NOC: Introduction to Airplane Performance
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Lecture – 42
Stability: Wing and Tail Contribution

Good afternoon friends, last few lectures we might have seen kept on talking about static stability, control, C P, aerodynamic center, C g I think too much I have talked. So, before I start, what is the contribution of wing or tail or a fuselage towards making an aircraft statically stable. And, also it can be trend at positive angle of attack, we will just quickly glance through, what you have learnt maybe in 5 minutes time and then, try to formulate the wing contribution, tail contribution and fuselage contribution in a manner, so that it will help us in designing an aircraft.

The basic question, which comes to our mind whatever I may be talking stability, control, dream, etcetera, etcetera. Basic question is, can I fly an, this airplane or particular airplane at a particular C L; that means a particular alpha at a given velocity at a given altitude that is the question.

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Then, what we will learnt in an axial was, if I am talking about longitudinal part, longitudinal in stability, that is angular motion in the vertical plane and we have seen the same versus C L or C m versus alpha, by now we know C L and alpha related through some scalar term. So, this radiation should be like this, where the slope at the equilibrium here, should be less than 0 or it should be negative, so 1. And, we know that for a statically stable airplane, that is I need to see the slope at the equilibrium, equilibrium this point is, because C m is 0, at this I have to check that d C m by d alpha is less than 0, so it is statically stable.

Also, I have to ensure that, if I should stream at a positive alpha, then not only the slope I should have defined C m naught by C m at alpha equal to 0. If, I could generate that, then I am happy that my airplane, the moment it goes to that alpha or the requested velocity and then, it will automatically generates C m naught, because the configurations or layout are there. I need not put any elevator at that point and that is a very efficient way of flying, because if you put elevator it will have some drag.

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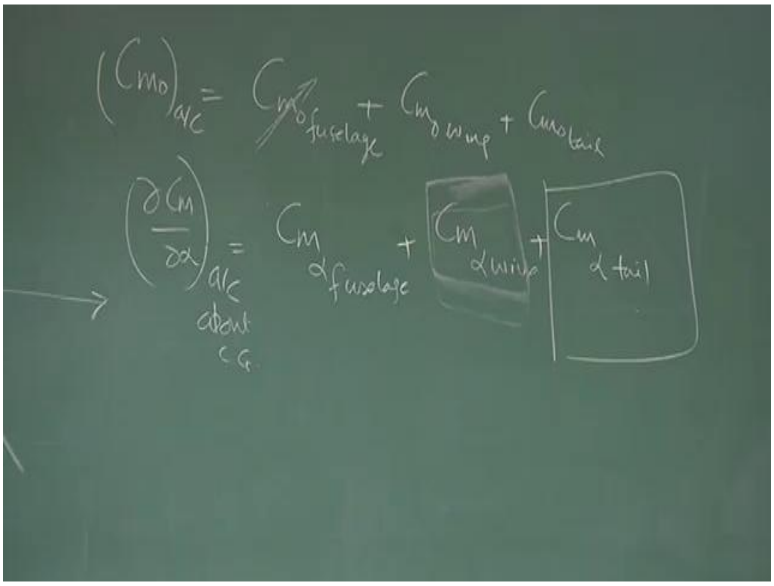

Now, the question comes, if I need C m naught of the aircraft to be some value, then who will contribute, who are the C m naught. Naturally, I know C m naught because of fuselage, C m naught because of wing and C m naught because of tail, they are the three contributors. Of course, in a relative sense, we can say this is the negligible compare to other two that, does not mean it is 0, so that is this C m naught C m at alpha is 0.

Then, similarly d C m by d alpha the whole aircraft, which is about C g, we have in forward in that, about C g the contributor will be C m alpha fuselage. Similarly, C m alpha wing plus C m alpha tail, but you can very well appreciate that the C m alpha the static stability part, we are expecting it primarily from the tail, because this is also called and that is why this is also called horizontal stabilizer. Wing, we are not expecting too much from stability point of view, because wings say how dear friend your primary job is to produce lift that is all and fuselage, what is it is primary job.

It is primary job to contain the passenger cargo with a volume. So, we are very clear that fuselage has a distinct role, wing has a distinct role and tail has a distinct role and comes to stability, it is the tail oriental tail for longitudinal stability. Now, our question is can I formulate, so that I know, what are the parameters that control the contribution towards stability and contribution towards C m naught and that is the purpose of today's lecture.

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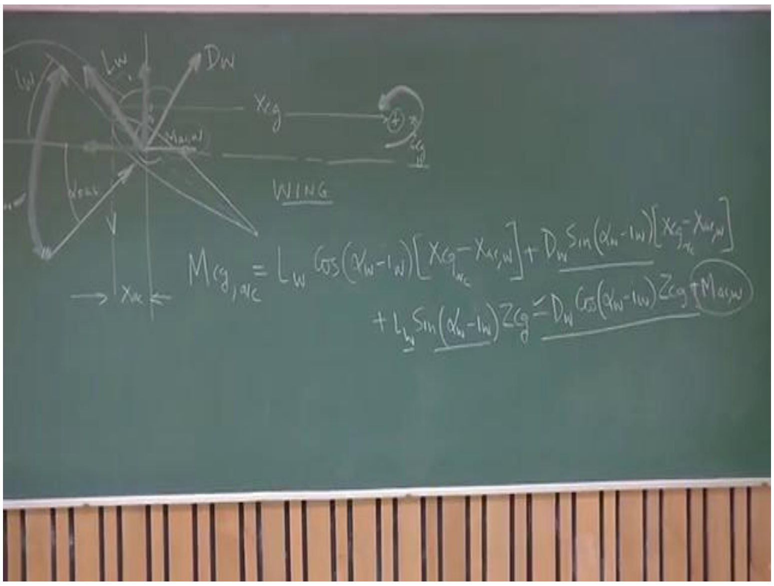

Let us, draw a semiotic of wing location, tail location, let say I have installed the wing like this, it is little exaggerated related, but we understand this purpose. And let us say, this is relative air coming like this V and let say this is the aerodynamic center and I call this angle as I W, that is wing setting angle. What is the center line? It would actually define, if I draw it like this, which is the fuselage I am drawing like this. So, I call this line as fuselage reference line, so in short it is F R L. So, what is wing setting angle? It is the chord line, how much angle it is making with the fuselage reference line.

