Aircraft Dynamic Stability & Design of Stability Augmentation System
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Module 6
Lecture No 35
Flight Handling Qualities

Good morning friends. We have discussing very preliminary things about stability augmentation system. Although they are preliminary but they are very fundamental in nature. When you will be doing some high-level course, you will understand how important are these understandings.

And we have kept our focus on the damping ratio and natural frequencies and we have been telling that we are concerned about the handling qualities of the airplane because the pilot has to be comfortable, passenger has to be comfortable. And there are, based on experience, based on numerical data, based on lot of psychoanalysis.

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There are some guidelines that has been postulated which somehow gives guidelines for handling qualities. I will just glance through those. And these handling qualities are postulated in terms of, we will see, the damping ratio and natural frequency of particular mode. For example, there is the Phugoid mode, so these handling qualities will tell what should be the limit on the damping ratio?

If it is short period, then what is the limit on natural frequency or damping ratio based on type of aircraft, based on type of flight phase and based on the failures. For example, if we are designing a large transport airplane, then the criteria will be different than a lightweight airplane. For a large airplane, the additional criteria will be, even if one engine fails for a multiengine aircraft, the aircraft should have minimum these these these these performance characteristics.

It should be able to execute those. With a single engine, it should be able to have a climb of this much. It is natural frequency or its damping ratio should be this much or it should be able to complete the flight phase or it should be immediately, abruptly cut down the flight phase. All those things will come. And to understand that, to make it more systematic, the airworthiness committees in association with the designers, they have given some criteria, some guidelines.

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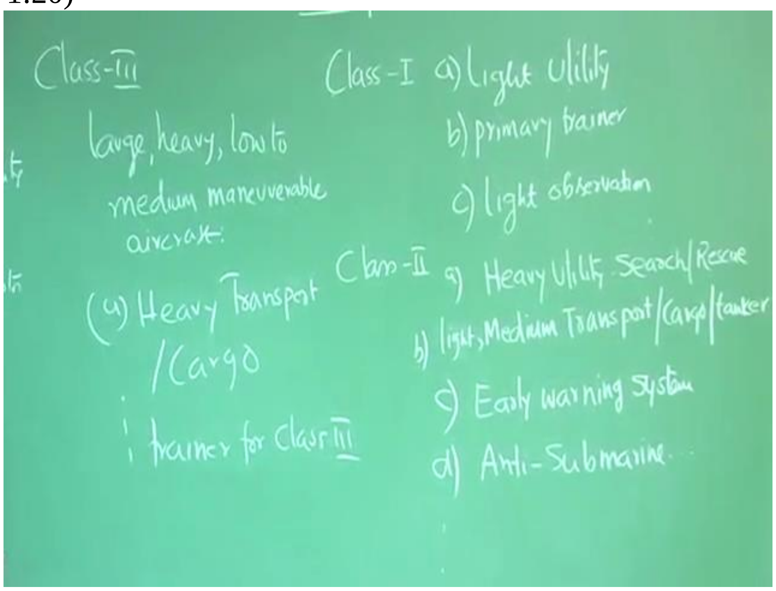

In that 1^{st}, what they have done, they have defined airplain classes. In class I, class I includes some addresses, light utility aircraft, primary trainer, and light observation aircraft. So all those aircrafts which come under light utility category, they are classified as class I type of aircraft. In class II, you have heavy utility like maybe search or rescue. It also has light medium transport cargo tankers.

Then, early morning systems, antisubmarine and there are so many other type of aircrafts which are summarised in class II. And in class III, there are large, heavy, low to medium manoeuvrable aircrafts, like heavy transport cargo airplane. Then, trainer for class III. All these types of airplanes are classified in class III.

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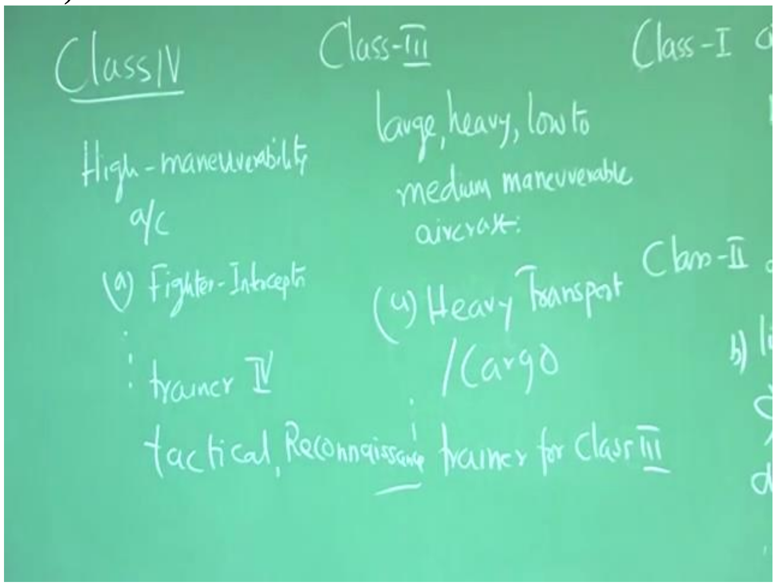

