NOC: Introduction to Airplane Performance
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Lecture - 38
Stability and Control: Designer's Perspective

Good morning, we were discussing about stability and control of an airplane, more explicitly, we were trying to understand the relationship between stability and control. Whereby, our own perception and own understanding using common sense, you understand that, if a vehicle is statically stable and if I go on increasing, it is stability, static stability. Then, to change it is equilibrium from one known equilibrium to another equilibrium, I have to apply larger effort, because since it is highly stable, so it will always try to stay in that original equilibrium point.

So, if I want to make an aircraft highly manoeuvrable, so I will ensure that, stability is not that high. In fact, all fighter airplanes you find, it has negative static stability, so it is manoeuvrable. But, we are talking about stable airplane here and we are trying to understand the relationship between stability and control, from designer perspective; that is important.

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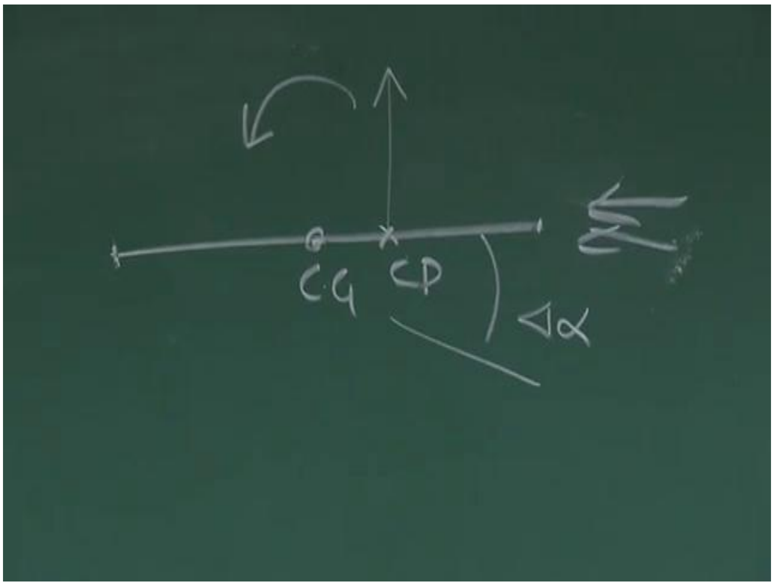

What we did was, so let us say this is that magic plate, George Cayley's plate and let us say center of pressure is here and center of gravity is here. By now you are expert, you know since center of pressure is ahead of center of gravity, so this is a case of statically unstable case. Because very simple, you can check, if there is a disturbance delta alpha, there will be a force here, which will give a nose up moment and the angle will further increase, it will not have any initial tendency to come back to the equilibrium.

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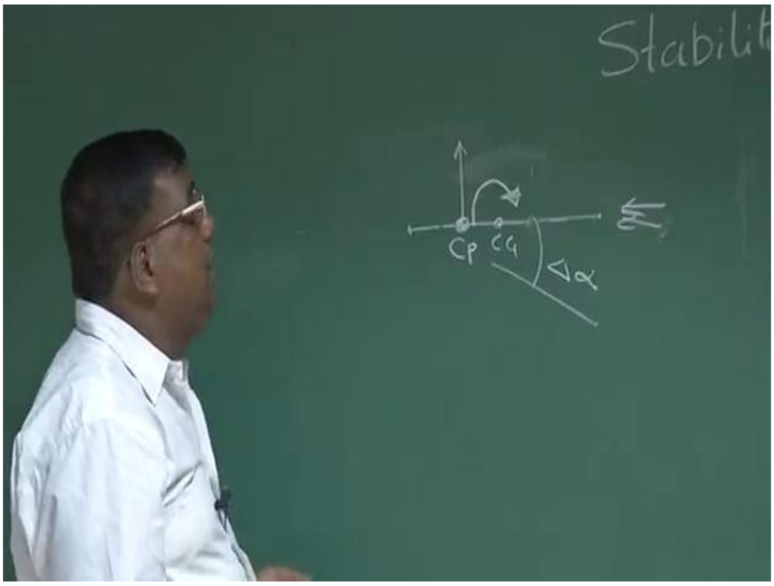

In contrast, if I put this center of pressure behind center of gravity, then you know this becomes a case of statically stable case. That is, if again you can check, if this is the delta alpha disturbance, you have given, now there will be force here, which will try to give nose down moment. So, it has initial tendency to bring back the plate to it is normal equilibrium case, which it was alpha equal to 0 or alpha equal to some fixed number.

