Flight Dynamics II (Stability)

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Module No. # 04
Longitudinal Stability and Neutral Point
Lecture No. # 11
Power Effects on Neutral Point

The last thing that we have under this heading, power effects on pitch stability, is because of the jet engines, right. So if we have jet engines mounted on your airplane, then the effects are going to be little different. Let us try to look at them. But before that I want to tell you how the neutral point is going to shift because of the propeller on the aircraft.

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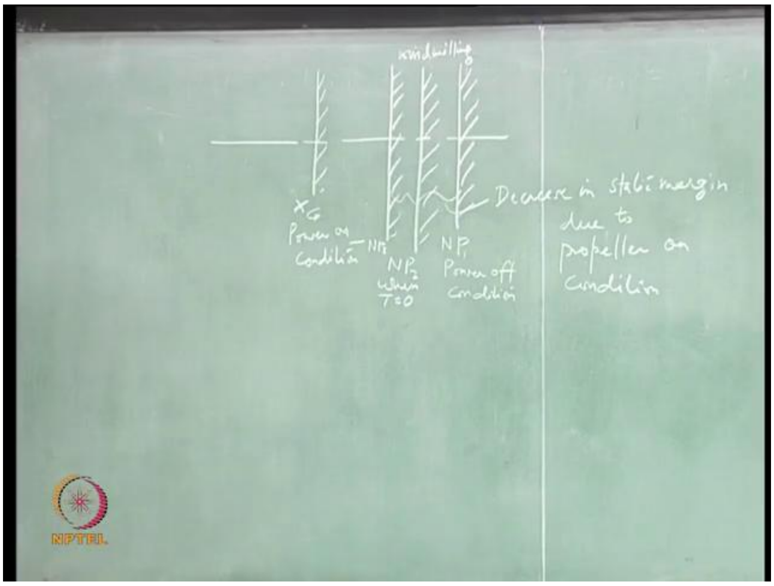

Let us say we have this neutral point without engine, so here is a power-off condition. Let us say the propeller starts running when it is not producing any thrust, it will have some effect on the neutral point. The effect is to take this neutral point location forward. So, this is the neutral point when, thrust is not produced, it is wind milling. This further moves forward when you have power-on condition. So, what is decreasing here? Stability margin, because stability margin is defined by the distance between the neutral point location and CG location on the airplane. Stability margin or static margin or static stability margin are interchangeably used to mean the same. Clearly you can see that when you start running a propeller and the engine starts producing thrust then there is so much of decrease in the stability margin. So, this is on and so power here is being produced; whenever we talk about the turboprop engines we talk about power. The effect, net effect is to decrease the stability margin.

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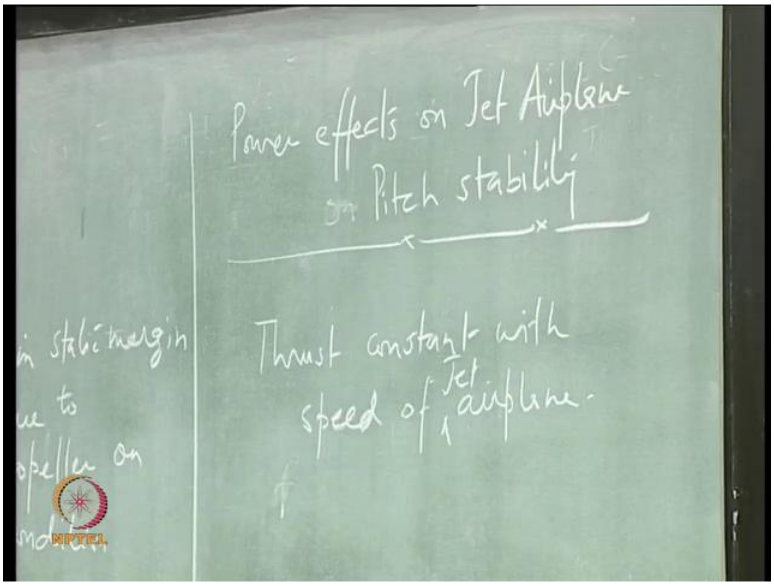

Now, let us look at the effect. Main effect because of the propeller was, you know, due to the flow field, which gets affected behind the propeller due to propeller slipstream, is it not? Here also something like that may happen, if your tail is lying in the, let us say, exhaust of the jet engine, jet engine thrust is not changing with velocity roughly, so thrust can be taken as a constant.

