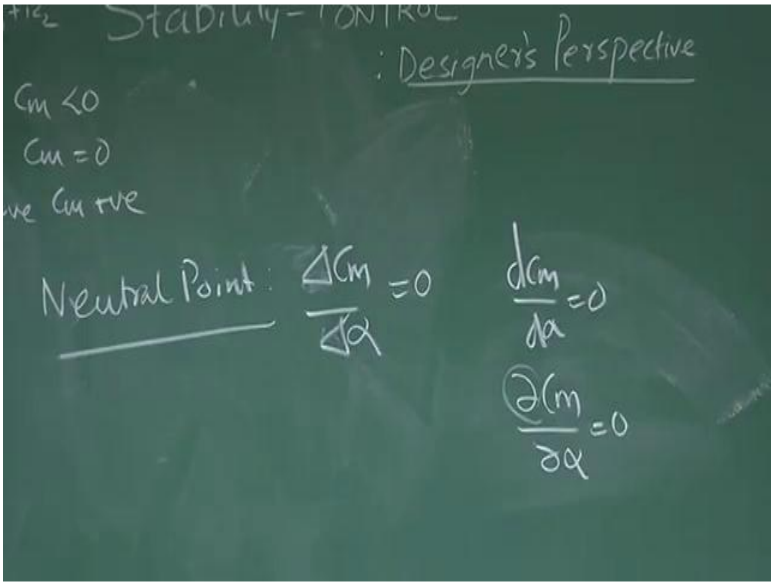
NOC: Introduction to Airplane Performance

Prof. A. K. Ghosh
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture - 39
Stability and Control: Designer's Perspective Continued...

So, we were talking about something called neutral point. What is that point? What is that C G location about which there is no moment, everything is balanced. And if I take the C G either side of the neutral point, either it will become statically stable or statically unstable. This is the meaning of neutral point.

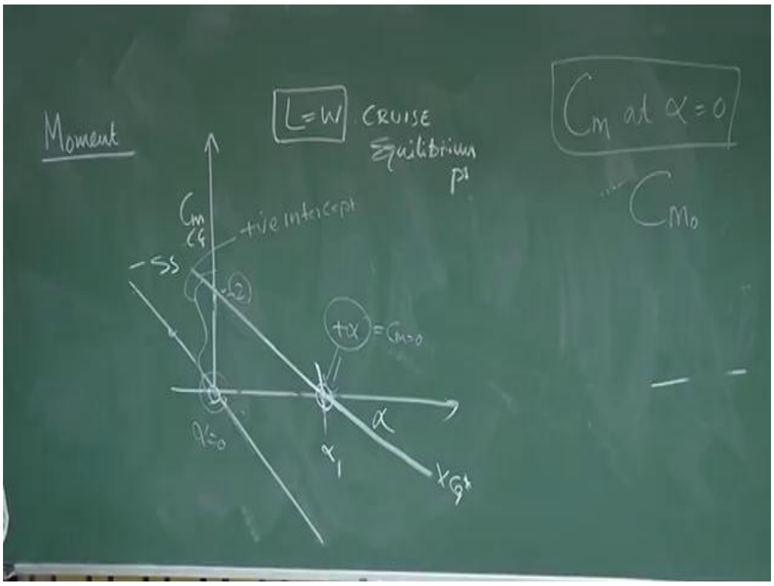
(Refer Slide Time: 00:30)



And in mathematically, neutral point means, where this C m, delta C m by delta alpha, the slope becomes 0, which without taking much of liberty d C m by d alpha equal to 0. You will find textbook of d C m by d alpha is written like this, ((Refer Time: 00:50)) because it is like a partial derivative, because C m is function of not only alpha, even elevator etcetera, etcetera.

At this point, let us not mix up the issues, you only understand that, the slope of C m versus alpha graph should be negative about the trimming point to justify that, yes, this is statically stable. Now, just few minutes back, I was trying to make you aware that, back of our mind, we have an aircraft. Though, we are giving examples through plates and all we are using the magic plate of George Cayley. So, what is the purpose? Purpose is, I should fly at an positive angle, so that there is a enough lift to balance the weight.

