Flight Dynamics II (Stability)

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Module No.# 06.
Longitudinal Control and Maneuverability
Lecture No. # 15
Control Requirement, Pull-up Maneuver, Maneuver Point

Two effects that I said we will discuss in this class are these: ground effect on control force requirement or the stick force requirement, and other one is, in maneuver what happens. So, force requirement and maneuvers, or elevator, elevator deflection requirement, right. So, of course, if you remember, we said that ground effect will only take place when we are trying to land, right. When we are trying to land, we are actually try to slow down. How do you slow down? Increase the angle of attack right, perfect landing is when you are landing at stall, landing at, touching down at stall is the perfect landing condition.

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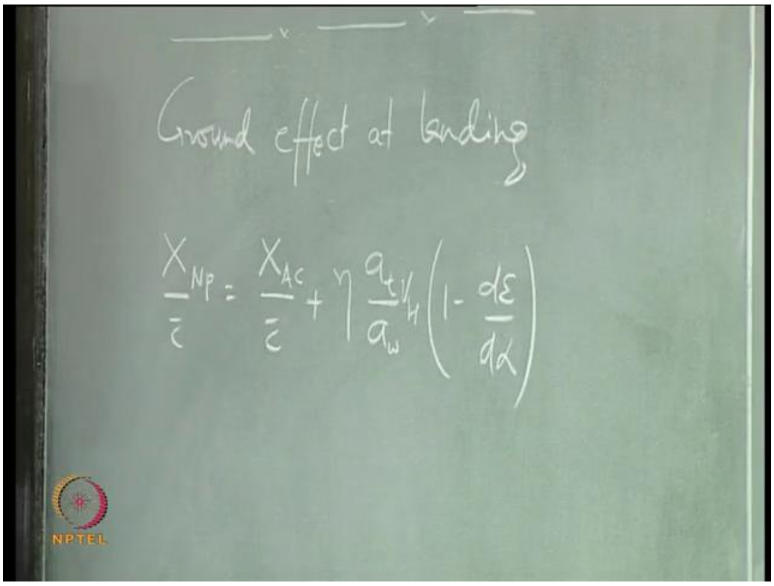

So, ground effect will take place let us say, I will say, ground effect while landing. Two things which can happen, we said that downwash is going to be less, right, much less and that is going to… that is going to reduce this quantity ($d\varepsilon/d\alpha$), is it not? right. And when this quantity reduces and this location (XNP) is, goes up, right.

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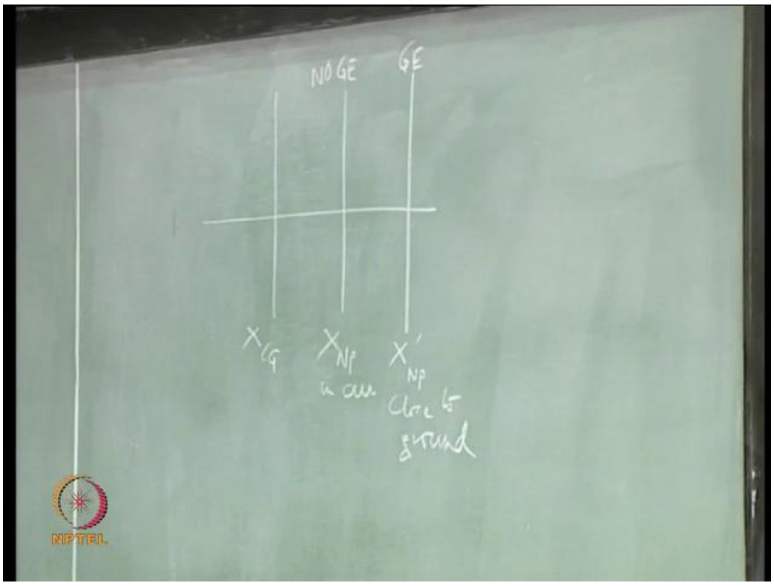

So, if this was my XNP in air with no ground effect, then, the new XNP lies somewhere here, close to ground. So, I will, I will write this no ground effect and ground effect - GE for ground effect, right. So, if your c g is fixed, what is increasing because of this, static margin, so, stability is more, right. Look at this picture.