And class IV is high maneuverability at aircraft like fighter, interceptor, the trainer of class IV. You will find many such type of airplane. If I add one more, it is tactical reconnaissance. Like that. So what is the 1st approach? Depending upon the type of aircraft vis-a-vis type of performance required, there are 1, 2, 3, 4 categories or classes of aircrafts. This is one.

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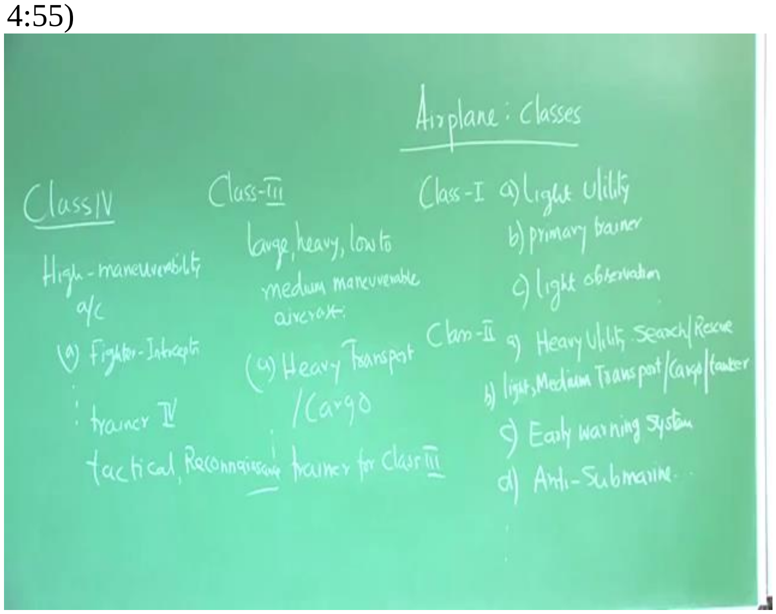

Second comes is definition of flight phase. What was the force? How it was characterised to give you a complete idea about handling qualities? First thing was, you identify this aircraft belongs to which class? Class I, class II, class III or class IV? 1st exercise is this. And which aircraft should be class one? You have to check. Is it light utility? Is it primary trainer? Is it light observation?

Like that you have to make a judgement and you classify the airplane. So after class, our classification is based on the type of aircraft, we are not discussing about definition of flight phase because all these handling qualities, it is not only important whether it is a light utility aircraft, whether it is a high manoeuvrability aircraft, we need to know about the flight phase.
And how they are characterised, that I am now going to list out.
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Category A. And that is like air to air combat. Then B, ground attack, I have started with military aircrafts. Forgive me. I do not believe in war and all. And at the same time, we should be strong enough so that nobody can dare to trouble us. So it is important that we know all these things. In-flight refueling.

We have then close formation flight. There are many, you can Google through and you will get. This material, I am presenting, referring book by Roshcoe. So this is category A which is defining the flight phase.

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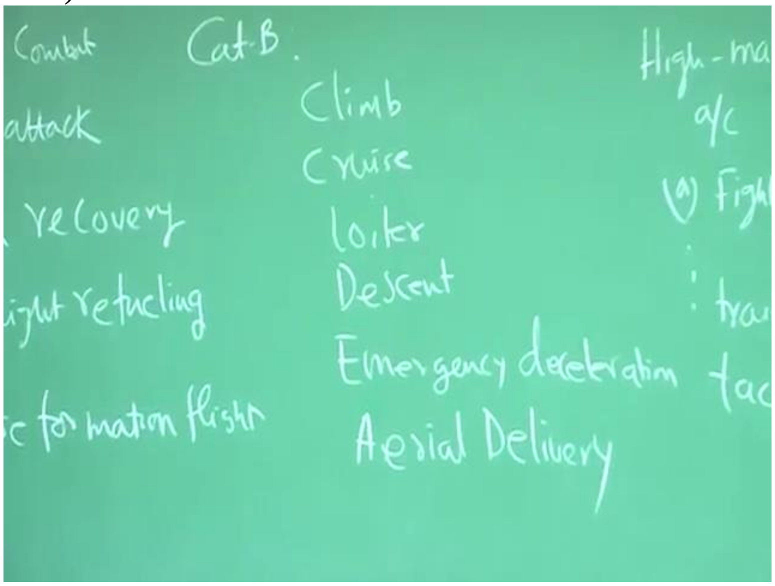

