Flight Dynamics II (Stability)
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Module No. # 07
Lateral Directional Static Stability and Control
Lecture No. # 21
Power Effects, Roll Control, Aileron

So, just for the sake of completeness, what we will look at today is power effects on directional stability. Actually it not so much, at least in the text books available, you do not find much of mention of this part.

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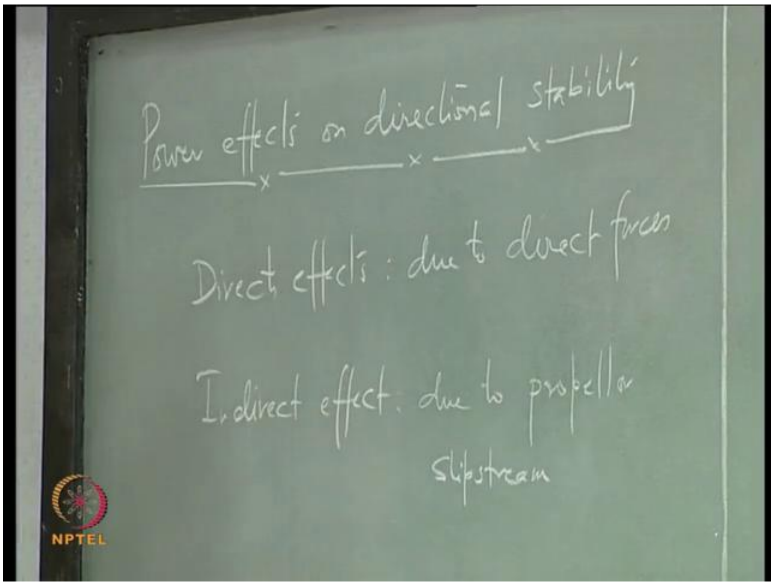

So, even though we have some information available in the book by Philips, and in Perkins and Hage, other than that, most of the text books will talk about the difficulties involved in finding contribution of indirect effects of propeller on $C_{n\beta}$ and $C_{l\beta}$. So, direct effects are … are coming from the direct forces which are being generated at the propeller disc right, and indirect effect is due to …..

So, indirect effect is due to propeller slip stream.

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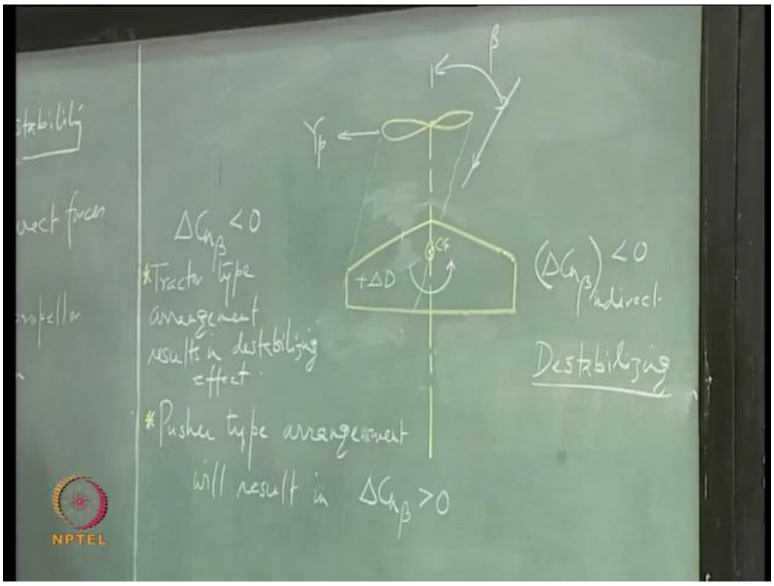

So, let us say the propeller is rotating, right, and there is an unbalanced force because of this propeller, which is in the negative Y direction right, and this force can be, because of this side slip angle. So, which way it is going to create a moment, negative yaw moment.