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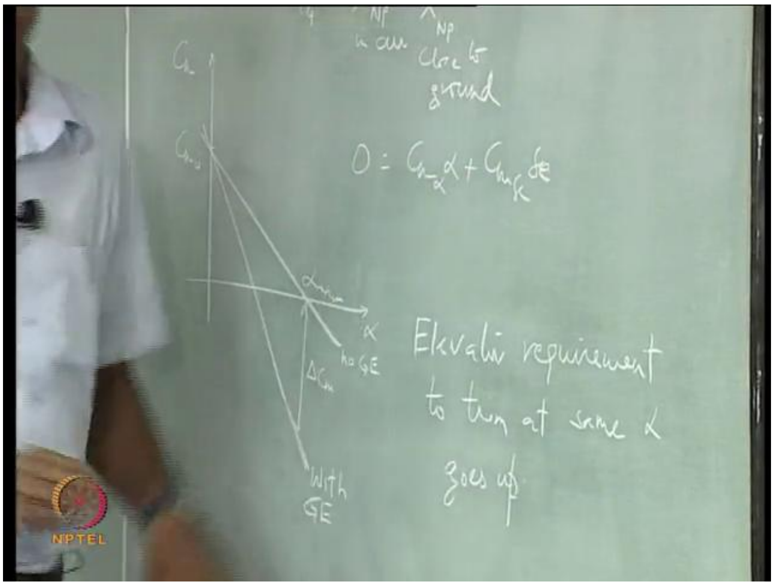

So, you are able to trim at some angle of attack in air, right. This is alpha trim; this is no ground effect, right, no ground effect. What happens, when I am including the ground effect in this - this curve will have steeper slope, right. So that means, you have to make up for this extra ΔC_m to trim at this alpha, is it not? And that will require what? I am trying to make up for this ΔC_m , right. This is with, with ground effect, right. So, I have to make up for this ΔC_m to trim at this alpha, right. What we have to do?

We are trimming.

Right, we always trim. Is it not? We are trying to make up for this ΔC_m, which has happened because of the ground effect, what is going to change? What we have to do? We have to apply more elevator deflection, right. In which direction? which direction? So you are at some alpha (α), right, let us say elevator, alpha is positive. So, elevator deflection is up, is it not? Now, you want to make up for this. We have to move your elevator further up, is it not; because you want to create a pitch up moment, alright.

So, elevator deflection….. right. Also clear from this, this trimming condition, is it not? I want to keep this alpha fixed, $C_{m\alpha}$ has gone up, I will need more δe right, more δe up, alright. What is the second effect? So, this is one effect, what is the second effect? Remember, we are talking about only one effect so far. This is the derivative of the downwash angle ε with respect to angle of attack α, right. What is the other effect? You know, lift will…

Because the loop is closed.

Right.

So, the circulation (( ))

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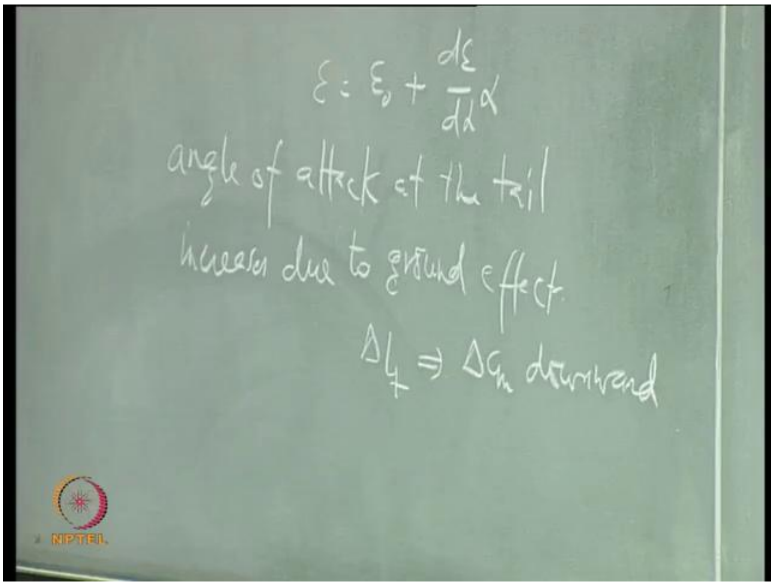

ε_0, you know this epsilon has two terms, right, right. So, angle of attack at the tail is also going to increase, and what happens because of that? Let us say elevator is fixed at some value, right, and then, you have this epsilon 0 ε_0 which is increasing the angle of attack at the tail, right. So, there is a … I am getting elevator up means more lift downward that is giving me a pitch up moment, because of which I am getting different alpha trims, right. More angle of attack is when elevator is up, and the lift produced at the tail is down, is it not?

