be a positive roll, so we can say the CL DELTA A is greater than 0, and next control derivative CN DELTA A for the positive deflection of aileron means right aileron up and left aileron down if I see the front view, this is the front view right aileron up and left aileron down in this case, this wing will feel the more lift, and as you know the CD = CD0 + KCL square and here you can see the CD.

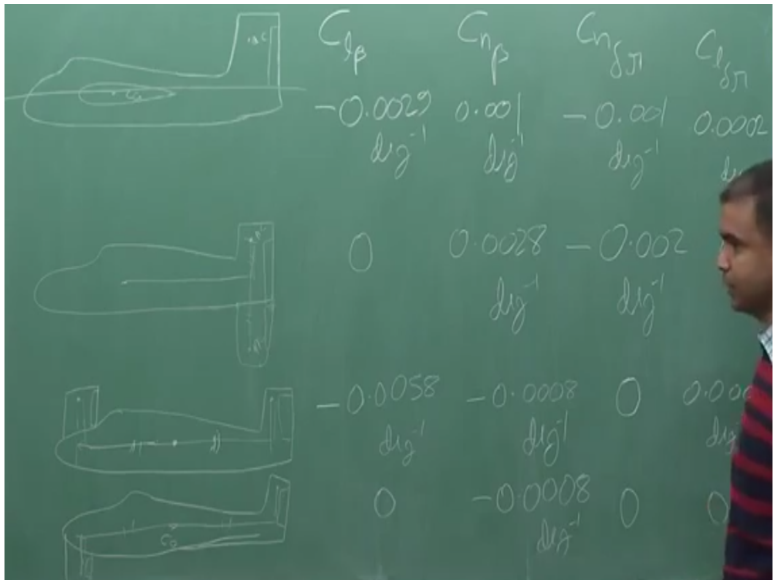
Is increasing with the square of value of the CL means, if the lift increases on the right wing this will significantly increase the value of drag, and this will give yawing moment. If I see the top view of the aircraft, on this wing there is more drag and this will try to yaw the aircraft with some negative magnitude and that is why for the positive deflection of aileron we are getting value of Yaw. So CN DELTA A will be negative. Let us solve one problem for a closure look of these derivatives.

(Refer Slide Time: 05:39)



For a conventional design the vertical tail contribution for the CL BETA is – 0.0029 per degree CN BETA is 0.0018 per degree CN DELTA R is – 0.001 per degree and the CL DELTA R is 0.0002 per degree and the wing and the fuselage contribution for the CN BETA, ring and fuselage is – 0.0008 per degree, and the contribution of wing and fuselage towards the CL BETA is 0. So what will be these variables for the aircraft?

(Refer Slide Time: 07:22)



Let us find this is our design suppose, suppose this is the CG the aerodynamic center of the vertical tail is somewhere here this is the body X axis now this is the rudder what will be the value of CL BETA for this design? We can see the contribution of the CL BETA of the vertical tail is – 0.0029 per degree and the wing and fuselage contribution to CL BETA is 0.

So the net value of for this aircraft for CL BETA will be – 0.0029 per degree. What will be the value of CN BETA? The contribution of wing and fuselage to the CN BETA is – 0.0008 per degree and don't get confused with this - sign because if our CG is located in such a way, if we have only wing and fuselage and about this axis about Z axis this portion is creating more moment.

Then this person in that case this will be negative because the positive BETA this will generate a negative yawing movement that's why this CN BETA wing and fuselage is this. But after installing a vertical tail, our net value will become positive and that is our requirement for the stability means the vertical tail is providing us the directional stability so what will be the value of CN BETA for this configuration? We have to add it this simply wing and fuselage contribution is – 0.008, and the vertical tail contribution is 0.0018, so net will be 0 point 0.01 per degree.

Now coming to the CN DELTA R the contribution of the wing and fuselage is 0 the CN DELTA R is – 0.001 and this will remain as it is so this will be – 0.001 per degree coming to the CL

DELTA R the rolling coefficient derivative with respect to the rudder deflection. CL DELTA R is given towards is the 0.0002 so this will remain as it is 0.0002 per degree. Now the question is if the designer installs one more vertical tail.

