NOC: Introduction to Airplane Performance
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Lecture - 36
Positioning of Centre of Pressure of Static Stability

We will again go back to George Cayley and remember, we started from George Cayley only.

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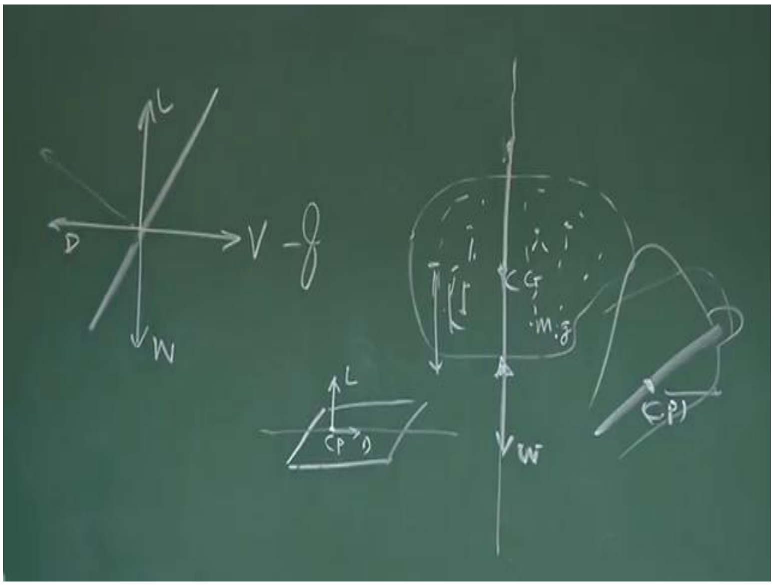

Let us say this is the plate and realize that, if it can be given a speed through an engine, let us say, there is an engine thrust. Then, this is of the reaction by now, you are expert, this is the lift and this is the drag and off course, there is a weight. We never discussed about, what is this point as far as weight is concerned, you know this is the gravity, centre of gravity.

But, question is, we have not discussed about this pointer publication of this aerodynamic forces in terms of it is relationship with the centre of gravity. That is, whether this centre of pressure of the aerodynamic forces should be ahead of centre of gravity or behind centre of gravity. You understand what is centre of pressure, you know what is centre of gravity, if this is the mass, I can represent whole effect of this mass. All are put by m and m i g and I can represent their effect equivalently by it is point called centre of gravity.

That is, if practically if you see, if I put a pointer here, which passes through the centre of gravity, I will be able to balance it, nothing will happen. If I take this pointer here, this will fall like this, if I take point here, it will fall like this. So, this is the point where everything is balanced and that is our definition of centre of gravity in physical sense. Centre of pressure is no way different, here when you talking about centre of gravity, we are talking about the each individual particle being attracted by force m i into g.

When, you talk about centre of pressure, you know that a body when interacts with air, there are pressure distributions and this each pressure distribution will act upon finite area and there will be forces, this pressure gets converted into forces. Now, we are asking a question, what is that point, where I can represent as an overall effect, total force is acting at that point. That is, about that point, all the moment due to forces etcetera are nullified is 0; that is the centre of pressure. It is is true that, if I change the angle of attack, again the pressure distribution will change.

So, in general as I change the angle of attack, the centre of pressure will also change, but since we are talking in very small angle. It is not unfair to assume that, centre of pressure is not changing very much, because disturbance will be of 2, 3 degrees and they are flying at around 2 to 3 degrees, maximum 7 degrees sometime, so you know, what is the centre of pressure.

So, I will take at this stage with this minimum understanding that, if this is the plate, this is the chord, I can represent total effect of the force, lift, drag at centre of pressure. This is not exactly the same as aerodynamic centre. You know, what is aerodynamic centre, aerodynamic centre is the point in aerofoil about which the pitching moment is independent of angle of attack.

So, you change the angle, pitching moment will not change, for a small angle and for thin aerofoil, practically centre of pressure, aerodynamic centre numeric will be at the same point, almost close point. So, since we are not doing any course on stability and control, allow me to assume that, we will be using centre of pressure concept to discuss on stability.