(Refer Slide Time: 01:34)



Let us say cruise is our equilibrium point and you know if lift equal to weight, what does it mean, it means C L equal to 2 W by S by rho V square. So, whatever altitude you are flying, whatever speed, cruise speed you are having, if you know that, if you know the weight and the wing area, you know what will be the C L requirement. Let say that C L is 0.2, the C L 0.2 will also correspond to a particular angle of attack, because you know this C L is expressed as C L naught plus C L alpha into alpha.

So, once I know if it is 0.2, once I know this value, this value, I know what is the angle required and that is that angle I want to fly, I want to trim the plane at that angle, which is the positive angle. Now, tell me, if my C m C G versus alpha is passing through the origin, it says the trim is that alpha equal to 0. So, naturally for general airplane, I am assuming, it has a symmetric aerofoil, I am not talking about cambered aerofoil at all now.

Then, it will not be able to generate any lift, because it is saying trim at alpha equal to 0, for normal case, I do not want to fly like that, because I would not be able to generate lift. To generate lift in normal case, I need to fly at a positive angle of attack and now, at this alpha if you want to fly and I want that it should be statically stable; that means, the slope here should be negative.

If my airplane has this sort of a C m versus alpha rather than this, then I can get a positive angle, where I can fly with the appropriate speed to maintain lift equal to weight. If I ask you a question assume that, these two lines are parallel, which configuration is more stable, more statically stable? By now, you know when I talk about static stability, I only check sine of d C m by g alpha, the slope of the line C m versus alpha that decides, whether it is statically stable or not.

But, if these two lines are parallel; that means, both are having same d C m by d alpha, both the graph has same slope, both are negative. So, both are equally statically stable. Then, what is the difference? Difference is, if I am having a configuration like this, then I can trim that airplane at positive alpha, because at positive alpha C m is 0. But, to trim this airplane, my alpha is 0 for a trim. So, I do not want to fly like this, because I cannot generate lift in normal case.

So, I will be interested to ensure that I get positive alpha, while I am flying the airplane. So, graphically if you see, what is the difference? Difference is, although these two straight lines have same slope, but their intercepts are different. That is, this line has got positive intercept, whereas this line is passing though the origin. This positive intercept, whatever you are seeing here, I can write this for representation, it is C m pitching moment coefficient at alpha equal to 0 or notation wise, it is written as C m naught.

So, what is the message? Message is, if you want to fly at this alpha and if your airplane is statically stable, do something in your configuration. So, that it generates this much of C m naught, this much of nose up moment.

(Refer Slide Time: 05:50)

Now, let us take an example to understand this concept, this is a very popular configuration, wing alone configuration and you know popularly they are called flying wing. We will visit our design lab, where we will show you, how we are making all these configurations, how we are translating, whatever we learn in the blackboard and actually produce it and fly it. That is very important closing activity that will be there in part of this course, so that you get a feel.

(Refer Slide Time: 06:40)

Student: Welcome friends, this is the flying wing, it is called flying wing, because it is whole structure is enclosed in aerofoils and in this you can see, we have a very large root chord and very small tip chord. As a result very small taper is here and we have a very large sweep angle for the leading gears and because of this, the flow which would be coming somewhere here will get separated somewhere here.

And the flow which would be coming from here will get separate somewhere here and the flow coming from here will get separates somewhere here and as a result, there is very complex interaction between the flows. And the leading gears vertices are formed, which is the disadvantage of the flying wing at lower speed, but as we increase the speed, the flow which has separated earlier; that gets reattached.

And the leading gears vertices disappear; that is why the flying wings are preferred for the high speed of applications only. As you already know for an aircraft to be stable, our aerodynamic center must be behind the center of gravity; that we can achieve by adjusting the weight distribution. If our aircraft is unstable, it does not mean, it cannot fly, it can fly by giving some suitable feedback into the control surfaces, like our body is unstable to move on a road, but we can move.