We also have category B and in that we will have climb, flight phase is climb, cruise, loiter, descent, emergency deceleration and aerial delivery. I am just mentioning a few of them. So this is category B. That means we are now defining different different flight phases.

In category A, these are the flight phases that are included. In category B, climb, cruise, loiter, descent, emergency deceleration, aerial delivery, these are the flight phases categorised under category B.

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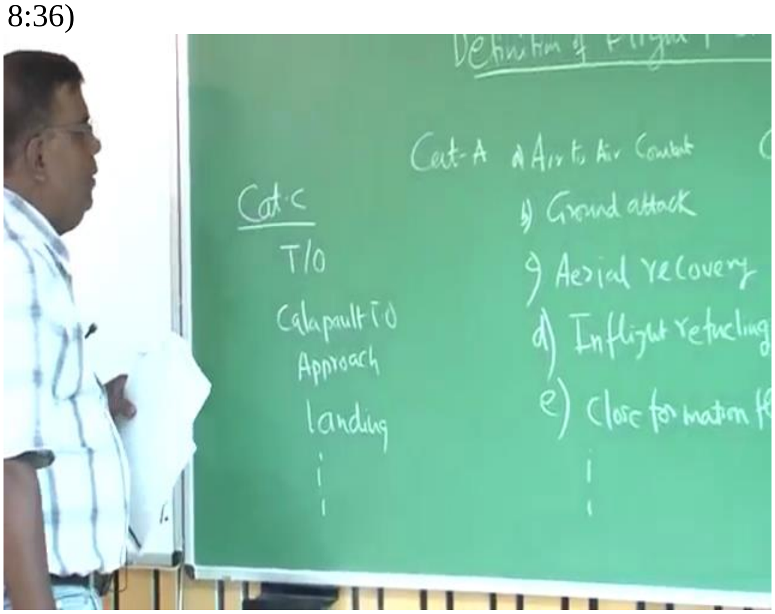

Similarly we have category C. In category C you have takeoff, you have catapult takeoff, you have approach, you have landing and many more. That comes in category C. So, what we have seen? How it has been handled? How the guidelines have been structured? First look for the airplane classes. Which class the air plane belongs to?

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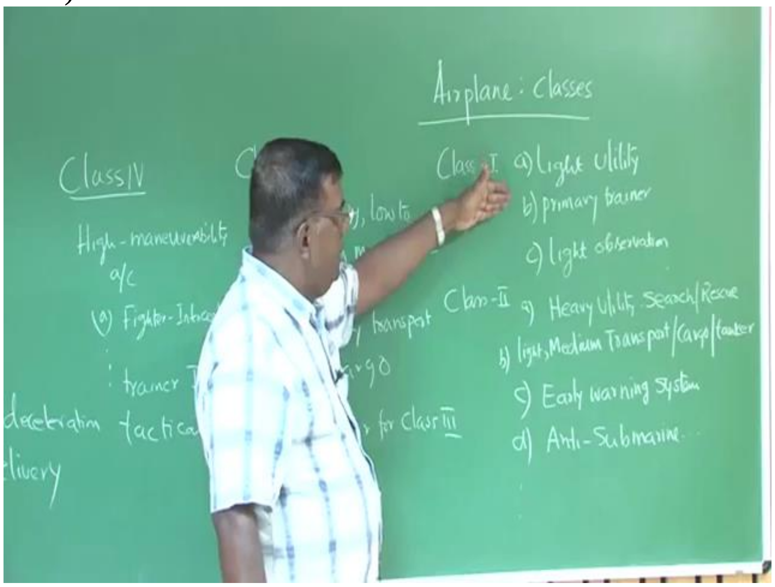

Looking at these attributes, if it is in class I or class II, then we check the flight phases whether it belongs to category A that is air to air combat airplane, or is the air to air combat flight phase we are talking about. Similarly if I want to go for category B, I need to look for cruise, climb, loiter, all these flight phases and category C, the takeoff, catapult, approach, landing, etc. These are the flight phases under each category. So we have classes, we have categories.