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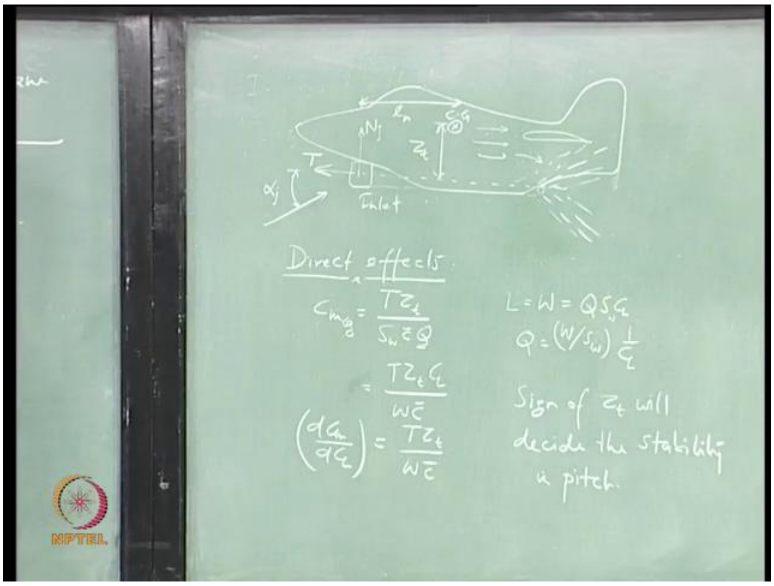

So, I am drawing here a picture where, let us say, the engine is here at the bottom. Here we have exhaust, the exhaust is going to be, so, jet engine, so, airstream coming out of this nozzle is going to expand. And if your tail is going to lie behind, or in this flow, then the flow is going to get- what, decelerated, because here you have the free stream and this is going to affect this flow. So, what kind of effect it is going to have? Relative wind at the tail will, relative speed of the wind coming at the tail will go down- is it not? And also this is going to sort of pull down- why is that? This jet is coming at high speed, so there will be a drop of pressure and then, it starts pulling the flow which is going over the tail- is it not?. So, there are two effects actually which can have on the tail itself- one is, tail is going to see a drop in relative wind speed, and also the angle of attack at the tail is going to change because of this. So, this is very complicated, I mean, if one wants to go into analysis, you know, of finding out what is happening to the delta alpha and the velocity, it is going to be really complicated, so what you would want to do is, you want to avoid as much as possible keeping this tail in the wake of the jet.

So, let us not right now bother about that, we are only looking at some initial estimates, we want to design an aircraft, I mean, we want to account for all these effects and only a first-hand estimate. If you want to get a correct estimate, very accurate, you have to design this complete airplane, put it in the wind tunnel, and wind tunnel is going to give you the best measurement, right. So, right now we are only doing a paper design and we want to estimate the effect of all these components on the, its stability.

So, what is this engine doing? It is taking air in, so this can be at some angle of attack. So, this is inlet of the engine and this line is the duct axis - so, the thrust produced is along this line. Do you think there will be a normal force also, here? It can be. So, there will be a normal force also, you know, created at this, you know, inlet of the engine. And let us say my CG is somewhere here ok, at a distance l_n, and this distance is z_t. So, you clearly, now, you can find out what moments these forces are going to create about CG- that is all I want to find out. So, these are direct effects, effects coming directly from the forces.

