NOC: Introduction to Airplane Performance
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Lecture - 43
Control: Elevator

Very good morning dear friends, I am sure your eyes must be tried, seeing so many expressions, very dirty looking expressions generally. But we have practice of feedback from the student, we called a reaction survey in IIT, Kanpur. And for many times, when I got the reactions from the student, there was one common observation ((Refer Time: 00:35)) board work is very dirty, immediately in next semester I will try to improve it. But, suddenly again the board work will become dirty.

So, few of my students again ask sir, again I said I am statically stable as far as board work is concerned. So, that is why we are trying to see, how I can fly a statically stable airplane. Why I am saying statically stable airplane? Because, I know that airplane, which is statically stable, it will not allow or oppose any change from the equilibrium. We are trying to understand, how can you fly a statically stable airplane; what is important to observe, when I am talking about statically stable airplane; that statically stable airplane means, it has an inherent initial tendency to oppose any change.

That means, if I am flying a 2 degrees, if I want to fly a 3 degrees, angle of attack C L corresponding to 3 degree angle of attack, it will oppose. So, I have to hold the control and take the airplane to 3 degree angle of attack and balance my forces and moments. About that equilibrium, again it is statically stable, so it will try to say in 3 degrees, even you want to change it to 4 degrees angle of attack, again it will oppose.

So, you have to put a control through the elevator, give a moment, come on, hold on, balance all the forces of moment, again that becomes a new equilibrium, again about that equilibrium, it is statically stable. That is how we ensure that, I can fly, can design a control, which should know very clearly it statically stable, it has inherent density to come back to the original equilibrium. That is the preamble of our discussion today and to understand this in a manner through modelling, we wrote all these equations, lift and the wing, tail, try to find out moment.

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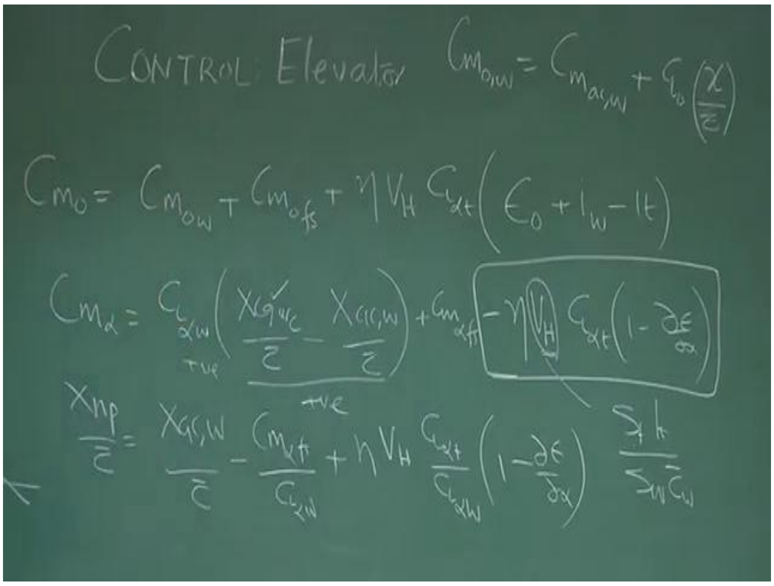

And we got neat expressions, one was C m naught as C m naught wing plus C m naught fuselage plus eta V H C L alpha tail into Epsilon naught plus i W minus i t. And we got C m alpha as C L alpha wing into X c g aircraft by C bar minus X a c wing by C bar plus C m alpha fuselage minus eta V H C L alpha tail into 1 minus d Epsilon by d alpha. And also we find out neutral point location as X a c wing by C bar minus C m alpha fuselage by C L alpha wing plus eta V H C L alpha tail by C L alpha wing into 1 minus d Epsilon by d alpha. This looks much neater, whatever effort we made yesterday, ((Refer Time: 03:58)) was this three expression, let us visit them as a designer.

