Flight Dynamics – II (Stability)

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Module No. # 05
Longitudinal Control
Lecture No. # 14
Longitudinal Stick Force per ‘g’, Ground Effect

So, remember I said, the amount of aerodynamic moment or hinge moment, that you have to overcome, you know, . We will also decide the stick force that the pilot has to apply, right. And it will also depend upon the lever arm that he has, but that cannot be too long or too short. It has to be at a comfortable level, so that every pilot can operate it in a comfortable fashion. So… And we said that, there is one situation where elevator is free to rotate, right, that means, the stick force is not required to change the elevator deflection, and, that free deflection of elevator can be found out, by setting the hinge moment to zero, is it not?

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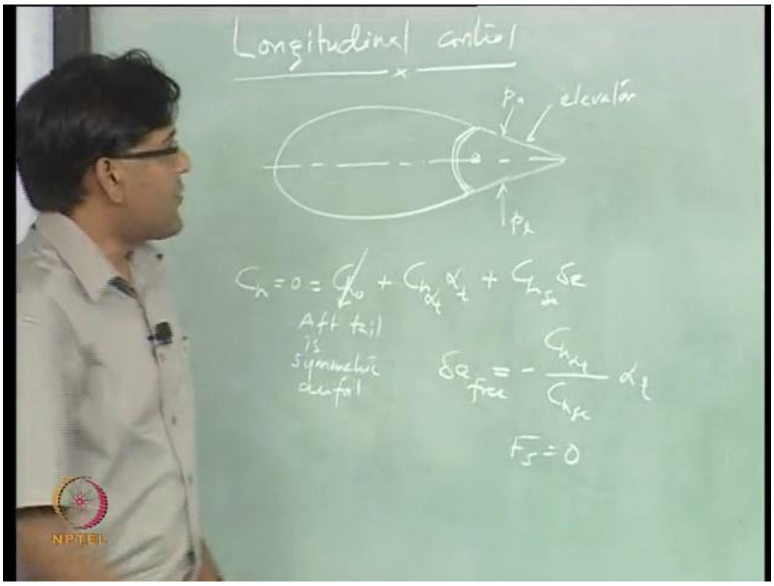

(No audio from 01:15 to 01:36)

Right. So, we are talking about the hinge moment and that hinge is here. Is it not? So, you have, (No Audio from 01:49 to 01:54) .... and this is your elevator. So, we said that we are going to set this C_h to zero and C_{h0} is actually zero for symmetric airfoil, for this tail, tail which is symmetric airfoil all the time, but canard is not a symmetric airfoil. This is the aft tail, aft tail is usually symmetric, but canard may not be symmetric. So, there this C_h, C_{h0} term may not be zero. .... (No Audio from 02:37 to 02:50) right. When I set this hinge moment to zero and assume that the aft tail is symmetric, you know, made of symmetric airfoil sections, and this goes to zero, and we found an expression for delta e free equal to minus Ch alpha tail over Ch delta e into alpha tail.

$$\delta e_{free} = -\frac{C_{h\alpha t}}{C_{h\delta e}}\alpha_t$$

(No Audio from 03:21 to 03:31)

So, for every angle of attack at the tail, you can find a delta e free, right. And, if I want to now start using the elevator applying the stick force. What it means is, you are not applying any stick force here. Elevator has automatically assumed that position. Is it not? So, for alpha t which is positive, this delta e free is negative, which is upward. Right.

Now, starting from… So, this is where stick force is zero, right. Now, if I want to deflect the elevator, I will deflect the elevator only from this point, right. I have to deflect the elevator negative or positive; I have to overcome the aerodynamic moment starting from, with this as the reference, right. So, where is this aerodynamic moment coming from, or the hinge moment, is coming from the pressure distribution, right. So, if I call this, you know, only on this part, only on the elevator, this as p_u and this as p_l right.