At the same time our requirement is to trim our aircraft at positive angle of attack. In cambered foil, we have negative C m naught. If you remember in conventional design, we have negative C m naught, because of the wing, but we have horizontal stabilizer to contribute a large amount of positive C m naught. And as a result of the whole aircraft, we have positive C m naught, but here we do not have horizontal stabilizer.

So, we need till ensure something in this design itself. So, that we have positive C m naught to trim at positive angle of attack and that is why in flying wing, we use reflexed aerofoil. In reflexed aerofoil, we have positive C m naught. To control longitudinal as well as lateral motion, we have common control surface named a Levon; it acts as both aileron as well as elevator.

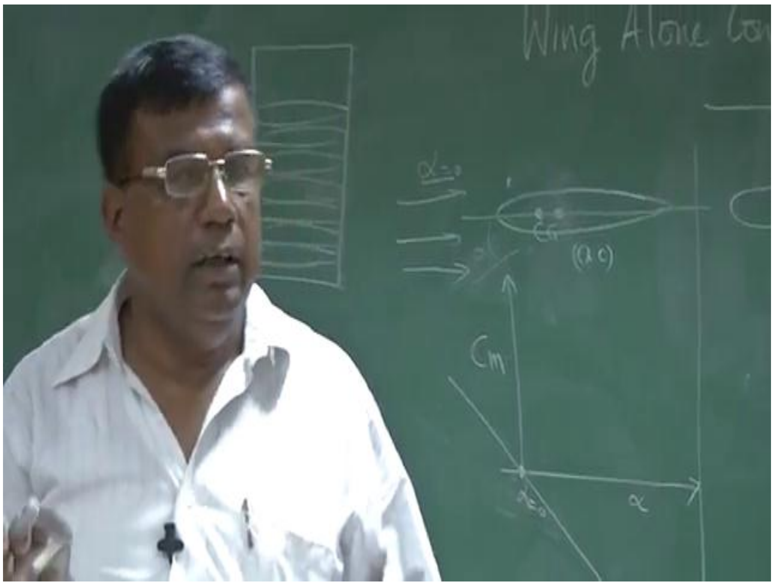
When, this is deflected symmetrically, it works as elevator and when this is deflected asymmetrically, it works as aileron, because we are using common surface for both aileron and elevator. Suppose, I am giving a climb with a right turn, so what will happen, I will give symmetrical deflection for the climb and because I am taking right turns, I will reduce left aileron deflection and I will increase the right aileron deflection.

So, what happens the right aileron deflection will become very high and that will enter into non-linear region. It is designing of control becomes complicated, because we need to handle that nonlinearity which as arise because of entering that deflection into non-linear region. You can also see, we do not have any known lift producing surfers; that is why it has better aerodynamic efficiency than conventional design.

We do not have any vertical surface and vertical surface reflects the electromagnetic waves very significantly, but here we do not have any vertical surface. Therefore, it is a reflection to rudder wave is very small and as a result, it is rudder cross section is very small. At the same time, if you coat it with some rudder absorbent material, it becomes almost invisible to the rudder and this is the most desirable property in the overall applications.

Thank you.

(Refer Slide Time: 10:39)



Let us say there is a wing which has symmetric aerofoil, here cambered aerofoil and if I typically I say this is your wing, although in market, people you see will be more attracted by delta wing triangular shape. I am not talking about those; I am taking very simple example. So, this is the wing I want to ensure that, this wing is statically stable by itself.

So, what I have to do and these are the location, where I am putting the aerofoil, it is not really I am putting the aerofoil, not a correct statement. The contour of this wing is decided by the contour of the aerofoil at planer sections. And let us say, if I want to make this wing alone statically stable, by now you know, I should ensure that C G should be ahead of, what do I write, should I write center of pressure now or I write aerodynamic center.

By now, we know that, when you talk about aerofoil, we have conveniently found a point called aerodynamic center, where you can represent all the forces acting, why you choose aerodynamic center as a point, because about aerodynamic center, the pitching moment is independent of angle of attack. So, it is very convenient for us. So, I will now switch over from center of pressure to aerodynamic center for a small angle, for our understanding, they are almost same.