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What is C m naught? We know that, if I want to fly at some C L or alpha, I need a particular value of C m naught. We also agreed, if I have designed the airplane efficiently, I should automatically get this C m naught without giving any elevator deflection. By giving elevator deflection, suppose this is a tail, by giving elevator deflection, I can generate moment C m naught even at alpha equal to 0. So, this graph can be shifted here, here, depending upon what deflection we have given.

But, for efficient design, I will ensure that, I should be able to trim my aircraft by this C L or alpha without giving elevator deflection. That means, this C m naught contribution should come from C m naught, because of wings and C m naught, because of fuselage and then C m naught, because of tail. And we have not done any explicit expression for C m naught fuselage, which is generally very low and those, who are interested, they can read books, they are very, very low. So, we are more focused on C m naught wing and C m naught tail.

And in second was C m alpha, the message was what, that C L alpha wing; that is wing that there, they should be placed, the history of the wing should be placed in a manner. The tail should be placed in a manner that overall C m alpha should be less than 0, thus slope should be negative, total contribution. And then, you try to find out, what is the limit at which I can lay out my C g or I can take C g backward.

At that point, the aircraft become neutrally stable or at that point C m alpha will become 0. The message is you could take C g beyond that, then it will become statically unstable, these are the three interpretations. If you see in C m naught wing, you have seen this is C m a c wing plus C L naught into X bar; that is the difference between, I just say if we write X by C bar and we try to understand that one first from designer perspective.

What a designer should do to ensure that, C m naught, because of the wing is finally is positive. We not be able to compensate for whatever C m naught is required, but it will ensure that, it is not negative.

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Because, we are using cambered aerofoil, for a cambered aerofoil C m a c wing is less than 0, so I have to do something with the second term. What is a second term? Second term is, if this is the a c of the wing, I will ensure that C g of the aircraft is behind the a c of the wing. So, that alpha equal to 0, I know there is a lift force or C L naught and this distance is X. So, this will give you nose up moment or it will give C m not positive and you should be sufficient enough to counter this negative value.

At least this should becomes 0, very good, if you can get some positive value, because finally, you have to get so much of C m naught in combination with tail and fuselage. So, message is very simple if the cambered airfoil, try to put the a c of the wing ahead of C g, although this will give a destabilizing contribution that you could from here the moment I put C g behind a c of the wing, this term is positive, this is positive. So, whole wing contribution to C m alpha is positive, which is destabilizing.

But, you should do not worry, what is the problem our friend is here. So, what is the problem, the stability part will be taken care by our friend tail, horizontal tail. So, this is always negative. So, I can go on changing the value of V H, which is tail volume ratio and try to compensate for stability loss, static stability loss, because of wing a c being a head of C g.

So, messages is clear, do not worry about wing in terms of stability, static stability, give some considerations, so that it can help us in giving C m naught. Because, anyway cambered airfoil, if we put the a c of the wings behind the C g, C m naught from the wing will be further negative. So, difficulty in trimming, you put a c of the wing ahead of C g, it will have a destabilizing component, it does not matter. Tail will take care will appropriately design the volume ratio, which is nothing but, tail area into the tail momentum term divided by wing area and mean aerodynamic chord of the wing.

Typically, this value I have to can start 0.5, 0.6 good enough and this man tells you what, as you are designing the airplane; that is a configuration. We have selected some wing, some tail, it is a tail, the wing and depending upon it is location of a C, Location of tail, because tail volume ratio contains l t. All this things you can get a fixed number for neutral point. So, let us say neutral point is somewhere here.

The message is, when you layout in the C g, you will not move the C g beyond this line, beyond this point and this gap between the C g and the neutral point, we call it stability margin. A stability margin and it could be between 5 to 15 percent of the chord, this is, that is an initial estimate. So, once I understand this, now I ask a question, if I want to change the equilibrium of the airplane from one flight condition to another flight condition.

How do I deflect my elevator; that is, what we say, elevator control or will be talking about elevator control power or final aim to find out, how much elevator should I deflect to trim a aircraft at a particular C L.