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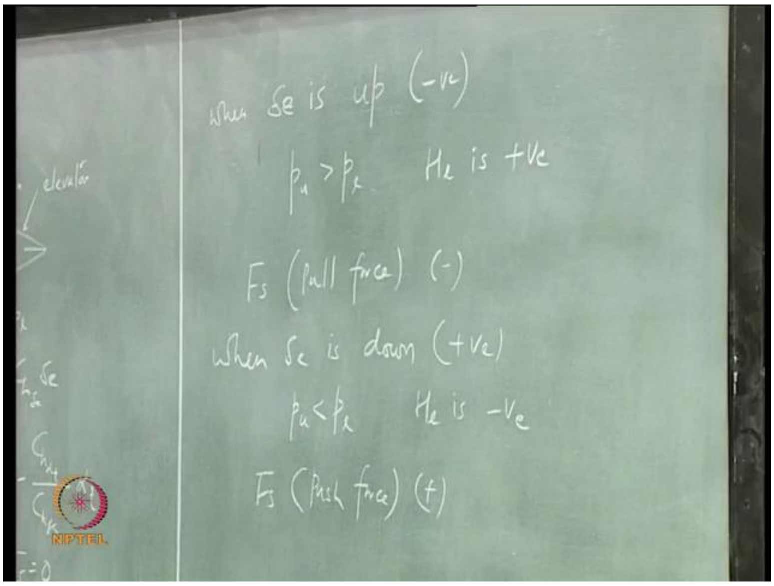

So, delta e (No Audio from 04:56 to 05:05) up from the neutral position, neutral position will be decided by this; neutral position of the elevator will be decided by this. And beyond that if delta e δe is up negative right, what is happening? What is p_l? p_l and p_u which one will be larger?

p_u will be larger.

Larger, because the camber is negative. So, p_u is larger in this case. So, you are getting a lift downward, is it not? So, if p_u is greater than p_l, then which way the aerodynamic moment is acting on the hinge point? It is positive (No Audio from 06:14 to 06:24) you said it right. So, it is, is it not? Now… So, I have to overcome this moment. So, what should be the stick force? I am deflecting the elevator up, right. So, yesterday you saw that the mechanical arrangement was such that I have to pull *Fs* or the stick towards myself to deflect the elevator up and that is *Fs* .... right. And the convention is that, this pull they use that as a negative stick force. I am not sure if I said something different yesterday. So, let us use this convention. (No audio from 07:39 to 07:52) ...... So, this He - the hinge moment is positive. (No audio from 07:59 to 08:31) *Fs* (push force) required to deflect the elevator down.

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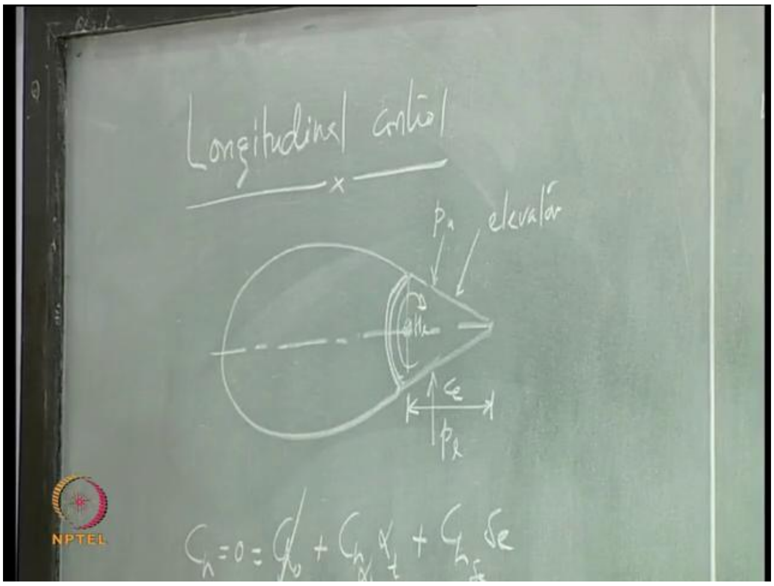

But if you remember we have been talking about the hinge moment considering this as the reference chord. This is where this whole action is taking place, pressure. Now, I can only talk about the force distribution, you know behind this hinge line. Is it not? And that moment only I am using to define the hinge moment, alright. What happens to this part?