More important thing is, any disturbance it is trying to counter it, trying to make it 0, it has an initial tendency to make it 0; that whatever disturbance it is there. So, in a natural you know, if I want to make an aircraft or it is plate in particular, since you are talking about the plate here to be stable, I must ensure that, center of pressure is behind center of gravity.

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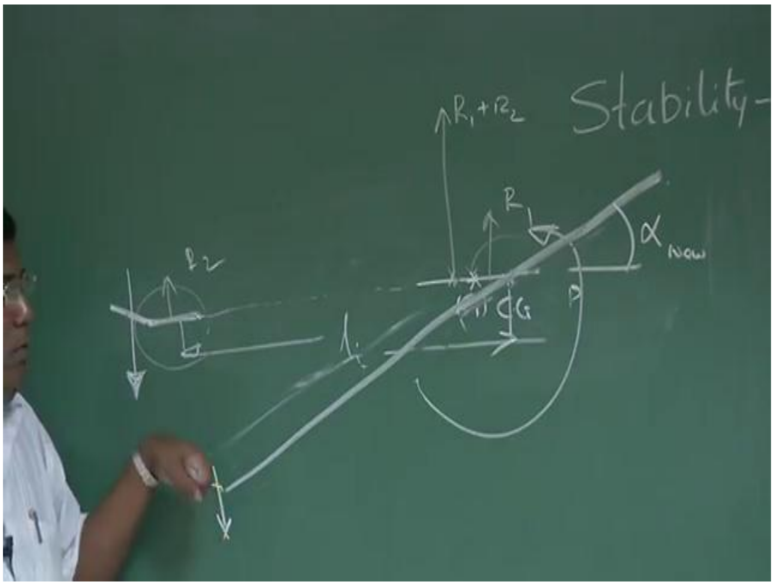

But, the question is, suppose it so happens that center of pressure is ahead and center of gravity is behind, you have no options left to change the center of gravity, assume that. This true because, for an aircraft will be graduating from here to an aircraft, the center of gravity location is more controlled by the layout designer, because he has to have his options to keep ((Refer Time: 03:20)). Then, all those engines, where you will put, where the cargo will be there, passenger seats, washroom, auxiliary units.

So, there is a generally a layout engineer will not like too much of changing the C G's. So, there is always fight goes on between a configuration designer and a layout designer. So, let us say after that fight they have decided, this is the C G, now no more C G shift is allowed. So, in such case, suppose center of pressure is ahead, then what do I do. Our understanding is very simple, if I want to make it statically stable, somehow I have to bring the center of pressure behind C G.

So, what I do, let us say, I attach a rod and I add another small area at a distance, let us say l t from the center of gravity of that plate. So, what happens, whenever you see some angle of attack, there will be some force acted here also, some force here. Now, the resultant of these two forces will come back to this side, so your left hand side and I can find out a point, where I can represent resultant as R 1 plus R 2. Let say it is R 1, this is R 2 and I define that point as a center of pressure; that is above that point net moment is 0.

So, I can assume that whole resultant force is acting at that point, which is the center of pressure. Now, how much I should be able to draw these center of pressure backward for this total configuration will obviously depend upon the force here; that means, the area of the fin here or area of the tail here and also on the moment arm. Because, after all it is a moment that will bring the center of pressure backward, because we are defining center of pressure at the point, where it is total resultant will act.

However, about that point no moment will act like center of gravity and we also realize that, once I do like this, then I can write that overall center of pressure, let us say has come backward. So, it is statically stable. So, our one problem that I want to make it statically stable is handled through another plate here small area, but at the longer distance from the center of gravity of the whole this system.