What is Cm? T into this length divided by the reference conditions, into Q: $C_{mcg} = \dfrac{Tz_t}{S_w \bar{c} Q}$.

Now, this Q is going to depend upon, or we can actually calculate, back calculate, when I am talking about a level flight condition, the lift is equal to weight. So, you have, and I will put a W here, so, this Q is: $Q = \left(\dfrac{W}{S_w}\right) . \dfrac{1}{C_L}$. W is the weight of the aircraft. What I want to find out is the derivative of this with respect to the CL- is it not- that is what is going to give me information about the stability. So, dC_m / dC_L is what? $\dfrac{dC_m}{dC_L} = \dfrac{Tz_t}{W\bar{c}}$ this. So, as long as yours this distance (z_t) is- what?- negative, you can get stability in pitch! If this z_t is negative- so, the stability is actually depending upon this term, the sign of z_t.

Let us look at the other effect, so, this is one effect. So, clearly here z_t will define the stability. So, where do you want the engine to be located? Close to the, this z_t should be small, if you cannot put it, you know, if you cannot bring this CG below this line, then you should at least try to keep that distance very small. It depends, how this effect is being produced.

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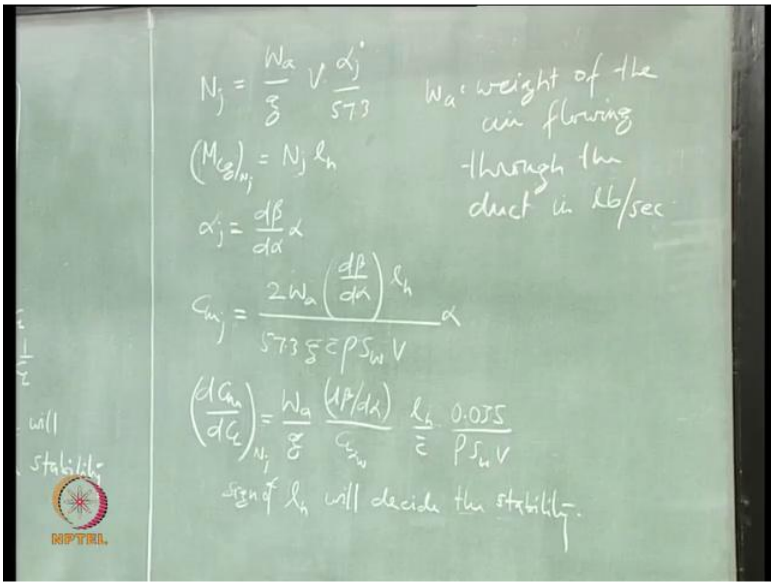

So, I will give you an expression for this normal force, and clearly it depends upon. So, this alpha is in degrees, you know, what the engine inlets is seeing, you know, the angle of attack at the engine inlet is this alpha j in degrees, Wa is the air mass flow rate , and this is in pounds per second - you have to remember, these units are very important, when you are trying to calculate the derivates they are very important, I mean, when we come to write, come to talk about the dynamic stability, there I will show you how they are going to, how any change in the unit can make a difference of course, any change in unit can make a difference in this number itself. So, if it is given to you in degrees and somehow you skip that and you put it as radians, then you are going to fall in big trouble, and that we will see afterwards. This alpha j α_j will also depend upon the upwash, which is created because of the wing. So, this engine is lying in front of, or the inlet is lying in front of the wing, so, it is going to affect the angle of attack that the engine-inlet is going to see.