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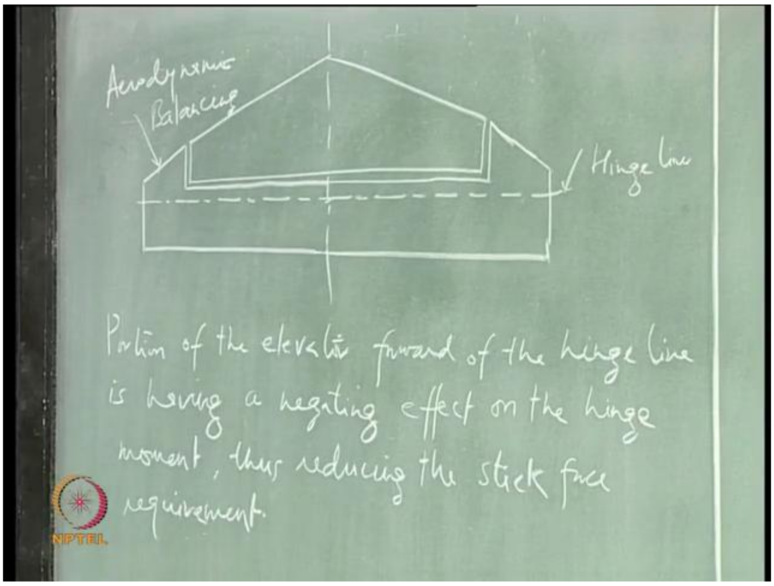

So, let us draw a picture, and a big picture here. Let us say, this is the tail on which I have to locate my elevator.

(No audio from 09:44 to 10:27)

This is your hinge line. This part is elevator, what I have done here? I have extended this portion. So, that it joins nicely with this part, is it not? Why I have done that? So, look at the aerodynamic moment that is being created, its only because of the forces on this part, you know, the part behind the hinge line, what happens to this part? Now, this is having a negative effect on the hinge moment.

So, if we extend this part, you know, in front of this hinge line, you know, forward of the hinge line, that part is going to give you a negative moment, you know. So, when He is being created, because of this part, this other part of the flap, or the elevator, which is ahead of the hinge line is going to create a moment in the opposite direction. So, it is negating that effect. So, this is very important, when you are sizing your elevator or designing your elevator, this is very important, the portion of…

Delta e (( )) with respect to the delta e free.

Deltae free, yes.

(( ))

So, this part, which is forward of the hinge line is also going to play an important role, right, is going to have a contribution to the hinge moment (No audio from 12:20 to 12:48) ......is…

How is generally delta e delta e (( )). (Audio not clear. Refer Time: 12:58)

Actually this delta e δe, all I am talking about right now, you can measure the δe with respect to this zero line. But what we are talking about is the amount of aerodynamic moment that you have to overcome by applying the stick force. Then, it has to be with respect to this δe_{free}.

(( )) above that and even in the elevator is above that free point, we can still have a positive sign.

Actually, you can adjust that; that adjustment is made by using the, setting the tail incidence angle. So, you can have, but that may not be changing at every α_t. So, this is only, can be used as a reference for calculating the aerodynamic moment, you know, accordingly you have to find how much stick force you have to apply. Portion of the elevator forward of the hinge line is having a negating effect, ... (No audio from 14:15 to 14:57).

So, I have to actually decide, you know, how much forward, you know how much surface I want, forward of this hinge line, on the elevator. Because I want to reduce the hinge moment, because that will reduce the work load on the pilot, is it not? So, this sizing is called aerodynamic balancing. You can read this. So, our effort is actually to reduce the pilot work load. Usually, you know, transport aircraft which is, you know, designed for long flight, there you do not want to burden the pilot. So, there, what they will use is, the surface for setting the trim. That surface is called trim tab.