Then, as on when required aerodynamic centre will be switching over to aerodynamic centre, but you should understand physically, if they are for this discussion take them as same, but strictly they are not same, please understand. So, let us come back to George

Cayley, I hope you understand this diagram, if I take this plate ((Refer Time: 05:06)), put it like this, this is what this plate I am talking about and it is moving at an angle.

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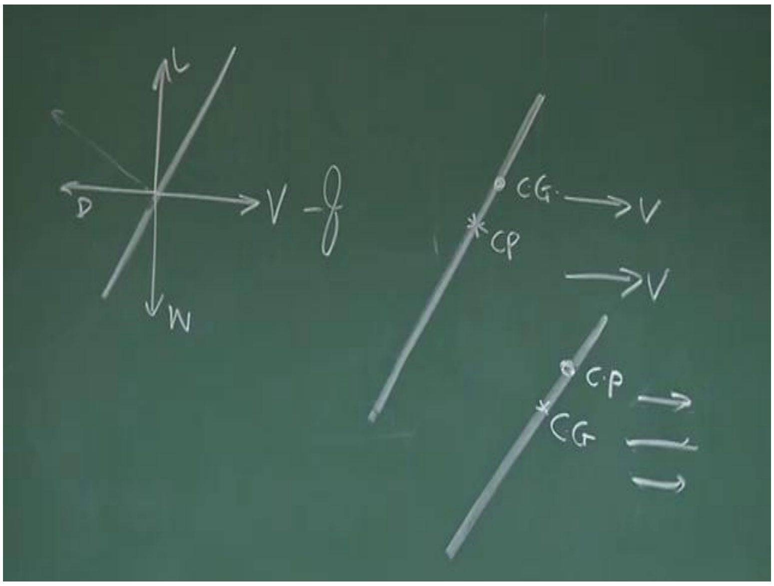

Now, let us take a case, let this plate is having C G, that is centre of gravity ahead of centre of operation. So, it is going like this, this could be one of the configurations. Now, you want to check, whether this has static stability inherent in it or not, number 1. Second case we will discuss, if C G is here and C P is here, whether it has inherent static stability or not and third case; obviously, you all will tell, we will discuss third case when C P and C G are at same point. I am sure, once we explain first to third one, you yourself will be able to predict. So, let us see this point very carefully.

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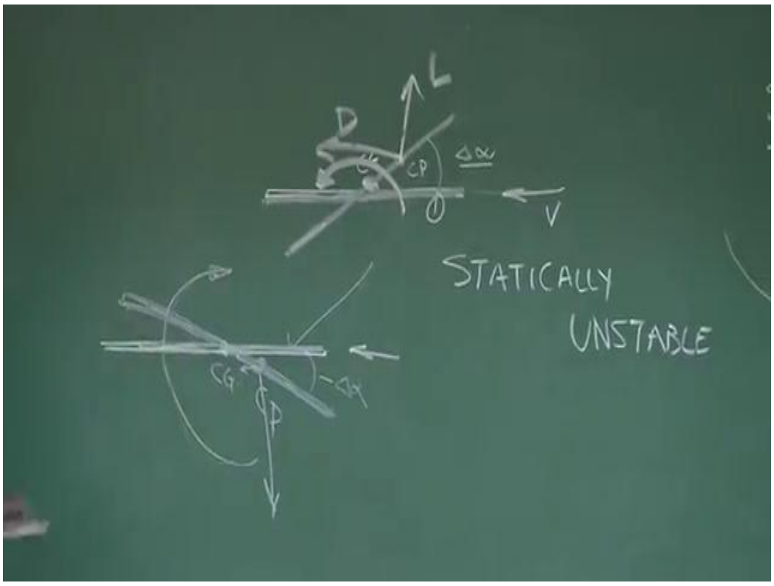

Let me draw this flat plate, the relative airspeed and let us see that, I want to disturb it by some angle delta alpha. Delta I use, because we are trying to remind you that we are talking about small angle disturbance. Because, if you give a large angle disturbance, then aerodynamics maybe non-linear. So, we are not going there and let us see one case, where C P is here and C G is somewhere here. What is the meaning of that? The centre of pressure is ahead of centre of gravity, when I am flying like this.

