Introduction to Flights
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Lecture No. 10.66
Effects of Gusts on V-n Diagram

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Ok! Now, we come to the last part about V-N diagram, which is "what happens when you have a gust?" Ok, Gust basically means what, gust means a disturbance of the wind.

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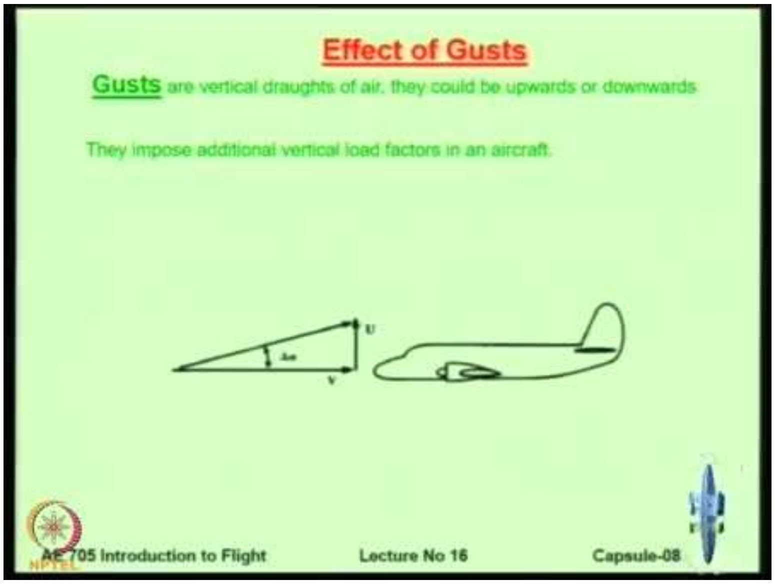

So, these are drafts of air, they could be vertical, they could be sideways, they could be inclined, they could be cosine shape, sine shape, tan shape, whatever whatever. Any disturbance, aircraft is flying smoothly and suddenly you find disturbance. So what will happen your gust will impose on load factor, called as a gust load factor and that should not exceed or take you out. So, any gust especially in vertical direction will impose vertical load factor, because there will be some delta L because of the gust that delta L will give delta Nz.

So, let us say an aircraft is in level flight, for what velocity is V and now sudden gust acts on it. For the purpose of simplification assume it to be a sharp vertical gust. Normally the gust are not sharp , because we do not have air coming only in small column straight, sometimes it happens, but generally it is gradual, it will build up slowly over a time. But for purpose of demonstration let us say, you have a forward speed V and now there is a vertical speed also acting on the plane. So, the aircraft is going to have now effective speed will be at an angle delta alpha, so the AoA of the aircraft will change from the alpha to alpha plus delta alpha.

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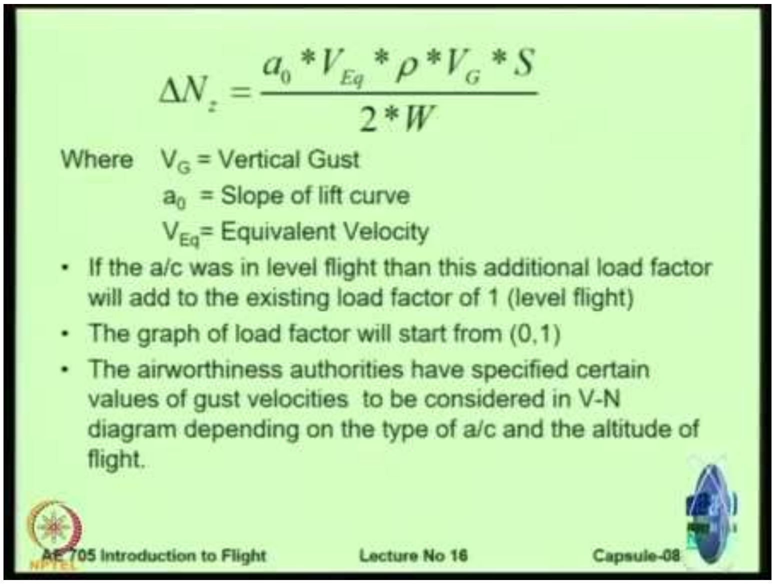

So, the additional load factor that will come is delta L, which is equal to half rho v square. So, the W on the denominator is because of Nz, it is L upon W. So, what we have done here is, we have used a0 is the lift curve slope, ok. So, the delta alpha will give you, delta CL or delta L, which will be equal to the lift curve slope dCL by d alpha into the alpha. So that delta alpha will give you delta L which is equal to delta alpha into dCL by d alpha. So that is why we have got delta Nz

$$\Delta N_Z = \frac{a_0 * V_{Eq} * \rho * V_G * S}{2 * W}$$

So, what we see is that, if you are flying level N is equal to 1, and now you have a gust acting not so fast relatively, so you will get delta Nz. In another words the delta Nz in level flight will be above N equal to1, so the push will start from N equal to1, because we are already in level flight. So the agencies say that, it is possible.