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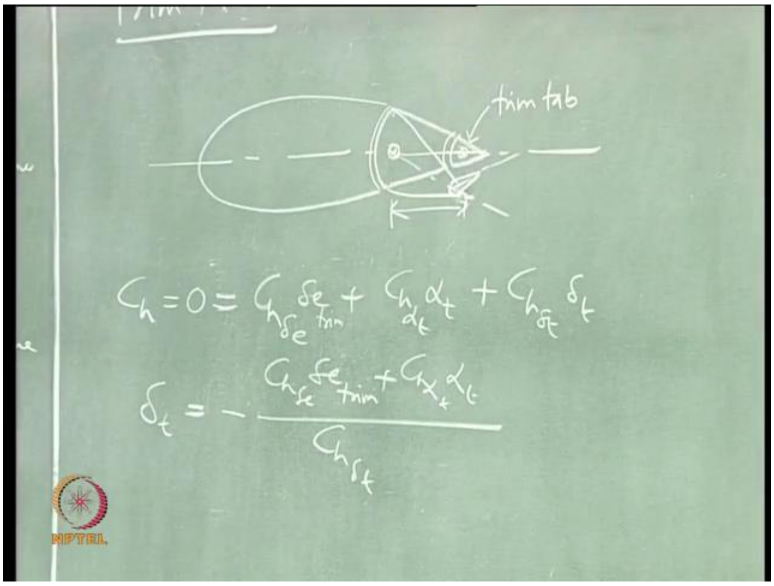

So, trim tab is a small surface located at the trailing edge of the elevator. So, if you want to look at this section, what you see is this ...... (No audio from 16:50 to 17:27)

What will you do? What is our idea? We want to…

Cancel the, this hinge moment, is it not? So, now if I want to include this trim tab to make this hinge moment zero which is about this hinge line, ok, and it is free to rotate. So, moment about this point is already zero. Look at what is happening; it is not going to change the lift on the tail much, its such a small surface. But the length, arm length that it has, is quite large, is it not? So, it is actually going to give a significant moment, but very small lift - negligible lift.

Now, let us look at this expression again for the hinge moment coefficient that is …Ch equal to zero equal to Ch delta e into delta e trim plus Ch alpha tail into alpha tail plus Ch delta t into delta t.

$$C_h = 0 = C_{h\delta e}\delta e_{trim} + C_{h\alpha t}\alpha_t + C_{h\delta t}\delta_t \implies \delta_t = -\frac{C_{h\delta e}\delta e_{trim} + C_{h\alpha t}\alpha_t}{C_{h\delta t}}$$

So, I want to trim the aircraft at a particular elevator setting, and I want to find out the trim tab deflection - free deflection. So, that the moment at the hinge is, hinge point is zero. (No audio from 19:05 to 19:35) So, what will the pilot do actually here? Now, he only has to play with this tab and not with this whole elevator. So, once he sets, you know, the trim tab, he is actually setting the elevator angle, you know, for any free trim tab deflection, elevator angle will be automatically set, and he can achieve different elevator trim. So, he has to only play with this small surface. He has to probably not even actually have to apply any force, he can do it through some gear arrangement. So, if the elevator is downward, which way the trim tab should be? Upward, it is understood. (No audio from 20:40 to 20:57) . Why we are changing the elevator deflection? Because we want to change the trim speed, we want to fly different speeds.