Now, what question I am going to ask, I am going to ask, whether this plate exhibits static stability or not in terms of angular motion. The moment I disturb it by delta alpha, what is our George Cayley's postulation or guidance to us. So, it will generate lift and it will generate drag. Now, you are expert about it, now you have agreed that point of application of aerodynamic forces will represent at centre of pressure.

I remind you, conventionally we present it at the aerodynamic centre of an aerofoil, but we have agreed for time being, we will not mix up these two issues, we will be only using centre of pressure. Now, if there is a disturbance delta alpha, we know here, there will be lift, there will be drag. What this lift and drag will do? This lift and drag will give further moment like this, about C G, because body will rotate about C G.

So, whatever delta alpha you are given, this plate will further increase the angle of attack, because this lift and drag will give a moment like this, so nose up. So, it will further increase the angle of attack, does it have any initial tendency to come back to where from it started. That is, does it have initial tendency to come back to this state 1, where it was in equilibrium, yes or no. Definitely no, because small angle, the small distribution if I give, centre pressure will have lift and drag and they will rotate this plate and go to some other orientation.

So, it does not have any initial tendency to come back to the equilibrium. So, I will call this is statically unstable. Many of you may get a question, what happens if the disturbance in the negative direction, which is natural. So, let us see for negative disturbance, suppose this is the plate, many of you will have a question, what happens if this disturbance is negative, which is very natural. It should come, if it is not coming, that means, you are not understanding. So, again revisit, then that this question must come to your mind.

So, let us see, if I give a disturbance. So, that this plate, it is a negative alpha, negative delta alpha. As you know centre of pressure is ahead of centre of gravity, this is the case where studying investigating. Now, for negative alpha, again George Cayley forces will be downward. So, lift direction this way and drag will be this way. So, you could see that, this also again will give a moment about C G in this manner, which will further take this to negative angle.

So, it will not have any initial tendency to come back to that equilibrium, which is the state this, with negative angle force acts downward and this will rotate this plate like this, the plate will further go like this. So, you could see, whether it is a positive angle disturbance, negative angle disturbance. As long as C P is centre of pressure is ahead of centre of gravity, this will only give static instability or we call, it will be statically unstable.

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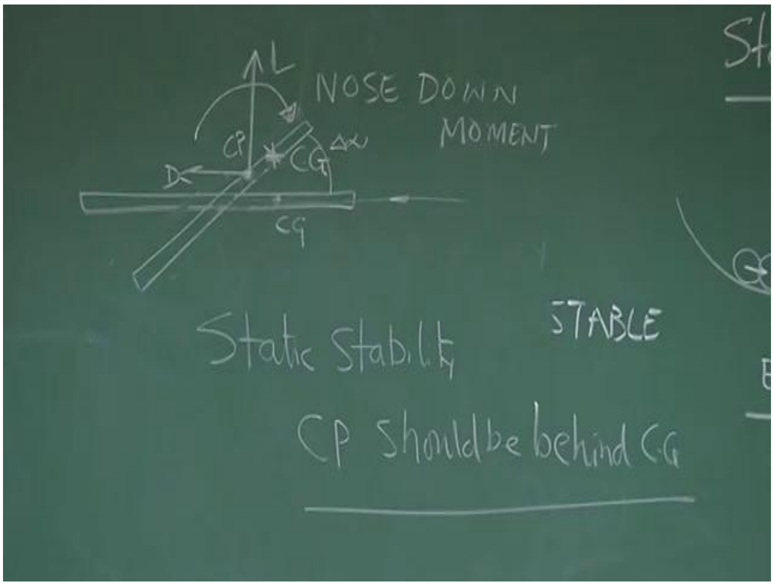

To make it statically stable, what should be done, by now, you know the answer, I am sure you know the answer, to make it statically stable, see as per the centre of pressure is concerned that you cannot change, because that depends upon the geometry. What you can do, you can ensure that the C G location is different. So, now, what we should do, we have seen that, if C P or centre of pressure is ahead of C G, I am flying like this, it is a statically unstable case.

So, I want to ensure that, the centre of pressure, if it comes to the back, what will happen and centre of pressure coming back, it is a relative statement, centre of pressure you are not changing for this plate, for this plate, you can change the centre of gravity. Let us say by distributing this mass in the plate, I have ensure that, centre of pressure remains same place and centre of gravity has come ahead of centre of pressure, is this clear diagram. Now, the centre of pressure is behind centre of gravity as your flying like this.