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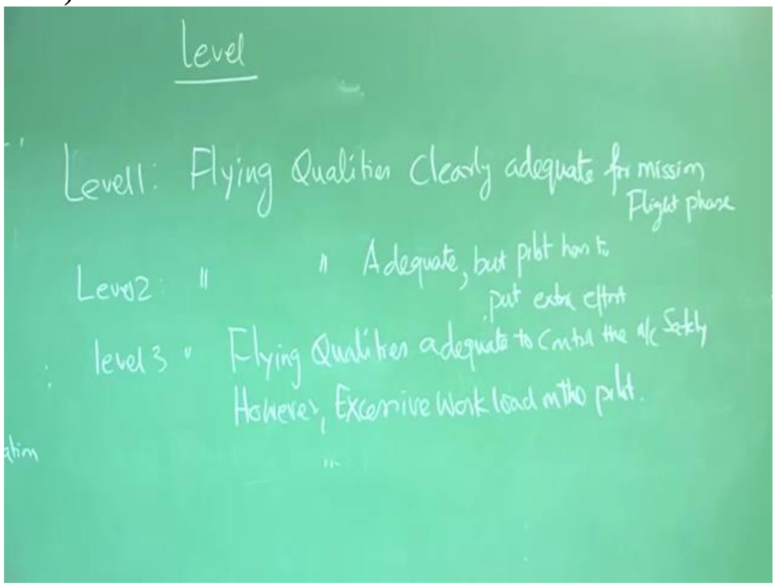

Now we are talking about level. When you say level I, it means flying qualities clearly adequate for mission flight phase. Let me write the 2nd one. Then I will explain. For level II, flying qualities, adequate however or but pilot has to put extra efforts. And this is level III. You could question about is level III? Flying quality is such that the airplane can be controlled safely. Flying qualities adequate to control the airplane or aircraft safely.

However, excessive workload on the pilot. I am not writing everything. Just to give the quality statement which are good enough to excite you and read from different textbooks. Level I says flying qualities clearly adequate for mission flight phase. So absolutely fine, so level I aircraft. Level II, it is adequate but a little bit of pilot has to put extra efforts.

And level III is, flying qualities adequate, adequate to control the air plane. That means the pilot has to now put a lot of extra efforts. So that is the level III, that should understand, these 3 levels, level I, level II, level III are extremely important. So what is the approach now you could see?

First we identify the class of aircrafts. Then we identify the flight mission or flight phase and then we are saying, now there are level I, level II, level III handling qualities. If the handling qualities are such that it is clearly adequate, pilot nothing extra he has to put, that is level I aircraft. Level II, little bit he has to put.

And level III is, quality is good enough for safety. To control the airplane from safety point of view but a lot of excessive effort comes from the pilots. That is the level III handling qualities. Now with these 3 understandings, now we will come back to how these things have quantified through Zeta, Omega N, etc.

I will give some representative number. Once we identify class, category and level, handling quality level, as I told you, we will be looking through the damping ratio and natural frequency of different modes.

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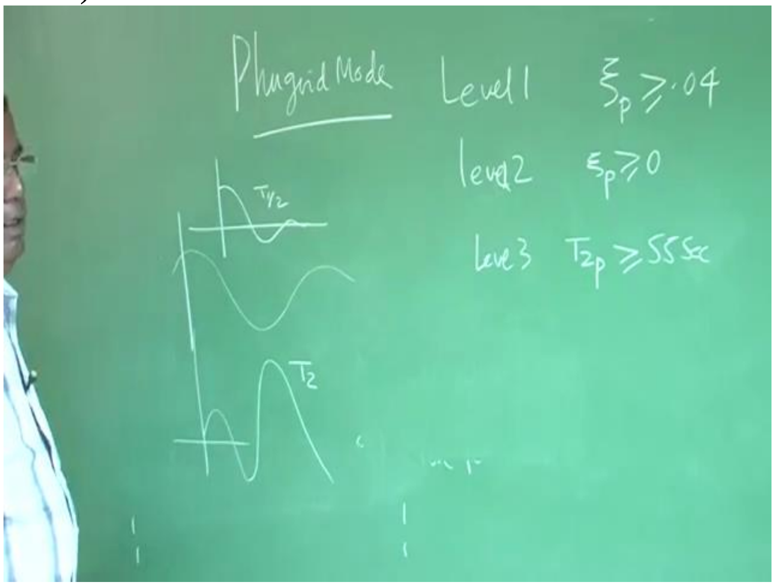

If I take Phugoid mode, the requirement is for level I qualities. For level I, you to ensure that Zeta Phugoid is greater than 0.04. For level II, it should be Zeta P greater than equal to 0 and level III, time to double for Phugoid is greater than 55 seconds. Do you understand time to double for Phugoid, I know Phugoid is this. Time to double means it is actually going on increasing.