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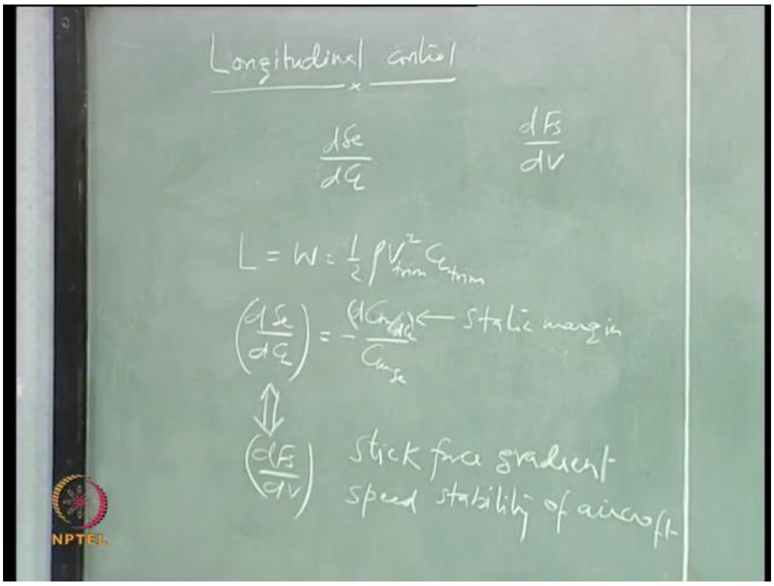

So, actually $d\delta e/dC_L$ should also be somehow related to, with this.... dFs/dV, this gradient, is it not? Because when you talk about a level flight condition, (No audio from 21:40 to 21:50) when you are changing, let us say you want to fly a different speed, what you have to change? You have to change this C_{Ltrim}, and C_{Ltrim} you change by deflecting the elevator, and elevator is being controlled by the stick force, is it not? And that is, so somehow these two must be related. And if you remember, we said that, this is related to the static margin, or probably, this is dC_m/dC_L. So, this is related to the static margin, and static margin is giving you the stability, is it not? So, more stability we have, the more control that we need to change the trim, this we have discussed.

So, what it automatically means is, that this gradient -gradient of the force with respect to the trim speed, is also dependent upon the stability - stability margin, stability of the aircraft. Is this clear? So, this quantity is actually depending upon the stability of the aircraft. So, where do you think that stability of the aircraft will change? We have talked about a free flying condition, we are flying at some altitude, is it not? Let us say, we are coming down, and approaching the runway, about this landing situation. Do you think this is going to change? (No audio from 24:26 to 24:35) Or any other flight also where you know, you have this thing changing, its automatically going to affect this - elevator requirement, and it is going to affect this, all of them are connected. Is this clear?

So, let us try to tell you where the work load on the pilot may increase, even if it is not there, in let us say cruising condition. This minus… I think it is there, you can check back in your notes. Let us try to find out what this derivative is. This is called control force gradient or stick force gradient. (No audio from 25:28 to 25:39) And it is related to aircraft speed stability. .... (No audio from 25:44 to 26:00) So, let us first try to find out an expression for this force in terms of the hinge moment.

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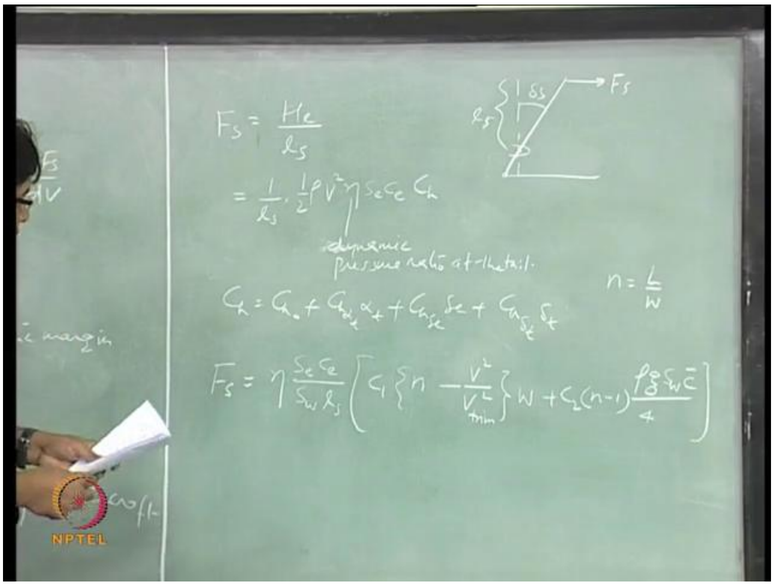

