NOC: Introduction to Airplane Performance

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Lecture - 24
V-n Diagram

Good morning friends, we have been discussing about the manoeuvre. And how does the manoeuvre happen? We say that for a cruise flight, lift is equal to weight or if I want to manoeuvre it, I have to ensure that the lift is more than the weight.

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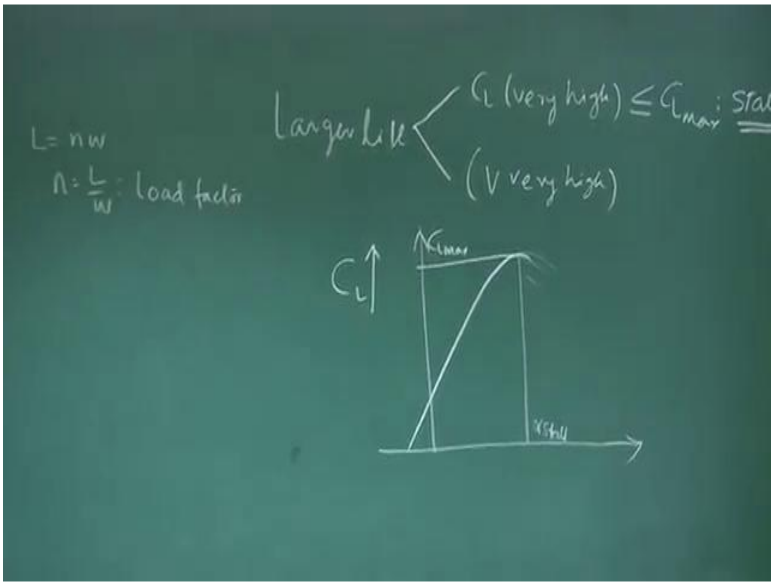

So, we write lift equal to n w where n is L by W, which is called load factor. Typically, you will find those fighter airplanes. They can do a straight pull up like this, they can do roll pull out like this and for straight pull out, now modern aircraft can go up to a load factor of 8 g, then for roll pull out it will be between 4 to 6 g. Mostly, it is 4 and 5 around that.

So, there are always an effort to see that, how we can increase the load factor to make the aircraft more agile and highly manoeuvrable, it is a natural choice or natural desire. If you also understand, the moment you sit inside a plane or an aircraft and specially if it is a aerobatic type aircraft or a fighter aircraft, it is a natural tendency to play around with this airplane in terms of, how fast it can turn, how fast it can pull up, how fast it can go from one point to another point.

So, there is an implicit dimension of a youth, adventure and romance, when you are sitting inside an aircraft. But, then, as you understand once I mix adventure and romance, you have to be very careful, it may lead to disaster. In real life also it happens, I am sure all young boys and girl will appreciate it more than me. So, coming back to this concept of load factor and generation of load factor through airplane, I must understand one thing nothing will come free of cost.

If, I want to have larger load factor means larger lift for a given weight. Larger lift means, I have two options if I say larger lift, I can two option one is I have, I need to have C L very high or I have velocity very high. Of course, when I am talking about this, assuming that the weight and the altitudes are fixed for a given weight and altitude. Now, see when I say C L I want to increase C L, what are the limitations I have got.

I know that; if I take a conventional aircraft and I am not using any flaps or any high lift devices. What are high lift devices, we will be discussing. But, by the name high lift devices you understand, there are some external mechanism, which when we use they will increase the lift in terms of C L. We will see that in detail, we will have a session dedicated for high lift devices. But, the point is this, there is a finite value I call it C L max and corresponding to this is alpha stall.

Why alpha stall we know by now, that beyond this angle the flow goes into a stall region, where there is a flow separation. There is a vibration oscillation of flow, lot of increase in the drag and so many complicated things happen and I am going into detail that it is simply a subject. But the point, which I understand the flight mechanism now, there is a limit; beyond which if I fly I will be going into a danger zone.

But, remember one thing, when I say that it does not mean if an aircraft has gone into a stall, I would not be able to recover it, a good designer ensures that. To a larger extent if the airplane goes into a stall, the pilot should be able to recover it back to a normal stable or normal non separated or non stalled region. So, I know as far as C L is very high, it is restricted by C L max or to avoid stall.

Similarly, you can argue I will not increase the C L to the extent of C L stall, but I will increase the lift by increasing the speed, I will go on increasing the speed. What is the limitation? If I go on increasing the speed, what will happen? The question is this.