At this position these both vertical tails are identical and there momentum arm from the CG the yawing momentum arm is same for both the tails and the rolling arm suppose the aerodynamic center of our for this tail is somewhere here, and this 1 is somewhere here, these are also same so what will be the derivatives for this design? Let us see the CL BETA when we had only one tail for the positive side slip angle it has a tendency to roll the aircraft with some negative value.

Now for the positive BETA this surface will try to roll with some positive value and both are identical so both will nullify each other and the resultant value of the CL BETA of this aircraft will be 0. Because there is no contribution of the wing and fuselage this is 0 now what will be the value of CN BETA for this configuration?

For the positive side slip angle this surface has a tendency to provide positive yaw this also feel a force to outward this board, and that will also try to give a positive yaw and both are identical this yawing arm is also same, so the contribution of this will be added to this aircraft into this the vertical tail contribution of the CN BETA is 0.0018 and of this design its 0001, so net will become 0 point 0.028 per degree, now coming to the CN DELTA R, suppose this is the rudder in this surface also there is a rudder.

And the sign convention is same for both the rudder, if you give a positive deflection into the radar this will try to give a negative yawing moment, this also will try to give a negative yawing moment, because for the positive deflection this will also feel a force in what to this board and that will give a negative yawing moment. So net will be doubled and this will become – 0.002 per degree.

Now coming to the CL DELTA R for the positive deflection of the rudder, if this is the aerodynamic center, we can assume the force to applied at this point and because of this moment arm, it will have a tendency of the positive roll, and for this surface the force the direction of the force will be similar for the positive deflection of radar but this will give a negative roll so net will be 0. Now coming to the next part of this question the designer has installed.

This is our original design and now the designer has put one more vertical surface at this position. The momentum for this suppose this is the aerodynamic center of this one and for this aerodynamic center is here, for the both the moment arm is same suppose the CG is somewhere here. So what will be the values of these derivative?

Coming to the CL BETA due to this surface, it was - point 0029 for the positive BETA, this surface will also have a tendency of the negative roll, so both will be added up. Now this arm is same for the both surfaces so the magnitude of moment will also be same and the net will be added and this will become – 0.0058 per degree. Now the CN BETA for the positive side slip, this will have a tendency for a positive Yaw and this surface will have a tendency of the negative Yaw with the similar magnitude because the arm length is same.

So the net will be wing and fuselage contribution and wing and fuselage contribution for the CN BETA is – 0008, so this will become – 0.0008 per degree. Coming to the CN DELTA R for the positive deflection of the rudder this surface had a tendency for negative Yaw and this surface will have the tendency for the positive Yaw and this moment arm is same for both the surfaces, so their net will become zero so this derivative will become zero for this configuration.

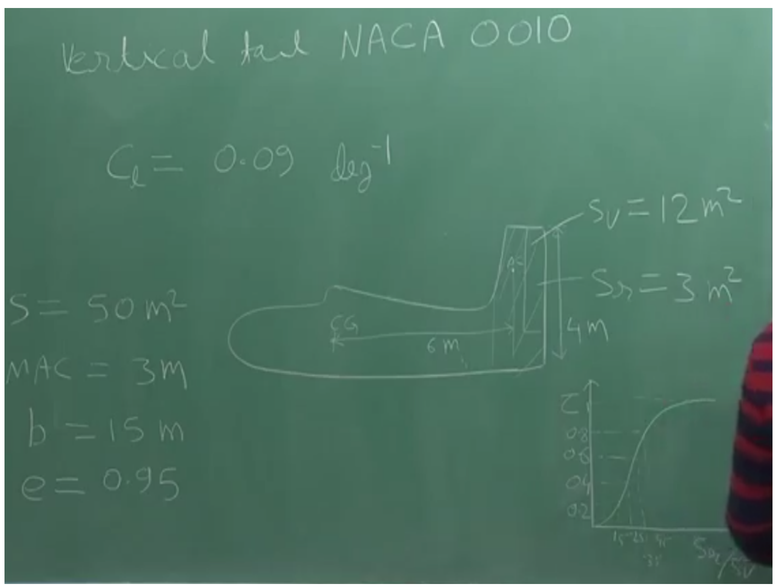
Now what will be the CL DELTA R? For the positive deflection this surface has a tendency of the positive roll and this also will have a tendency of the positive roll for the positive deflection, the force applied here will be inverting this board, and this will try a positive roll, and this will become 0.0004 per degree and the last of this question is now the designer has installed one vertical surface here.