So whenever it is diverging, we say time to double and whenever it is converging, we say, we try to use time to half. That is time to double the amplitude, this is time to half the amplitude. Okay?

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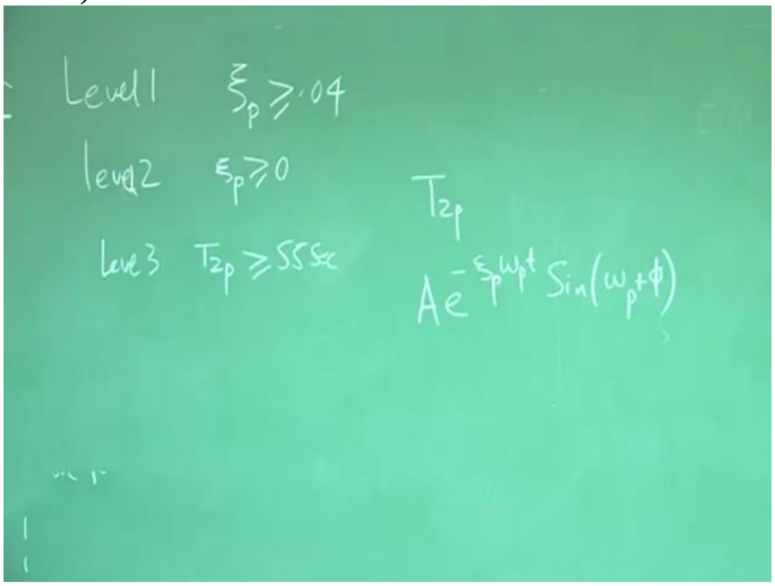

So let us see something on time to double in Phugoid and you know that the Phugoid response I can write in terms of A E to the power - Zeta Phugoid Omega Phugoid T into sin Omega Phugoid + Phi. Okay? The Phugoid response I can express like this. It is like a sinusoidal with a damping through exponential.

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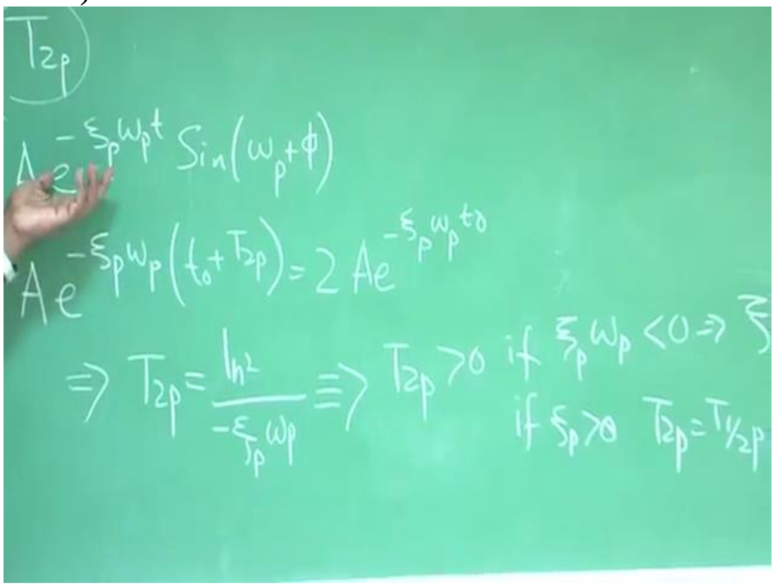

If I come back here, this is a response for a Phugoid which is a sinusoidal component and exponential component which will decay or it may increase the envelop also depending upon sin. And if I want to look for time to double, then I can easily write A E to the power Zeta P Omega P T not + T2 P is equal to twice A E to the power Zeta P Omega P into T not.