So, I call this, this angle the velocity vector and the fuselage reference line as alpha F R L and then, this angle is already I W, wing setting angle, so total angle velocity vector to the chord line, this will be alpha of the wing. Total angle velocity vector, the chord line is the alpha of the wing, then chord line making with fuselage reference line is I W, wing setting angle. This is called derived wing setting angle and this is of course, is alpha F R L alpha fuselage reference line and we would see from geometric, alpha F R L is nothing but, alpha W minus I W. Is this clear?

And, let say C G is somewhere here, because tail will be somewhere there and I say, now this distance is Z C g location of vertical location of C G from the fuselage reference line, I am putting symbol Z C g. Now, along the X direction I am taking the leading edge of the wing and from here, as I am measuring the C G location I am calling it X C g. Similarly, from the leading edge, when I am locating the aerodynamic center of the wing I am naming it as X a c wing. Is it clear?

What is X a c wing? From the reference leading edge, what is the edge distance of the aerodynamic center of the wing. What is X C g? It is the location of the center of gravity of the whole airplane from, which reference from leading edge of the wing. What is Z C g? Z C g is the vertical height of the C G, from which reference, from the fuselage reference line. These three things should be clear. If this is clear, now let me erase this part, you know this part.

What is our aim? Our aim is to find out, how much this wing will contribute towards reaching moment to find out, what is C m alpha contribution because of wing that is static stability part and if at all, it is contributing toward C m naught or not that is the question. What I was telling, we are trying to find out the contribution of wing towards C m alpha that is static stability and C m naught, which is essential for streaming at positive angle of attack.

And, we know that this contribution could come for wing, from tail or from fuselage, now we are trying to see what is the wing contribution and try to formulate. This diagram is now clear to you that this angle is wing setting angle, now the chord line how much angle is making with fuselage reference line, the fuselage reference central line is with the fuselage. So, the wing is got set like this, please understand generally we have this is the wing set like this ((Refer Time: 09:16)), so the wing setting angle is 0.

Now, wing is set like this with respect to the fuselage central line and this is alpha F R L Fuselage Reference Line and this total angle from chord to the relative velocity direction is alpha of the wing that is the angle of attack seen by the wing. Because, of velocity because of angle of attack the wing is getting aerodynamic forces. Because of cambered aerodynamic wing, we writing M a c of the wing also here and this is the lift on the wing and this is the drag on the wing.

What is our aim? We have to find out, what is the contribution of this force moment structure in terms of writing, what is the moment about C g of the aircraft due to all this wing aerodynamic forces, very simple. Now, if you see here I can easily write, let me write this equation, so that I can explain it better. Do not worry about so many terms you will find, soon we will neglect them and make our life simpler. There is the one by one, this L W I can resolve into two component one component here, that is L W cos of this angle, this angle you could see easily is nothing but, alpha W minus I W.

So, this vertical component is L W cos of alpha W minus I W and the momentum is what, momentum is up to this point from here to C g. But, you know from the wing leading edge this total distance is X C g and from wing leading edge, the a c distance is X a c, so this distance is nothing but, X C g aircraft minus X a c of the wing. What type of moment this will give? This is acting vertically up, above C g it will give nose up moment, so this is positive.

Second, you could see for drag, drag also have two component the vertical component, if you see here, this will be 90 minus of alpha minus I W, so the cos will become sin, so you have D W sin alpha W minus I W into say X C g aircraft minus X a c wing. Similarly, we could see that L W angle has the horizontal component, which is here which is the sin component, which is here L W sin alpha W minus I W.

This is acting here, the C g is over the fuselage reference line, so this also will give a nose up moment, so it is here positive. As, for drag is concerned you could see the original component is in this direction that is, D W cos of alpha W minus I W, but this component will give a moment about C g in the nose down direction. So, this component has a negative sin here and also of course, you should not forget M a c of the wing, because of the cambered or in general you have assumed the cambered ahead, clear.

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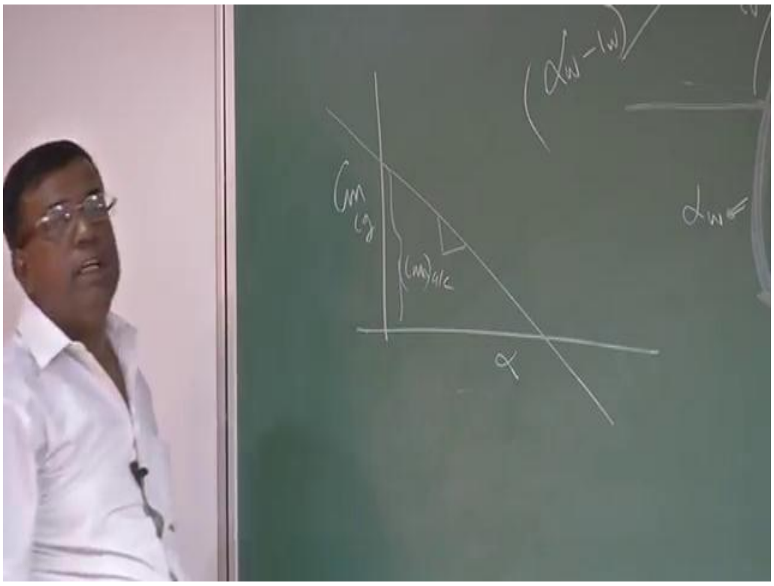

All of you can write yourself this is a question. But, what is our aim? Please remember, let us not lose our interest, our aim is C m C g versus alpha you want to plot. And, we are checking this slope whatever desired slope you want, how much out of the desired slope wing is contributing and how much whatever C m naught we require, the whole aircraft how much the wing is generating or contributing, so we will be talking in terms of C m C g.