No, that is what I am telling you, for this formula, if you are using this formula, Wa is in pounds per second, if you want to write it as kg per second, then you have to multiply it by some factor. Yes Wa over g, yes, g is gravitational acceleration. This is very interesting, nobody will give you this correct figure, you know, it is a (trade) secret. Now you get the formula, you will find out everything yourself, because getting the data for the aircraft is the most confidential thing. You know, you are building an aircraft and you have gathered the data over such a large period of time, over a period of 5 years, 10 years, you do not want to just give it away to somebody. So, if all the data are given correctly to you, then you can actually look at the dynamics of the aircraft very accurately using the aircraft equations of motion, and further on, you can actually design controllers. There are huge implications of, you know, generating this data set for any particular aircraft. All we can actually, I can tell you about these effects is how they are getting affected.

I am not saying that, that this formula, is accurate only to the level of writing it in the textbook, for example. Just for telling you what effect this is going to have on the pitch stability and I cannot guarantee anything beyond that. And it is very interesting that these formula also are not available in every book- so, look at any flight dynamics book it is not that you will see this formula available everywhere. You have to dig out some NASA report to find out this. We do something in the wind tunnel, we take some measurements, we just do not want to give it away to just anybody, right!. So, this is where the trade secret is, you can look at the aircraft and think about, I can design this aircraft because I have seen the geometry and outside features, and you can try to replicate it, but is it possible to make another aircraft like Sukhoi or, you know, just by looking at the geometry? You cannot do that. So, it is only a guideline, you know, first estimate of how we are going to find out the effect of each of these components on pitch stability. Some of the effects are pretty clear, we talked about the wing contribution, which was very clear, so, not much of problem there, but some of these effects are actually difficult to estimate, right. How do you estimate it? You have to do some measurements, put your engine on the aircraft and then, start changing this and see what is happening to the pitching moment, that is how you are going to generate this data- is it not- it is not such an easy thing.

In terms of this, now, Cmj is $C_{mj} = \frac{2W_a(d\beta/d\alpha)l_n}{57.3g\bar{c}\rho S_w V}.\alpha$ .... So, moment about CG due to this force is N_j into l_n and that is a positive movement. Finally, we get this expression which is $\left(\frac{dC_m}{dC_L}\right)_{Nj} = \frac{W_a}{g}.\frac{(d\beta/d\alpha)}{C_{L\alpha w}}.\frac{l_n}{\bar{c}}.\frac{0.035}{\rho S_w V}$ ... And this clearly depends upon the velocity itself, the speed of air at the inlet that can be slightly different as the free stream velocity, because free stream flow is taking a turn here. Beta is coming because of the, it is the upwash, because of the wing, the flow field will change here, right!. So, many questions that you will ask me, you know, for example, and ask me for an accurate answer, I cannot give you, right!. There is something happening around this place because engine inlet is sucking air. That is what we are trying to calculate, right. Where do you, I mean, what moment you want to calculate? You want to calculate moment about the CG due to the forces, and this is the direct effect, so, I am talking about the moment which is about the CG of the aircraft due to these forces. Again, this is based on the observations- will you take it like that? - because I would not know the exact details. What do you want to vary? So, let us take it as a first estimate. We have this jet engine and here is this normal force being produced, right!. So, moment about CG due to this normal force is going to be $(N_j l_n)$, and this is positive, it is pitching up. So, finally, what we want to find out is this quantity. So, jet inlet effect is ..., there is clearly, it is a clear difference between you and the way I am thinking. I am very happy that somebody gave me this estimate, you know, because imagine how much work you have to do to just arrive at this formula. And because I am working in the area of flight dynamics and controls I do not want to keep doing all these, I want to take all the data as much accurate as possible and trust the data and start my work from there, right!. So, this is, probably, this aspect should be covered in propulsion or aerodynamics courses, and I want to start after that. So, flight dynamics is the subject where you are beyond that point. We are here easily taking this CL alpha to be positive, where is that information coming from? From the aerodynamics! So, I am directly lifting it off, I am not actually seeing how it is coming, somebody did experiments, he plotted CL versus alpha for the wing and that is how I got the plot, I do not really bother about that in this course. I believe that the data, or the information that is given by the people working on the engine aspect or the aerodynamic aspects, you know, the information are correct and then, afterwards I start working on it.