So, now, if this was C G and some are centre some are here, now if it is disturbed like this, what will happen, I have given a disturbance like this delta alpha, what will happen, the lift force will act here, drag will act here. Now, you will see, C G is ahead of centre of pressure, so this will give a moment like this, which we call nose down moment. What this moment will do, this moment will ensure, there is an initially tendency to bring this plate back to the equilibrium, because it will give a nose down moment like this.

So, it possesses static stability, because it has a initial tendency to bring it back towards the equilibrium. So, what is learning? Learning is, if I somehow can make sure that centre of pressure is behind centre of gravity, then I should be able to ensure this plate has static stability. This is also by common since you can understand, more this separation between centre of pressure and centre of gravity, it will be more stable, because the moment will be larger as the distance increase, the restoring moment also will increase. So, it will become very stiff. So, for static stability, this centre of pressure should be behind centre of gravity, this much we have understood.

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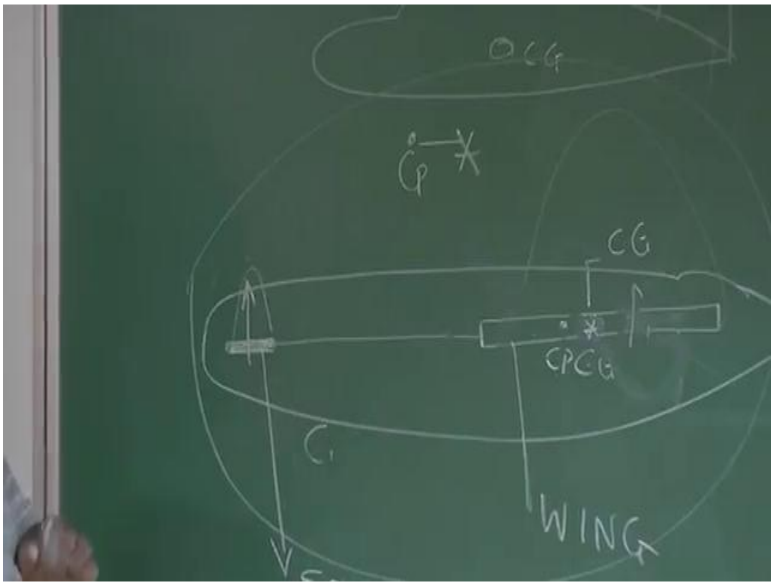

Now, the question comes, suppose this is a plate, same plate we are talking about and you can assume that, if it is a uniformly distributed plate, the centre of gravity will be almost at 50 percent, some are here, centre of gravity will be there. Now, you know the centre of pressure also will be around at 25 percent, generally 25 percent from the leading edge of the chord, almost like this aerodynamic centre.

So, centre of pressure in normal case, it will be somewhere here. So, if this is a plate of uniform mass, this is a case where centre of pressure is ahead of centre of gravity. So, this is a statically stable case or statically unstable case. We know that, if centre of pressure is ahead of centre of gravity, it is a statically unstable case, you can cross check, if there is a disturbance, there will be a force here, which will give a moment here. So, it will further go up like this.

So, there is no restoring tendency, when centre of pressure is ahead of centre of gravity. But, we want to make sure that do something, so that it is become statically stable. So, one option is what, if this is the centre of pressure, let me not change the centre of pressure, I somehow redistribute the mass and bring C G here, I can do that, I can make this portion heavier, I can move the C G from here to here. Now, centre of pressure is behind centre of gravity, so statically stable.

Think of a situation for an aircraft. For an aircraft, the centre of gravity is more decided by the layout designer, where there will be chair, where the passengers will be sitting, where will be the cargo, where is the engine located. All these things decide the centre of gravity and if you tell the layout designer, you please shift the C G, then he will simply say, thank you very much, I will not do anything, there is a always fight between layout designer and a aerodynamic designer.