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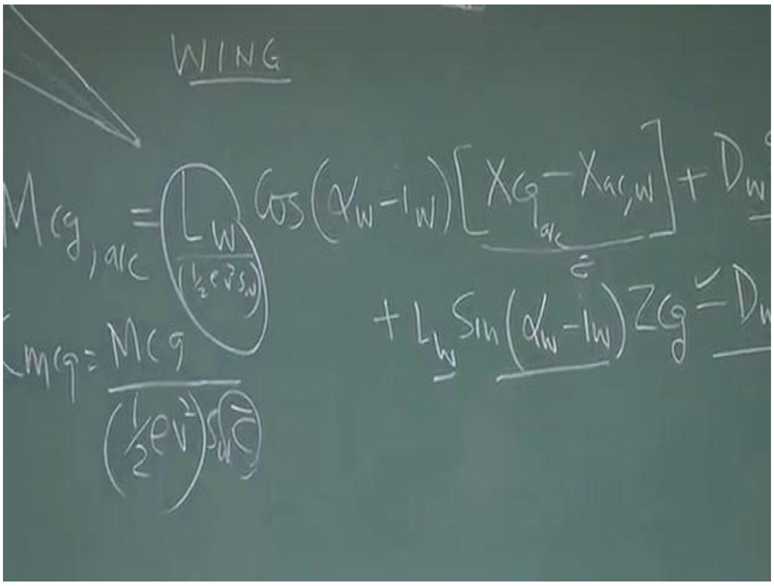

So, from M C g how do I come to C m C g, I know you are expert now, this is M C g divided by half rho V square S of wing into C bar, C bar is because C m is a moment, M C g is the moment. So, this is dynamic pressure into area force into length is a moment, so that it become not dimensional. If, I divide by half rho V square S C bar, what should I get. If you divide by half rho V square S W C bar, then M C g will become what, M C g will become C M C g of course, this is of an aircraft. This will be equal to what.

See, half rho V square S will come here half rho V square S W. So, this will become what, this will become C L wing by definition, then this C bar which is left that will come under this.

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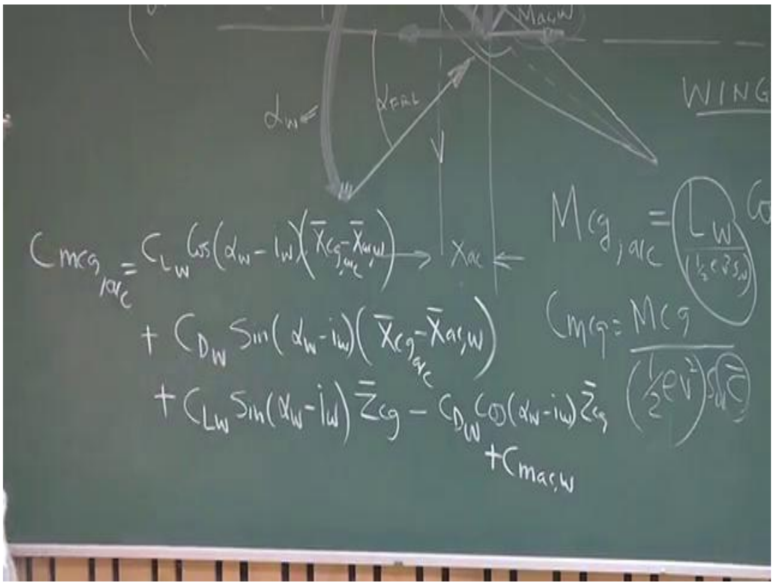

So, I can write this is equal to C L wing into cos of alpha wing minus I W into X C g minus X a c wing. This is of aircraft bar I am putting bar, because now I divide it by C or in fact, divided by C bar if I divide the every term by this. Similarly, second time I Will get plus C D W into sin of alpha W minus I W into C C g aircraft bar minus X a c wing bar, bar means X C g distance divide by aerodynamic cards C bar. That happens, because I dividing M C g by half rho V square S W C bar, that is a taking that to the last expression.

Similar, the third one will be C L W the sin of alpha W minus I W into Z C g bar again Z C g bar mean Z C g divide by C bar and that last term is C D W into cos of alpha w minus I W into Z C g bar plus C m a c wing do not forget this very important element. So, let me start writing this expression only, so that we can focus more of this.

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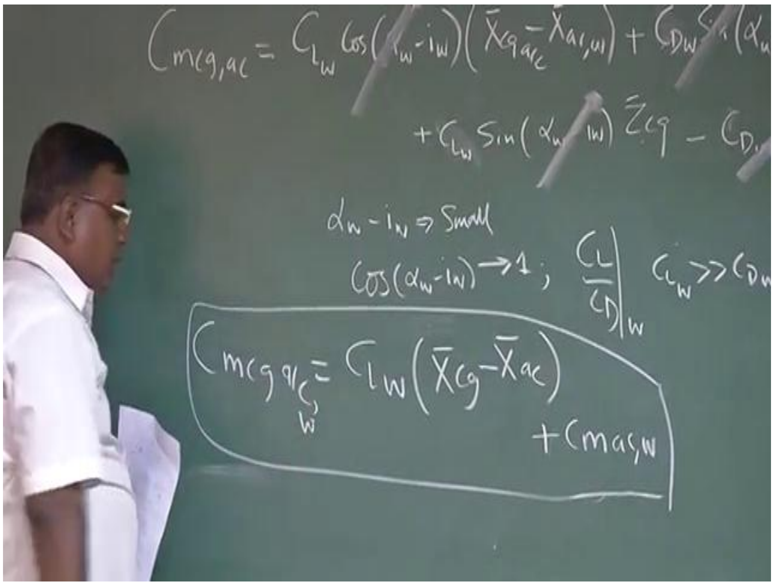

What do will say now? let alpha W minus I W is very small, so cos of alpha W minus I W is tells to 1. Also, see here wing we also that simplify further, we are happy just this term will become 1, you say C L by C D of the wing is, such that C L of the wing is greater than C D of the wing. So, will also plus alpha minus alpha wing I W was small are, it is very simple we have to make a clear term we want to get it of this, we, want make sure that becomes 1.

Still life is complicated, we say let assume that the C g on the fuselage reference line, so this Z will come 0, so this also goes this also goes Z C g 0 means the C g on the fuselage reference line, which an indicate the airplane with try to do that. So, after cutting, so many terms, what is left to us we have C m C g of the aircraft equal to C L wing and this one is one into X C g bar minus X a c bar plus C m a c wing that is all life is, so simple. I told you we handle this term, let us try to given interpretation do this, what is this C m C g aircraft that is the non dimensional which is coefficient C G of the aircraft, because of the wing.

So, I put a notation wing also, so that you understand is the contribution, because of the wing, what is the X C g X C g is the whole aircraft, so I put aircraft, if this is clear. Now, Let us do further simplification, I do not want to two many expression, so what was the assumptions to get this inter expression that alpha W minus I W is small C L is must larger than C D the C L of the wing is much larger the C D of the wing and Z C g is 0 at is C g are the fuselage reference line, which every realistic assumptions.