So, this effect is again going to depend upon this sign of this term, which is the arm length, Ln. Is it clear? So, somebody gives me the data, somebody, you know, and this is something that you will need at the initial design stage itself, when it is a paper design, you are trying to work out all the stability derivatives, see if the aircraft is statically stable or not, but static stability means nothing, ok, you have to look at the dynamic stability, and there you will see that, you will need each of these data, right!. Yes, this is a positive term because it is in the upwash, you know, this inlet is in the upwash of the wing. Let us not go into the detail of that, because again, I will not be able to answer your question accurately. So, whatever we are doing, you know, in the first part of this course is only trying to tell you what component is going to have what effect on each of these term so that we can take a rough estimate of the stability of the airplane, and later on, when we are looking at the dynamic stability, that is the actual stability in motion, then the effects will be all the more complicated because it will be combined, coupled effects, and that we will see later. So, right now we just look at the static stability, you know, you change something and want to see how is that thing going to affect the stability, it is only the restoring force, it is like a restoring force, or restoring moment.

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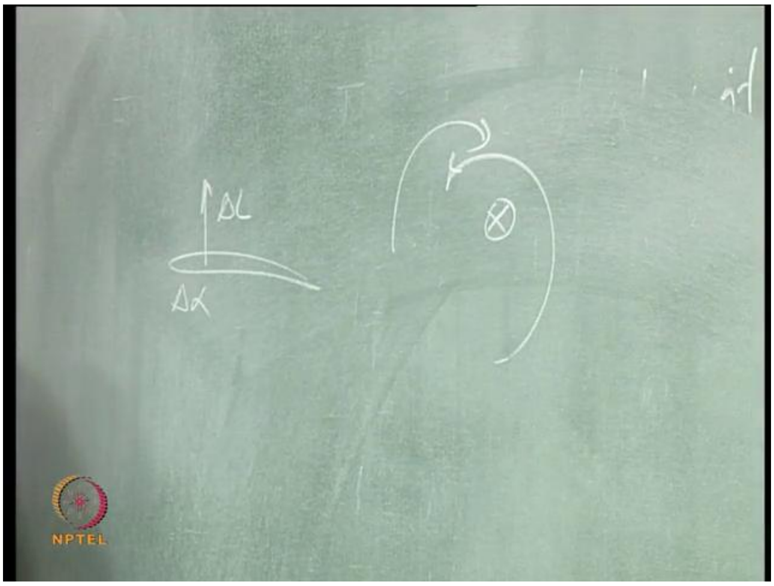

So, you change alpha, how is the restoring moment developing. If I am changing alpha, I know that the lift over this wing is going to increase, so I am going to get an increase in pitching moment. Now, my aircraft should posses static stability, in the sense that any change in delta alpha or delta L, you know, can be killed if the aircraft has static stability in pitch. So, it is automatic, it is, it is like, is the inherent property of the aircraft, you know, it is coming from the design, your aircraft will immediately respond to this change in delta alpha at the wing, or at the airplane. Whenever there is a change in, small change in angle of attack, you know, small means very small, and that change will go away, it is like an impulse. So, something comes and hits your aircraft and there is a small change in angle of attack, now, my aircraft should be able to, in time, restore itself to the original flying condition- is it not?- that is what is stability. So, this should happen automatically, not that I should apply any control for getting this, right. And so far, we have not been taking about controls, we have only said that when you add the horizontal tail behind this wing, that is going to act as a stabilator, stabilizer, we call it stabilizer because it actually produces an effect which is going to kill this delta alpha, and this delta alpha can come from anywhere.