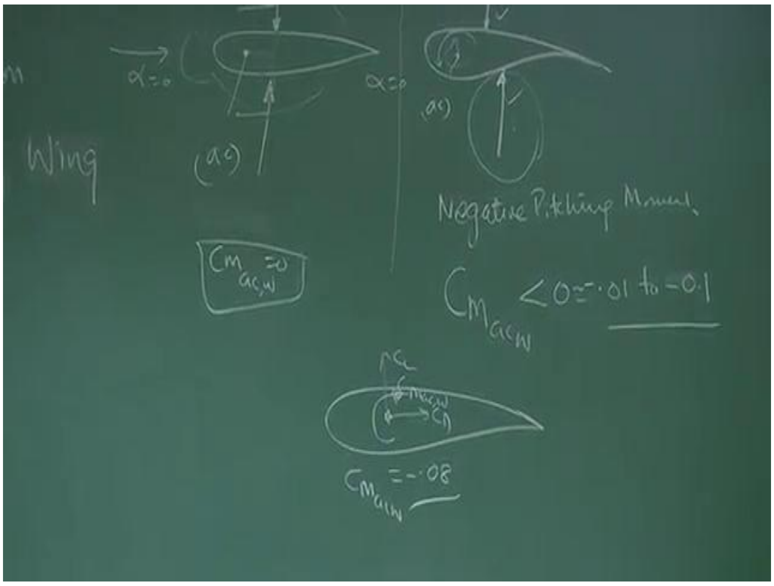
Although, center of changes it is angle of attack for general configuration, but let us say for us almost the same concept with little bit of error, does not matter. So, when you are trying to think, you think in terms of center of pressure, now we are talking about aerodynamic center, which is basically a point about, which the moment is independent of angle of attack, pitching moment. And that is generally the quarter chord point of the wing and we take it as a point of reference, we represent, all the lift coefficient, drag coefficient, moment about that point called aerodynamic center.

Now, suppose this is the wing and it is to be flown like this, what do you think, this is statically stable or not, we can check, any disturbance, C L I can represent here, lift I can represent here and it will give a nose down moment. So, it has initial tendency, to come back to or to counter the disturbance, alpha, come back to the equilibrium. So, I say this is a case of static stability. And by now, you are expert you know, the aerodynamic center is behind C G, it has to be statically stable.

If I now draw C m versus alpha, how this graph will look like; that is the question, if you see here at alpha equal to 0, symmetric aerofoil, symmetric aerofoil wing with symmetric aerofoil. So, it will not produce any lift. So, no C m this point is here, positive alpha we have seen, it is give negative moment. So, here it will, so yes, you are right, slope is negative. So, if I make a wing alone with this symmetric aerofoil, it will be indeed statically stable.

But, think of if I now take that wing and throw it with some angle like this, what will happen, it will try to trim at alpha equal to 0, because statically stable the equilibrium point is only alpha equal to 0 here. So, it will not produce any lift, it will just go like a projectile and fall like this, no lift in trajectory you will get. Because, it is statically stable, even if I throw it to some angle of attack, because statically stable, it will try to come back to the trim point alpha equal to 0. And since that alpha equal to 0, it is symmetric aerofoil nothing will be there as far lift is concerned. So, it will simply fall like a projectile.

(Refer Slide Time: 15:05)



Now, from here we try to investigate, if this wing alone configuration or the flying wing was having cambered aerofoil. Before, I do that; let us understand certain difference between a symmetric and a cambered aerofoil. Specially, at alpha equal to 0, at alpha equal to 0. It is fair enough to make an understanding that whatever pressure distribution comes over here, here, here, the top surface if I integrate and the bottom surface if I integrate, they will be of equal magnitude at alpha equal to 0.

And their point of application resultant of the lower surface a resultant of the pressure integrated over the upper surface, the resultant will be of equal magnitude and that point of application will be at same place. So, if I am transferring this whole force combination to aerodynamic center, you know I have to transfer it by force and the moment, this force comes here and the moment and since they are opposite in nature and same distance, they are from this point.

