Aircraft Stability and Control

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Lecture- 08
Neutral Point and Fuselage Contribution

If we are continuing our last problem where we are trying to calculate CM0 of the whole aircraft, which consist of CM0 of wing CM0 of tail and we have learned how to compute them, and then we have also seen how the CM Alpha or the stabilizing contribution of wing and tail can be computed and in that we have seen for this particular example, the wing was destabilizing so, CM Alpha of the wing was positive.

And CM Alpha tail was negative as tail is a stabilizing component, and then when we add up CM Alpha wing and CM Alpha tail, total gives CM Alpha negative that means once you put the tail with that dimension, the appropriate VH tail volume ratio you get particular level of static stability, also we learn that if I give a tail setting angle in this example it was -1 degree and for that it generates sufficient CM0 value, and that value.

We have seen what exactly it is, we have also seen CM0 because of wing, CM0 because of tail and total CM0 also we have computed, so we have learned this art the skill how to calculate CM0 of the whole airplane, how to calculate CM Alpha of the whole airplane, of course we have not talked anything about fuselage contribution which we will do in some session right? But to end this another important thing comes into our mind, okay.

I know CM Alpha of the wing CM Alpha of the tail, let see the CM Alpha of the airplane I need to know the neutral point where is the neutral point? Why is it important? Let's understand that, what is a neutral point?

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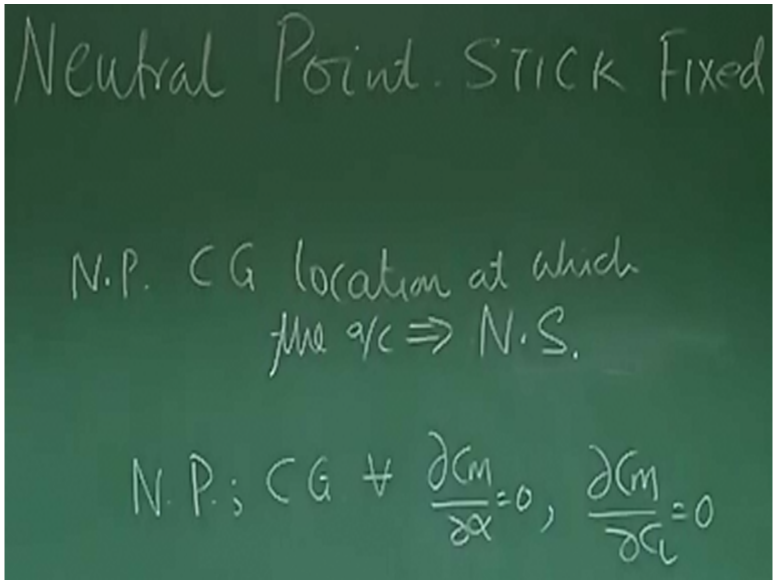

Neutral point is that CG location at which the aircraft becomes neutrally stable, neutral point how do I define again? Neutral point is that CG location at which the aircraft becomes neutrally stable so I will use NS, when I write NS it is to be understood it is neutrally stable. And if I try to translate this into mathematical definition we say neutral point is that CG location, for which DCM by D Alpha = 0, that is neutrally stable or equivalently I can say, DCM by DCL = 0. Please note that in neutral point I have also used the word stick fixed that means I am not allowing any floating of the elevator okay?

So initially we will be talking more and more about stick fixed, and then at some point again we will come back to stick fixed little bit so that your concepts are clear. So let's focus on the stick fixed, the understanding is this if I leave the elevator free it has natural tendency to float up most cases however, we are saying no we will not allow that floating if I want to go for a five degree then I will take it to five and lock it okay? So, let's come back to the neutral point and let's try to understand this from a simple example.