And the moment arm for this and moment arm for this tail is similar and the rolling moment arm is also the same. So for this configuration CL BETA due to this vertical tail it has a tendency of the negative roll for the positive BETA and for the positive BETA for this surface it will have a tendency of the positive roll so net will become zero. Because both has the equal moment arm for the roll, and the CN BETA this CN BETA for the conventional diagram.

We have 0.001 and for the positive BETA this will have a tendency of the negative Yaw, and the magnitude will be – 0.001 per degree, so the net will become – 0.0008 per degree, and the CN DELTA R for the positive deflection of the rudder this rudder it has a tendency of the negative Yaw and for the positive deflection of this radar it will have a tendency positive Yaw and the net will become 0 because this moment arm is same now the CL DELTA R.

For the positive deflection of the rudder this surface has the tendency of the positive roll this will have a tendency of the negative roll. So the net rolling moment coefficient will become 0.

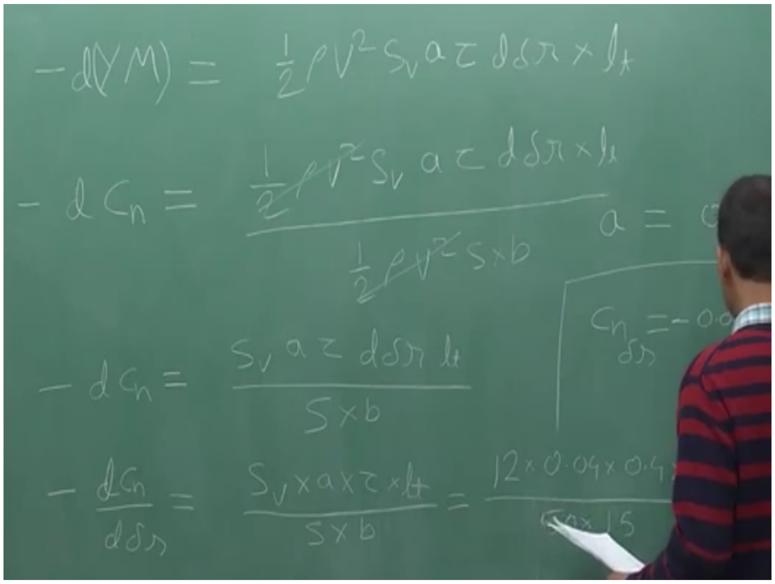
(Refer Slide Time: 20:11)



Coming to the next problem, an aircraft has vertical tail having a symmetric aerofoil NACA 0010 with lift come slope of aerofoil 0.09 per degree and the vertical stabilizer area 12 meter square and the rudder area is 3 meter square. And the span of the vertical tail is 4 meter and this aerodynamic center of the vertical tail from the CG of the aircraft is 6 meter and we are given the wing area is 50 meter square.

And the mean aerodynamic chord is 3 meter and the wing span is 15 meter and the dynamic pressure at the tail is free stream dynamic pressure, and the span efficiency factor is 0.95. And we are given this plot this is SR by SV and this is TOW we have to find the rudder control power. What is the rudder control power? It is nothing but the CN DELTA R.

(Refer Slide Time: 24:08)



We can write the yawing moment due to change in the rudder deflection, for the positive deflection we will have a negative yawing moment, so we can write - DYM, DYM because the change in the deflection. And this will be the force, and this vertical tail multiplied by this moment arm so this we can write area of tail that is SV and we need the lift coefficient of this vertical tail and we have the 2 D lift coefficient.

Now we will have to convert it into 3 D lift coefficient and we know this is given y ,suppose A is the 3 D lift coefficient, then we can write it A0 by 1 + A0 by PI AR aspect ratio into E this is A0 and here substitute these values this will be 0.09 divide by 1 + 0 point 09 by pie, and aspect ratio of this surface this span is squared by area span is 4.