But, next problem is severe that I want to fly at different, different angle, I want to fly now at 2 degrees now at some other instant, I can have a requirement to fly at 5 degrees. So, I have to change the angle. So, again I have to change from one equilibrium to another equilibrium, but since we have designed it statically stable. So, it will oppose to not allow by itself; that is a beauty of static stability.

So, to counter that, I have to generate additional force, which will give a downward force and it will give a moment about C G and this moment should be good enough equal to the whatever restoring moment coming because of static stability. And if I can make it balance, then I can fly this whole system at some other angle; that is, I have now flying it like this some alpha mu. This we have discussed and we are very clear so that, somehow we have to apply this moment through this force to hold this airplane. Because otherwise, since it is statically stable, if you do not have this force, you try to come back to original alpha and this is what in a very holistic manner, the control problem.

You can very well understand, how much you can turn will also depend upon, what is the force generating capability of this surface or what is the moment generating capacity of this whole system through this, that will be decided by not only the force, but also the moment arm. So, these are matter of details. If you have understood this, let us try to use it and try to see stability and control aspects of an airplane through this basic understanding.

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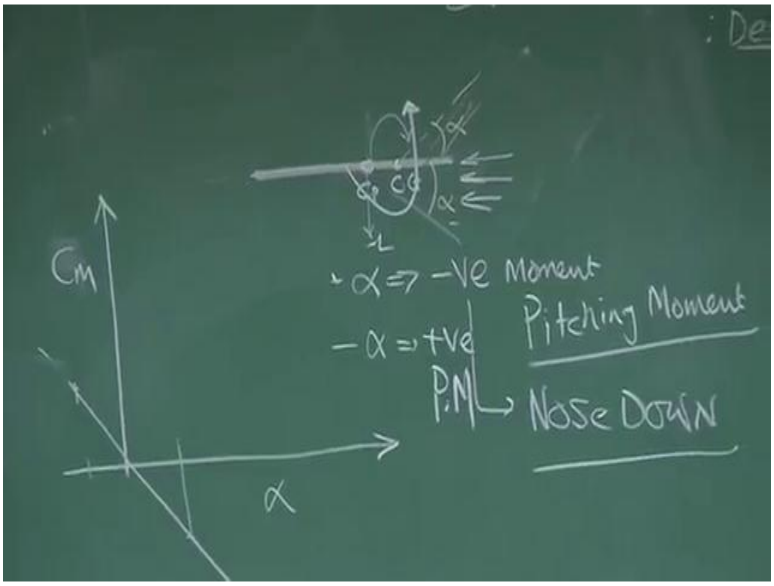

Again, we go back to George Cayley, suppose this is that magic plate and let us say center of pressure is here and C G is here. So, I am taking a simple case that, this plate is design such a way that you have given more mass towards the nose of this plate. So, that C G is in front of center of pressure or I say center of pressure is behind C G or center of pressure is at top C G and this is you know very well, this is statically stable case.

Now, let us try to represent this understanding through some formulation. So, that a designer can use it very extensively, what do we have seen, if there is a disturbance alpha, then it generates a force here. Actually, it generates a force through pressure distribution over this surface, but we are representing the overall effect by representing the total force acting at the center of pressure; that is understanding.

So, what is happening for positive angle of attack, if this plate has to be statically stable by itself, then it should generate a negative moment, which moment, negative pitching moment. What is the pitching moment I am talking about, this is the airplane like this, this is the x axis and this is the y axis, this is the pitching moment in the vertical plane. So, positive alpha and this plate will generate a negative moment, negative moment means nose down moment and positive moment by convention is nose up.

So, pitching moment negative when I say, it is nose down, this is a matter of convention, just take it like that. Similarly, if I have a negative alpha disturbance; that is let us say something like this, disturbance is coming that is some gust is coming from the top like this, that will give a negative alpha. So, now, what will happen, now because of negative alpha, air is coming like this. So, it will generate some sort of a lift downward and this will give what type of moment, this will give moment like this nose up.