Now, because of this term which disappears when you are close to ground, angle of attack at the tail is going to increase, right. ......Right. And that small ΔL_t, right, is going to create a downward pitching moment. So, further elevator up you require, is it not? So, in both the situations, right, combined effect is that, you have to, you know, you need more and more elevator to change the, or to maintain the same angle of attack, and also to, you want to change the velocity, you know, when you are landing, landing speed has to be lower, is it not. See, you are on approach with some velocity and then when you are trying to land, this speed has to go to further small, actually it should be V_{stall} into some factor.

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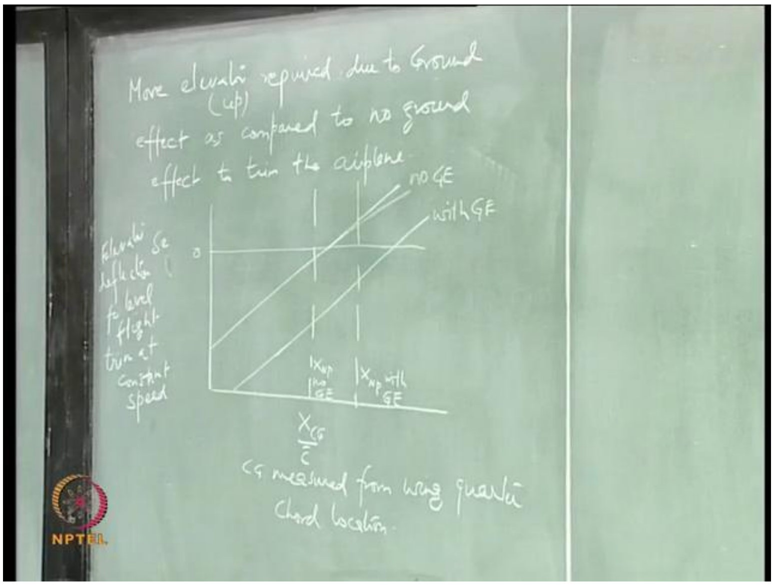

So, more and more elevator, and this is up all the time, because when I am landing, I have to maintain this alpha which is, goes to alpha stall α_{stall}. .....We want to see the plot, how elevator deflection requirement .... changes for level flight trim at constant speed. Let us talk about only level flight trim condition. And then let us plot the effect of, the ground effect right. I am plotting this against $X_{CG}/\bar{c}$. So, typically this, the XCG is, this plot, the textbook from where I got this plot, they are measuring XCG from the wing aerodynamics center. So, this CG is measured from wing quarter chord location. So, these two should be parallel. So, this plot is the plot of elevator required to trim the airplane in level flying condition at constant speed, right, with respect to the CG location.

So, no GE, right. How will the plot for the stick force gradient look like? Qualitatively, it will look something like this, same as this, right, because, the elevator is directly related to the stick force, right. We are going to apply the stick force and the corresponding elevator deflection is this, right. So, this is the effect of the proximity of ground, when the aircraft is trying to takeoff or it is trying to land, right.

Let us look at another effect and that is maneuver, what happens in maneuvers. So, what is a maneuver? Maneuver is when you are trying to…. Even landing is a maneuver. So, any, any flight will be called maneuver. But here in this, we are talking about the case when the rates are also involved, right. So, they are maneuvers where rates are all fixed right. Steady state maneuvers, for example, level flight condition, all the rates are 0 right. Even in landing, the rates are all 0 right and taking off, but there are maneuvers where rates are not 0.

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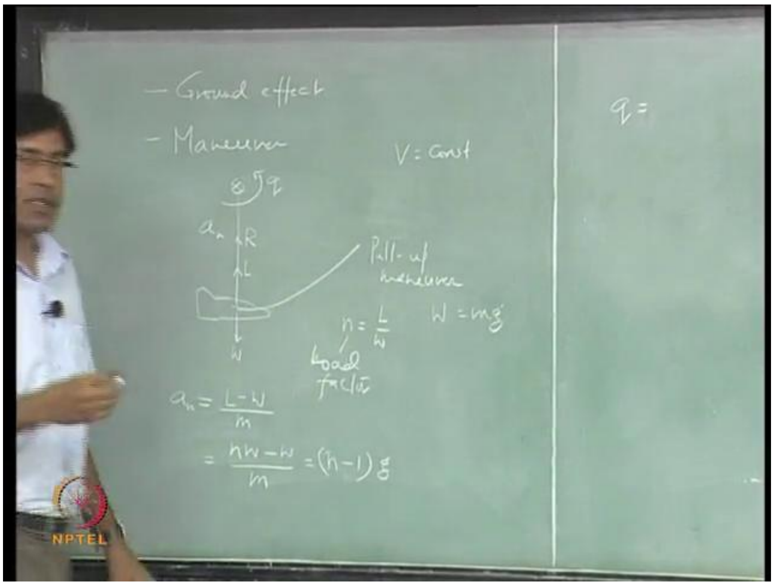