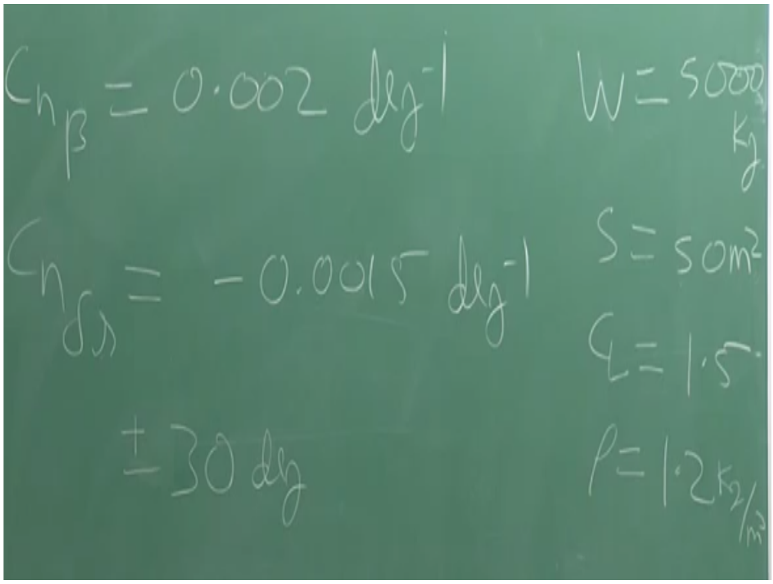
So we can write aspect ratio, span is 4 meter so 4 square by 12, and this will be 1.33 and is going to 0.95 and keep in the mind this we always write in radians and this is in per degree, we have to write in per radian so we will have to multiply it by 57.3 the unit of this will be unit of this, and this will be always in radian.

And by solving this we will get the 3 D lift coefficient of the vertical tail, and this is 0.04. Now let me erase this part, this is A lift coefficient and now we need to multiply this with the angle also, and as we know the Tow is = D BETA by D DELTA R the change angle of attack absorbed at this vertical tail with per unit change in radar deflection. For our vertical tail this SR by SV, we can write it 3 by 12 and this is 0.25 and corresponding to 0.25 we have the value of TOW 0.4 and from here we can find D BETA and this is TOW into D DELTA R.

So I can write it angle as TOW D DELTA R and because this is the moment, so I need to multiply it this arm length and suppose we write this is LT into 6 meters. Now to find yawing moment coefficient, I need to divide this by half row V square wing area and wing span, and then I will get - D CN half ROW V square S into B this will be canceled, and now we are left with - DCN is = SV into A into TOW D DELTA R LT divided by S into V, and now if I bring this D DELTA R the left side, so I have - DCN by D DELTA R = SV into A into TOW into LT divided by S into V.

And now I substitute this values SV area vertical tail and it is 12 meter square, the 3 D lift coefficient is 0.04, the TOW we got it 0.4 of 1 into point 25 SR by SV and LT is 6 meters, they divided by wind area this is 50 meter square multiplied by the wing span, that is 15 meter and I solving this we will get the value of - DCN by D DELTA R and this will be 0.001536 per degree, and DCN by D DELTA R is nothing but the CN DELTA R, this will be – 0.001536 per degree.

(Refer Slide Time: 32:27)



Coming to our next numerical an aircraft has directional stability, CN BETA is = 0.002 per degree and the radar control power CN DELTA R is – 0.0015 per degree and the maximum allowable radar deflection is + - 35 degree we have to find the maximum cross wind velocity, that can be handled during landing.

(Refer Slide Time: 33:49)

And we are given with the weight of the aircraft, 5,000 kg the wing area as 50 meter square, the CL during the landing is 1.5 and at the C level the density of air is 1.2 kg per meter cube now we have to find the maximum. Allowable cross wind that can be handle during landing, suppose this is the top view of the aircraft, due to the cross wind here will be BETA, and due to BETA there will be one force acting on this vertical stabilizer in this direction.