So, Fs is He over ls, ls is the stick arm length. Remember I (No audio from 26:21 to 26:38) drew this picture. So, Fs is actually He over ls. Now, again the expression that I gave you yesterday was based on the work balance. Here it is the moment balance. So, let us look at this. (No audio from 27:06 to 27:25) ce is this length into C_h. (No audio from 27:39 to 28:04) So, this C_h is now sum of all the terms. This is an expression which has been worked out in the book that just now I referred to, Mechanics of Flight by Phillips. And this expression for the stick force is this. (No audio from 28:46 to 28:59) This includes the maneuver effect - maneuvering. So, n is the low factor here, L/W. (No audio from 29:10 to 29:52)

Actually, there is a nice derivation which gives you this. So, this expression has been derived, this is not an empirical relation. So, what we have to do? We have to find out what this derivative is. So, what we are trying to do is, we are trying to look at this force through which pilot is going to get a feel for the stability. Or this gradient which the aircrafts should process in some fashion, so, to counter the effect of change in stability from the trim speed.

(No audio from 31:00 to 31:36)

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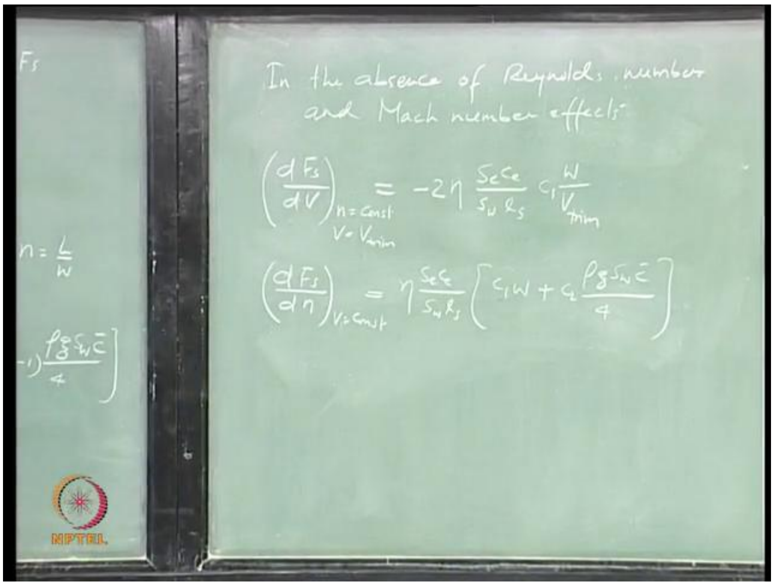

For subsonic flights, actually we can find an expression for this control force gradient at a constant load factor and a trim speed which is … (No audio from 32:05 to 32:27) And if you want to find out the longitudinal force per g, that is given by this ….. (No audio from 32:36 to 33:11) Of course, you do not see any, anything defining the stability here, right. So, you would wonder why this should be related to stability, but I have not given you the expression for c_1 so far and this is …. (No audio from 33:31 to 34:05)

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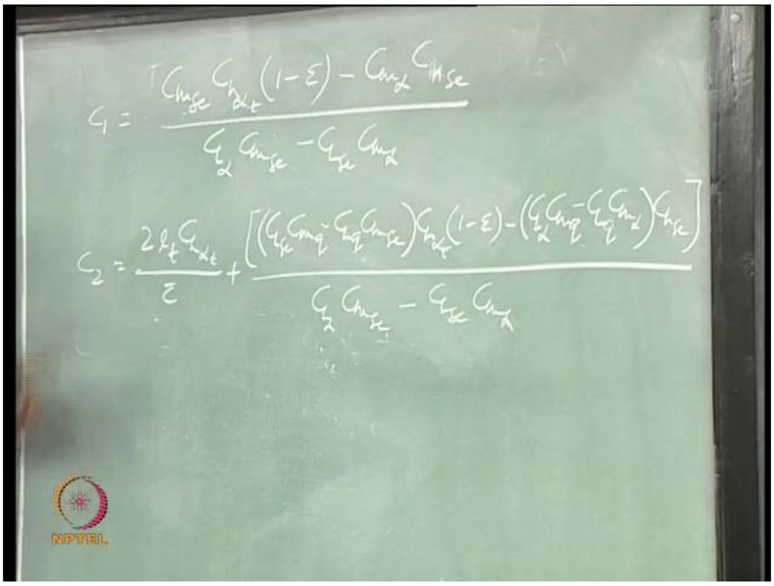