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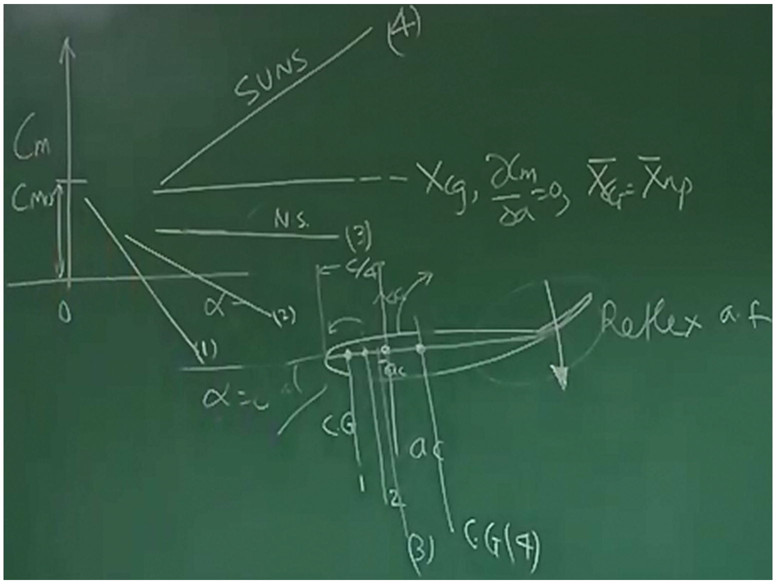

Suppose I have got a wing, flying wing and it has a reflex aerofoil, you could see reflex aerofoil configuration and let's say its aerodynamic center AC, where will be the AC for low speed? You all know you are expert by now it will be at quarter chord point or twenty five percent of the cord, Right**?** Now let us see if I put CG somewhere here, will it be statically stable or not? That is the question. Although we know by now that whenever AC is behind CG it gives stabilizing moment you can always cross check, it is better to cross check.

Suppose if I give a disturbance some Delta Alpha here I see there will be a Delta CL acting here, which gives a nose down moment about CG that means it will try to discourage the Delta Alpha or it will try to come back to. It will have initial tendency to come back its original equilibrium, so we say this is a statically stable case okay. And from the definition point of view if there is a positive Alpha, there is a Delta CL which gives you nose down moment so I say Delta CM so you could see that because Delta CM is negative nose down is negative.

So again here DCM by DCL is less than 0 or DCM by D Alpha is less than 0. So both are mathematical conditions for attributing towards statics stability, right? So what is land that as long as aerodynamic center is behind CG for a flying wing this will have stabilizing effect and the flying wing will be statically stable right. And this is the CG and this is the AC. Now think of a situation suppose I start moving this towards AC of the wing that is and I am shifting the CG from this location towards AC that can easily be done you can redistribute the masses here you say were the flying wing CG can move AFT what is the meaning of that.

What will happen if CG from station one it comes to station two that means this momentum has reduced okay so the is storing moment magnitude will reduce although sign still remains negative so you say it is still statically stable although the degree of stability static stability or the amount of static stability has reduced because this momentum has reduced. Now imagine if I take CG further close to AC what will happen?

As longer that CG is a head of the C of the wing for a flying wing configuration please understand I am talking about the flying wing there is no tail at all as long as the AC of the wing is just behind CG of the aircraft it will have a stabilizing effect natural question comes. What happens if CG and AC of the wing coincides same point and what will happen? There is momentum is 0 so there will not be an any moment even if there is any force so it will not generate any moment for any angle of attack. So that is the point where we say it does not have an any restoring moment.

And it is a state where you say the aircraft and flying wing is neutrally stable now if I try to draw understand this through CM versus let's say Alpha graph let us I want to draw CM versus Alpha graph for this configuration. So this Alpha is = 0 so what is your guess?

At Alpha = 0, will there be any CM? Look here, if it is symmetric if it was just like this at Alpha equals to 0, definitely they is no CM because the forces here, forces here are equal in magnitude, they canceled each other. To be more precise the pressure difference neutralizes and there are no net force, so naturally net moment will be zero, but the moment I have put a reflex aerofoil, this is reflex, you could see.