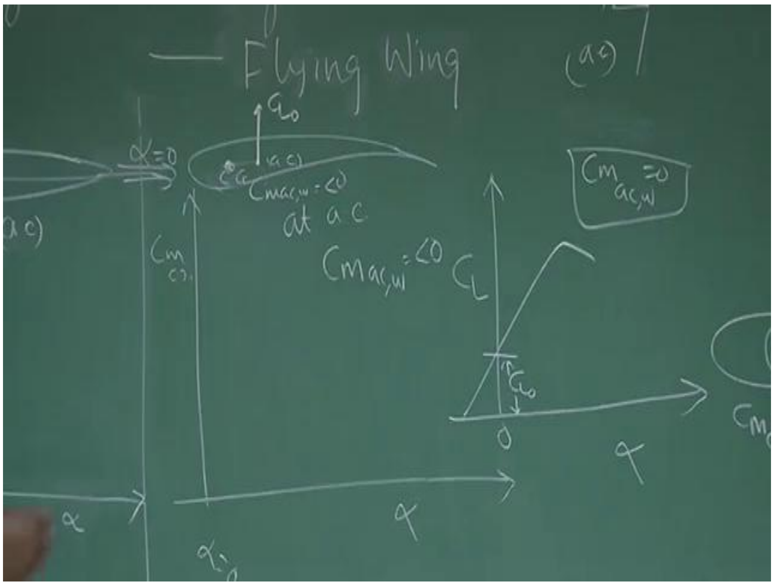
So, net force or net lift will be 0 and all those moment, which I need to transfer, when I am transferring force from that location to a c, they are also in opposite direction. So, cancel each other. So, at this point a c, we do not have any lift 0 and also C m, a c wing is equal to 0, this is the main point, which we are more interested to compare. Now, if you see in the cambered aerofoil in contrast what happens with the pressure distribution, because of cambered part? You will find that, if I take the resultant of pressure distribution over the top surface converted into force by taking appropriate area.

The resultant will be some at somewhere at this point and for the bottom surface, it will be somewhere here not at a same line. So, when I transfer this to the a c, you can very well see at alpha equal to 0, since these two magnitudes are not same. In fact, this is more than this magnitude. So, you will find there is a positive lift at alpha equal to 0 and also, when I transfer this force from here to here, I have to give a moment like this, when I transfer this force to this point I have to give a moment like this.

So, the resultant will have a negative pitching moment a concentrated moment; that is why we write C m a c wing for a cambered aerofoil is less than 0. And for your understanding, the magnitude will be in the range of around this minus 0.01 to minus 0.1; it is fair enough good number to have a feel. So, now for cambered aerofoil, how do I write, I will represent it like this, a c, whatever C L C D and C m, this is a a c wing, this is the convention for positive, but is a negative value.

So, this value is minus, this is a 0.08 some value. So, as a designer I understand, if there is a cambered aerofoil since C m is a c wing is negative, it will have a natural tendency to come down like this. So, C m is negative means, try to put the nose down.

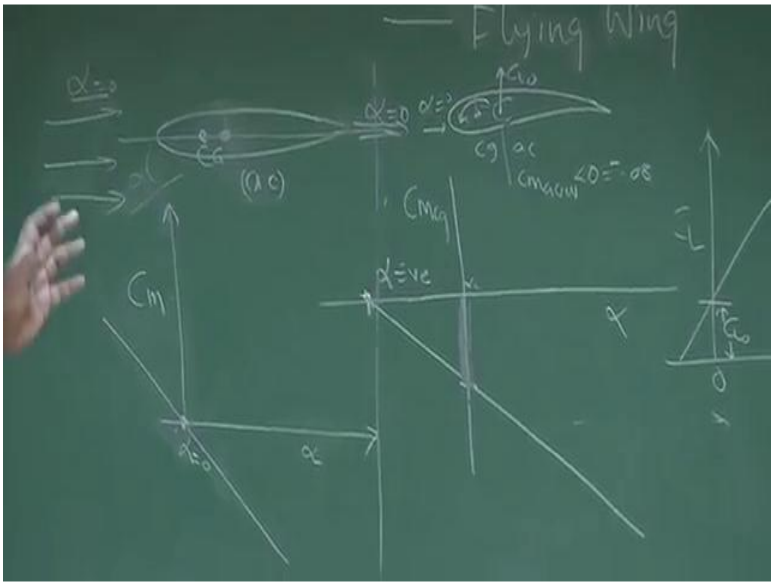
(Refer Slide Time: 19:04)



