Introduction to Flights
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Lecture No 10.5
V-n Diagram as per FAR 23 Regulations.

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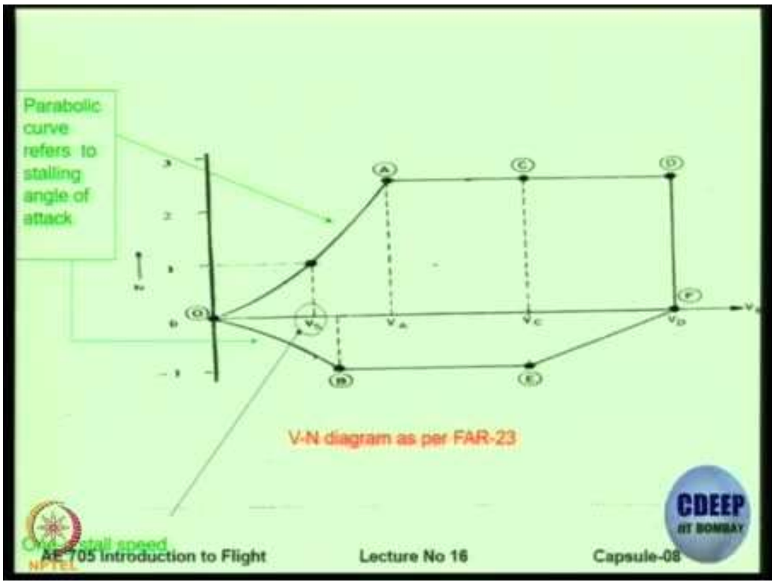

Alright, so this is the now V-n diagram as per another regulation. What is the difference in this diagram compare to the previous one? The previous one was from AP970 this is from FAR23. What difference do you see between this diagram and the previous diagram? No, do not worry about the numerical value, because that comes from the regulatory body. Whether it is three or nine, look at the, look at the figure and tell me is there a difference in the figure compared to last time. So, what is the difference?

The point, point D, haan, so what happened in the previous one there was a cut was given correct. So, between C and D there was a point between, D and F there was a point and there was a cut given ok. So, the question is there is a cut in this on the bottom but not on the top correct. So, do you think other thing remaining same that means the aircraft class remaining same.

Therefore, Nz the maximum will same and the minimum will remain same. Do you think it is more difficult to design as per AP970 or FAR23? So, the numerical value of the Nz max and min will remain same. Whether you do AP970 or FAR23, this number will come from the aircraft of you are designing. So, in both the cases. which one will impose more constraints and why?

Which one will impose more constraint and why? Anybody who can answer this let us get your point of view. Please take a mic, constraints, the answer is right but why? Correct. The portion that has been cut off and thrown away in AP970 means that you do not have to show compliance in that area. Which means at the speed between Vc and Vd. In AP970 you do not have to, show that Nz equal to Nz max will occur.

So, it is a concession, ok. You are right here basically the aircraft could be operated at any point inside this diagram, ok. This diagram represents the limit of operations. Take any point let us say there is point which is, “A” at point A you have some VA and you have Nz maximum that means the designer has to show that at a speed VA, if the net load factor is equal to whatever 2.8 or whatever as this figure, the aircraft structure is safe.

So, any point in this diagram should be structurally manageable by the aircraft. So, if I give a cut and if I exclude some portion, I am giving you concession. So, yes AP970 is giving a concession. But why are they giving you concession and why are they not giving a concession. The answer is that AP970 is meant for military aircraft and this is meant for other aircraft, general aviation etc. etc.

FAR23 is normally for small aircraft. So, it so happens that the regulatory body who has given permissions for these class of aircrafts. They feel that this is an area in which a rookie or an unskilled pilot may take the aircraft by mistake. So, we do not want to give a concession. Whereas the fighter aircraft pilots are generally very trained pilots. Secondly, we will see very soon. You can answer the question actually when we go little bit towards the end, ok.

Now, let us look at the various parts of the V-N diagram. We have this part which is O to A. So, O to A is a parabolic curve and it refers to the stalling angle of attack. How can we say that? Why is it referring to stalling angle of attack? Because, it represents the maximum permitted load factor at the lowest possible velocity along the line, correct.

Now, in that we have marked a line called as Vs. Vs basically stands for stalling speed. So, do you think flight is possible on the left of the Vs line? Sustained flight is not possible. Aircraft cannot maintain a speed lower than VS, it will fall down. So, technically speaking there should be a vertical line at the Vs line and the area on left should be exempted because, you cannot be there. So, that is an actual case. That is what it is.