What will happen, because of this portion right there will be a force generated even at Alpha equals to zero, which will intern give a moment like this about CG and which is positive moment. So this tells me that at Alpha equals to zero, there will be a positive pitching moment, so I can tell at Alpha equals to 0 there is a positive pitching moment coefficient as long as it is reflex aerofoil clear?

So, if I draw it, so at Alpha equals to 0 there is some CM0 okay? Now, what about the slope? CM versus Alpha that I know if I again draw it a bit cleaner for you to understand.
Let us say first case, this AC is at C by 4, let's say CG is here I call it one, so this is CG location okay? Please you understand this is the AC which is C by 4, and this is the one of the location of CG. So now you know because of this, AC behind CG or CG being ahead of AC.

There will be a nose down moment, so let me erase this to be more precise that you do not get mixed up. So let me draw it this is C by 4 so since CG is ahead AC for any disturbance there will be a nose down momentum of CG, so CM will be negative so I know that now that slope between CM versus Alpha will be negative in this case right? So let's say this is the CM versus Alpha slope for CG 1 okay?

Now what I do? I put the CG little close towards AC, so let's say I put it here number two, what will happen? Will the slope become positive? No because, there is still a momentum which will give force, which will give moment because of the force here, so again then the nose down moment will come so slope will still remain negative, but magnitude will reduce because momentum has reduced.

Now I take it to point number three further close to AC now you know the momentum has further reduced, although momentum has reduced but still the AC is behind CG, so there will be a negative moment. So it may look like this, so three this tells you or tells us that if this CG concise with AC of the wing then there will not be any slope or there will not be any change because of Alpha so what will happen that this line will become something like this, this is XCG.

At which DCM by D Alpha = 0, and this XCG location is nothing but our X neutral point correct. So, what is the neutral point for a flying wing? For a flying wing the aerodynamic center itself becomes the neutral point of the flying wing is it clear? Okay? Why it is a neutral point because if I bring CG just coinciding with AC then it will have CM Alpha = 0 or DCM by DCL = 0. What happens if CG goes further up aft, if CG comes here CG 4 locations?

Now what will happen, now the AC of the wing is ahead of CG, suppose some disturbances there then this Delta CL will give a nose up moment, right? Nose up moment so, it will not have any initial tendency to come back to equilibrium so we will say this is statically unstable case and in that case the slope is positive.

Now CM is positive for Alpha so the line will look like this, This is XCG four location this is statically unstable and these all statically stable and this is neutrally stable. Why it is important if you are designing a fly wing you must ensure that the AC of the wing is always behind CG of the airplane, right to have some static stability. At this point I must also tell you that unstable does not mean uncontrollable you can still fly in a unstable airplane.

By using all controllers and flight control system in a simplistic way if I take a stick on my finger it is statically unstable but still I can control so, what we say unstable does not mean uncontrollable. In fact we will find most of the fighter airplanes increase the maneuverability it make them statically stable but marginally okay. So this is the understanding of a neutral point in a simplistic manner. How do I extend this understanding to aircraft?