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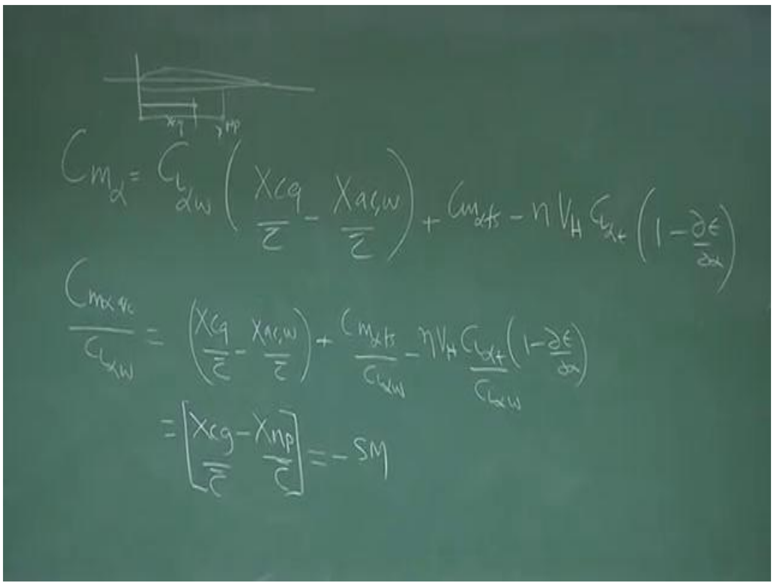

So, to understand that, let us do little bit of reappreciation of the expressions and we try to get an additional designers perspective. Note this C m alpha wing is X c g by C bar minus X a c wing by C bar plus C m alpha fuselage minus eta V H C L alpha tail and to 1 minus d Epsilon by d alpha, I divide by left hand side and right hand side by C L alpha wing. So, what will have, I have C m alpha of the whole aircraft by C L alpha wing is equal to X c g by C bar minus X a c wing C bar plus C m alpha fuselage by C L alpha wing minus eta V H C L alpha tail into 1 minus d Epsilon by d alpha divided by C L alpha wing.

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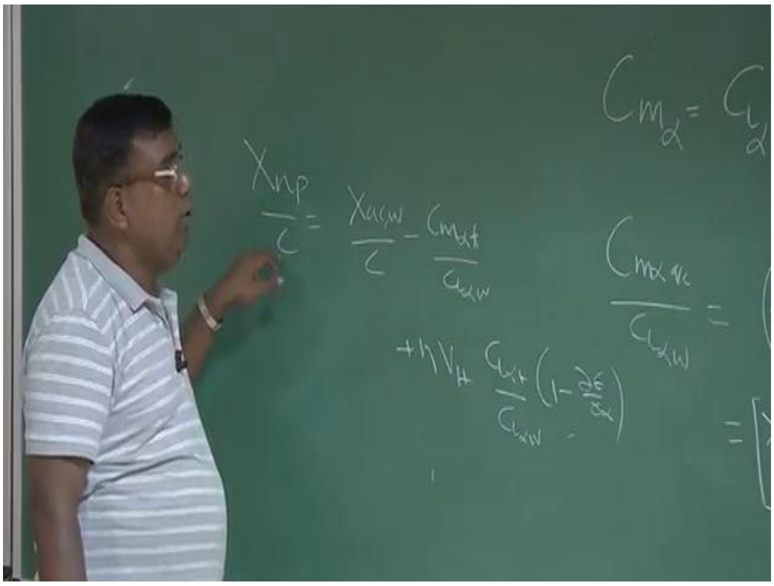

Now, what was the expression for neutral point, see X n p by C, if C it was X a c wing by C minus C m alpha fuselage by C L alpha wing plus eta V H C L alpha tail by C L alpha wing into 1 minus d Epsilon by d alpha. This are expression already you have, now carefully see the right hand side, if I just manipulate this I can right, this equal to X c minus X n p. You could see, if I take minus sign common here, then X a c by wing minus C L alpha id large by C L alpha wing plus eta V H wing alpha by tail by C L alpha wing, 1 minus d Epsilon by d alpha.