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So, delta C n beta contribution in this case is $\Delta C_{n\beta} < 0$, for positive beta you are getting, a negative yaw moment, right. So, this is the destabilizing effect. Again to quantify which way this force will be acting, you know someone has to verify that before, you can comment on this part, before you comment on the directional stability. What happens if this propeller, you know, this is a, what kind of arrangement it is, it is a tractor arrangement, you are pulling the aircraft.

The aircraft where you have pusher engines, in those cases (Yp is behing the CG giving poisitive yawing moment), ...Now, this gives me a positive yawing moment for positive side slip. So, pusher type arrangement, this is giving me a stabilizing effect ($C_{n\beta} > 0$) in the directional motion.

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What else? These are direct effects because of the forces being created at the propeller disc. Indirect effect is due to the propeller slip stream. So, how propeller slip stream is going to affect the flow behind, that is what is going to also add to this delta C n beta. And we said if the flow is coming at a sideslip angle beta, look at what is happening because of this particular arrangement.

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So, flow is affecting this part of the wing right, and because of which, there will be an increase in what, the drag (D) on this part. So, delta D which will be increased, because of this propeller slip stream. So, you know that you are going to have a yawing moment, because of this increase in drag. So, delta C n beta contribution indirect, positive sideslip is going to give you a negative yawing moment $(\Delta C_{n\beta})_{\text{indirect}} < 0$.

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You know, when we have a tractor type arrangement, because of this sideslip beta there will be an unbalanced force in the XY plane, which will create a moment about the c g, yawing moment, and that yawing moment is what, is negative right, because it is rotating like this. So, your Y is moving towards X axis, that is when we say that it is a negative yawing moment. So, delta C n beta is going to be less than zero. For positive sideslip you are having a negative yawing moment. And that is a destabilizing effect. For the same, now you can argue in the same manner and you can say that the pusher kind of arrangement can result in, for positive sideslip, can result in positive yawing moment, and that is a stabilizing effect. C n beta should be greater than zero for stability in yaw ($C_{n\beta} > 0$).

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And third case is this. When propeller slipstream is affecting the flow over the wing, that is going to create additional drag on this part of the wing (portside, left side), and that is going to give you negative moment. Now, let us, so, we are more or less done with this part; the only thing remaining is now, the control, control in we also looked at the directional control. So, one control which is left is now the control in roll.

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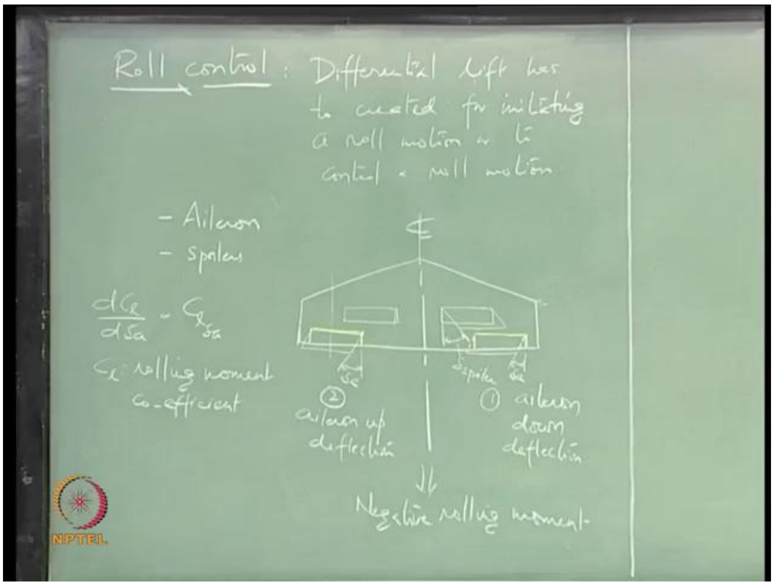

So, you know that to initiate a roll motion or control a roll motion, you have to create differential lift over the two sides of the wing.

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Which control is used for, which control surface can give you this? Aileron right, anything else? Aileron and spoilers. So, let us look at (sketch) .....