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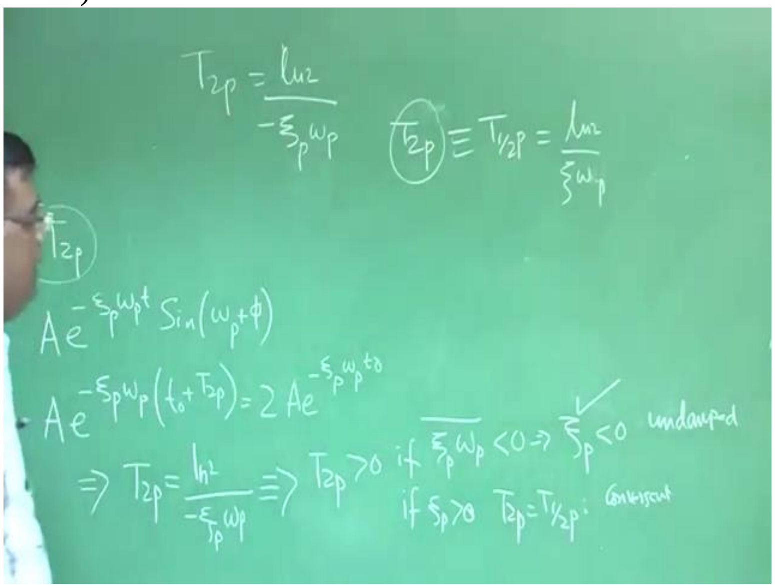

And when I equate this, I find the expression, T2P is LN2 by - Zeta Phugoid Omega Phugoid. And you could see that if I want time to double to be positive, then Zeta P, Omega P should be less than 0. And Omega P is never less than 0. The only way it could be possible is the damping ratio is negative. Then only we talk about time to double. That means, undamped system. So we say Phugoid is undamped.

Second, is Zeta P is greater than 0, then this time to double is no more valid. So this is now interpreted as time to half and that is LN2 by Zeta Omega N Phugoid or Omega Phugoid. So that way, level III you could understand. If time to double is 55 seconds, that means what you are telling, that the airplane has a divergent undamped Phugoid but still if it meets this criteria, pilot by putting extra efforts, excessive of course in that nature, will be able to control the air plane to safety.

This is what? What is level 1? Is Zeta P is greater than 0.04, fantastic. Not much effort on the pilot. But let us say this is not greater than 0.04, just greater than 0, so Zeta P is basically positive. Then also handling qualities will be okay enough for the pilot to put extra effort.

And this is level III where we are talking about time to double means the Phugoid is actually undamped. But as long as this is greater than 55 seconds the pilot will be able to control the airplane to safety. Okay, that is the understanding. So that is the level I, level II, level III handling qualities expressed in terms of Zeta and Omega M for the Phugoid mode.

Remember? That is exactly what I was telling, they will be postulating every requirement through Zeta P and Omega N. It reminds me one thing. Please understand, unstable does not mean uncontrollable. Now these modern aircrafts are statically unstable. So unstable does not necessarily mean uncontrollable. So if the Phugoid is undamped, does not mean that I cannot control it.

But as long as this Phugoid has this criteria satisfied, then controlling the airplane by putting extra efforts with the pilot, we will be well within the handling qualities for level III requirement. That is the understanding. Or to tell this, suppose at some altitude, the Phugoid damping is just 0.02.

So now you have to use the SAS to ensure that for that time, the Phugoid damping becomes more than 0.04. That is where the SAS is important. Now this was Phugoid and now we are talking about short period.

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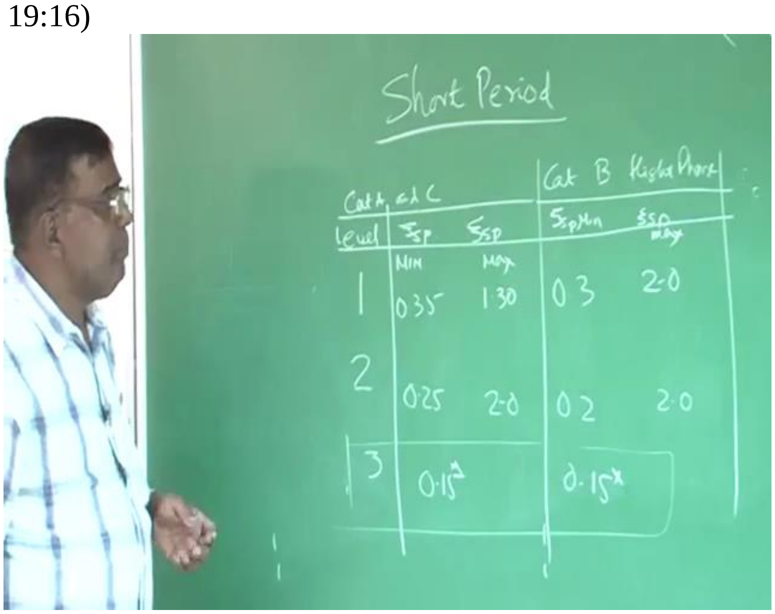

Mostly you find, the SAS is used for short period and short period requirement is, before I come to short period, please remember Phugoid damping for a glide phase, it goes inversely with CL by CD. So if we want to increase the Phugoid damping, best way to increase it is, decrease CL by CD. So that concept should come from there.