So, changing C G is not a very easy option beyond a certain point. So, what we do, we tell the layout designer, you keep the C G around 35 to 40 percent, whatever depending upon thing, then we try to put the wing etcetera, etcetera. So, let us forget about for aircraft, let us forget about that to change the C G, say C G we will not be able to change, let us say that big term, C G we cannot change. We want to make it statically stable, but centre of pressure is ahead of centre of gravity. So, how to make it statically stable? What do we do? We create another pressure distribution somewhere here. So, that the resultant of this and this ensures that the point of location is behind C G possible.

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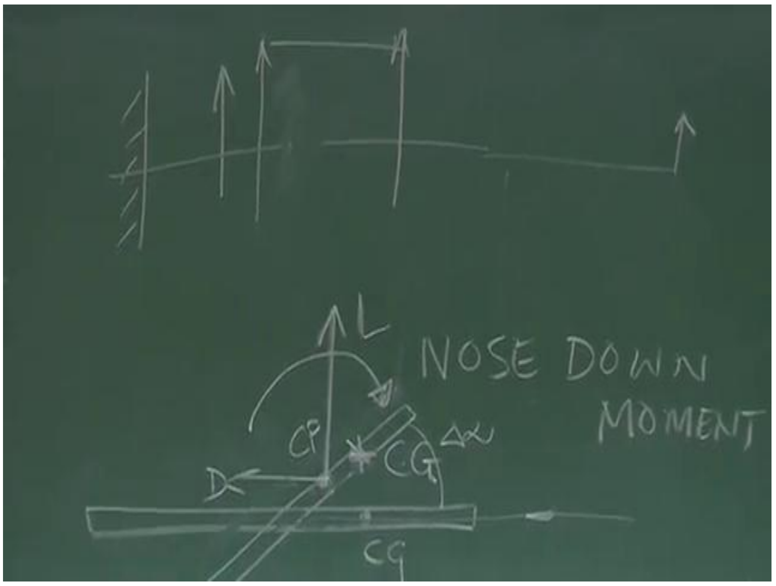

Suppose, I have one reaction here and one reaction here, the resultant is somewhere here, let say I am looking from here. Now, if I want to shift this to this point, what I can do, I can shift this to somewhere here, it is a moment that will shift this resultant. Because, ultimately question is, what is that point, where I can put all the forces, so that net moment is 0.

See this gives us a hint what we do, let us say I attach a stick with it and put another surface here, smaller surface and ensure that, once it is in motion at some angle, there is a pressure distribution over this, there is a pressure distribution over this. Because, now it is moving some angle ensure that, this pressure distribution and this pressure distribution, when they are combined, the total centre of pressure is brought from here to behind centre of gravity. It is possible, because now for any angle some force will be here, some force will be here, so resultant can be pushed.

As long as I decide, what is the length from here to here and what is the area; that is how much moment I am giving like that example. What is that small portion I have drawn here, if it now try to look for an aircraft, if I cover it like this, you could see this is the wing and this is what, this is the stabilizer, this is the horizontal tail or we call horizontal stabilizer. Because, by putting this stabilizer with the appropriate area and at an appropriate location, I can bring the overall centre of pressure behind centre of gravity, which is here, this centre of gravity.

So, centre gravity was here, now the centre of pressure is somewhere here. Now, I know centre of pressure the overall system is behind centre of gravity. So, and now it is statically stable. Do you think the problem is solved; we are only talking about stability. So, what is our main problem, main problem is, it is not only static stability, we want to control it also; that is we also want to take the airplane from one equilibrium to another equilibrium or one angle of attack to another angle of attack and that is typically a control problem.

We know by shear common sense that a system is highly stable; that is the distance between centre of pressure and centre of gravity is very large and centre of pressure is behind centre of gravity. Then, as I increase this distance, this aircraft or this body will go on becoming highly stable, statically stable. So, highly statically stable means, it will resist any change, if it is flying at 2 degree, it will resist, if you want to make it 3, it will say, no, I will not allow, I am statically highly stable. So, you have to control it, you say nothing doing, please move and that is a control aspect.