So, Vs is a numerical value of stalling speed. But the point which is shown is at Nz equal to one. So, that point corresponds to level flight stalling speed. So, when the aircraft is flying at the minimum, now hang on a minute. The minimum permitted speed of flight is slightly more than stalling speed from safety point of view. It is normally 1.1 times stall speed; 1.15 times stall speed. So, let us ignore that, that is the operational limitation. Technically speaking the aircraft can fly at V equal to V stall and now remember the X axis is equivalent to air speed so this is a speed to any altitude.

At Any altitude there is a same equivalent stalling speed. That is the beauty of equivalent air speed. So, the pilot does not have to remember at what height I am and should have maximum speed. The pilot has only one speed to see in the indicator. The true air speed or the indicator air speed. So, the aircraft will stall at the same and equivalent air speed. At all altitudes, ok. So, there will be this point which is V equal to Vs and N equal to one.

So, we call it as a one g stall speed. You will see this in many aircraft documents. What is the one g stall speed? That means what is the stall speed when the aircraft is in level flight, ok. We have this speed called VA. What is special about this point VA? VA corresponds, to the lowest speed at which N equal Nz equal to Nz max. Do you agree? So, it is one of the corners of the V-n diagram. But it is the most important corner.

Once again, lowest speed at which N equals to Nz maximum. So, what is special about this part? Remember the formulae for the tightest turn and fastest turn and I have stressed in the slides and I also ask a question in the quiz. What is the condition at which you have the tightest turn and the fastest turn? Highest load factor, lowest speed. That is the point, ok. So, what will happen when you fly at VA? You are allowed to do the tightest turn. If you go tighter than that, you are going to exceed the structural limit. So, you cannot do that. So, that is the corner speed.

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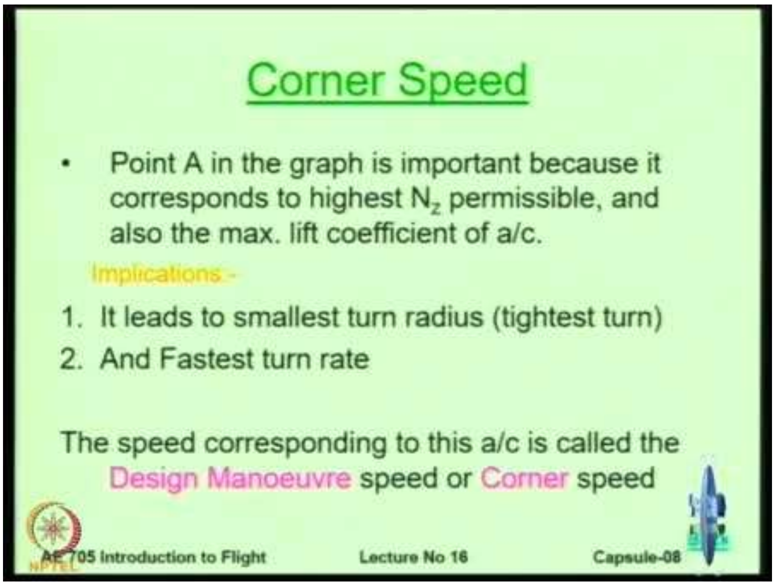

Now, why do you say that the lift coefficient is maximum? Why is it maximum? It is the least speed. So, lowest speed comes only when you are having Cl equal to Cl max. What are the implications? Implications are, smallest turn radius, fastest turn rate. Best turning performance. So, this is such an important point. That sometimes, we use it to compare two aircraft. Somebody says, how does F16 compare with let us say LCA?

There are many parameters. We saw it last time also. One parameter is, what is the corner speed? So, whichever aircraft has the lower corner speed. It will be better than the other. From the point of view of manoeuvrability. Because, If I can do the same turn rate and the same turn radius, at a lower speed. I have an advantage over you because, you have to fly at a faster speed to do it.

When I'm at a lower speed I can quickly point my artillery towards you. So, two aircrafts or let us say two versions of the same aircrafts F16 ABCD. Whichever has a lower corner speed is more manoeuvrable and the chances are that in a combat situation it will win over, in a dog fight equation it will win over. So just checkout yourself looks for two competitive aircrafts look for their corner speeds and then find out which one has the.

It does not mean that the one who is the lower corner speed will always win, because there are other things. armaments, pilot skill, more important is now a days there is no need for a dog fight. You have a fire arm forget weapons. So, let us I want to bomb this television, ok. I can go this way; I can go this way and far the missile and then go that way the missile will turn and hit the television.