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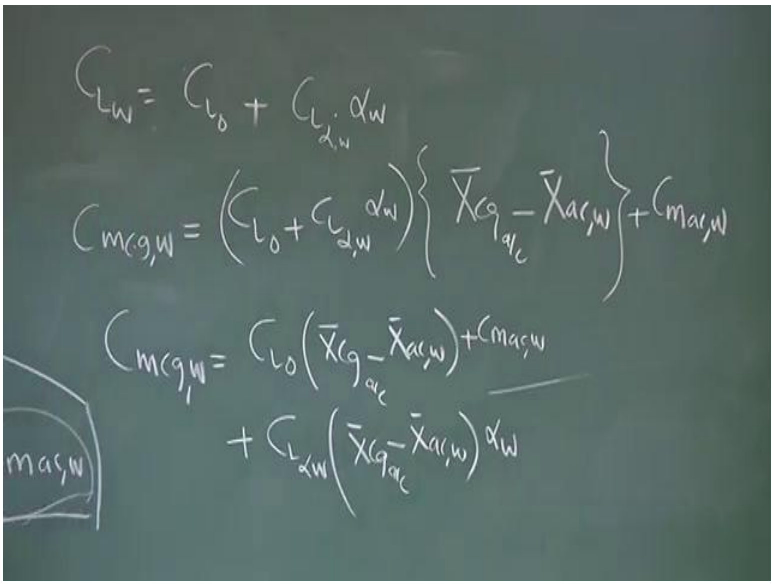

Now, if this is the expression we also know C L of wing I can write as just we are taken in cambered wing C L naught plus C L alpha into alpha of the wing, so we substitute here. Still C L wing will be writing C L naught plus C L alpha of the wing into alpha wing, so this will alpha of the wing this is be careful, if, I do that, what I get C m about C g, because of wing there is often C m C g, when I say a dash C wing.

So, the aircraft redundant equal to C L naught plus C L alpha of the wing the alpha of the wing that we can C L into X C g bar the aircraft minus X a c of the wing. Get to this further I can write as C m C g of the wing are I feel differently C m, because of wing about C g of the aircraft is C L naught and of course, some where the C m C m of the wing is also here less that about forget this we will see this will magic of road, we have 10 days to forget this friend at this should be our, one of our worst friend he can create problem, so do not forget it.

If I do this, what I get C L naught into X C g aircraft minus X a c of the wing plus C m a c of the wing and put at one term plus C L alpha the wing into X C g of the aircraft minus X a c of the wing to alpha W, look at this expression clearly.

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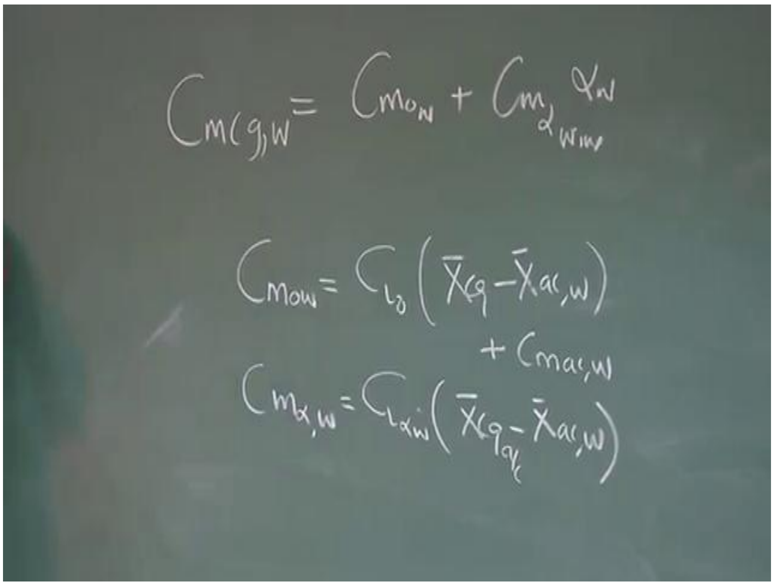

I can now, write this as C m about C g because of wing C m, about C g of the aircraft, because of wing I can write C m naught wing plus C m alpha wing into alpha wing. Then, what is C m naught wing this is coming to be C L naught X C g bar minus X a c wing plus C m a c wing and C m alpha wing is coming out to be C L alpha wing into X C g of the aircraft minus X a c of the wing.

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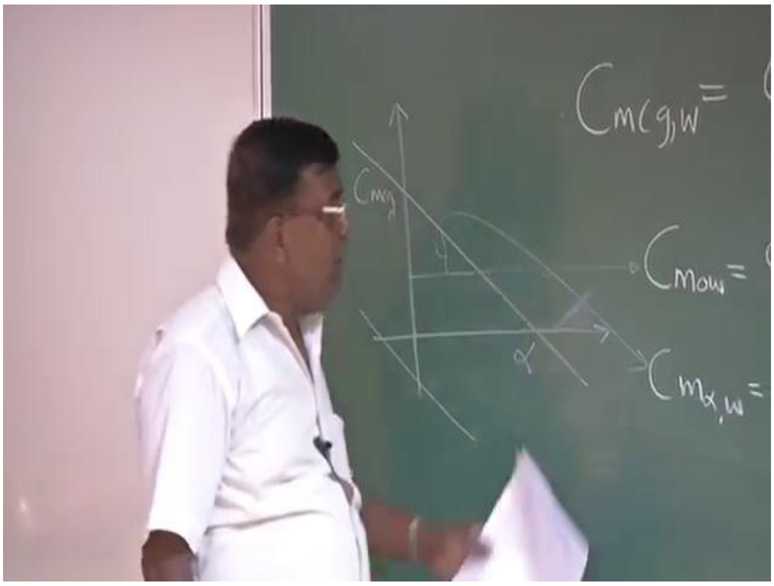

Now, focus here, immediately you think, what is our aim, we should not loss the inside this is the C m C g I have the alpha, we wanted the slope to be a particular value, we wanted C m naught to be particular value. We, are trying to see, how can I model, how much wing will contribute to C m naught, how much we will contribute you will C m alpha, that is why slope how much you contribute decided by this expression, how much C m naught we said by this expression clear.