So, if I now draw that cambered aerofoil, this is the a c, let us say this is the C G and lets a c is behind. Now, again if draw C m versus alpha, C m means C m C G versus alpha about this point statically stable. So, slope will be negative no issues, but what about at alpha equal to 0, what is the C m, you know, because that a c already C m a c negative is there. So, at a c, there is a C m a c wing, which is negative over and above, we are trying to of course trying to see what is the behaviour at alpha equal to 0, do not forget that.

We are trying to find out, what will be the C m C G at alpha equal to 0. For a cambered aerofoil, you also know, if I plot C L versus alpha at alpha equal to 0, there is some positive C L, we call it C L naught. So, what is happening now, if flow is coming such that alpha is 0, this much C L naught will act at a c, no issues, over and above, there is a C m a c wing, which is negative. So, overall moment about the C G at alpha equal to 0 will become more negative. So, although this is statically stable.

(Refer Slide Time: 20:50)



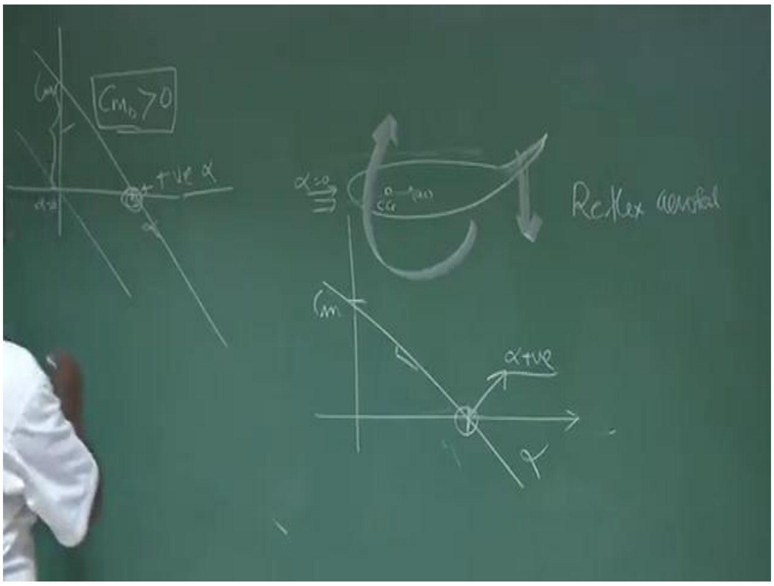
So, you will get let me draw it, what we have observed, if this is the cambered aerofoil, if this is the C G, this is the a c. Since, there is a C L naught at alpha equal to 0, this will give a nose down moment plus you know that C m a c wing is also less than 0; that is opposite of this sign typical value will be minus 0.08 minus 0.05. So, the point to understand is, if I plot C m C G versus alpha.

Now, at alpha equal to 0, what will happen, at alpha equal to 0, this C L naught will give a nose down moment which is negative, C m a c is already negative. So, at alpha equal to 0, I will some value here. However, since a c is behind C G, it will have a C m versus alpha slope negative. So, if I draw it like this, it will look like this and the condition, where C m equal to 0 will happen at alpha negative, left hand side.

Please understand, whenever I write C m a c wing I give clockwise arrow as a part of convention for a positive direction, but I know by number, the C m a c wing is negative. So, this C m a c wing and C L naught into this distance non-dimensionalized; that will give a nose down moment. So, we know that at alpha equal to 0, I will get a negative moment.