So, for example, there is one maneuver which is called pull-up maneuver. What all I need to have for this aircraft to pull up? So, you want to create an acceleration, you know, a normal acceleration upward which should be equal to… So, this is the weight and this is your lift L, right. So, you can pull, you can do this maneuver only when the lift is going to be more than the weight, right, that is clear. And that ratio is called the load factor, right.

So, if I want to write down an expression for this a_n, let us say, I want to do a pull-up maneuver, this is signifying the g factor, right. So, 1 g is pulling 1 g maneuver which is the case when you are flying level flight condition. Any other value of n greater than 1 will also give you a normal acceleration, right. So, what is this a_n? a_n is $(L-W)/m$, if m is the mass of the aircraft. And W is equal to mg, right, this is … So, these are normal accelerations in any maneuver. And also say that this radius is R, of this loop, and how it is happening? How it is happening? How you are able to pull-up? So, you are trying to…

Apply the elevator.

Apply the elevator, so that you can create a pitch rate, right, and that is going to take this up, right, and you can do it at constant velocity. So, let us say velocity is constant. This is happening because of this pitch rate, right. What is this, pitch rate is $2\pi/(2\pi R/V) = V/R$. So, that is like a distance, right. 2π is the angular displacement over time, right. Correct. I can also write this q in terms of this acceleration, and that is $q = (V^2/R)1/V$ … Right, centripetal acceleration is this V^2/R.

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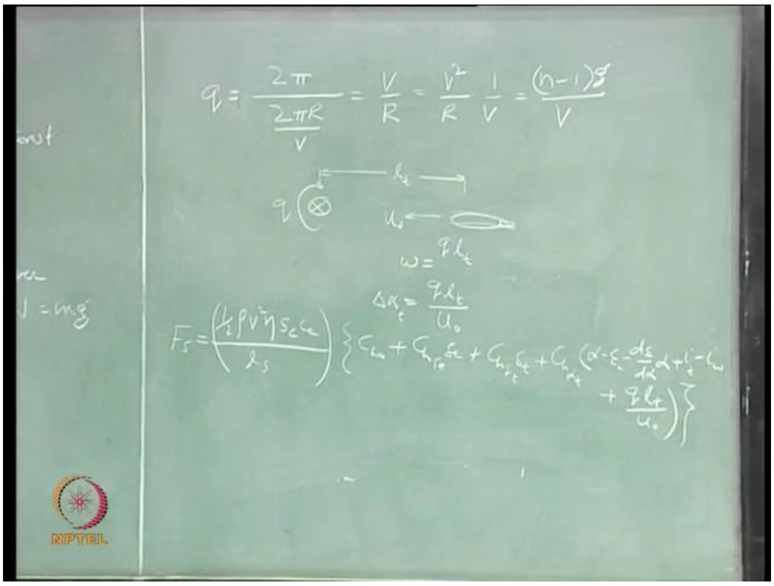

Pull-up maneuver at constant velocity, right, at this load factor, this is how pitch rate is related to the load factor and the velocity, $q = (n-1)g/V$. What this pitch rate is going to do to the aircraft? Now, I am trying to rotate the aircraft right, what is it going to do? Now, I have to find out the control requirement, right. That is what we are discussing, longitudinal control. So, in such a maneuver, what is happening when we are pitching the aircraft?

(())

No, delta e is there, delta e is going to give a pitch rate. Yes, that is alright. Any other thing, anything else happening, because of this pitch rate.

(( )) angle of attack (( ))

Angle of attack, where?

Student: (( )) only at the (( ))

Angle of attack is going to change, where? (( ))

This I am giving delta e which is causing a pitch rate, right, because of that what is changing, angle of attack is the right answer. Where is it changing, in what ways?