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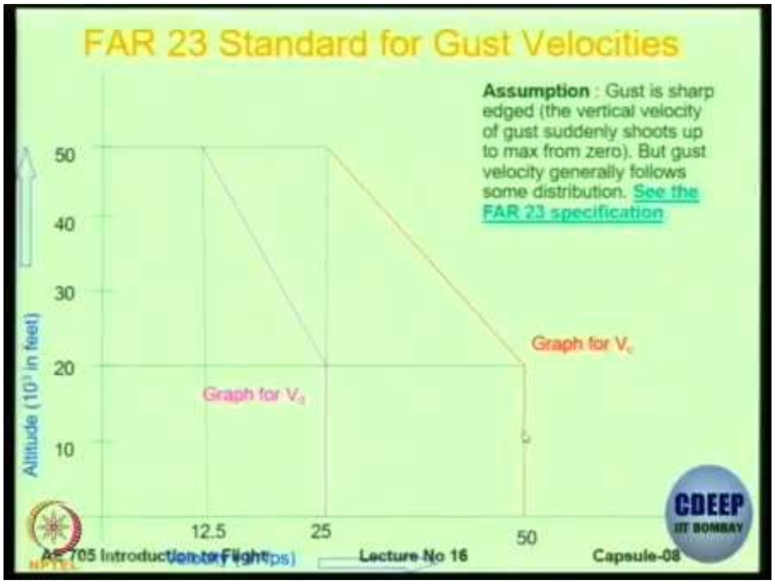

So let me show you in the V-N diagram then it will become little bit clear to you. We will come back to the diagram, so now, question is "What is the gust velocity that you will assume?", because higher the gust velocity, higher delta Nz, higher the chance of exceeding the limit.

So the regulatory body say OK!, we have done some studies and we feel that if you assume a gust of approximately 25 feet per second up to a height of 20000 feet and higher than that, it reduces linearly to 12.5 and above 55000 feet; we assume that the gust is going to be only maximum 12.5, this is when you are at VD , the design diving speed, at cruising speed the delta , the , the delta, the gust velocity is 50 feet per second till 20000 feet constant, and less below that. So, what basically you have to do is, you have to now start calculating delta Nz at various values of flight, ok. Now, this one is for a sharp gust, but gust is never sharp, right?, I told you the gust will never be sharp, the air will slowly start increasing and then raise some value.

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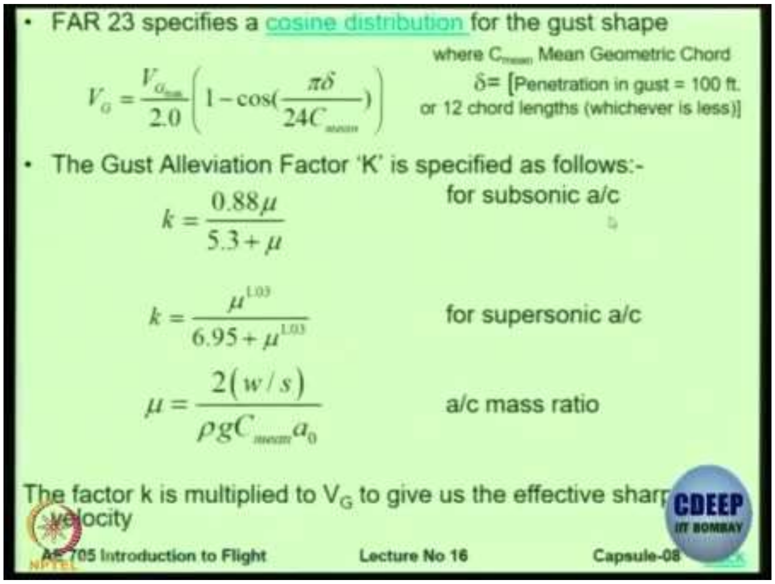

So therefore, something called as Gust Alleviation factor. So, if you look at FAR23, their calculation or their assumption show that the gust follows a cosine distribution.