So, again you see it has an initial tendency to ensure that, this alpha goes to 0, the disturbance goes to 0. So, again; that means, we have come down to a case, where it is again stability case. And now for a negative alpha, what it is tells you that, it should generate positive pitching moment. Suppose, I am going like this, positive alpha negative pitching moment, so this disturbance is becoming 0, so initial tendency to make the disturbance 0.

Negative alpha, if it is coming like this, then nose up moment, so this disturbance is becoming 0. So, it is coming again back to alpha equal to 0 or whatever original alpha is there. So, it has initial tendency, so we said statically stable.

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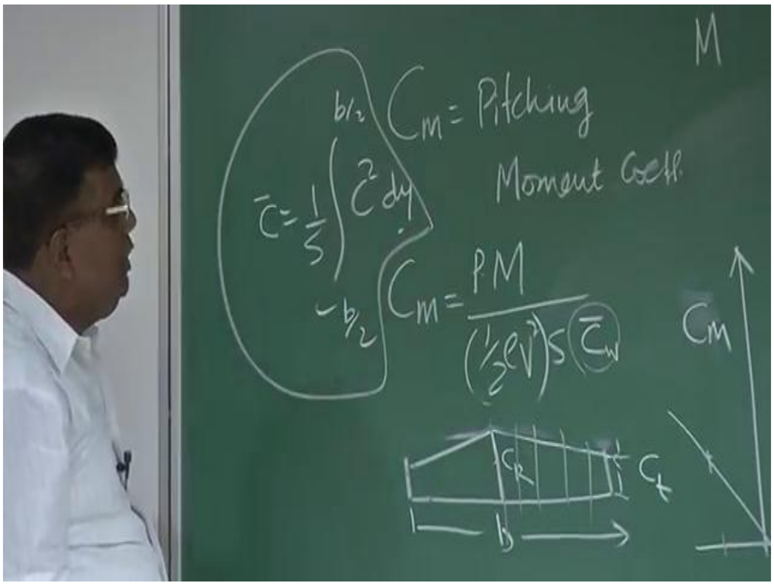

So, if I translate this in a graphical form, what should I write, I said the moment, if I write it moment here, write it alpha here, I have seen for positive alpha, it is negative for negative alpha, it is positive. And since this is symmetric plate at alpha equal to 0, it is 0, so this will look like this. But, we know we do not work in terms of moment, we know that we are working in terms non dimensional coefficient; that is C m like we do not work in terms of lift, we work in terms of C L lift coefficient. We work in terms of C D drag coefficient.

So, we will not work in terms of moment, we will work in terms of C m, which is pitching moment of coefficient. How do I define C m, a simple the pitching moment which is m here divided by half rho V square S into chord, we call it min aerodynamic chord. It is important; you will understand all wings are not rectangular. So, there will be a tapering of wing. So, it is something like an average chord, at this stage, you understand that much.

So, now what I will do, when I plot this m versus alpha instead of m, now I will use C m, it is a matter of dividing that pitching moment by this number. And to give little more insight on C bar, which I think I will give you more on during the little bit of addition to design aspects. But, at this stage to give you some feel, say this is the rectangular wing, this is the span you know by now and this is the chord.

Now, you will find there are wings like this. So, here if I call this root chord C R, I call this tip chord C t, they are not same, for a rectangular wing, they are same. So, it was very easy for me to talk about C. But, here because this chord is changing at it is station, so we define something called mean aerodynamic chord and that is exactly we are writing here with a bar and it is a mean aerodynamic chord of the wing. So, I can write C W also and now, with this diagram we can understand in a average sense, this is a weighted average chord of the wing.

And mathematically, it is defined as do not give too much of weightage to all this integral now, try to understand, what is the meaning of this and why the span direction. So, it is weighted by the chord for you and me at this stage assume that, this is an average chord, which will help me to visualise as if it is a rectangular wing with C bar and b as a configuration parameter.