What does it says? see the first expression, let see the C m not expression, let us we will clear we some C m naught from wing to the positive definitely not negative. At the most 0, but why should have negative, because it is negative I have will be negative stream at positive angular for attack. So, over all C m naught I want positive, so I Which always look for C m naught, because of wing to be positive, whatever small amount it will be that is all I will never like it to be negative, now show, what are the meaning of this.

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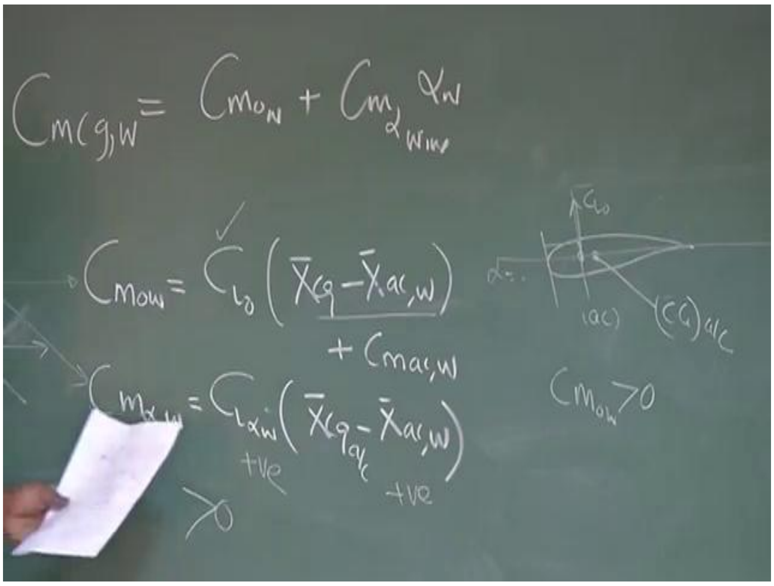

So, this is the line and let say, this is the wing and this is the a c and this is the C g, let say some of C g I simplify diagram. what is the says? says C m naught wing C L naught less at alpha equal to 0, there will be C L naught and this C g here, so C L naught in to this is distance, will give you a C m naught positive. So, what is the meaning of that, meaning of that is if you put the ac of the wing ahead of the C g of the airplane it will give up positive C m naught.

In, practice will find a c of the wing and C g of the whole airplane will be somewhere very close. So, this is the C g of the whole aircraft this diagram is the exaggerated to make you understand the actual will find the a c of the wing as C g lending here, there will be almost very close. But, what is important, if I want C m naught wing to be positive I am ensure that ac of the wing is ahead of C g of the aircraft it is very clear from here.

If, a c is ahead of C g of the aircraft, then this is X C g minus X a c could be positive C L no is positive, we will get positive C m naught. For, what is the problem, this is C m alpha at the wing the moment I cannot C m alpha of the wing, you are C m alpha of the wing is positive no issue, what about this term X C g minus X a c this it is also positive, so C m alpha is becoming positive.

So, actually the wing is contributing towards positive slop, so it is to the stability or the wing is contribute towards unstable static stability this is the correct statement. What you do not mind this? We know we are told you earlier also wing primary role is to be left. So, whatever C m naught positive it has given I am happy, rest will take care from the tail, so now we come to the tail portion.

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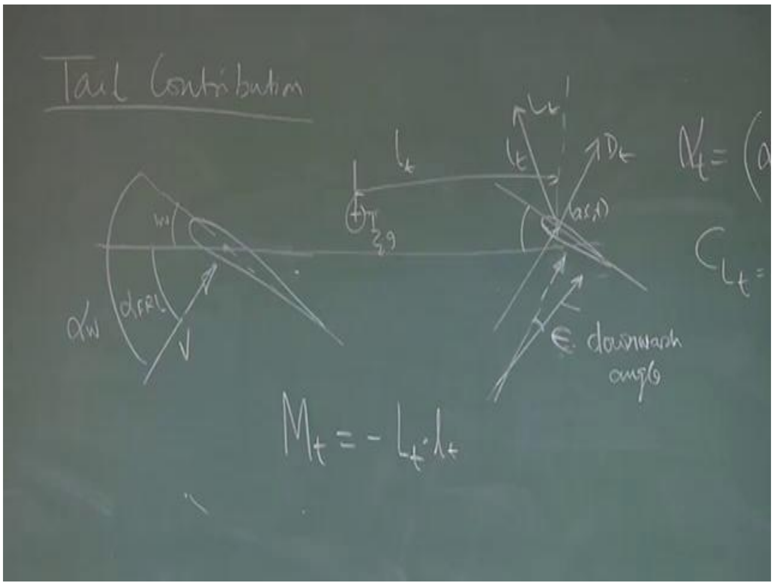

So now, will have tail contribution towards static stability, before we go to any detail expression, which I will avoid, so let us understand one thing if this is the wing or in, whatever wave we have represented the wing is having setting angle. We, are also telling the tail which is symmetric tail, we are setting it at angle I t, which is called tell setting angle. But, there is one point of different that you must understand that very important, what you have seen it is the finite wing, because of presser difference there will be, what is the different, that will be downwards.

So, if this is the vela from direction, which wing is C, because of downwards wing generated the angular attack add that tail will not be seem as angular at I have a wing actually the velocity, where trivial not parallel it will be little bit of till date. If it was parallel to the wing velocity vector, whatever this direction is here, actually because of the downward component this vector will be till dead line this will by how much by Epsilon and which we called downwash angle this is what should be understood.

So, if I try to right to, what is the angular vector by seeing by tail I will write, whatever the alpha W minus I W was there, minus Epsilon plus I of t that is all. If, there were no downwash than angular, if attack till would have been alpha F R L plus I t, but alpha for L is reduce, because of Epsilon here, because the velocity vector as tilted like this we have downwash this is the alpha tail. What is C L tail than? C L can will be C L alpha tail in to alpha of tail, that is C L alpha tail to alpha W minus I W minus Epsilon plus I t.

So, this should be kept in mind, rest things similar one think should understand this is the s c of the tail, then local lift here, will be perpendicular to the local velocity vector, that is not with the free stream velocity vector local velocity vector. So, I draw banner to this and there is on drag on tail this is lift on tail center line, how where you defining the C L for the whole airplane, then you will take the component of lift drag all in the free stream directions.