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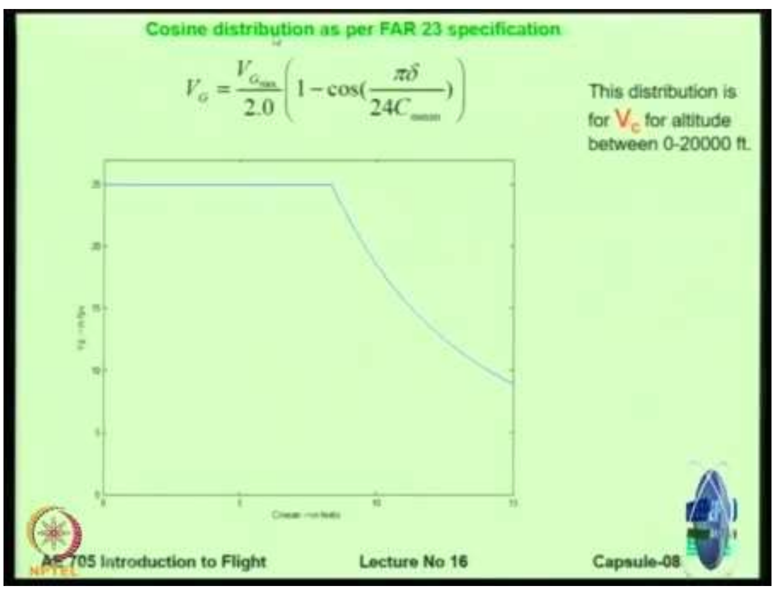

That means, when the distance is from 0 to 15 feet, ok.; The velocity is actually following some kind of a curve, so Vg is equal to V g max by 2 ,1 minus cos etc., ok. So, they they say that do not assume sharp gust, assume that the gust is going to be linear, but these are detail, which we might like to skip.

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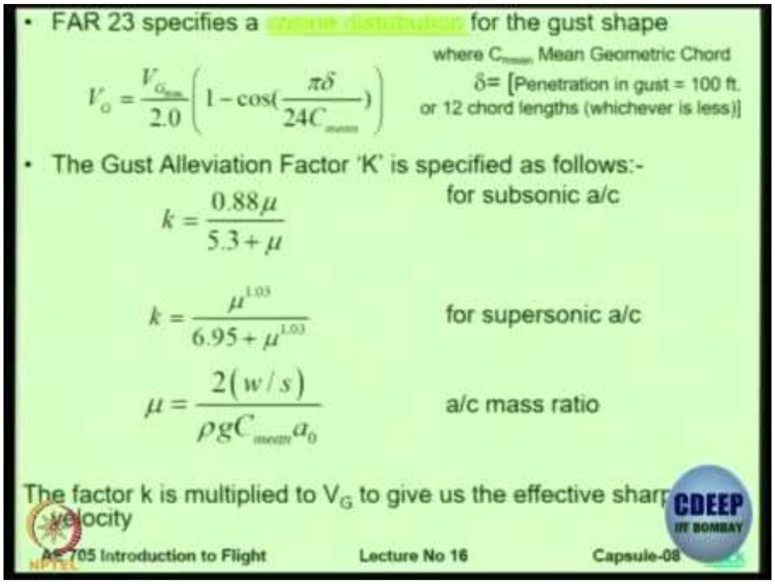

So there is a Gust Alleviation factor K, which takes care of the fact, that gust are not very sharp, they are smooth, so it reduces the numerical value, it reduces the numerical value of the gust, that has to be calculated.

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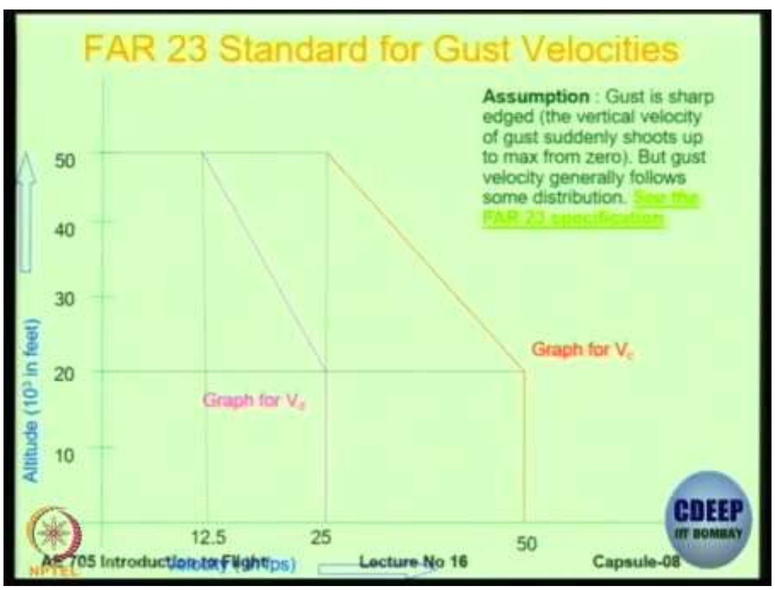