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So, look at how they look like (sketch).

(No audio from 14:45 to 14:50)

This spoiler is a flap which is on the top surface of the wing. It is mainly used for creating drag. So, it will be somewhere .... So, if you do not want to, know, create drag, but you only want to change the, or initiate a roll, you just deflect one of the spoilers, it cannot go down, it can only move up. So, on the top surface of the wing; so, you can deflect one of the spoiler, and that is going to change the lift. So, differential lift is created even though the other is in the neutral position. Is it not?

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So, main control for roll is aileron, we know that much, and where should it be located on the wing? Towards the tip, because we want a larger arm length. So, it will be located somewhere here (outboard side of the wing).

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And now I can change the camber of the wing by deflecting aileron, at these locations, in this part (where ailerons are located). So, that I can create or, or I can change, change the lift by some amount so that I can get roll.

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Now, convention is that, like we have, what we have been seeing for C n delta r or C m delta e, you know, the control power is having a negative sign. Cm delta is negative and Cn delta r is also negative. So, a positive aileron deflection should give me a negative rolling moment ($C_{l\delta a} < 0$). So, what should be aileron deflection up on the, what should be the sign of this aileron deflection? So, if you want a larger roll, you can simultaneously deploy (aileron on) both sides. So, this (left side aileron) will go up, this (right side aileron) will go down. Is it not? You cannot have both of them up, because that is not going to give you a differential lift.

So, this, let us say I deflected aileron up what rolling moment it is going to give me and that side is let us say down.

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Let us say both by same amount. So, this (right) one is going to give you a change in, positive change in angle of attack at this section on the wing. So, correspondingly increase in the lift. And this (left) is, up deflection, is going to decrease the lift, and what is the sign of the rolling moment, because of this? Lift is more here. So, what will happen? Z will move towards Y, Z axis will move towards Y axis, is it not? What kind of roll that is? Negative.

So, in this particular arrangement when on this (right) part of the wing.

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Because of this, we get a negative rolling moment.

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So, this is a positive arrangement of aileron deflection right which is giving me negative rolling moment and let us try to find out an expression for this derivative, or change in rolling moment coefficient with respect to change in aileron deflection ($dC_l/d\delta a = C_{l\delta a}$) right, C_l is the rolling moment coefficient.

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So, let us try to find out an expression for this parameter.

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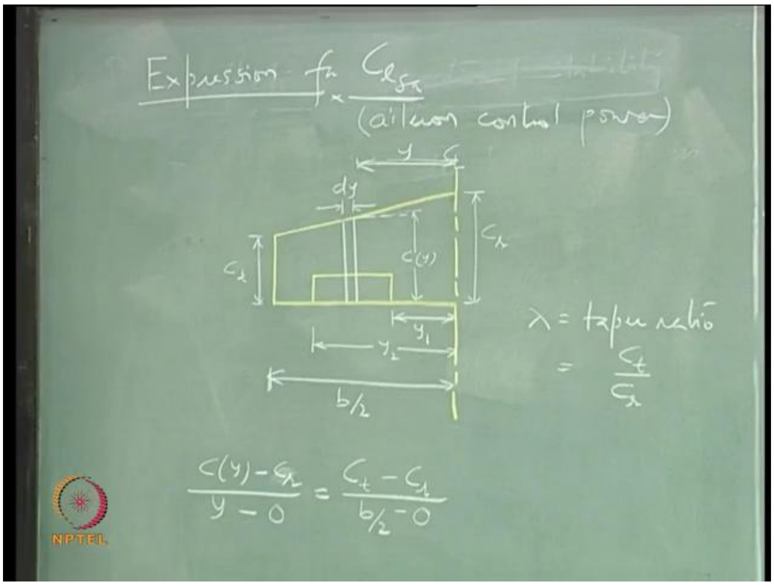

We can also call this $C_{l\delta a}$ as aileron control power, is it not?