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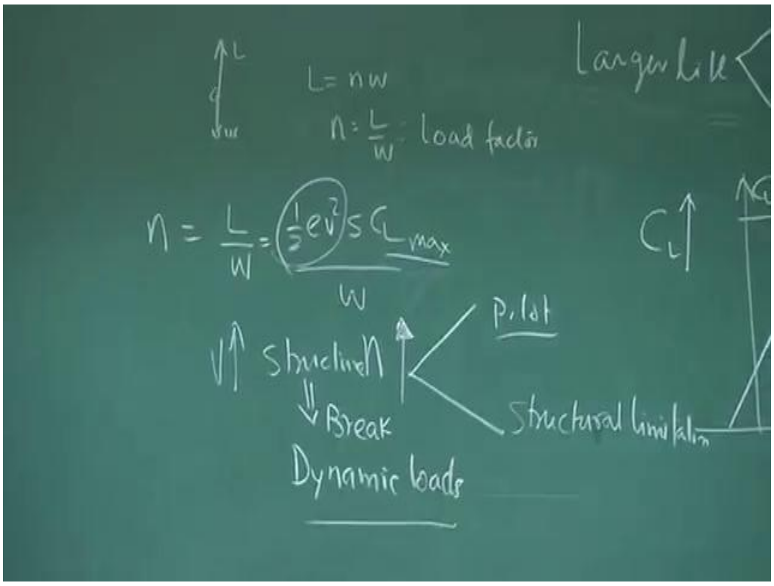

Since, I know n equal to lift by W and n is nothing but, half rho v square S C L by W. Let us say, I am flying at C L max, because I know beyond this C L max I cannot fly, because I will be going into a danger zone, which is a stall for us. So, I am fixing that C L max, but I argue I will still increase this n as I go on increasing the speed.

If, I am increasing the speed of the velocity, what it means for an aircraft designer? You need high power engine for a given weight, high power means again a weight of the engine increases and weight of the engine increases means the wing loading changes. So, there is a limitation from the engine side as well, when I think in totality in terms of wing loading. However, even if those things are taken care let us say, the problem is as I am increasing the v, number 1 the load factor if go, if it goes on increasing, there are two issues.

One is after all pilot, who is a human being will be flying this machine and all our human being, mechanism or system has a limitation on the load factor. So, we want a certain load factor normal human being will not be able to withstand it, because if I am going with a high g, high load factor vertically up, then the blood will try to come down. You know, because of inertia force and I will see busy, totally business.

Although trained pilots are there, who can extend this limit of n; however, there is a limitation because of human being, so that is one restriction. Second is, as I increase n the structure also will undergo lot of inertia load, the structure may disintegrate, the electric circuit boards may get disintegrated, so there is a structural limitation.

Further, you see carefully as I increase the speed, the dynamic loading on the aircraft structure will go on increasing with v square and there is a limit beyond, which the structure may not be able to withstand. So, the structure will break, so we have to keep this thing in mind, so if I go on increasing v, the structure may break or fail, because of dynamic loads.

So, one is C L max limit one is limit because of n, which has pilots limitation, then structure limitation to withstand large inertial load and also, because of high dynamic load through half rho v square dynamic pressure. The structure may break these will draw the boundary of, what is the speed and what is the load factor, the pilot is safe to fly.

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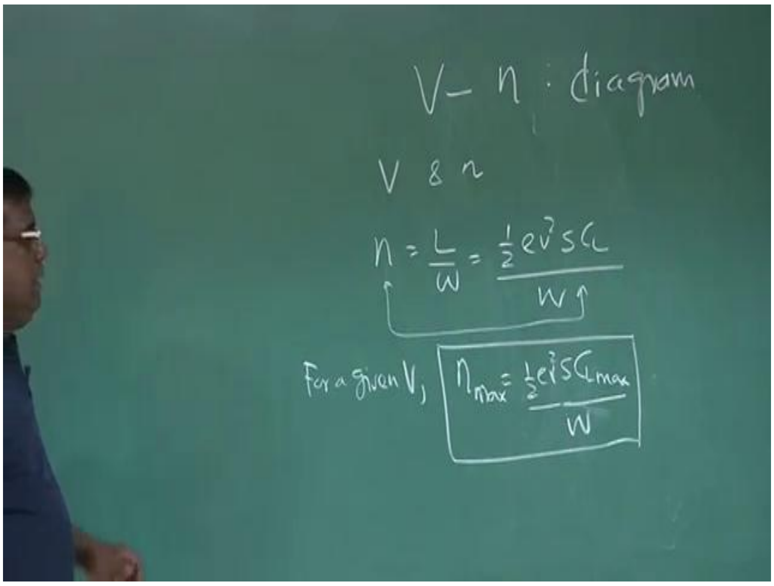

So, that is exactly is called V n diagram, that is typically V n diagram represents or for a pilot, when he sees a V n diagram he knows what are the speeds he should avoid, what is that envelop, he should know a priori, because he go for flight.

Now, let us try to draw a very simple V n diagram, we will have a one more session on V n diagram, little explicit. But, as I told you that we will be evolving this course along with you, I am not in favour of pumping information’s every information at one time. So, we will have a very simplistic look on V n diagram. The purpose is I have to plot V and n I know n is nothing but, lift by weight, so it is half rho v square S C L by W.

Now, I can use this equation to understand two things, one is for a given V n max is simply half rho v square S C L max. What is a message you have here? Divided by of course W. What is a message here? That, if I have put the angle of attack in such a way that it is at the C L max level, so for the given speed that is the maximum load factor I can get.