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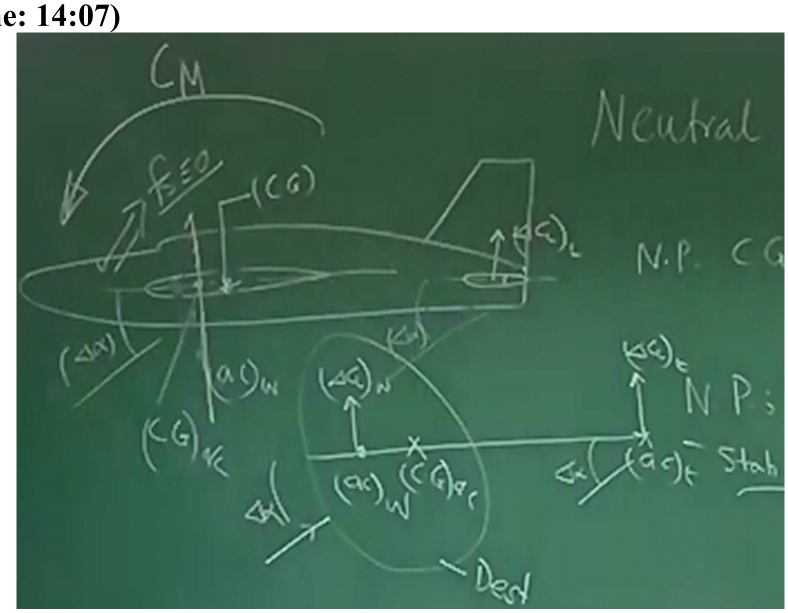

Let us see this is the aircraft. Listen this is the AC of the wing for time being assume fuselage effect is 0 okay you are neglecting the fuselage for timing. Now if the configuration is like this and if CG of the airplane is somewhere here what is your answer whether this configuration is statically stable or not? It does not have any tail please understand it does not have any horizontal tail as per diagram it goes but answer is very simple.

You know that the AC of the wing is behind CG. So the wing will be giving stabilizing component and so the CM by D Alpha will be less than 0, since we neglecting fuselage effect so we are saying this is statically stable case, okay. Now, suppose I change the CG, this is CG is here or let me further make it simpler to you that you can understand clearly, let say CG of the airplane is coinciding with aerodynamic center of the wing.

I repeat we are not considering fuselage effect at all. So in this case, what will happen the aircraft will be neutrally stable right okay. And if I further bring this CG aft of AC of the wing it will become statically unstable, this much you have understood. But now let us see what happens if I put horizontal tail here when the moment I put the horizontal tail there and even if CG is conceding with AC, do you think it will be statically unstable or statically neutrally stable.

You say okay CG of the airplane and AC of the wing are same point, what is your answer? Please see here, let us see this case, if CG of the aircraft and AC of the wing are at same point, when tail was not there we realize it is a neutral stable case, right. So it will not that any CM for Alpha, So DCM by D Alpha will be 0.

But the moment I put a tail here, even its AC of the wing is at CG of the aircraft, if I produce some disturbance Delta Alpha and roughly Delta Alpha also will be here if I neglect downwards and all, even If this not giving any moment about CG but remember here there will be a Delta CL tail which will be a nose down moment, nose down pitching moment so that we are writing CM, so this make the whole configuration again have being DCM by D Alpha less than 0. Is it clear?

So that is the beauty of keeping a tail. So, what is actually happening? Earlier when tail was not there you have a limit that you cannot put the CG beyond AC of the wing otherwise it will become statically unstable. But the moment you have put tail you can easily to some extend some degree you can put CG behind AC of the wing also because this man the tail will care of the restoring moment what will happen suppose this is the CG of the aircraft this is the AC of the wing and here AC of the tail.

So even if there is disturbance Delta Alpha there will be Delta CL because of wing even but CL is supposed to be perpendicular to the velocity vector but for an small angle. I am just drawing it like this, ideally should be perpendicular to velocity vector right. The similar Delta Alpha here also will be way Delta CL tail, right this man this wing contribution will generate what type of moment stabilizing or destabilizing? Check here AC of the wing is the ahead of CG, so this will give a destabilizing.

What about tail? Tail will give Stabilizing, so now even if the AC of the wing is the ahead of CG, if you put in a appropriate tail, you can make this whole configuration having a DCM by D Alpha or DCM by DCL appropriately negative and that is what the problem what we solve was telling us right. And most of the cambered aerofoil aircraft we will find AC of the wing is the ahead of CG because we have seen by putting AC of the wing ahead of CG.