Why should I come towards the television? Dangerous, because I will not be welcome by my enemy's here. Aajao, please come and hit. There are going to be ready with their artillery. So, now a days we have FNF weapons. So, all this discussion is all meaningless. But suppose, there is a situation where you have an enemy aircraft coming and we want to now intercept it and now you have this dog fight. Then this corner speed becomes an important. So, we also called is a design manoeuvre speed. But more common word is corner speed, ok.

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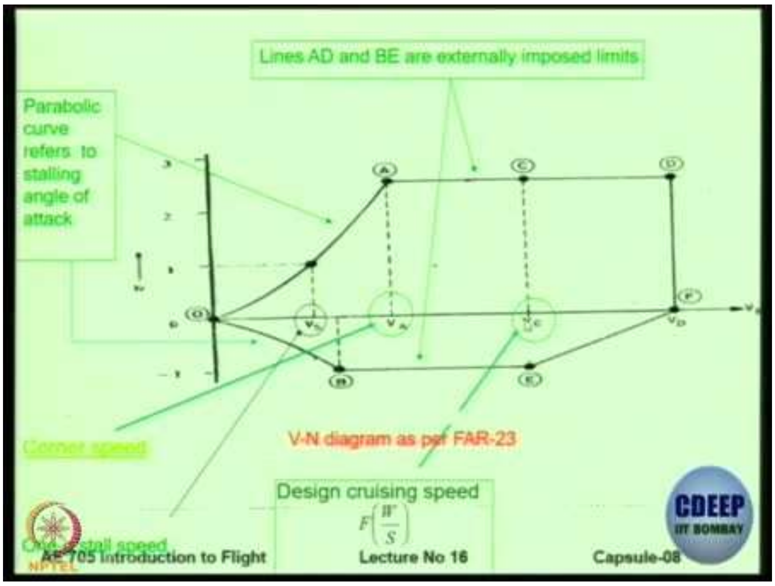

Now the vertical, the horizontal lines A, C, D that line and the bottom horizontal line this is not something natural. This is something which is externally imposed. We called them as a placard limit. What is meant by placard limit? In every aircraft there is a small placard. Saying, do not exceed NZ equal to three and NZ equal to -1.8 or 1.5. Just list it is a document, ok. This is not natural. Flight on the left of O and A is impossible. Naturally you cannot fly below O A.

If the pilot wants to fly at the speed less than V stall he cannot ok. I cannot be operating at this point, even if I want to I cannot, because aircraft will stall. Similarly negative I cannot, it is a negative let us say inverted flight you stall. You cannot do, but upper and lower limits are not natural. We will see, we will see how they are imposed and what happen if you exceed them. Then there is one speed called as cruising speed.

So, cruising speed is the speed which is a function of wing loading of the aircraft W by S and a function of also the power and thrust produced. And then you have a design diving speed ok. For VC true speed, there is no number given it depends upon the aircraft design and engine and all that and the aerodynamics. But there is a maximum dynamic pressure which the aircraft can take from the structural point of view.

After you design the aircraft for some structure. So, half rho V square is the dynamic pressure acting on the aircraft. Beyond the particular V, the aircraft structure will fail. So, that V is called as the normally you get speed in dive. Because, if you can fly at some mach number in level flight you can fly faster than that in the dive. So, the maximum speed you can ever attain will be only in a powered dive. Imagine diving with engine full on with after burner on.

So, you might exceed this speed because power plant is very powerful. However, you do that the structure fails. So, therefore one limit is imposed by the designer himself not by the regulatory bodies. That typically this number is twenty percent higher than the cruise speed, typically from transport aircraft. For military aircraft it could be much higher than that.

But whatever it is there is a vertical line beyond this I cannot go even if want to go I cannot go. The structure will fail on the left of this. I cannot go because aerodynamics will not permit me. Above and below I can go. If I, I can go but there is a problem.