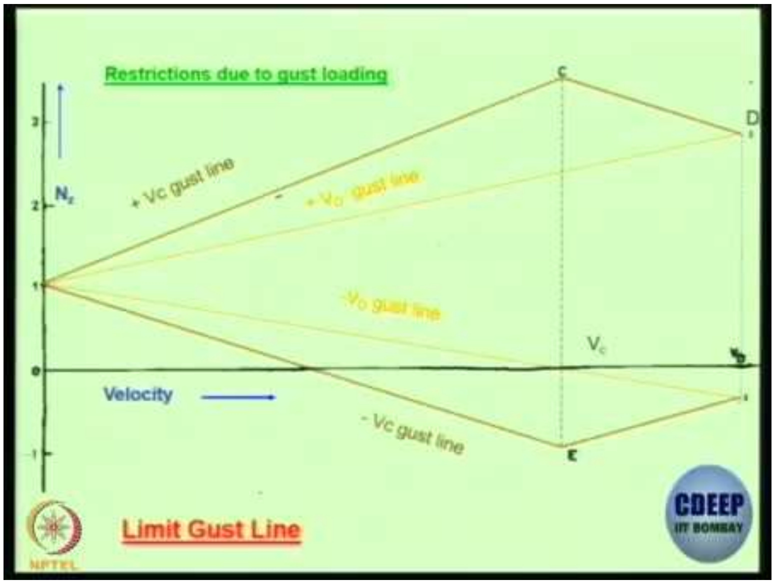

So just to make things easy for you, let us see this is the vertical axis Nz and the velocity axis. You start from one comma zero because that is what is level flight. And as you go from speed equal to zero to speed equal to Vc, you have to keep adding, the gust velocity. So, remember it was 50 feet per second up to 20000 feet per second and less than that, half of that, beyond that, so what will happen is ,if you are in level flight, if your forward speed is large and vertical gust acts then you are going to get larger Nz up to the Vc.

So at Vc, that means you are, let us say you are at this point, you are flying at a cruising speed, and let us say that cruising speed is below 20000 feet, Now the gust, that will be acting on it is going to be 12.5, so with forward speed 200 knots, you have 12.5 knots you have an angle, you have delta Nz that will be higher compared to; when you are at lower speed.

So, this line is basically from the line 1 onwards, 1 because it is level flight. So, from level flight line, so from this, from this horizontal line, this shows you that delta Nz because of gust at various speeds. And when you go beyond Vc upto Vd the values are half, 12.5 and 25. If I go back to the graph, you will remember the values were 50 and 25 for upto Vc and they were 25 12.5 beyond above Vc upto Vd. So, you get this kind of a line.

Now, the negative gust lines are going to be little bit inside. So, these are called as a limit gust lines. That means, once again in level flight if a gust acts, you could be pushed anywhere in this diagram, depending on the numerical value of the gust line. So, the regulatory body insists that any point inside this the aircraft can take, which means this becomes the limit gust lines.

So, if somebody says draw the diagram showing the limit gust lines then this diagram tells you up to where you can be required to be. So, on that, this is our limit maneuver envelope or the typical V-n diagram that we know on this we super impose those lines, so now we have something strange.