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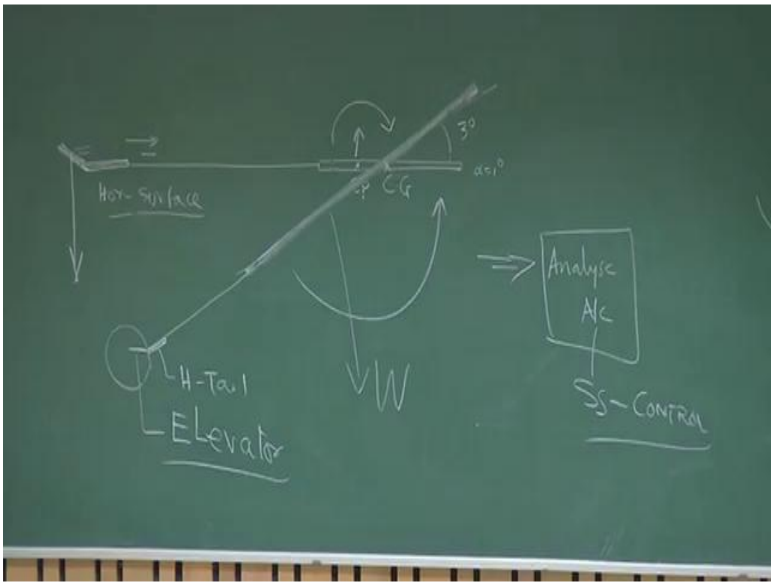

So, if you see here, this was the plate, this is the rod and here, I have put the horizontal surface to ensure that, the overall centre of pressure comes behind the centre of gravity. Although, please understand the moment I put a tail here, the original centre of gravity is supposed to come little backward. So, I am neglecting that, that is small, but more I am focusing on, I should generate enough pressure distribution or force per a given angle of attack, so that the overall centre of pressure comes behind the centre of gravity.

And let us say I am successful in doing that by selecting appropriate area of the stabilizer and the moment arm that is distance from the centre of gravity, assume that is happening. So, it has become statically stable. So, I say the C P has come, let us say somewhere here. But now you want to take it to some angle say 1 degree or 2 degree, you want actually now, now you want to rotate, I want to take it to 3 get degrees, let us say.

Suppose it was flying at 1 degree, I am now trying to take it to 3 degrees. So, I have to rotate it, but the problem is the aircraft is statically stable, the moment, I will try to take it away from equilibrium, it will generate a force here and a nose down moment, it is a nothing doing, I will not allow it to go. So, as I said you have to overcome that, how do you overcome that, now what I do, I deflect some portion of this vertical stabilizer.

And now, what will happen as it is moving like this, you know by George Cayley, these will generate a force downward and this force will give a moment in the nose up direction. So, whatever because of static stability it was resisting, if I can counter this by appropriate deflection here at a given speed, then I will be able to manage this at this angle and still there would not be any net moment, because that net moment is 0.

Now, this restoring moment is cancelled by the moment, because of this deflection. So, this is again a case, where net moment is 0. So, we say, it is again has come into equilibrium, new state. So, now I can fly at 3 degrees at this equilibrium state, if there is a disturbance, then because it is statically stable, it will try to maintain or it will have a tendency to initial tendency to maintain this 3 degrees. So, this is what is done in control.

You can understand, if this separation between C G and C P was very large, then this moment would have been very large. So, this moment also required would have been very large. So, the deflection here should have been also very large. So, we say, it is very difficult to control, if it is highly statically stable. Now, you could recognize, this part you have recognized wing, this part you have recognized horizontal tail and what is this part, which is giving the pitching moment, pitching means about y axis. So, in a vertical plane moving like this, what is this, this controls the pitching motion and this is called, you know by now call elevator. So, the concept behind flying is clear now.

One thing, you have to make it statically stable by ensuring that the centre of pressure of the overall airplane is behind centre of gravity. Second thing, you should have elevator to control it, elevator powerful enough to give that moment to counter the restoring moment and we also know that, the whole task of making this aircraft stable lies with the horizontal surface. The primary role in normal case; that is why, we call it a horizontal stabilizer.

With this understanding, we will now go and analyze aircraft. Aircraft static stability and control in a very pretty meaty sense, because stability and control is a second course. But, since we are talking a performance, we need to know little bit, C L is there, C D is there, how the airplane will generate to satisfy that query, I am covering this in maybe 2 or 3, 4, maximum 4 lectures.

Thank you.