$$\left(\frac{dF_S}{dV}\right)_{\substack{n=const\\V=const}} = -2\eta\frac{S_e c_e}{S_W l_s}.c_1\frac{W}{V_{\min}};\left(\frac{dF_S}{dV}\right)_{V=const} = \eta\frac{S_e c_e}{S_W l_s}\left[c_1 W + c_2\frac{\rho g S_W \bar{c}}{4}\right]$$

$$c_1 = \frac{C_{m\delta e}C_{h\alpha t}(1-\varepsilon) - C_{m\alpha}C_{h\delta e}}{C_{L\alpha}C_{m\delta e} - C_{m\alpha}C_{L\delta e}};$$

$$c_2 = \frac{2l_t C_{h\alpha t}}{\bar{c}} + \frac{\left[(C_{L\delta e}C_{mq} - C_{m\delta e}C_{Lq})C_{h\alpha t}(1-\varepsilon) - (C_{L\alpha}C_{mq} - C_{m\alpha}C_{Lq})C_{h\delta e}\right]}{C_{L\alpha}C_{m\delta e} - C_{m\alpha}C_{L\delta e}}$$

So, clearly $C_{m\alpha}$ is appearing here. So, this force gradient is depending upon the stability. The longitudinal force per g is also going to depend upon the stability, because c_1 is a function of $C_{m\alpha}$ and c_2 is … (No audio from 34:30 to 35:38) c2 is 2 into lt, tail arm length, ch alpha t over c bar, mean aerodynamic chord - chord of the wing, c l delta e c m q minus c l q c m delta e c h alpha tail into 1 minus epsilon - epsilon is the downwash minus c l alpha c m q minus c l q c m alpha c h delta e over c l alpha c m delta e minus c l delta e c m alpha. This is a big expression, but all its indicating is longitudinal force per g which is this..... (No audio from 36:28 to 36:39)

It is going to depend upon these factors. You would notice this q is appearing here, q is the pitch rate, when you are trying to do a pull up maneuver, there a rate is involved, you want to pitch up the aircraft, when you want to do a pull up maneuver. So, that is where this, these derivatives are coming into picture. Let us try to quickly see what actually this means.

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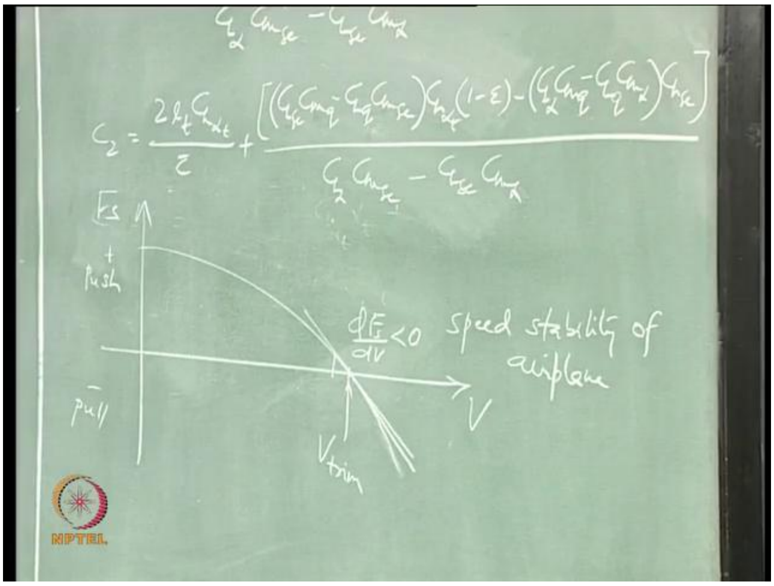