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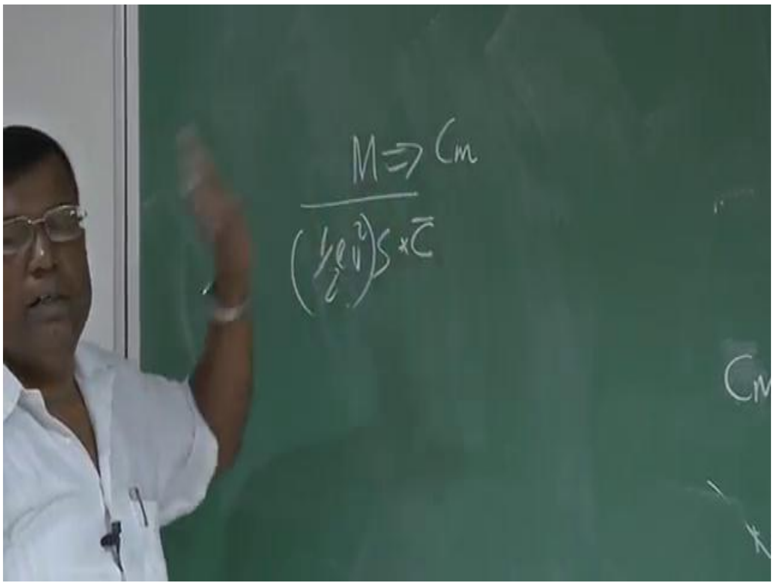

Let us stop this discussion here only and you also understand why we have divided by C; that is because, this is the moment I want to convert to C m. So, I have to divide this by half rho V square into S, which is the force, so I have to have one length and that is why divided by C bar, so that, it become non dimensional.

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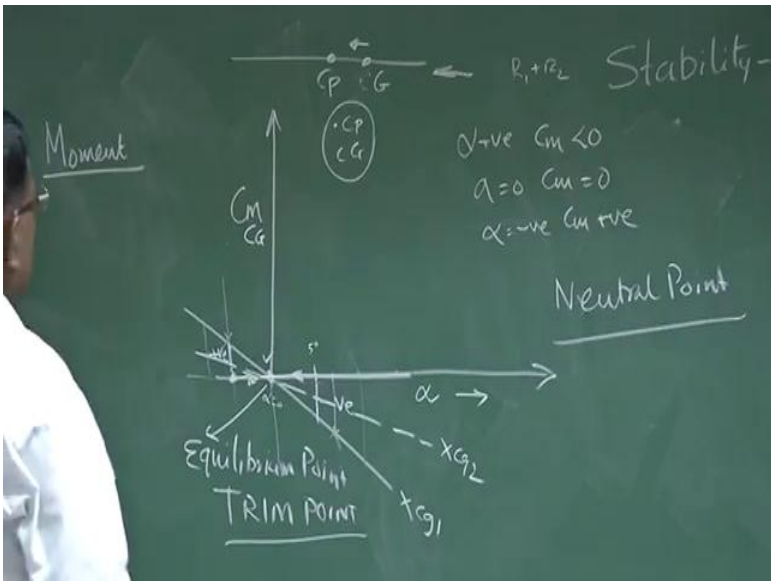

Now, come back to this, this is important focus your attention here or let me drop this little bigger, because this is most important part of today's lecture, whatever I have said just now, till now, already I have discussed in the last lecture. So, now let us very carefully understand this concept, what we are saying, this is the C G and C P is here and it is like this.

We know that is statically stable, I now translating this to behaviour of pitching moment coefficient with angle of attack and what we have noticed that for alpha positive, C m is negative for alpha equal to 0, C m equal to 0, for alpha negative, C m is positive. So, if I try to plot this in alpha positive, C m negative, let us say let me take somewhere here. So, I will get a graph something like this, alpha positive, C m negative, alpha negative, C m positive, alpha equal to 0, C m is 0, satisfying these three conditions, very simple.

Now, I will try to see, whether this representation indeed tells me that the aircraft or this plate has static stability. Now, recall how do we define static stability, we say if a system is disturbed from it is equilibrium point and if it has initial tendency to come back to that equilibrium, then this system is statically stable, very simple. So, what is the catchword, catchword is equilibrium point, how do I find, which is the equilibrium point here, do you think this is equilibrium point, if I see this point, there is unbalanced moment here.