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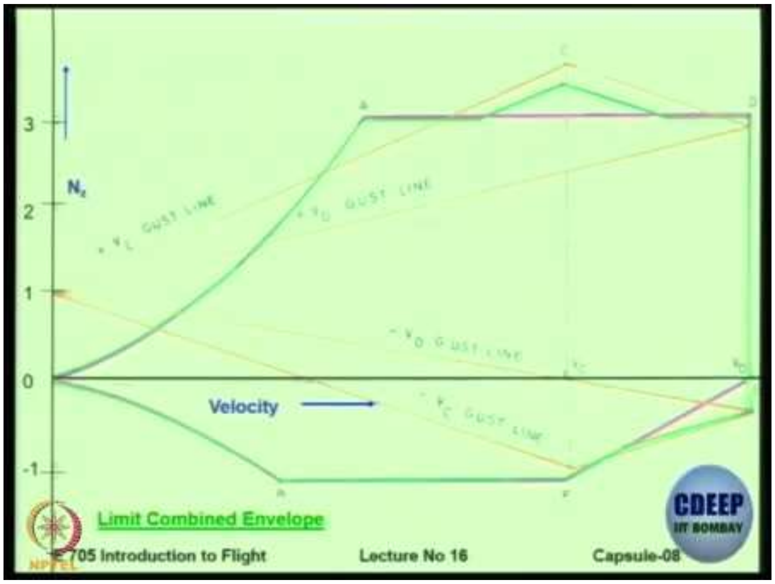

So remember that, this area anyway is not feasible because of stalling, so do not worry about it, but what we see is that this additional triangle gets added. ok, see the limit maneuver envelope was already covering this area, but no problem, but the limit envelope assume that the angle will be only so much, but now you can go here also, so at this speed if you are flying at let us say this speed in level flight and a gust acts, you may actually go here, beyond the maximum permitted by maneuver.

If there is no gust, and if you just go by maneuver, you have to be inside the purple box. If you have no maneuver, but only gust, flying level and you are thrown up, you should be inside the yellow diagram. But both can happen at the same time. You could be maneuvering and then there is a gust, so therefore, the requirement is something like this. Now, this green line is by mistake little bit inside, you ignore that, assume that this green line is actually starting from here, going here and coming down.

Why has this mistake come? Because there were 3 transparency sheets, which I used to use earlier and I used to keep one transparency above the other and the third transparency there was a slight mistake, so that is why it has come like this, ok. These are scans of 3 transparencies, so, in our words, the limit combined envelope within which, your aircraft has to be certified, is the super set of both these envelopes. So it will be starting from here, you can always cut this portion and throw it off, because of the V is tall.

So this way, this way, then this way, then this way, then this way and here again you have some extra portion, this way, then this way, sorry, this way, till here, then here and then back inside. So, the super set of both these curves becomes the limit combined envelope. So, what is the repercussion of this? The repercussion is that, if you are flying; let us say you are flying at this speed, some number, some number, below below Vc, some number. Let us say this value; you are cruising at that speed, so, where will you be? If you are cruising you will be at this point, because N equal to 1, V is equal to some value below Vc but high value and now a gust can act and that gust can take you, here, that is why you should be having this yellow envelope capability.

Now, imagine you are a military aircraft or a aerobatic aircraft, and now, you are doing a maneuver, so you are at this point, let us say you are at this point, so your Nz is not 1, you are like into a small dive pullout. So, your Nz is 1.5, let us say, so that means you are at this point. And now, while doing this maneuver, a gust acts, so what can happen is that delta Nz which acts when you do a maneuver, it may take you outside the envelope.

So, this is the reason why, many a times aerobatic displays are cancelled, during bad weather. There are many instances, when people have airshows, Paris Airshow, Canada Airshow, people pay lots of money, and they want to see the aircraft flying. You go there; they say "Sorry, flights display is cancelled", why is it cancelled? It is cancelled because, the weather conditions are gusty and they know that in these conditions, if you maneuver, you are likely to exceed the limit envelope, there can be an accident.

So, many people do not understand this and they say "We have paid lot of money, we have planned, we have come to see", but obviously the passengers may like to see, the people who pay the money for airshow, they may like to see a crash, but look, we do not want aircraft to crash as a, you know, as a as a spectacle for you, you know I am happy to have a video of that unfortunate instances. So, this is what we have to keep in mind, ok. So, that is the end.

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So, I will just sum up very briefly, we have another few minutes remaining. What is the diagram about? This diagram is basically a structural limit, within which, the designer has to ensure, that the aircraft can withstand the loads coming, without any permanent deformation or damage, ok. So, whenever a flight test engineer is supposed to certify an aircraft, you are given some flight profile, which will take the aircraft to the corner of the V-N diagram and it is a bit dangerous, because normally planes do not go there, but you have to do it.

So, I have some experience of doing this on MiG-27 and whenever we have some slot I will try to, give a general talk in the department, in which I will share my experiences. So, thanks once again to Rahul for giving me this presentation, which I am using. I have of course made some changes to it but, the essence of these remains the same from the time he made it.