I can reduce the CM0 negative reflect of the wing because of CMAC okay. So this is the understanding, so we will now try to calculate neutral point for the given problem and it is straight forward when you understand this if I write the formula for neutral point.

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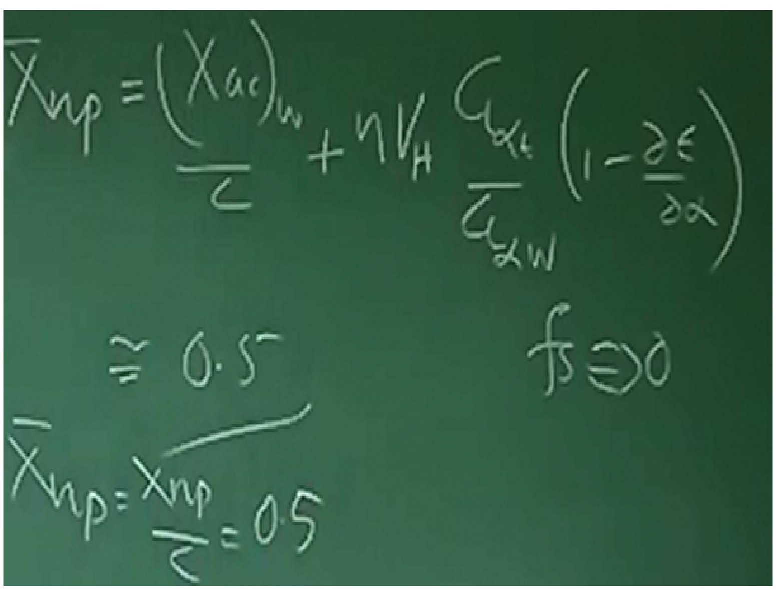

That was XAC of the wing by C, let me write this, + Neeta VH CL Alpha tail by CL Alpha wing one - D epsilon by D Alpha we have neglected fuselage of effect altogether here. If I put this number I should get this value around point five. So simple, so once you get XNP by C which is XNP by Bar which Is = XNP by C = 0.5 so what is the meaning how do you interpret this as a designer. Let's that be very, very clear.

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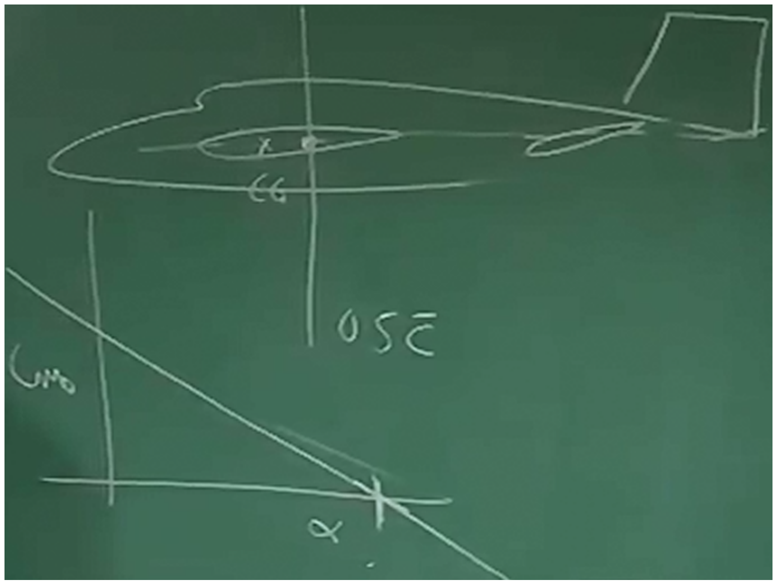

Let me draw the airplane, here the airplane, here is the tail, here is the wing, of course this tail is having some negative setting angle. So this big one degree so I will draw it something like this tail and if this is a line with CG is here and the neutral point is coming it around point five C or C bar and the meaning is if I fly this airplane I will be able to generate CM0 positive and the slope at trim DCM by D Alpha will be negative.