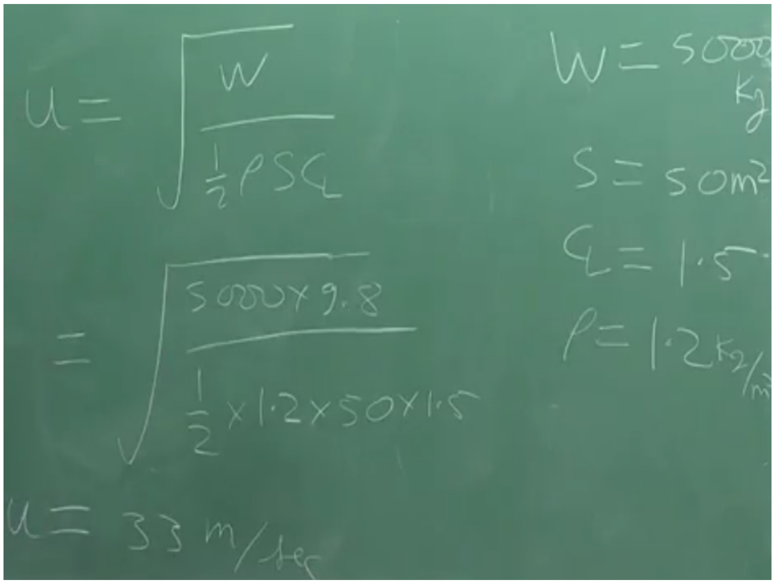
And for the landing we will have to balance this force by deflecting the rudder and now suppose the BETA is positive in that case we will deflect the rudder in this direction, now we have to find the maximum allowable cross wind speed. And for the maximum speed we will have to deflect with their maximum amount, so we have to deflect this rudder with the thirty degree, this is the maximum rudder deflection given to us.

Now during the equilibrium, due to the rudder deflection the force will be acting in this direction, this force will be acting in this direction, and we have to balance the moment about CG, at the time of landing so both moments must cancel each other, or we can say the algebraic sum of the both moments will be 0. So we can write CN BETA into BETA + CN DELTA R into DELTA R is = 0 to do not get confused with this positive sign because this CN DELTA R is already negative so this is taken care of.

And from here I can write the BETA is = - CN DELTA R into DELTA R divided by CN BETA and if I substitute this value in this equation I will get BETA is BETA is = 22.5 degree. Now we have this BETA and as we know we are given with the CL, and weight of the aircraft from here we can find this forward speed, suppose if I write.

If I write this with the U, I can find U from here if I have the BETA and U I can find the crosswind velocity the maximum crosswind velocity also, so now let me calculate the value of this forward, speed U.

(Refer Slide Time: 36:43)



And I can write U is = route over W by half ROW S CL during the landing and if I substitute these values, 5 thousand into 9.8 let as to constant half ROW is given to us 1.2 kg per meter cube, the area is fifty meter square and the CL is 1.5 and from here I will get the value of U, is = 33 meter per second. So now I have this U 3 meter per second and BETA 22 degree from this U and this BETA I can find this velocity the resultant velocity.

Of the cross wind and this forward speed and we know this U is if I write this with the capital V so U is the V COS of BETA and from here V is U by COS BETA and the cross the maximum cross wind speed will be V SIN BETA. So I can write and I write this with the small V, I can write V = V SIN BETA, and this will be U by COS BETA into SIN BETA and this will be U Tan BETA and if I substitute these values into this will be the U is 33 meter per second.

And BETA is 22, so TAN 22 degrees this will give as the value of maximum crosswind that can be handled with the radar and that will be 13.66 meter per second, so now we have the maximum cross wind speed, that we can handle with the with this radar. During landing that is 13.66 meter per second, now here you can absorb the BETA is - CN DELTA R into DELTA R by CN BETA, and you can see if I increase CN BETA means my aircraft becomes more stable.

In that case I will have to either I will have to improve this CN DELTA R, or you can say the radar control power or you will have to deflect the radar with the more amount, so the message if your aircraft is more stable means higher the value of CN BETA, the pilot will require more effect to fly the aircraft. Thank you.