Now, what is our aim to find the moment, so this is Z C g C is any where being all simplifications very common since say. If, this angular is small, what is the moment, because of tail at the C g about the C g, how much it will be, simply because of will lift are the tail lift, because of tail into this, this distance from a c to obtain to C g. Let say, the L t it is being L t in to L t, what will be the moment, moment will be primarily.

Because, of tail I am assuming angle to be solve very common sense. You, can understand that this lift force in to this moment on L t will be the moment; however, I put a minus sign because positive will give nose down moment and nose down moment are negative as symbol rather.

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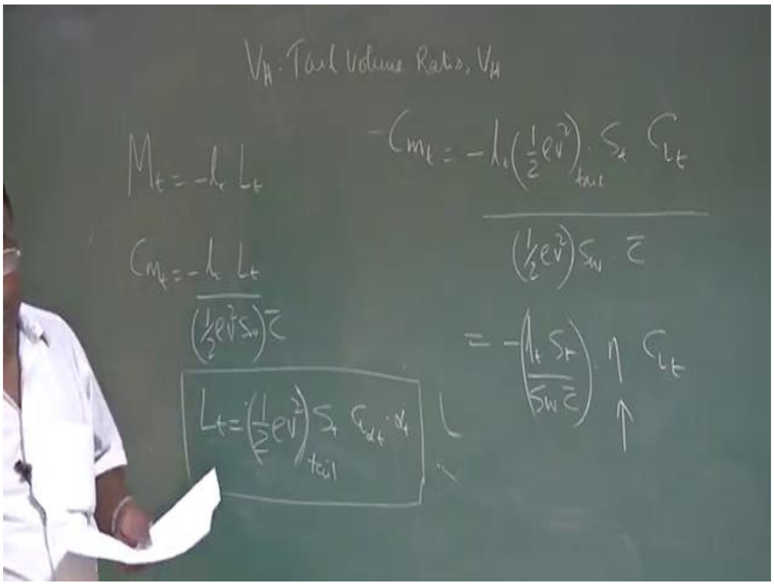

From, moment I can from M t lets L t in to capital L t, if I want to come to C m t I am, now expect I write L t into L t by of rho V square S w in the C bar that will be might C m t and what will be the L t, L t will be what, lift at the tail will be what, it will be half rho V square is important at tail, then pressure of tail, which will not be same as done equation free stream centrally who left will be dependent on the local condition into S tail into C L alpha tail into alpha tail this is clear.

Lift at the tail will defeat of the diagonal position at tail, which is half V square tail in to S tail C L alpha tail in to alpha tail and alpha tail you know is nothing, but this expression. So, if you use this C m tail is equal to minus L t for L t, I Write half rho V squared at tail in to S tail in to C L tail instead of C L alpha tail in to alpha tail this divided by half rho V square is stream S w and C bar. You know, C m tail now by substituting the value or expression of L tail in to this expression.

So, I get C m tail is this what is the C m tail it is the pitching moment coefficient, because of tail about the C g of the airplane this I can easily write as minus L t S t by S w C bar is one in to eta into C L tail. Eta is the ratio of dynamic pressure the tail the dynamic pressure the wing we could understand the dynamic pressure will be different suppose the engine is exposed falling on the tail surface horizontal surface.

So, dynamic pressure ratio eta wing become more than one typically the value there are one and this is C m tail, the this sin negative for positive C m tail is the positive alpha C m is negative there is historic tendency and this is what, the tail is suppose to do this country would take the static stability and the magnitude of static stability.

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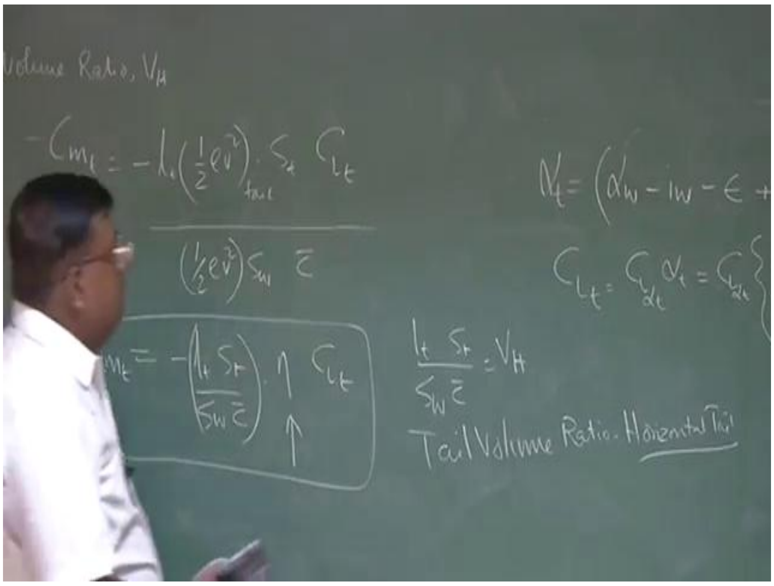

We will, depend upon this ratio L t S t by S w C bar, which is also called tail volume ratio or halogen tail volume ratio, tail volume ratio, this is for horizontal tail it would very easily see that. What is the L t? the L t is distance of ratio of the tail from C g, if I increase this L t the resolving moment will increase or for a given L t I can increase the area of this tail then they also is L t to S t increase or increase both.

So, what we are say the designer, if you increase V H tail volume ratio it will increase the static stability characteristics on the airplane. Now, if it you further some arranged at will find out, what will are actually trying to look for in terms of C m naught and C m alpha expression.