That tells me clearly I can trim this statically stable airplane at a positive angle of attack Alpha okay because I could make CM0 positive, okay, This was the problem I want to clarify you few things for whatever we have derived by expression and sometime we get lost into all the expression DCM by D Alpha, DCM by DCL what 0 but if you understand the physics understand the skill part of it you can easily translate.

This expression to your advantage and you can design a good aircraft. Before I take this lecture, I would like to tell you one thing that when we do some sort of recording and when I again see it myself there maybe some section which I would like to repeat and my friend who are doing the recording they say, sir please come with same shirt, same jacket because otherwise it will look different and I contest them that is not possible okay.

And our continuity is not through our looks or with jacket I am putting on our continuity through the subjects, the concepts which we're trying to reinforce by repeating many times many things we have seen. So please bear with me sometime we will find there will be a discontinuity if we try to focus through my uniform I wearing because for simple reason that I may recording it is in some other time okay. I am sure the young man and young girls seeing appreciate it. Let us come back to academics.

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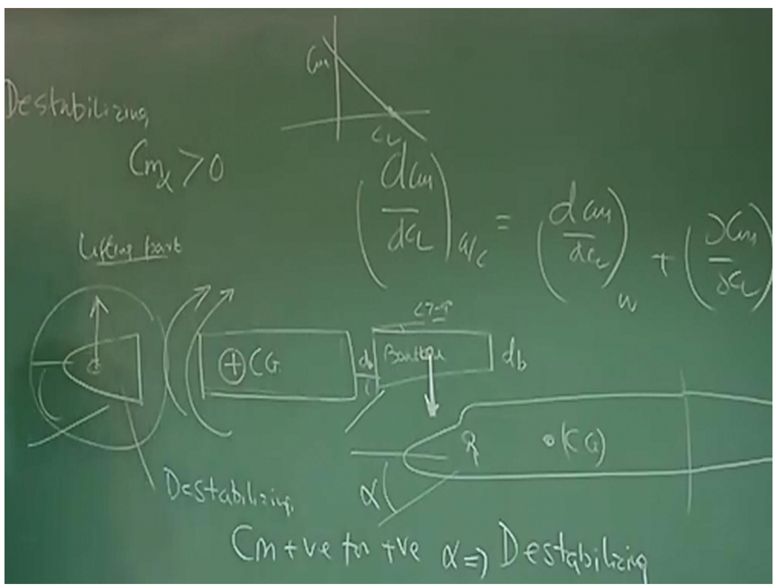

We have being talking about DCM by DCL and you know by now you must be expert by now this is CM, this is CL and DCM by DCL is the slope, that is slope and the trim and if it is negative then we say it as statically stable we always talking about the slope at the trim because we are trying to check static stability by disturbing the airplane at trim at equilibrium right.

So we talking about the slope here that is more important and we have seen this whole aircraft DCM by DCL we have broken into DCM by DCL of wing and then we say DCM by DCL contribution because of tail and then + DCM by DCL contribution because of Fuselage. Similarly if there is a engine we have seen that, that also affect the stability, so in some of form DCM by DCL from the engine contribution also will be there.

But we have not talked about how to calculate DCM by DCL fuselage and today in ten minutes will be covering that but before I cover I will give you a rough idea how to calculate but this things are generally computed through using a CFD computational flow dynamics more importantly through internal testing because fuselage steps are vary of variety or having a validity controls and there are so many attachment so very difficult.

To compute it through a analytical methods, however, you as an designer need to know need to have an hour to get the quick estimate of this and you can do that quick estimation so why don't you understand the physics behind it? What is the physics behind it; let's say this is a Fuselage. Typically, fuselage shape will be like this right. Here our friend honorable pilot will be here.