So, this cannot be equilibrium point, can this be equilibrium point, no, because at this point there is an unbalanced moment. So, what is equilibrium point, equilibrium point here is that point, where C m is 0. So, this is the equilibrium point or we also call it trim point. Now, let us see, what is the definition, if I disturb the system about it is equilibrium and if it has initial tendency to come back to the equilibrium, I say it is having static stability.

The catchword is, if it has initial tendency to come back to equilibrium, let us say I have given a disturbance here, it was 0, alpha equal to 0, some alpha 5 degree or something I have given disturbance. So, what will happen immediately, immediately this aircraft will generate or this plate will generate negative moment. Negative moment will do what, it will try to plane was going like this, there is a positive alpha disturbance. So, it is generating a negative moment. So, the nose will come down.

So, you could see, it has initial tendency to make this situation, where it again becomes alpha equal to alpha original. So, it is nullifying, it has initial tendency to nullify this disturbance. So, we say yes; that means, if it generates negative moment, the alpha will go on reducing. So, it has a tendency or initial tendency to come back to this equilibrium point.

Similarly, if it has a negative disturbance, let us say here, it will generate a positive moment nose up; again it will try to go towards this point. So, indeed above this equilibrium, this aircraft or this plate is having static stability is it clear. Now, there is a little finer thing you must understand, whenever I am talking about moment, what is moment, moment is an effect of a force about a point or a line.

So, this moment when I am writing C m, it must be about a point for the airplane and this is actually is about center of gravity, if you take this plate for this example, whatever C m I am writing here, it is about the center of gravity. Why, I am taking center of gravity, because I know in free air free space, the body will rotate about an axis passing through center of gravity. So, this is the variation of C m about C G with angle of attack alpha.

So, when I draw C m versus alpha, I must mention that this is for a given C G location. So, I am writing x C G 1. Now, think our situation, suppose I start drawing this center of gravity backward, what will happen, as I try to draw center of gravity backward, so distance between C p and C G is going to reduce. So, it is initial tendency through the moment will increase or decrease for the same alpha, because this moment arm means reducing. So, the initial tendency will reduce.

So, what will happen as I am moving C G backward, this slope will try to flatten out and there will be a point, when this C p and C G comes to a same point; that is there are conceded. So, I am moving this, moving this, moving this, moving this, moving this here, when this C G and C p coincides, then what is the restoring moment, there is no moment arm. So, it is 0. So, that time it becomes neutrally stable.

So, there would not be any moment, whatever disturbance you give the slope of this line will become 0 or it will become parallel to the x axis. So, what is the message here, message here is, whenever I am talking about C m versus alpha, I should be very clear about what point it is basically about center of gravity. And as I move the center of gravity closer to center of pressure, it will have an effect in terms of reduction in static stability and there is a point, which is for this plate center of pressure.

If I bring the C G to center of pressure, this plate will become neutrally stable. So, I can define neutral point by using this understanding. Neutral point means, the C G location at which the plate or the aircraft will become neutrally stable. So, with this background, now let us try to add little more understanding on this graph.

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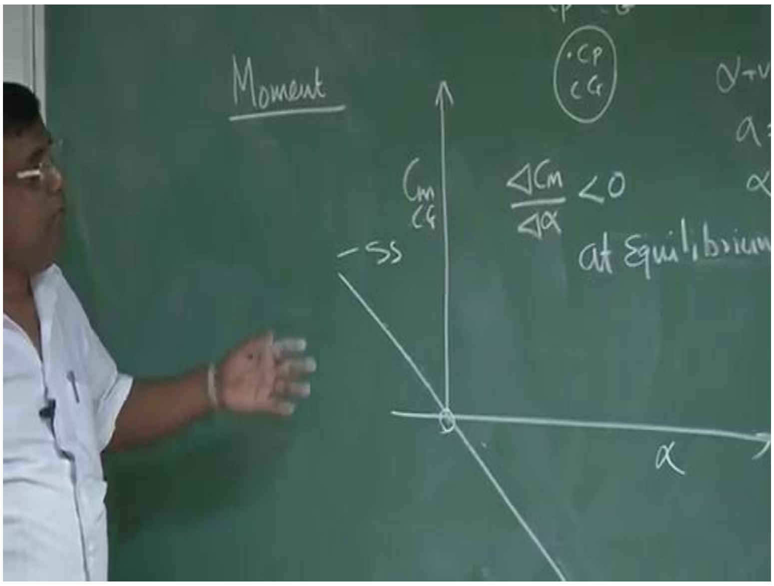