So, I am plotting here, the stick force against speed. And this curve is somewhat like this. So, let us try to find out the slope of this curve at *Fs* which is zero, that is a trim speed. (No audio from 38:10 to 38:22) What should be this force for stability? What should be the sign of this gradient? When you change, but right now this slope is what, positive or negative. It is negative, and this indicates speed. Your airplane should have this property, if you want it to be stable with change in speed, and let us see, what is happening? If you are changing this, let us say, there is some disturbance and the trim speed is changed, it has reduced. So, what is the stick force? Stick force is, should be positive, and for that the elevator deflection should be downward, and downward elevator deflection means, a downward pitching moment, is it not? So, this is also related to the pitch stability in some ways.

(No audio from 39:49 to 39:58)

Say, if your aircraft is having this speed stability and you have, keeping your hand on the stick, then you will automatically feel it. So, if you are flying the trim speed and let us say, the speed changed in flight, disturbed change, it is not a big change, but a small change, and immediately you will feel a force on the stick. So, that is what it means. So, now let us try to... So, clearly the flight in free air is going to be different from the flight very close to the ground. And all those effects… So, all those parameters that you see there are going to be changed, modified, when you are close to the ground.

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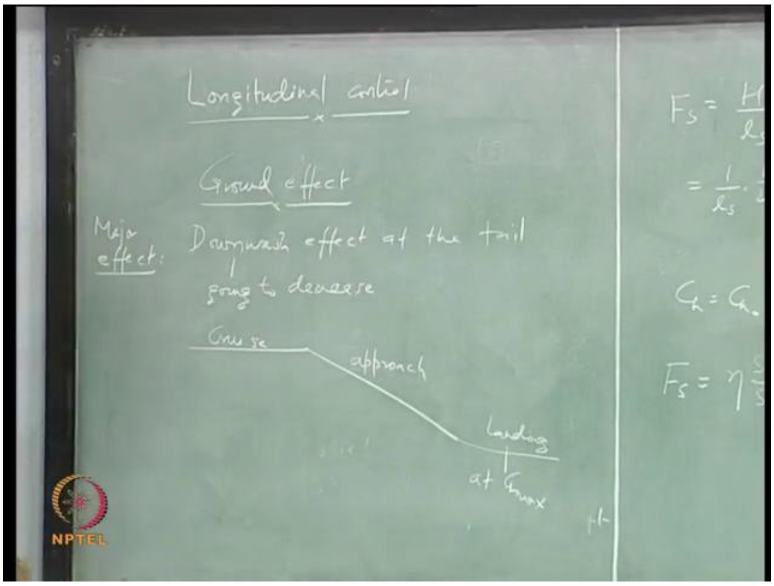

So, one of the main effects, is that the downwash angle, you know, at the tail is going to change, and that is going to change which way, it is going to increase or it is going to decrease?

Decrease.

It is going to, decrease. Decrease, downwash effect is going to decrease when you are close to ground. So, this is one of the major effect. Landing is a critical maneuver. It is not a… you know, many accidents will occur while landing. So, landing is actually a critical maneuver and you have to actually take into account of effects that are taking place close to ground. So, you have to change those derivatives. Downwash is going to decrease, what is it going to do? If the downwash is going to decrease; it is going to change the trim and stability characteristics, both. So, pilot should know that when you are trying to come down, you are going to actually, you know, from this cruise condition, you will initiate one, you know the approach maneuver, this is a approach, and finally landing. At landing what do you expect, I mean it should be landing at what C_L - $C_{L\max}$ actually.

(No audio from 43:30 to 43:43)

I think I will continue from here in the next class, any question.