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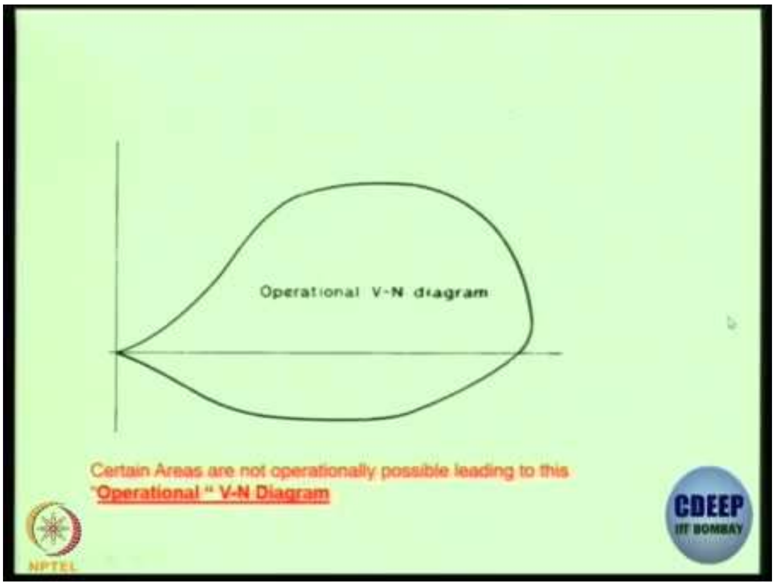

So, this becomes the operational V-N diagram. The areas on the top right and the bottom right which are actually cut by the AP 970. They are cut because of experience. Because of the power plant limitations, you really cannot go there. So, these areas are not operationally possible. Structurally possible but, because of the power plant limitations.

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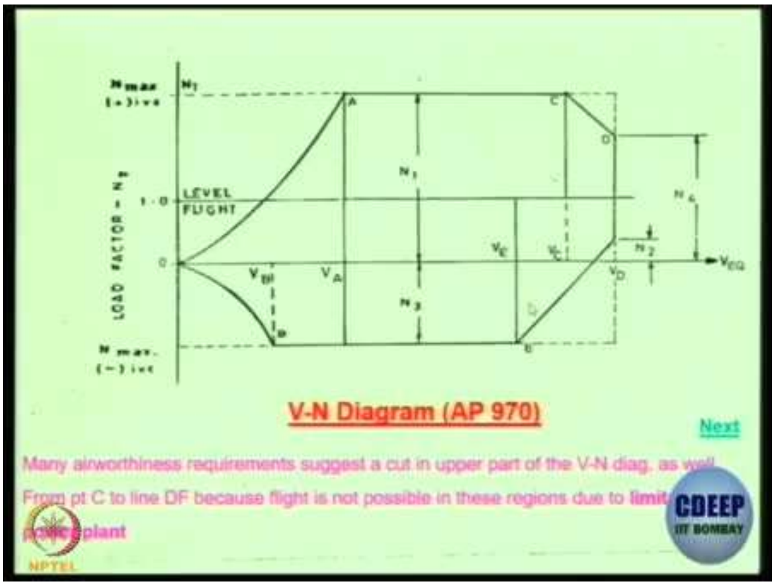

So, we come back to the V-n diagram as per AP970 because, in some cases there may be an assignment to do the calculations for this. So, it is just a method it just says that there are these various numbers given. So, there will be some formulae for n1, n2, n3, n4, etc. In terms of the values. Yes, can somebody answer this question? His question is that, we talked about dependency of V-n diagram on the angle of attack. But we have forgotten that now.

We have only worried about speed. Yes, what is the answer? Yah what you say. No, what you say. What you say is true, if you are approaching. If you are flying at the higher speed the alpha will be the minimum. But his question is, that for any point inside the V-n diagram. When you fly at that speed and that load factor. What did you do about the angle of attack? So, the answer is very simple the angle of attack automatically gets fixed.

When you have a fixed speed. Remember $C_L = \alpha \frac{dC_L}{d\alpha}$. So, the moment let us say I'm flying level. That is equal to weight, N equal to one. So, depending on V there will be some alpha they are related. Let us say, I'm manoeuvring N equal to three, lift equal to three times the weight. So, $L = \frac{1}{2}\rho V^2 S C_L = W$. So, the CL will be N times W upon rho V square rho SV square.

Once you have a V you have some CL, that CL is only at some angle. So, angle is taken care automatically. So, NZ depends on angle but we have replaced the angle by CL. I am saying that when you have the calculation for NZ that much lift has to be created by the aircrafts with the given density with the given area. So, the only variable will V. So, once you fixed the V in V-n diagram there is corresponding angle at which L equal to NW. So, it is taken care you do not have to say I want this V and this alpha. It is not possible; you cannot fly at different alphas at the same V.

For a particular V alpha is fixed. At which CL equal to Cl required. So, that is why we do not have to worry about angle of attack. That is why in aircraft you do not talk about; nobody asks the pilot at what angle of attack your flying. Even, I do not know my V is so much. So, my aircraft has automatically trimmed to angle. At which the lift time needed is coming from this aircraft at the appropriate angle.