My problem is now, I do not get a positive angle to trim for this, for symmetric, the alpha was 0, I cannot produce lift to balance weight and here it is negative angle, I want to fly at a positive angle. So, what is the solution, it means, if I throw a symmetric aerofoil wing; that is a wing alone having symmetric aerofoil, if I throw it to the angle of attack, it will naturally come to negative angle and fly like a projectile. If I throw a cambered again same thing will happen, it will come to negative angle and fly like this, but my mission is not fulfilled, I want the lift to balance weight for a flying wing configuration.

(Refer Slide Time: 23:22)



So, what is the option that is the question, so if I just summarize symmetric, this is cambered for symmetric, of course here it is C G, here it is a c, C G, here it is a c. So, when I plot it C m, C G versus alpha, it was like this. When. I plot it here it was like this and this is negative, negative angle and alpha here, which is less than 0. This part is clear to us and both of this configuration is not, what we are looking for.

That is, if I make a wing along configuration, whether it is having a symmetric aerofoil or a cambered aerofoil, if I just put the a c behind that C G; that is I do the mass distribution. Such that, C G is ahead of a c, where a c is governed by the platform, nothing to do with the weight, but C G I can change by distributing the weight. So, I distribute the weight in both the cases, such a way C G is always ahead of aerodynamic center.

So, they will be statically stable, my problem is what, my problem is I do not get positive alpha in either case, but if you want to balance lift equal to weight, in general, I want a positive angle of attack. So, what is the option, recall we have just seen that, if this is C m versus alpha and if I want a positive angle of attack, let us say even same static stability, then I must have C m naught greater than 0.

If it is I must have C m at alpha equal to 0 positive, if I have a positive intercept and d C m d alpha is less than 0, then I can fly at this positive alpha. So, I have to somehow generate C m naught that C m at alpha equal to 0 to be positive. What do I do, now I check another configuration which is like this, it is loosely opposite of cambered, loosely. But, this is called reflex aerofoil; that is, if you take a cross section of the wing the shape of or the contour of this will be like this, which is basically a reflex aerofoil, shape.

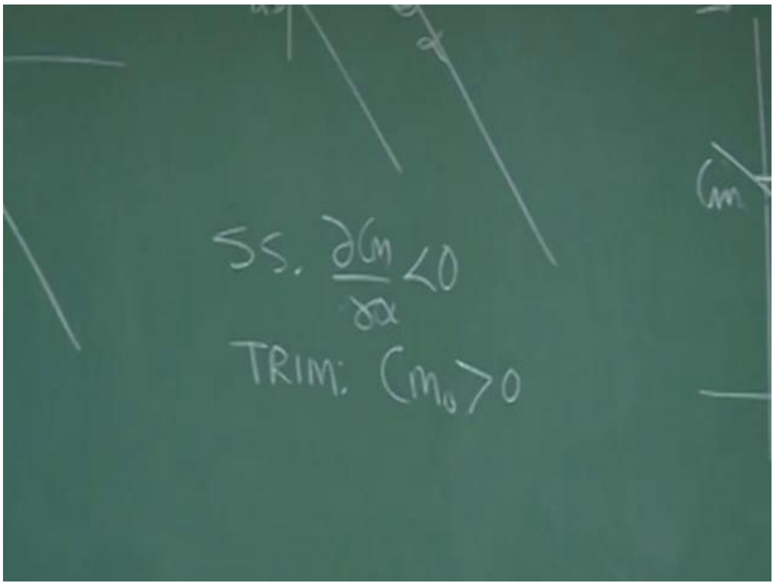
If it is like this, what happens now you see, suppose this is again C G same and I have put a a c of the wing here. So, again a c is behind C G. So, no problem statically stable, I am more interested to see, whether at alpha equal to 0, there is a positive C m naught or not, what happens at alpha equal to 0, air goes like this. Again, go back to George Cayley, this portion will be pushed like this in a simplistic manner, so it will give a downward force and that will give a positive moment about C G, is it not simple, no, do not think big, simply air is flowing like this, this shape is like this.