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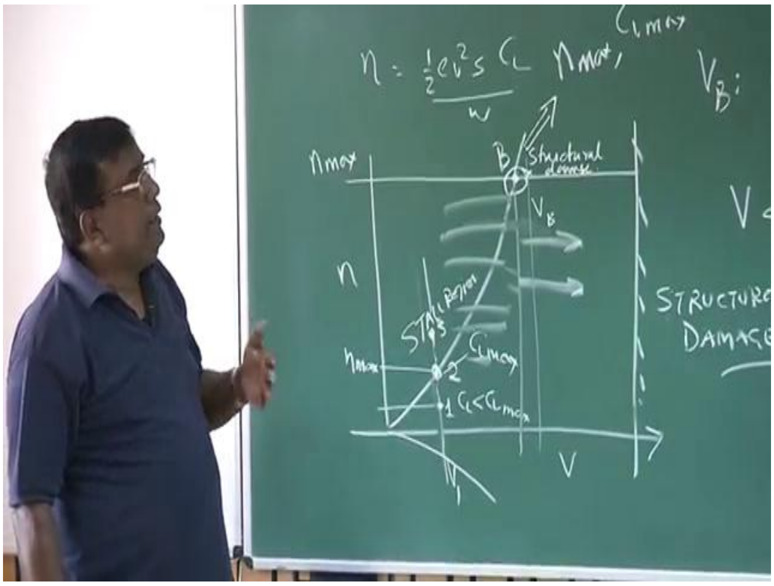

So, now if I come back here, if n equal to half rho v square S C L by W, so if I try to plot v and n, so this is y equal to x square type for others in constant, so you will get something like this. Now, let us try to give an interpretation to this. Let us say, I want to fly at speed v 1. What is the maximum load factor I can generate? That is the question. From here, what we have understood at a speed v if we want to get the maximum load factor, you have to ensure that C L is C L max and you cannot generate any load factor beyond n max, because after C L max the airplane will go into stall and you are not flying in that stall.

So, if this is V 1 I am trying to fly let say this 0.1 do you think this point is n max no, because n max is somewhere here this is n max this is load factor maximum at speed V 1. But, one if you see at one what is the meaning of that that the load factor will not be n max it is less than n max; that means, the C L, which I am flying the airplane is less than C L max this is C L less than C L max.

But, if you see this 0.2, what is the meaning here is at this V 1 I am getting maximum load factor and this point is C L max this is C L max, then what is this 0.3 this 0.3 is it is beyond C L max; that means, this point is stall region. So, a pilot will not fly in that region, so this is the stall region.

Please understand, another very practical thing suppose a pilot is flying in the airplane somewhere here, from this V n diagram, but this V n diagram is not giving any description about the gust wind gust available in the whole atmosphere. So, it is important, when you are drawing a V n diagram I should also superimpose, what is the gust profile.

For example, suppose I am going like this at an angle of attack say 10 degrees and certainly there is a upward gust, so that will change the angle of attack of the airplane. So, although pilot was not flying in the stall, but because of the gust load it has gone into the stall region. So, if you are really practical you will see a V n diagram and then superimpose what is the gust profile at different altitude and then draw the margin and make sure that you are never going into the stall region.

So, the question is now how long I can go like this as far the equation is concerned for any v there is a n, but we know that I have a limitation on n max as I discussed it could be, because of pilots limitation, human being limitation it be limitation of a structure cannot take load inertia load, so I draw a line. So, this is the limitation, because of structural damage this is 0.1 structural damage coming, because of the inertia load, so I am limiting the inertia factor.

Further, we have seen if I go increasing the speed the dynamic pressure will increase, so that will also give a load that will also fail the may fail the structure, so I put a limit, so this is again structure damage. So, these two limitations one is because of dynamic load and one is because of eta and this region is because of eta we call it n this there is a load factor.

So, now this is very important what is this is also called this is I call it point V B is called corner velocity or manoeuvre velocity what is, so unique about this point you could see if the speed of airplane is less than V B that is if I am flying somewhere here, V B is flying somewhere here, this is I call V B. Let me repeat, if I am flying less than V B some all these speeds region here. So, you could see that there is no way I can damage that structure I can go to the stall, but I cannot damage their structure.

But, if I am flying in this region that is when V is greater than V B, then there is a every possibility I can damage the structure. Because, I once I try to fly here I am going into that region, which will cause structural damage that is why this V B is very important the pilot will be aware of this region also it is interested to know that as we know omega is some g n by V, so at this point you could see very simply that eta or n is max and also C L max n is max and C L also max.

So, this speed if you see is nothing but or V B I say let me not put star it is 2 W by S by rho C L max at this speed the n is max C L is max and from here, you could see the angular rate is also maximum. So, pilot has this two information very explicitly when he is going for flying he will have a closer look on the V n diagram and then, he will draw conclusions.

For the negative angle, which is not very explicit as I am going to negative angle the flow will separate from the bottom and there is also an limit and we will be discussing about these things in detail, when I go to the next or upgraded value added lecture on V n diagram, but at this point it is important you understand these two things very explicitly.

Thank you.