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So, there is a wing which is swept back, the wing is also having taper; so, this chord at the root is c r, root cord length is cr and tip chord is ct. And aileron is at a distance y1 from the centre line, and it is having a length which is y2 minus y1, and span of the, half span of the wing is b over two. The chord length of this particular section of the airfoil section which is at distance y from the center line, you know, is c(y). It is going to vary, because there is a taper. The wing is tapered; so, one can write down an expression for the taper ratio which is ct over cr right. What is c(y)? We can find an expression for c(y) in terms of ct and cr and taper ratio.

$$\lambda = \frac{c_t}{c_r}; \quad \frac{c(y)-c_r}{y-0} = \frac{c_t-c_r}{b/2-0}; \quad c(y) = c_r + \frac{2y}{b}(c_t-c_r) = c_r\left[1+\frac{2y}{b}(\lambda-1)\right] \qquad (1)$$

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Chord length at y right minus root chord, which is at y equal to zero right, ct which is at b over 2, you know, minus cr which is at zero. So, what is c(y)?

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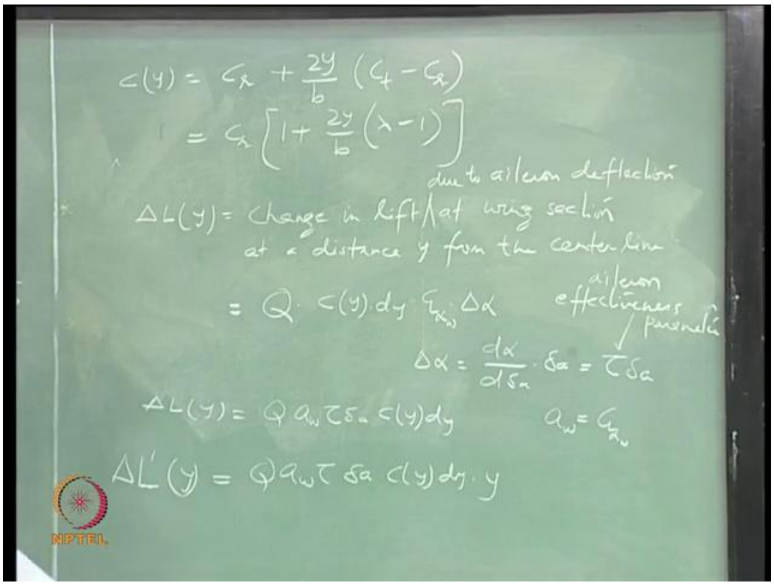

$$\Delta L(y) = Qc(y)dy.\underbrace{C_{L\alpha w}}_{a_w}\Delta\alpha; \quad \Delta\alpha = \frac{d\alpha}{d\delta a}.\delta a = \tau\delta a; \quad \Delta L'(y) = Qa_w\tau\delta a c(y)dy.y \qquad (2)$$

Now, I want to find out; what is the change in lift when I deflect aileron at this section. So, I want to find out change in lift.

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Change in lift due to aileron deflection at wing section at a distance y from the centerline right. What is that? Dynamic pressure into the area, what is that area here? The chord length into this thickness, and C l alpha of the wing into delta alpha, and this delta alpha is because of the aileron deflection. So, you can write this delta alpha as (Refer Eq(2))…

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And this C l alpha is C l alpha of the wing. So, I can also write this as a w. What is this quantity, it is like aileron effectiveness parameter. Is it not? It will depend upon the surface area of the, or area of the aileron as compared to the area of the wing right. So, you can use actually the same plot which we saw for elevator effectiveness parameter, it is actually the same.

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Aileron effectiveness parameter.

(No audio from 30:56 to 31:14)

Yeah into c(y), ... right, now the moment because of this, is going to be... (Refer Eq(2))… So, there is a change, I have deflected the aileron down. So, it is going to give me a positive roll. So, sign of that aileron deflection should be negative, because we have to maintain a uniform convention. So, all control derivatives will have negative sign. So, that aileron deflection which is going down on the, on this (right) part of the wing should be taken as negative. That is clear, now we need to find out what is the roll moment created because of the change in lift over this whole part, is it not? So, I have been writing L prime for the rolling moment coefficient. So, actually you can find out what is L prime y because of the lift at location y and you can probably put a delta sign here.