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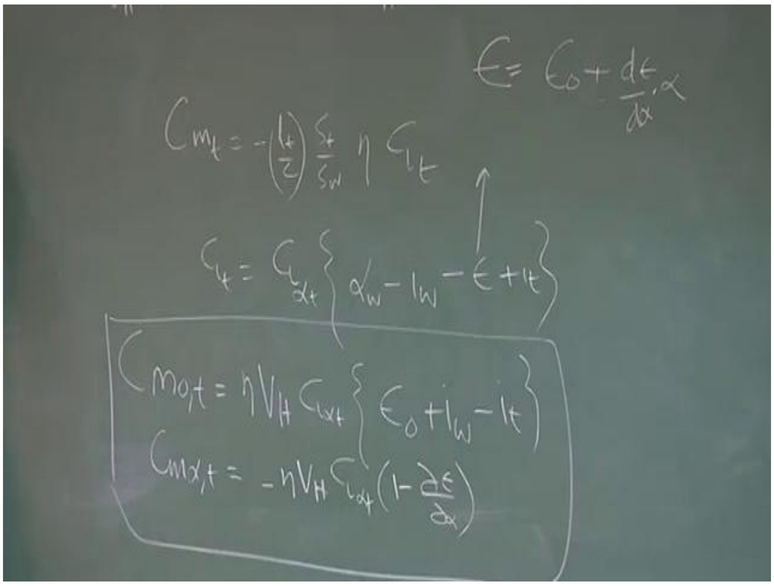

So, we have seen that let me write this C m tail equal to minus l t by c, S t by S w eta into C L tail and C L tail equal to nothing but, C L alpha tail into alpha tail is alpha w minus I W minus Epsilon plus I t. I will quickly going this derivation, because this is not a mean part of a this part of the course, I will all you touch about few things that I extract maximum thing in terms of design aspects.

And here, what I can do for simplicity I can model epsilon, what is the epsilon, the downwash, downwash is model to be function of angle of attack would on the standing as angular, what are the increases the lift increases the lift means the pressure difference increase, so what is the strength increases. So, there are linearly model as Epsilon naught plus d Epsilon by d alpha in to alpha, what is Epsilon naught divided alpha you can 0 to downwash which is the rightly.

So, if my wing is tempered in it alpha is equal to 0, there is a lift, there is a C L naught, so there is a pressure difference that will give also downwash that is Epsilon naught. If, the wing is symmetric the Epsilon naught value is 0, there are substitute here and then re substitute is C L t here, I can get an expression, which are write directly here, what I Will do now, C L alpha tail to this angle the tail and expand Epsilon equal to Epsilon naught plus d Epsilon by d alpha in to alpha, when I put this term here in this expression.

Then, I can show that C m naught of tail is equal to eta V H C L alpha tail and to Epsilon naught plus I W minus I t and C m alpha tail as minus eta V H C L alpha tail one minus d Epsilon by d alpha.

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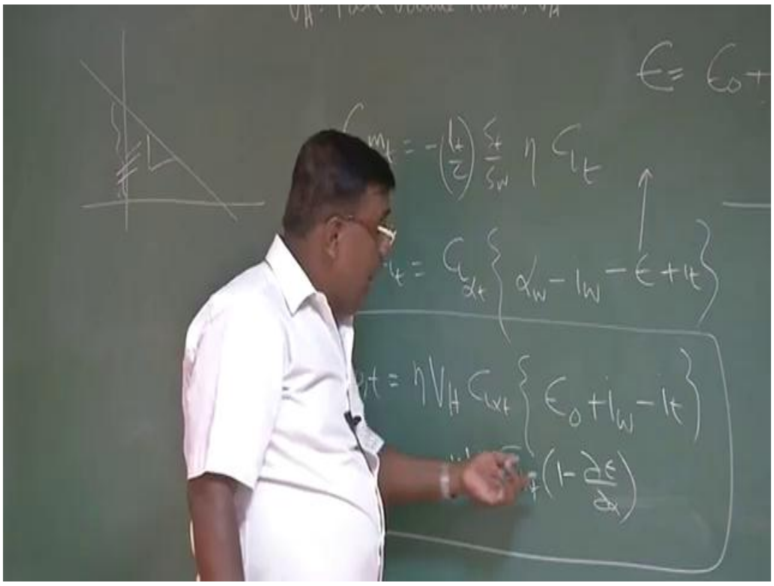

I again, take you back this remember the trying to see how much tail will continue you are addition C m naught here and to are the slow. What is the first expression telling, you could see this is positive this is positive this is positive Epsilon are suppose symmetric airplane Epsilon is 0. If, I do not put any put wing setting angle this is 0, so how can I get positive C m naught.

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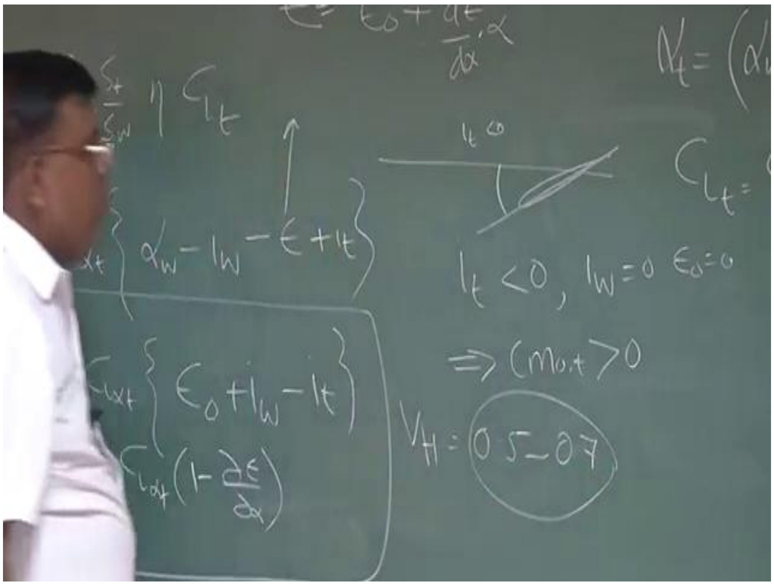

If, I t is negative; that means, what If I t is less than 0 and if I w is 0 is Epsilon naught is 0,then if I t is less than 0 this implies C m naught tail the greater than 0. So, I repeat C m naught tail express, where saying this observation is between to size for a designer and looking for the C m naught contribution from tail I know the even if the wing is symmetric. If, I do not put a setting angle I can get positive C m naught by putting I t negative it negative means if this is the fuselage refer this line I will be setting that tail horizontal like this is I t less than 0 typical the value will be around 2 to 5 degrees aircraft.

So, one of the major contributions that comes from the tail in terms of the C m naught, here tell also give a larger value that, I want to slow this is I want to slope tail is very clear eta positive V H positive C L alpha is positive and this is an negative sign here. So, as long as one minus d Epsilon by d alpha is positive, it will always give same alpha tail negative, always stay will accessing it is always positive typical value of d Epsilon by d alpha maximally 0.2 that is try to reduce this values by doing some configuration.