Now if I try to visualize it through most of the configuration which we have been expose too in aerodynamics these are the shape with (()) (25.24) shape with conical shape and the central portion I can think of a cylinder and the later part which I can think of as if a bow tail you know why this diameter is kept smaller than main diameter or maximum diameter.

That is called this ratio to this ratio had diameter at the base and diameter at where the bow tail is starting their ratio if I take the ratio is less than one that is to say this is less than this and we try to see that this angle is around less than seven to nine degrees in normal case otherwise flow will separate here so this here typically a bow tail. What happens what we are trying to find out, we are trying to find out if there is an angle Alpha right, how much?

This is going to generate the force and how much this will contribute towards movement about CG? One thing is very clear if I break this fuselage into these three shapes one thing I am pretty sure this is the most lifting surface or lifting part of the fuselage right. This is cylinder so at small angle of attack I can say this will not really contribute to the lift and there this is a portion the bow tail which is opposite of the nose so this will.

For a nose if for positive Alpha I'm getting a force like this for a bow tail reverse we will find this will act downward right. Now can you tell me if I now write down the force here downward and CG somewhere here you could see for a positive Alpha this will give a nose of moment so nose is destabilizing this is destabilizing because for stabilizing effect I want for a positive Alpha there should be a nose down movement but here for positive Alpha it is giving me nose up movement.

Now for bow tail even for positive Alpha you could see the since it is a bow tailing like this the force will act downward this also will give destabilizing effect okay .So what we are getting both nose and bow tail will give CM positive for positive Alpha. So this is destabilizing and the moment it is destabilizing we know that for destabilizing immediately I know CM Alpha will be greater than 0 because for stability CM Alpha is less than 0 right.

So CM Alpha because of fuselage will greater than zero or it will be destabilizing there are methods empirical methods to calculate value of CM Alpha or DCM by DCL through quick formula and that I will be giving you and it should be using it as when required.

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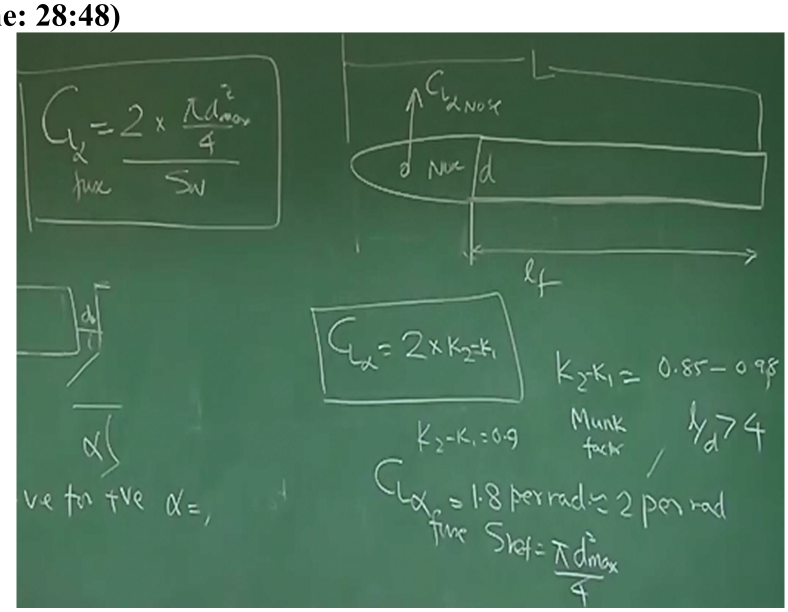

First of all this if is the nose of the fuselage this is let’s say total fuselage length then this is the length of the fuselage. I will consider it from here length of the fuselage LF I am not taking any bow tail effect and I’m assuming the cylinder straight you see then CL Alpha of the nose this portion is nose for small Alpha it can be approximated as two into some we call Munk factor K2 K1 and typically K2 K1 is a Munk factor these are for your information.