The only thing is, I cannot exceed angle of stall, ok. Ok, let us go ahead any more doubts. So, you see now this particular cut which you saw in AP970 is not a given fluke. It is given because, they know that area you cannot go because, the power plant is unable to give you that much NZ and that much speed. So, they give you a concession a priory, yes.

Student: Sir, the NZ is the maximum aircraft sustain in the vertical direction. So sir, how it is matter, at what speed as that do, for example if this V-n diagram is for a particular aircraft it can have a maximum Nz.

Yah let us say 4. NZ equal to 4. No. No. No. Not necessary. It can, the point is, the point is yeah if you fly. Let us say the line A to C represents, locus of operating points at which you are flying at the maximum NZ at various velocities. So, let us say dive pull-out. You are doing dive pull-out at V equal to two hundred knots. NZ equal to six you do it now at V equal to two hundred knots NZ equal to six.

You do it at three hundred knots NZ equal to six. But, when you fly at speed two hundred, three hundred, six hundred knots, alpha is getting fixed. So, that is what I told him. I said we do not care about at what alpha it is happening? Yes, AP970 and FAR the difference I am talking about is this cut, this cut. This cut CD is prescribe or permitted only in AP970. In FAR23 there is no cut there. So, these concessions are given by regulatory bodies.

So, what the regulatory body says? This is the defence regulatory body it says, we know that you will not be able to fly in this area anyway, because power plant will start packing up before anything else. So, they give you a cut. There the regulatory body says, there could be a pilot who is at a very high speed and pulls the G. So, that you come in this area, ok. So, that is the difference. So, the regulatory bodies decide the pattern based on the aircraft type which we are dealing with.

Somebody might say that I will not even give this cut. No, I will not give this cut. If you see the FAR 23, they give a cut in the bottom. Because, they have found out that it is very difficult for even a rookie pilot to be at negative load factor at very high speed and very high load factor. So, they have given a cut because otherwise the designer has to design the aircraft for such a high load at such a high speed. Hang on a minute.

Half rho V square is dynamic pressure acting on the aircraft. If V is more, load is more. That is only a ratio, your forgetting that the load on the structure is not the load factor. Load factor is the ratio of maximum lift upon aircraft weight. But, that lift comes from where? From dynamic pressure. So, if the structure cannot take that.

Let us say the wings breaks at half rho V square equal to some value. So, that is why there is a condition that you do not. So, the vertical line ensure that you never fly at a speed more than VB. Basically it is from that point of view.

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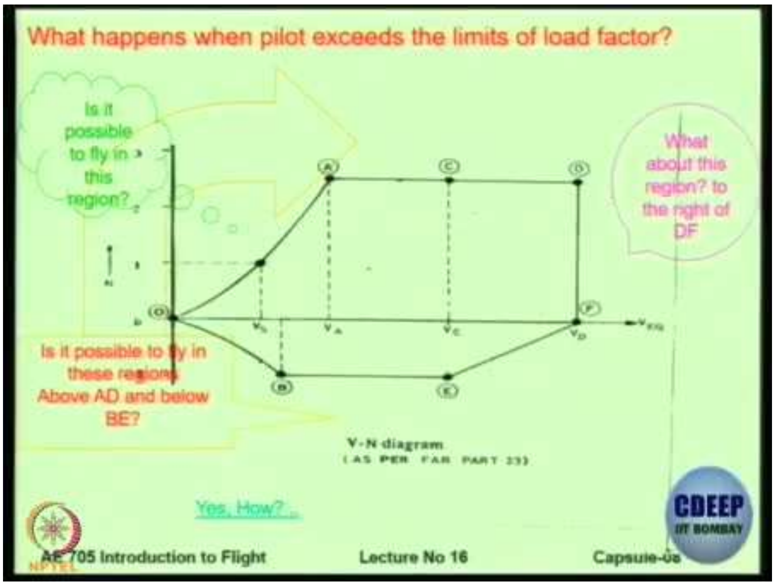

Let us go ahead and see. So, now will look at what happens when the pilot wants to exceed the limits. So, this is the V-n diagram now we will go back to FAR23. Just to show you and example, yes what is the point.

Student: So, what this diagram is saying is that these are the lines indicate the maximum load that aircraft can develop during any manoeuvre.