And that is nothing but, X n p by C Location of neutral point. So, this ratio is nothing but X c g minus X n p; that is, if be the aircraft, if I am measuring the X c g, this is X c g and this is a neutral points X n p. Then, this difference as I told you a static margin, so this is equal to minus of static margin, because static margin is define that X n p minus X c g, so minus of static margin.

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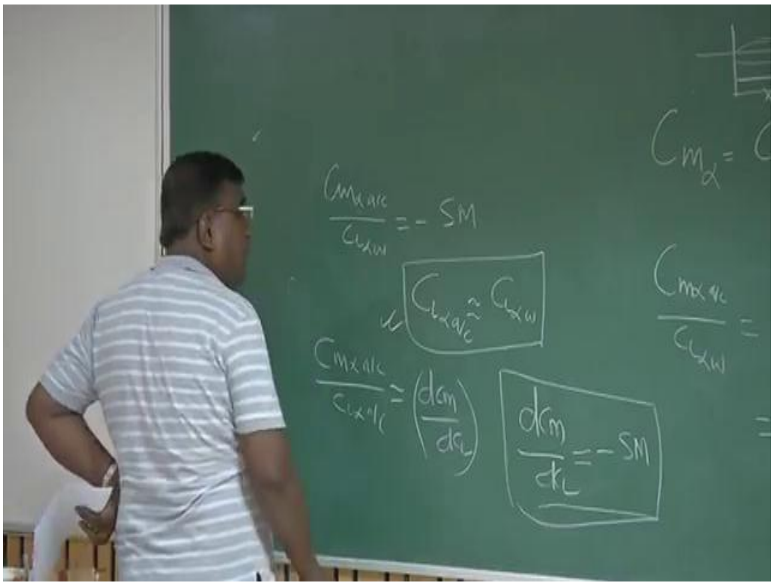

So, what we have got in a simpler term, I got C m alpha of the aircraft by C L alpha wing is minus static margin. Now, if I do an approximation, this is what I designer a place important role, because we are trying to get the initial estimates. You know, what is the primary role of the wing, given that later, so the obvious the C L alpha of the wing based on the reference area is the predominant C alpha of the whole airplane. That is, I can assume with a 10 percent in accuracy that, C L of the aircraft is nothing but, C L of the wing.

That is C L alpha of the aircraft is proximately equal to C L alpha of the wing, this is an approximation. This is I am doing because I understand the C L alpha of the tail based on the wing reference area will very small compared to C L aircraft of the wing. So, this is what the whole tricked to get a designers field, then I can write C m alpha of the aircraft by C L alpha of the aircraft and this is nothing but, d C m by d C L of the aircraft.

Hence, I can write with this approximation d C m by d C L of the aircraft is approximately equals to minus static margin, this is a wonderful for designer to design an airplane. That is why I am stressing at this point. You see, how beautifully I use this for designing an airplane.

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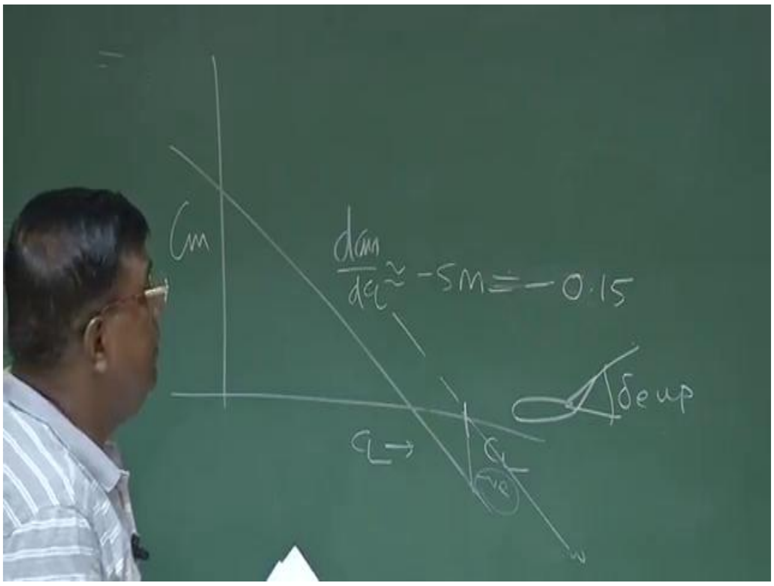