So, this is another interesting thing I can go on changing the slope of this line by changing the value of V H suppose I Wanted this slop, but actually the slope is something like this and increase the slop, then I have to make it more stable and I Will increase the V H here. So, I will be the tail volume ratio H t and in to L t H t separately L t separately are both, so remember this the typical value of V H, I know if the good designer will take the value from 0.5 to 0.7.

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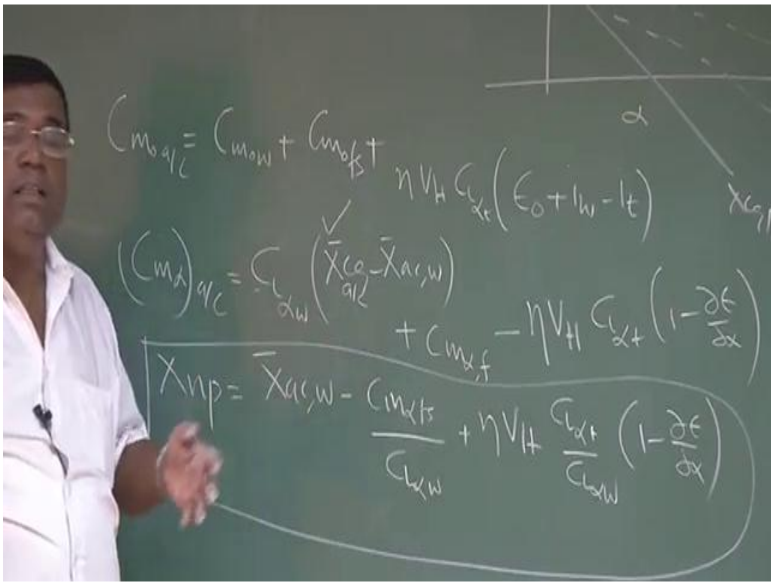

To, starts with this two complete this part I have seen one thing if it is C m verses alpha and this slope is the particular C g if I take C g aft. I know this slope goes on changing and there is a C g location, at which the slope is 0 and you call it the aircraft at this 0 pressure is become neutrally stable and that C g location, where the aircraft become neutrally stable you call neutral point, so you try to formula neutral point also.

So, we know now C m naught the aircraft as C m naught, because of wing plus C m naught of fuselage, which we have not derive the expression for the smaller value. Then, eta V H C L alpha tail into Epsilon not plus I w minus I t this is the C m naught of the aircraft then C m alpha of the aircraft. If, I ass up all I get C L alpha wing in to X C g bar minus X a c wing plus C m alpha fuselage minus eta V H C L alpha tail into 1 minus d Epsilon by d alpha typically C m alpha fuselage positive this stabilize 0 we are not estimated that and there we small values.

What is our aim? we want to find what is that C g location of the aircraft, so where C m alpha becomes 0 that is neutral point. So, I can put C m alpha equal to 0 and solve for X C g, so I will get expression as neutral point as X is C of the wing bar minus C m alpha huge large by C m alpha wing plus eta V H C L alpha tail by C L alpha wing 1 minus d Epsilon by d alpha.

It would note very strongly here one point then general confusion neutral point has nothing to do the C g location. So, this neutral point will depend up on, how the wing tail fuselage a laid out it was nothing to do is C g.

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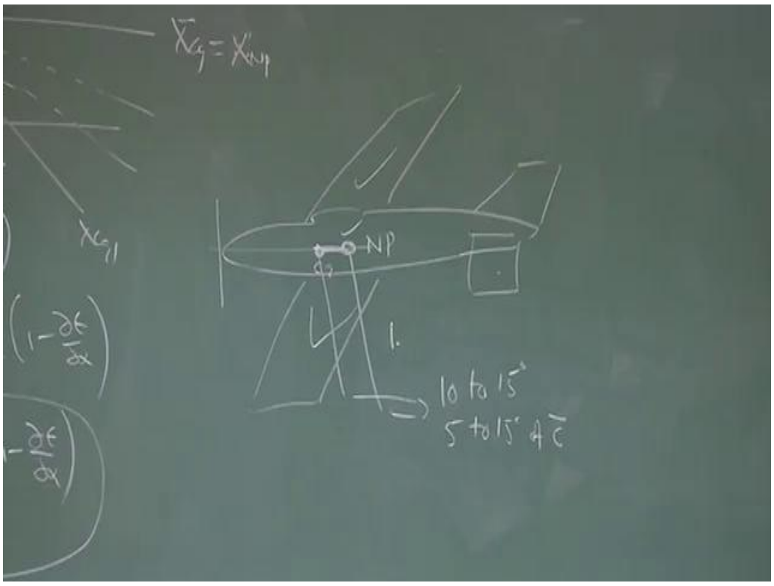

So, for example, for given lay out this is the airplane depending up, what is the C L alpha of the wing, what is C L alpha the tail, why this located for this aerodynamic aspects relevant to the size say etcetera neutral point decided it will going to decided coming somewhere here. What is the message to us? message is when you doing a lay out of your mass distribution, please ensure that first that is C g of the whole is the plane should not cross this resolve the C g comes here.

The aircraft will come neutral is stable second question comes, you should not appear ,how much should be the separation, how much I ahead you should be for your stability and control purpose, because you know if this separation is to high, it will be very highly statically stable. So, you need to have large control to force to control from one C L to another C L. You do not want that typically you say I want this separation to be 10 to 15 percent ordinary 5 to 15 percent of C bar this distance is typically 5 to 15 percent of midair academic called and that the quiet goods stability margin and you can have your control supplied comfortable.

So, that the concept of neutral point and you can calculated neutral point this is the nowhere the C of the wing, which you it is a quarter code point, we know how to calculate C L alpha of the wing, you also the how to calculate C m alpha the few is large although I have the cover and these are numbers. So, d Epsilon by d alpha is calculate, so I was I know that things is the I know that is the neutral point and I will design by the aircraft lay out the component is such a way the C g is ahead of neutral point by 5 to 15 percent of linear aerodynamic part. So, this is the whole essential of stability and control.

The next question what you going to ask is, how this neutral point and the control is linked that is I am telling again and again, if this is large, then control effort will be more, then that part also we will be talking in the lecture, then we will go for design, clear, again the premium part of design.