So, what we have learnt from this, whenever we are drawing C m, it is actually C m C G and alpha, whenever I am drawing graph like this, I should know that, it is about a particular C G. And for this plate or the aircraft to be statically stable, what is the condition, condition is the slope of C m versus alpha graph should be less than 0 at equilibrium, this is very important.

So, what do I do, I check where is the equilibrium, equilibrium is at C m equal to 0. Now, I check the slope of C m versus alpha at equilibrium and if I guess, it is indeed negative. So, I say this is a case of static stability or this configuration is statically stable.

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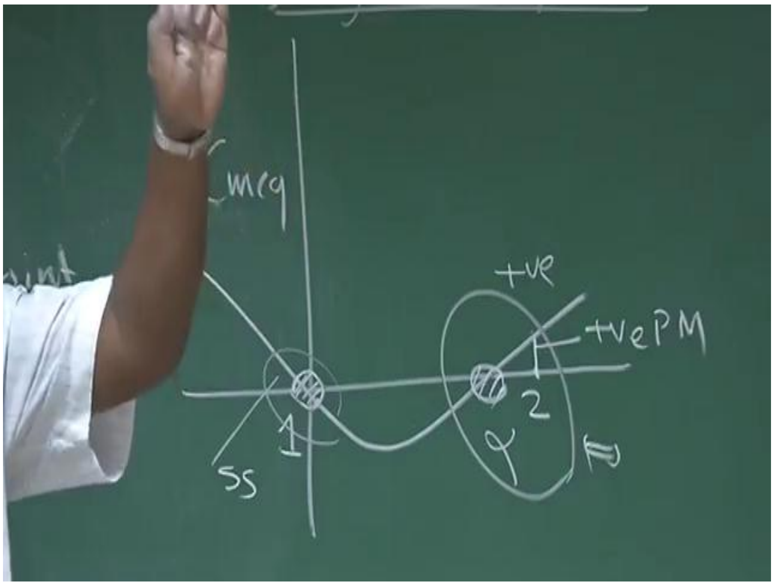

Remember, there could be cases, again C m C G alpha, there could be cases something like this. Typically, if you see parafoils and all, the C m versus alpha could be like this. Now, if I ask you, whether this system is statically stable or not, how will you answer, again you have to find out, what are the equilibrium point? So, now, you see equilibrium point means the point, where C m is 0. So, one point is here C m is 0, another point is 0 C m is 0.

Please understand, we are talking about static stability purposefully we have taken cruise as our equilibrium, this you should remember. So, now if I try to see here, whether this configuration is statically stable about trim 1 or not you have to check, what is the slope of C m versus alpha at this point, if it is negative, it is statically stable. Now, you check here yes indeed, slope is negative, so it is statically stable here.

But, if I come to the second trim point here, here I see that at that trim, this C m versus alpha or slope of this line is positive. So, above this equilibrium, this configuration is not statically stable, because it will not have an initial tendency to come back. You can check here, if I give a disturbance suppose the angle of attack increases, then this will generate positive pitching moment. The positive pitching moment will further take the angle. So, no initial restoring tendency; that is why if the slope is positive at trim, we say this is statically unstable.

This example is typically true for parafoils and a highly non-linear type of configurations, just to give you the importance of checking stability about trim point, I have given this example. For aircraft, for most of the aircraft will be having train like this, so from this point, now you forget about this graph at all.

Thank you.