So, the problem what you are looking for is, suppose this is your C m verses C L graph on the slope is d C m by d C L and that is, we have agreed that d C m by d C L approximately minus static margin. And if it is 15 percent so minus 0.15 C bar or minus 0.15 by it is 15 percent static margin, which is as per distance is concerned 15 percent of chord, mean aerodynamic chord. This is the separation neutral point and the C g, C g is the head of neutral point and it is statically stable minus 0.15.

Now, what we are trying to do is, I want to know, if I am flying at this C L or if I want to fly at this C L, another C L, I know by virtue of it being statically stable, it will generate a negative moment, nose down moment. So, I have to counter that and make sure that, this C L verses C L graph is passes like this from this equilibrium. So, question is how much moment, positive moment I should give to compensate this negative moment; that will be given by C L verses C L graph.

How do I generate this? I generate this positive moment now to counter this negative moment by giving what an elevator up deflection. So, the elevator up by the elevator up deflection should to generate enough moment, pitching moment, positive to counter this negative moment. So, that at this point, again the moment is 0. So, there at trim or there are equilibrium. So, if this understanding is there, then we will formulate.

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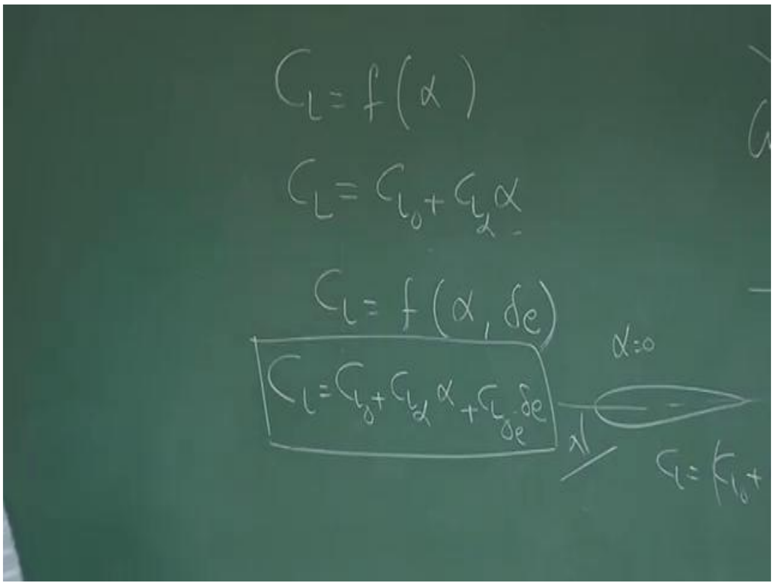

Let us see so far we are talking about C L is function of alpha for a given Reynolds number Mach number etcetera. So, we wrote C L as C L naught plus C L alpha into alpha. Now, if C L is also you could see, not only function of alpha, it is also function of delta e, do you agree with me or not.

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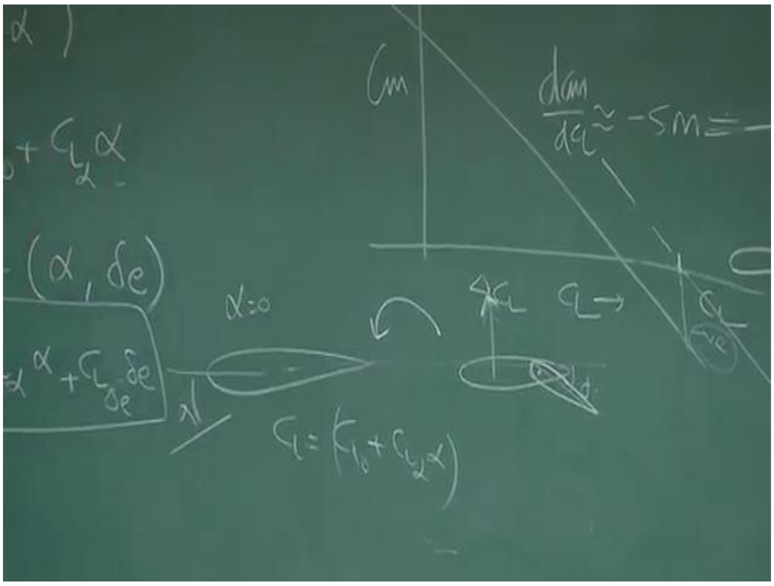