So, you are creating a moment about this CG which is pitching up, positive q, right, and let us look at what is happening to the flow at the tail. So, I will draw it as the symmetric airfoil. What is it going to do? So, when you are pitching the aircraft, aircraft is, this tail is going to see a relative velocity upward. Is it not? Right, you see that? (()) The aircraft is pitching up, right. So, tail is going down and tail is going to push the air down. So, relative air that is coming on to the tail is going to increase, is it not?

(()) The flow velocities to be placing their aircraft (( )). So, where is the additional value flow is going to place the (( )) of the aircraft and it is going to be parallel with the (( )) how is the angle of attack (( )) no velocity should be parallel to (( )) velocity should be parallel to.(())

Let us say, aircraft is flying trim, this level trim condition. Now, we want to initiate a pitch up right. What you are going to do? You are going to apply elevator up right and that is going to… So, that that q, how much q you want depending on that you will deflect elevator right. Afterwards what happens, this starts going down right, if this… So, earlier it was only having this velocity which was forward velocity, let us say V, right.

(()) yes.

(()) In this elevator portion, it will perpendicular to a s I mean to this thing that.

What is, what are you saying?

(()) I am saying that two things that elevator. In the elevator mean slow motion the angle you are saying that is due to the change in camber or not. (())

No, this is this is this is not due to the camber; this is only due to the pitch rate this is only due to the pitch rate.

Camber is not, I am not saying that camber is changing, I deflected the elevator, afterwards, I see a pitch rate, and then because of that pitch rate this this tail starts pushing air down. So, you see a relative air upward, and because of that the angle of attack at the tail is changed, right.

Student: (( )) the horizontal velocity (( ))

Right, vertical component of velocity will change which was not there, right. So, what is that velocity? Let us say, I call this w, q into l_t right. So, $\Delta\alpha$ is going to be $q.l_t/u_0$. Let us say this is u_0 right, is it alright? You see that it is going to change, only in this maneuver, right. So, what will happen to the stick force now? The Fs is ….. Now, I am writing this modified alpha t, right, and this will include the effect of the pitching. And I want to replace this q by this .... quantity. So, that I directly have a relation between this stick force and the load factor, right. While you are doing that, you should also non-dimensionalize it. So, this how the rate is non-dimensionalized, right. This is the non dimensional pitch rate $\bar{q} = \dfrac{qc/2}{u_0}$.

$$F_S = \left(\frac{\frac{1}{2}\rho V^2 \eta S_e c_e}{l_s}\right)\left\{C_{h0} + C_{h\delta e}\delta e + C_{h\delta t}\delta_t + C_{h\alpha t}\left(\alpha - \varepsilon_0 - \frac{d\varepsilon}{d\alpha}\alpha + i_t - i_w + q\frac{l_t}{u_0}\right)\right\}$$

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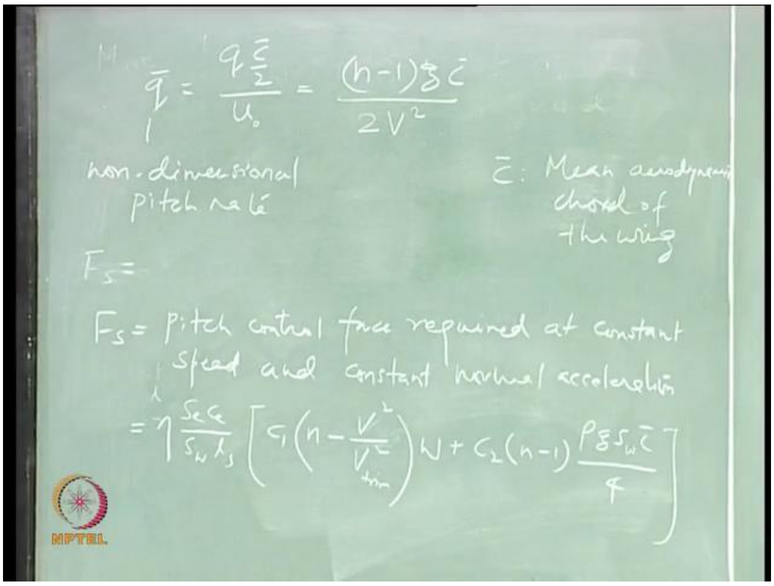

So, I am calling this u_0, u_0 is actually equal to V, right, V is equal to u_0; so, $\bar{q} = \dfrac{(n-1)g\bar{c}}{2V^2}$.