I will not able to add a lot of physics at this part of the lecture and this typical value it is between point eight five to point nine. Nine or nine eight for LYD greater than 4 if the length to diameter this is a diameter the length and the total length fuselage and this nose included if LYD is more than 4 than it is fair enough to take K2, K1 as point nine. So CL Alpha of the fuselage you will get around one point eight per radian.

For subsonic case you will find that many of the book or many of the designers take it as two per radian but one catch is there CL Alpha fuselage is 1.8 per radian and as I told you approximately people take it as 2 per radian per initial estimates. But then the catch point is it is based on the refresh area is Pie D max square by 4 this should be very clear so when you are try to combine this with other components being a wing and tail you have to convert this into reference area which is wing reference area.

So CL Alpha fuselage will be two into pie D max square by 4 and divided by reference area, wing area this value will be actually using for your all equations right so two into whatever the ratio come that is the CL. Alpha per radian based on wing reference area this is very important per radian right okay we may like to solve a problem but this is not important if you know this that's all right.

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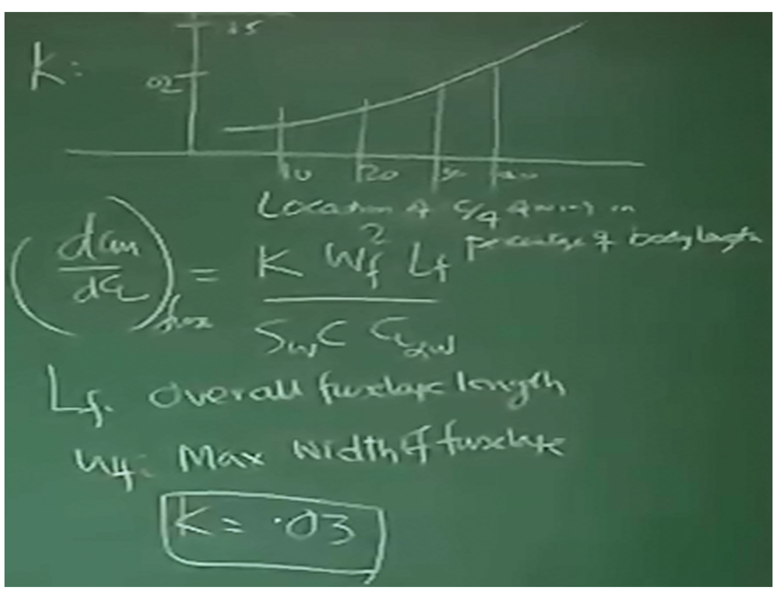

And then there is another which expression DCM by DCL for fuselage this impractical formula is given which is K WF square LF by SWCL Alpha wing I will explain you what is LF, LF is overall fuselage length right, WF is the maximum width of fuselage and SW you know the K part is arbitrary constant which is also called empirical factor.

That you can find out referring a standard design chart just I will give you a typical values chart this may be around point 0.5 this one and 0 2 these are given as ten, twenty, thirty, forty location of C by 4 of wing in percentage of fuselage length or body length that is exactly located it is location the C by four of the wing if this is the wing let's say C by 4 of the wing how that is located in terms of percentage of body length this location is what percentage of the body length.

We have this number we will get the value of K typically K value it can for or for practical purpose we can take 0.3 that will work you will get some realistic number that may not be very accurate okay you will understand the fuselage is not a clean fuselage the way I have drawn it okay there will be a massive, there will be a engine intake there will be landing gears downstairs so many things right the lipoids so it is better that one goes for a skilled or internal testing.

And get these values. Similar will be for the CM0 fuselage also, right? So for this I thought I will give some background so that you can understand what sort of value of CM Alpha for fuselage that would be or DCM by DCL for fuselage if not that you should be very, very sure that fuselage will be always contributing towards destabilization that is CM Alpha or DCM by DCL will be greater than zero you could see here DCM by DCL is given like this and this greater than 0, that as a fundamental understanding it should be clear to your mind. Thank You.