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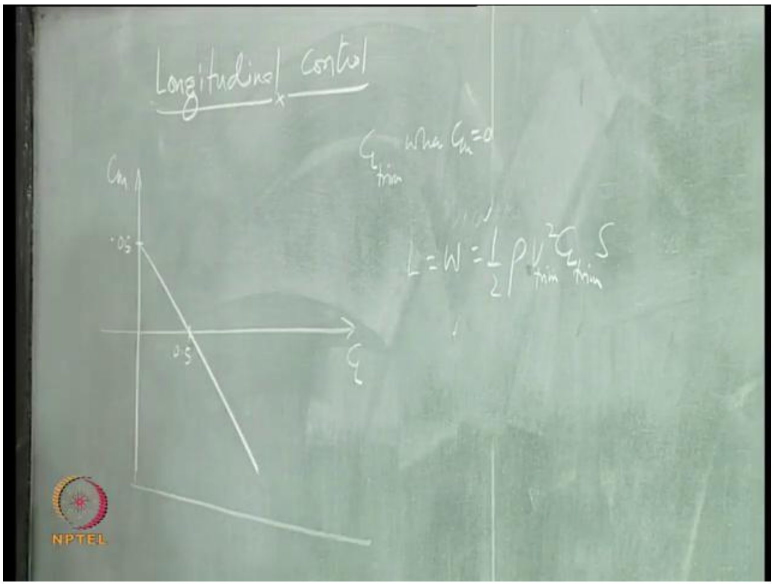

So, we will start a new topic today, and that is longitudinal control. After all that, whatever we have done in the last 4,5 lectures, let us say this is the final Cm alpha curve I get for my airplane- so, I will also give it some number- and let us say this is happening at CL which is 0.5. Now, I am able to trim at one CL, this CL is CL trim, whenever Cm is 0 that is, the trim point, so this CL is CL trim. So, think now without doing anything else I can fly any other velocity, so, right now I am able to let us say fly , this has to be equal to the weight, and CL trim is also corresponding to this one trim velocity- is it not? Let us say I want to change the velocity, or fly a new CL, that is why you are going to fly a different velocity, you have to, and still maintain a level flight condition- what you have to do?- if you want to change velocity, you have to change this CL trim, that is why we were going to balance these two quantity- is it not? So, to change the velocity you have to change CL trim.

What is there which can change the CL trim on the aircraft? You know, there is nothing that we said that we are going to change except the, now, we want to change it because we want to get into new trim. So, do you know of any surface which can do it? Trim tab- and what is that? Trim tab, not really, flap.

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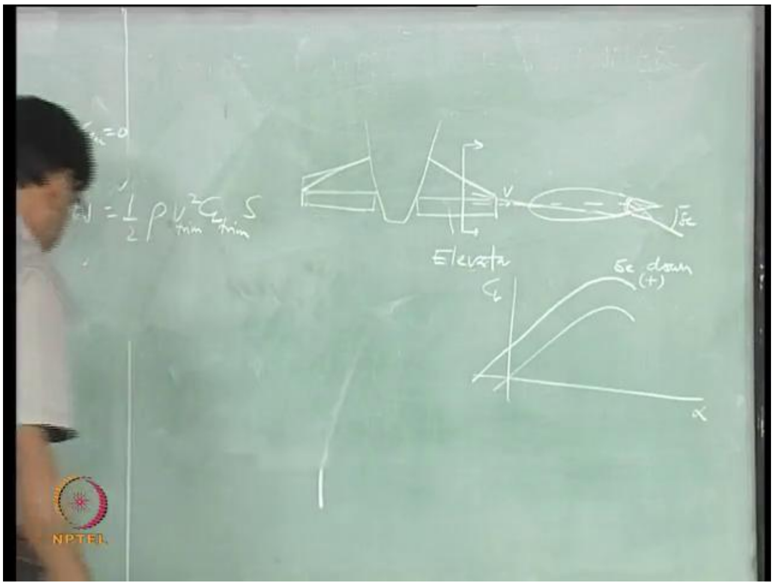

So, if you look at, so, this is surface, there is a flap at the trailing edge of the horizontal tail, which is called elevator. If you take a section of this tail, what do you see is, this small flap hints to this main tail body- so, this flap is called elevator; so, you deflect it, what is it going to do if you deflect it? No, moment will come later, moment is because of something else and that is because of something else. So, right now this horizontal tail is, each of the section of the horizontal tail is an airfoil which is symmetric, so any control surface, or any stabilizer will have a symmetric airfoil, and afterwards using the flap, deflection attached to that tail, you are going to change the camber; when you change the camber it automatically gives you a change in CL.