If you remember, I wrote this expression for Fs at... So, this is pitch control force required…Pitch control force required at constant speed and constant normal acceleration, right, and this normal acceleration will depend upon the load factor that we are trying to overcome, right. This is above the level flight condition, right. So, more than 1 g, whatever that normal acceleration is, you know, in terms of aircraft parameters. I wrote this expression in the last class, and we also found the control force gradient and the control force per g, that is given by this ....

$$\left(\frac{dF_S}{dn}\right)_{V=const} = \eta \frac{S_e c_e}{S_W l_S}\left(c_1 W + c_2 \frac{\rho g S_W \bar{c}}{4}\right)$$

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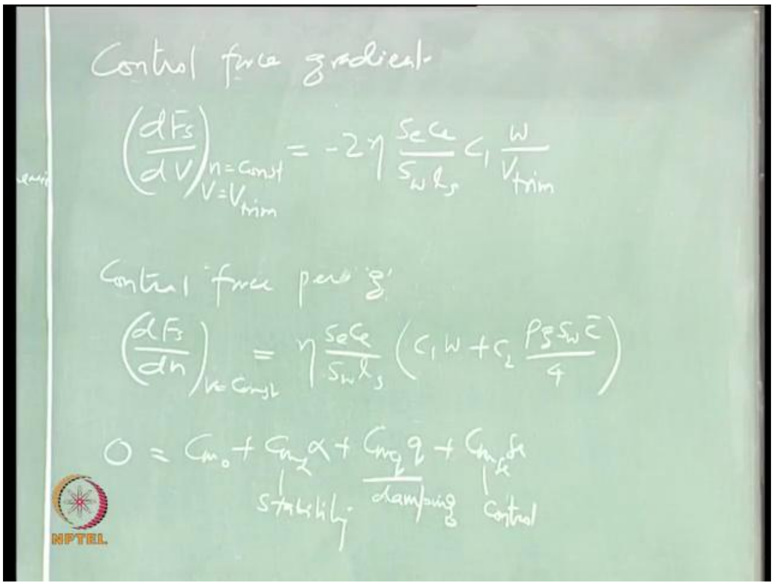

Both c_1 and c_2 are functions of, you know, all derivatives of aircraft. We have seen aerodynamic derivatives, right, we have seen control derivatives $C_{m\delta e}$, stability derivative $C_{m\alpha}$, and there is one more derivative, which is, damping derivative. So, now, if you want to look at the trim condition, which is C_{mcg} is equal to 0, that will have one more term and that is, this C_{mq}, and C_{mq} is the damping derivative - stability, damping, control, right.

Now, let us say I want to find out, what is the elevator requirement per g, how much elevator I need to get the normal acceleration, that also can be found out and…

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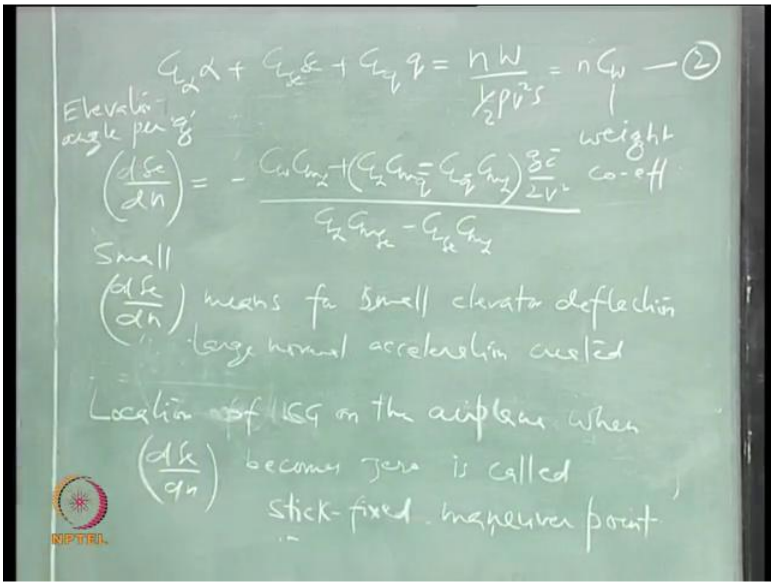

So, there are two, two conditions, one is one, equation 1, and the second one is… This has to be equal to, this is the lift coefficient, right, and this is equal to, lift is equal to nW, right. Whenever we have a rate involved, there will be damping created, right, air will also try to damp out the motion.