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So, remember this aileron deflection is negative; you have to keep that in mind. I can also probably put a negative sign somewhere. So, that finally, C l delta is negative. Let me write an expressions and then we can finally, do that.

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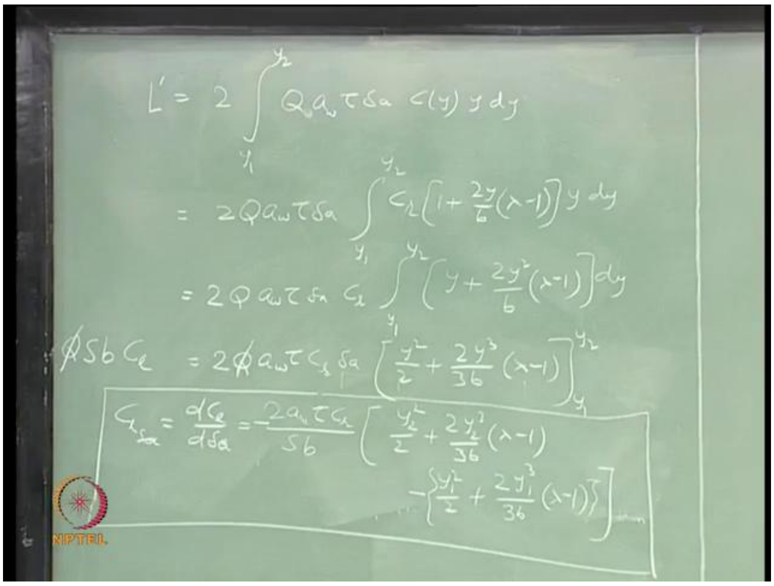

$$L' = QSbC_l = 2\int_{y1}^{y2} Qa_w \tau\delta a.c(y)ydy = 2Qa_w\tau\delta a\int_{y1}^{y2} c_r\left[1+\frac{2y}{b}(\lambda-1)\right]ydy$$
$$= 2Qa_w\tau\delta a\int_{y1}^{y2} c_r\left[1+\frac{2y}{b}(\lambda-1)\right]ydy = 2Qa_w\tau\delta a c_r\int_{y1}^{y2}\left[y+\frac{2y^2}{b}(\lambda-1)\right]dy \quad (3)$$

$$C_{l\delta a} = \frac{dC_l}{d\delta a} = -\frac{2a_w\tau c_r}{Sb}\left[\left\{\frac{y_2^2}{2}+\frac{2y_2^3}{3b}(\lambda-1)\right\}-\left\{\frac{y_1^2}{2}+\frac{2y_1^3}{3b}(\lambda-1)\right\}\right] \quad (4)$$

So, this is the rolling moment, total rolling moment, because of the aileron deflection. So, I am deflecting aileron on both the sides. It will have twice of that effect; is it not? So, one wing is going up, one aileron is going up, other one is going down and both of them are adding to the rolling moment right. So, its twice that effect and, between y1 and y2.

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I am writing an expression for this c(y) now (Refer Eq(3)).

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Now, I have to non-dimensionalize everything right, because I want to find out change in rolling moment coefficient because of the aileron deflection, and that has to be done with respect to the wing. So, QS of the wing into span into C l. So, that your C l delta a which is ... (Refer Eq(4)).

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So, this also has to be a negative sign. So, I can actually use this, you know this delta a is negative. And aileron up is also negative on the other side, that is what is going to give me this C l; so, you can put a negative sign here.

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Is this clear, you want to solve some problems now, which I will do in the next class; we will try to take up some problem and try to find out rudder requirement or the aileron requirement in different situations. So, we will solve some problems in the next class.