So, air will push downward force and this downward force will give you positive moment and this is happening at what angle, happening at alpha equal to 0. So, if I have using a reflex aerofoil in a wing alone configuration, I will indeed generate C m naught and if I have decided, what is the slope of this line; that is what is the degree of static stability I have, I can design my configuration to fly at this positive angle of attack.

So, in a nutshell, whether you are using symmetric wing or a cambered wing, a wing along configuration can be made statically stable. However, you cannot trim it at positive angle of attack; that is why I was telling we will be calling this equilibrium point as trim point as trim point. However, if you want to make flying wing, a wing alone configuration to not only be statically stable, but also I can trim at positive angle of attack.

Then, I have to use a reflex aerofoil, which looks like this, in a standard aerofoil data base; you will get different shifts of different aerofoil with different, different aerodynamic characteristics. So, I hope I have been able to make you understand the importance of keeping a c behind C G and importance of having positive C m at alpha equal to 0. To ensure I am able to fly first the airplane at positive angle of attack.

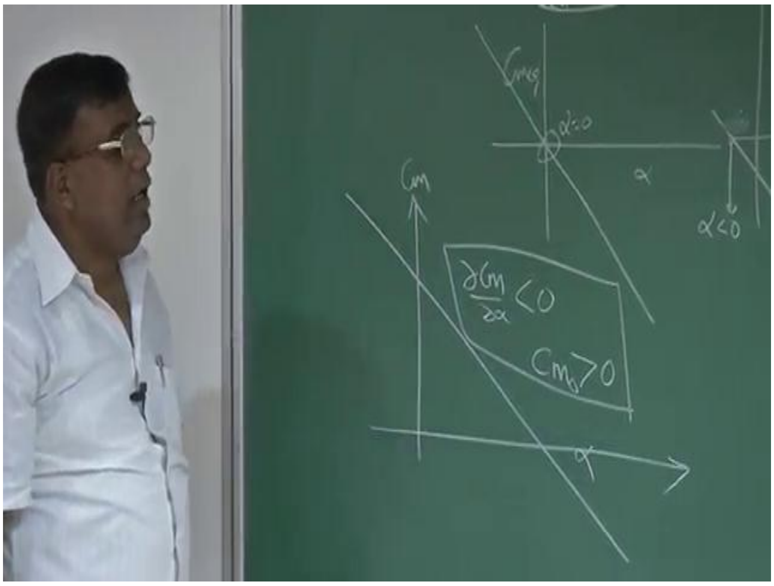
(Refer Slide Time: 28:31)



So, in a summary, when you talk about static stability, we say the slope d C m by d alpha should be less than 0; that means, a c is behind C G, if I am talking about just wing alone and for trim, we say C m naught should be greater than 0. Remember, when I try to translate this knowledge to aircraft, I will be using the same concept, but few nomenclature will change.

You see what happened, we started with a flat plate, we talked about center of pressure, center of pressure behind center of gravity, then static stable. We graduated towards wing with an aerofoil from center of pressure, we came to the concept of aerodynamic center. Because, we want a point, where I can represent C L, C D, etcetera and moment and aerodynamic center is a point at which C m is independent of alpha. So, it is our choice, we have chosen that point, which is incident in the quarter chord point we know that. So, from flat plate to an aerofoils based wing, wing alone. Now, from here, we will go to the aircraft.

(Refer Slide Time: 29:58)



But, please understand, whether it is a flat plate, whether it is a wing alone configuration, the basic understanding is clear; that if you want to trim an airplane fly an airplane fly an object or lifting object, which is stable. Then, d C m by d alpha the slope of this line C m versus alpha should be negative, if it is negative, then it is statically stable. But, if you want to trim it as positive angle of attack, then C m naught should be greater than 0. This is the understanding C m naught is C m at alpha equal to 0.

This should be very, very clear in our mind and that is the beauty of this understanding, if you have understood this, you will find understanding aircraft from stability and control point of view is so straightforward.

Thank you.