In the pre- stall regime of flight it will be linear; we all, we know, this whole course we are actually talking about pre-stall conditions, right. It may not be linear in the post stall angle of attack. So, if you solve 1 and 2, you can find out, what is, elevator required for the normal acceleration that we want, right. And that is given by this derivative. Remember this, these terms c_1 and c_2, they are not constants, they are depending upon derivatives. So, I will also put a bar here because I am talking about, which one?

$$\left(\frac{d\delta e}{dn}\right) = -\frac{C_W C_{m\alpha} + (C_{L\alpha}C_{m\bar{q}} - C_{m\alpha}C_{L\bar{q}})\dfrac{g\bar{c}}{2V^2}}{C_{L\alpha}C_{m\delta e} - C_{m\alpha}C_{L\delta e}}; \quad C_W = \frac{W}{\frac{1}{2}\rho V^2 S}$$

If I want to, let us say, see, the unit of each of these terms should be constant, right. That is how you have to look at. So, small δe, small $d\delta e/dn$ what does it mean; small elevator deflection required to create large acceleration right, is it not? But such an aircraft will not be easy to fly, you deflect elevator little bit and it gives you a large acceleration. So, it is not easy to fly such an aircraft, small .... right. So, such an aircraft is not easy to handle, it is not desired; minus of this whole term. So, this is also called elevator angle per g. Location of the c g when this ($d\delta e/dn$) becomes 0, gives you, what is called stick-fixed maneuver point, right. There is a $C_{m\alpha}$ term sitting here which is related to XCG minus something, right. So, location of c g when this term becomes 0; that is the point which is called stick-fixed maneuver point. Location of c g… Where do you think this will lie? So, I will quickly give you an expression for…

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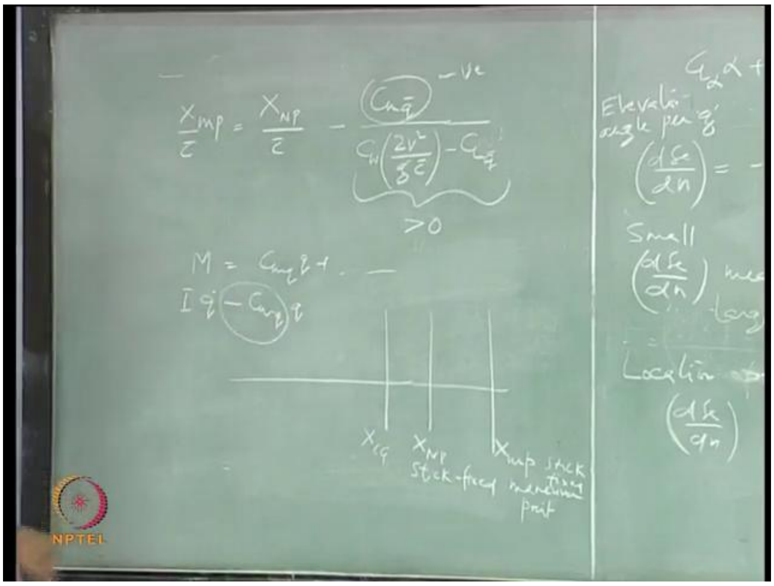

$$\frac{X_{mp}}{\bar{c}} = \frac{X_{NP}}{\bar{c}} - \frac{C_{m\bar{q}}}{C_W\left(\frac{2V^2}{g\bar{c}} - C_{Lq}\right)}$$

mp is the maneuver point. This quantity is usually positive, and C_{mq}, what should it be; positive damping means what; air is going to offer some damping when you are trying to rotate the aircraft, right. So, what should this quantity be? This should be negative, think about it, how we are writing the equation? We are writing equation as M equal to ... and so on, right. So, there will be a term like $I\dot{q}$, right. If you bring this to this side it becomes..., right, and for positive damping you should have C_{mq} which is negative, right. So, this maneuver point actually lies behind the neutral point, right. This is what it means, you have, this part which is positive, right. So, Xmp which is the maneuver point is lying behind the neutral point location, right. What does it mean? You can be unstable, but still you can maneuver, is it not?

So, marginal stability case when your c g is lying very close to the stick-fixed neutral point, you can still maneuver, because in maneuver, you have increased stability, right. .... We will stop at this point.