You have to fly in such a way that at such an angle that CL by CD is not that high. Or you increase the drag by putting some surface at that time. With that concept, you can increase the Phugoid damping for a gliding phase. Now let us come to the short period. When it comes to short period, the requirement is this.

If I draw it like this, this is category A and C and this is category B, this is flight phase. You know category when I say it is light phase we are talking about. And if it is level I, then Zeta short period should be minimum and this is maximum. So minimum should be 0.35, maximum should be 1.3. Similarly for category B flight phase, Zeta short period and Zeta short period, this is again Zeta short period maximum. Zeta short period, this is maximum and this is minimum.

For this, it will be 0.3 and 2.0. Please understand. For category A and category B airplane, for level I quality, the short period damping ratio minimum should be 0.35 and maximum, it could be 1.3. For category B flight phase for level I, the short period minimum should be 0.3 that is the damping ratio should be 0.3. Maximum, it could be 2.0.

For level II, you see, similarly it is 0.25 and 2.0. Here it is 0.2 and 2.0. And level III which is very rare, we need 0.15 and this is 0.15. But this is, we put an asterisk mark. It may get reduced as we are going higher and higher altitude. And this is the type of level III, very very rare. There are other criteria, other constraints come.

We focus here, level I and level II and the point which I was trying to draw that it is finally on the damping ratio and as soon as soon you find that, natural frequency will also come into play.

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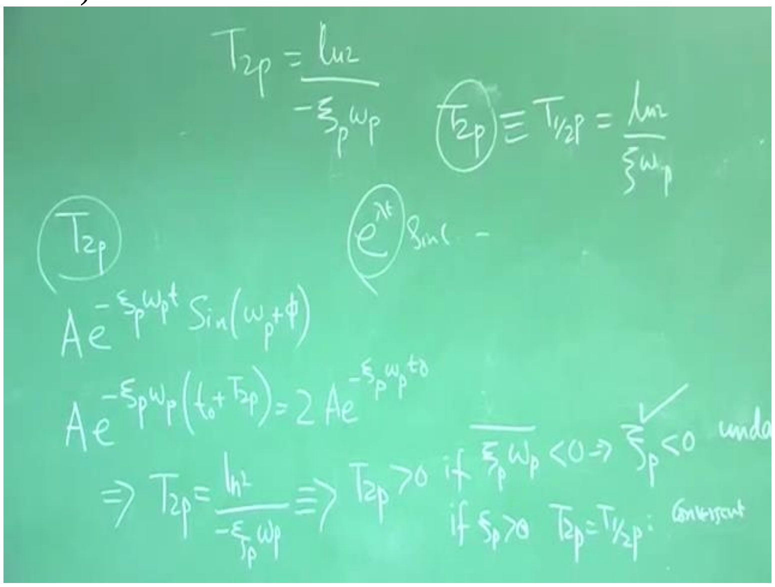

Please understand one thing, in dynamics whenever we wrote the equation, the response had E to the power lambda T. Then sin and all those things were depending upon if it is oscillatory or just 1st order response. E the power lambda have utility, that decides the amplitude envelope and also decides whether it is going to divergent or it is going to converge. Whether it is going to reduce or it is going to go on undamped like this. That is why, Zeta plays an important role.