If I want to see how CL is changing when you change the elevator deflection... So, let us say I have one condition. Ofcourse, for symmetric airfoil you will have, you know, this profile, CL versus alpha profile, for the, I am only talking about this particular component, this aerodynamic surface which is the horizontal tail for us. CL versus alpha is this for symmetric airfoil. How it is going to change when you change this? So, which way you deflect when you get higher lift? Down, because the camber is positive. You will see, this is for delta e down like this, this delta e is positive; so, downward deflection of this flap at the trailing edge of the horizontal tail is positive deflection, this we will take as positive- remember this convention.

And the angle of attack, so, for 0, so, this was the direction of the flow, V, and if it is symmetric airfoil and is there is no deflection of this flap, then you are going to see angle of attack which is 0- is it not?

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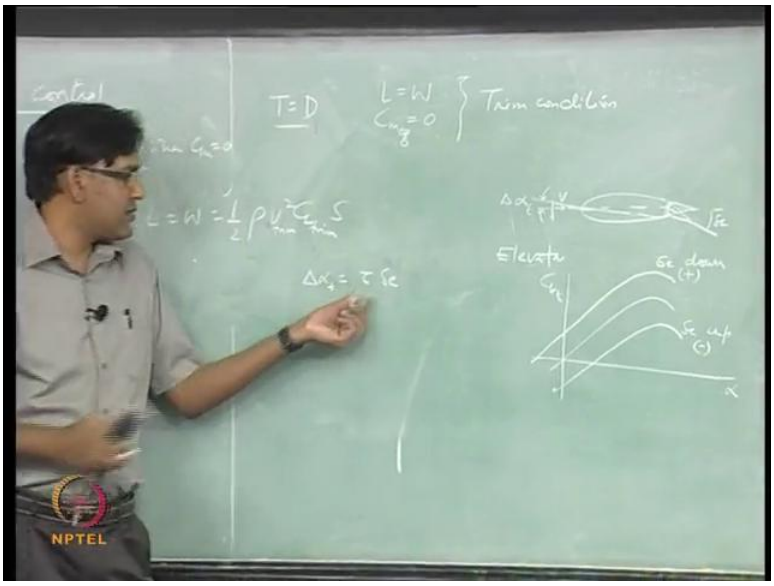

But now keep this velocity relative wind speed at the, in the same direction and change this elevator, what you see is this, this is the this is the angle of attack that you are going to see; I will say this alpha at the tail, you know, change in delta alpha at the tail because of the deflection of this flap. And positive convention is that you have to take it positive down, because it is going to give you an increase in lift, positive camber. For the same reason when you deflect it upwards it is going to give a negative camber, and you see a change in, decrease in the lift at the tail- and what is that going to do to the moment?

You know, remember, we have to talk about lift equal to weight and also Cmcg equal to 0, this will define the trim condition or the equilibrium condition, and we are also assuming that thrust is always taking care of the drag; so, clearly there is a change, you know, at the, change in the angle of attack at the tail because of the deflection of this flap, which is elevator in this case. So, I can write this delta alpha t equal to some, you know, some tau into delta e- it is not going to be directly, you know, equal, it is not that you deflect elevator by 5 degrees and you get increase in angle of attack by 5 degrees, that is not going to be happen, so, only going to be proportional to this deflection. And this will depend upon lot of things. So, any question?

Yes, I am going to talk about that, I am going to talk about how we get this all. We will come back to this in the next class.