Suppose, this is the wing, this is the tail right and total C L some of this alpha, then C L is C L naught plus C L alpha into alpha for the whole aircraft, C L alpha is for the whole aircraft. But, if I now give deflection of the elevator like this, which is positive deflection, then when the alpha is equal to 0 this will produce a lift. So, now, my C L will also become function of delta e.

So, in a partial derivatives sense, we are assuming it to be linear, I say the C L, I can right it as C L naught, when both alpha delta, you are 0. Then, find out what is C L alpha; that is C L alpha, if the per unit change in C L, because of the alpha, holding elevator and other thing constant. Then, I say at C L delta e into delta e, C L delta e means is, how much change in C L, because of deflection of delta e, holding other the other is constant, no change in alpha.

So, this will give me a description of C L and please understand all this value C L naught, C L alpha C L delta, they can be estimated depending upon geometry and flight condition. So, you assume that, these are available for a given geometry and given flight condition. So, if this is true the moment I have deflecting by delta, if not only given some C L or delta C L, it also gives the moment. So, now, I must modify the moment equation also.

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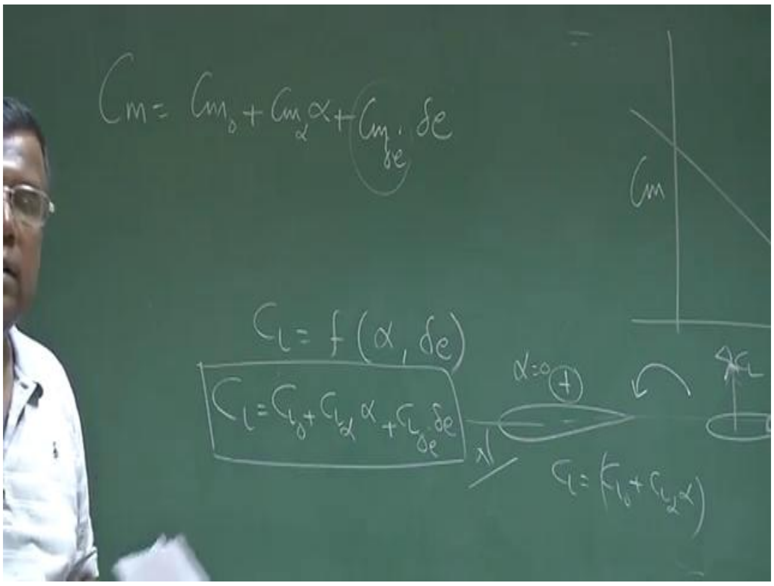

So, far how I was writing moment, moment I was writing, moment coefficient I was writing as C m naught plus C m alpha into alpha. Now, what does happened because of delta e deflection of elevator, there is an increase in C L or there is a change in C L, change in the correct word, it may increase, it may decrease. The overall C L of the airplane depending which way it deflected not only it will change C L by this force we create moment about centre of gravity.

So, it will also give pitching movement depending upon, it is elevator is up, then it will give a pitch up moment, elevator is down, it will give pitch down movement. In this case, it will give pitch down moment or nose down moment, if it was up like this, it will give pitch up or nose up moment. So, I need to add C m delta e into delta e, where C m delta e where I say the additional change in the pitching moment coefficient, because of delta e or in terms of the dimensional quantity, I say additional pitching moment generated, because of elevator deflection, all about centre of gravity

Thank you.