Professor: No, No, no they r not telling what the aircraft can manoeuvre they are telling what the aircraft should not exceed. This is a regulatory diagram do not exceed this. You can take it both ways regulatory body says, prove to me that the aircraft can fly safely at any point inside this box. This is what the regulatory body is asking the designer.

Show me that any point in this particular inside this particular graph inside or on this graph is attainable by your aircraft, ok. Plus, it also says do not exceed this. So, now let us look at this slide. This will you something, let us look at when you want to exceed, ok.

This area is impossible to fly. I had already told you, why? Aircraft cannot have sustain flight in that area because of stall.

Student: Between that VS and point VA is there any mechanism we can cross that line or it will automatically come back to that line?

It will come back. If you go from N equal to one and V equal VS which is this point, this point. Suppose, you fly at this condition so V is more than VS and N equal to this value but less than NZ. Now suppose you want to fly at this point. V is equal to more than VS but N is more than that value. You cannot because that line represents stalling. OA, OA the line OA represents flight at the maximum permitted angle of attack or CL max.

Above this is not possible to operate sustain on the left of VS. You cannot, because wont stall. Above that if you go you will come back, because the aircrafts cannot sustain it.

Student: So it has inherent tendency to come back to that line.

Correct you just can’t fly in that area. So, that is what I am discussing in this region. You cannot fly even if you want to, ok. What about this region, why? Power plant, ok. Power plant limitations, because you have reached something like V max, thrust is equal to drag now you do not have more thrust to create more flight, ok. What about regions above AD and below BE? Is it possible to go there? No, it is possible to go but structure might break.

So, pilot can try to go and then experience. So, on the left and the right pilot cannot be even go. Aircraft will not cooperate. Above AD and below BE you can go. if you have enough control power, you can go, ok.

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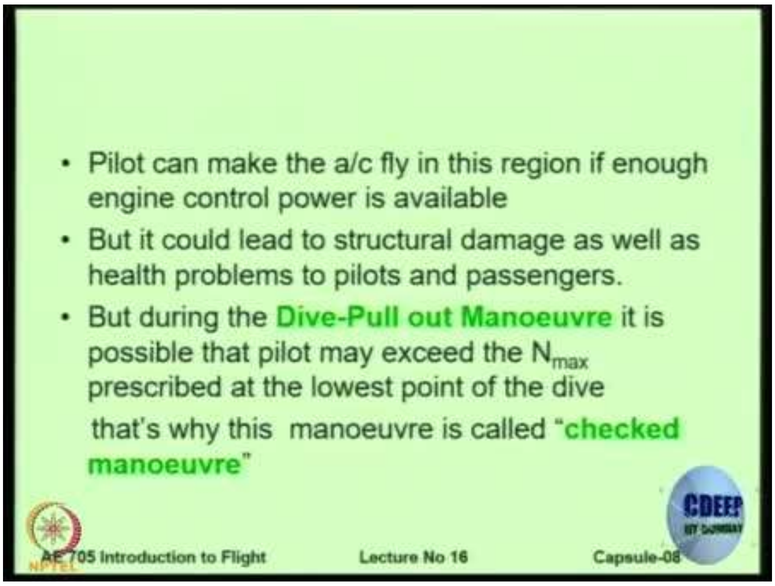

So, let us see how the problem is this, if you have enough engine and control power you can do that because what you need. You need to pull up very quickly or turn very quickly. So, if you have control power you can. But there will be a problem if you're a passenger you will start vomiting and if you're a pilot then you can start experiencing structural damage. So, therefore that is why this dive pullout manoeuvre.

Now, look at many of the videos available on YouTube of aircraft disintegrating during dive pullout, ok. Some very enthusiastic pilots pulls into a dive and then it breaks. It was happened that is why we called is as checked manoeuvre, you have to cheek. So, the pilot simply does not put in the controls. Check out todays aircrafts are such that the control system itself has an inherent limiter. So, that even a pilot who want to commit suicide cannot do it.

At using turn, you can take aircraft to do the ground no problem because, it is suppose to land. But if you want to do wilful deviation of flight performance. The control system may come in way today. As specially if you have a Fly by Wire system. Every input is an intension of the pilot. We will go to the computer which will say no this is a fineable input.

Sometime, it creates a problem also because the system miss interprets and we saw one crash happening. When the pilot wanted to bring the aircraft down to the land but aircraft thought it is a problem with the control system. So, the dive pullout manoeuvre is possible that the pilot may exceed NZ max. But we do not allow the pilot to do it by training. So, this is the dangerous manoeuvre because you might be able to take and cause a crash.