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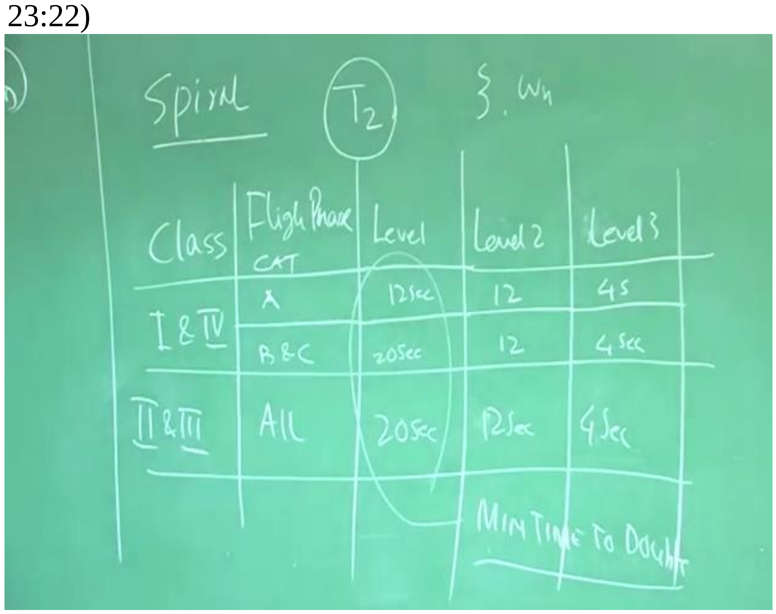

If we talk about spiral, then it is if I write class I and IV, by now you know what is class I and IV. And if I draw a line like this. This is flight phase category. Then I have level I, I have level

II, I have level III. The fight for category I and IV, for flight phase, let me draw a line, for flight phase A, B and C for level I. For level A, it is 12 seconds, this is 20 seconds.

What are these 12 seconds and 20 seconds? These are the time to above the amplitude. Okay, we are talking about spiral. This is time to double the amplitude. Again it is saying, when we are talking about time to double means it is showing undamped but unstable does not mean uncontrollable. For level II, it is 12 seconds. 12 here and here it is 12 seconds.

For level III, it is 4 seconds. This is 4 seconds. And for 2 and 3 class of airplane, this is flight phase, all flight phase, A, B, C, this is 20 seconds, 12 seconds and this is 4 seconds. And you could see when I am giving a guideline to the designer to ensure the handling qualities as per level I, level II, level III, what am I telling to designer?

Ensure that if you want a level I performance, then time to double should be of these values for category 1, category 2, category 4. And when I am talking about time to double, that means I am talking again in terms of Zeta and Omega M. Right? We have seen the expression of time to double. And this is typically, if you are allowing it to double then we are talking about spiral divergence, undamped.

And these are of course, when I say these seconds, this is minimum time to double. These are all, we understand that minimum time to double. Why is it minimum? Because if it is too fast, then it will be difficult to control. That is why, the restriction is on minimum time to double. So after spiral, we again come back to, I strongly suggest you people should read or Google search and have more insights.

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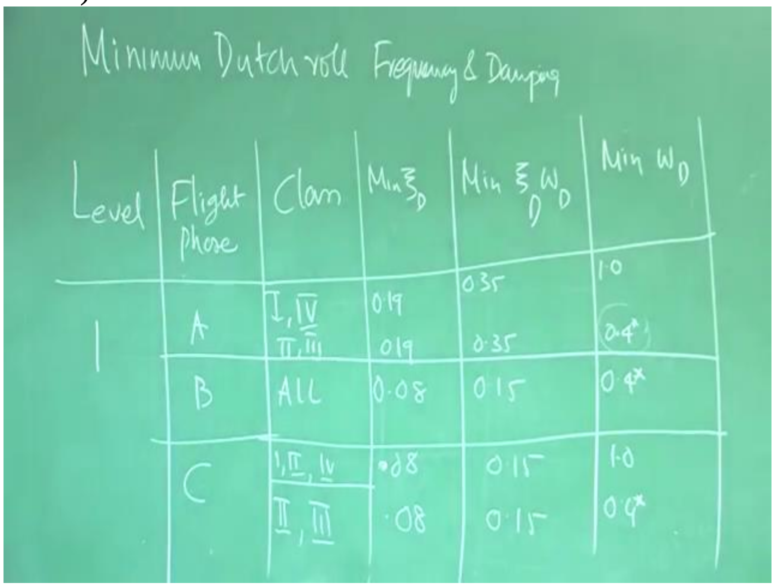

After spiral, now we will see minimum Dutch roll frequency and damping. Let me write. Again this is level. This is flight phase, this is category. Then comes class which we have been always talking about. Then it is minimum Zeta Dutch roll. Then it is minimum Zeta Dutch roll Omega Dutch roll natural frequency Dutch roll. Also, minimum Omega Dutch roll frequency.

It is postulated or the specifications are given like this. If it is for level I qualities we are looking for and if you have 2 types of class, 1A, 1B. Class I, class IV, class II, class III, then these values are, for I and IV, it is 0.19 minimum, here also it is 0.19. Here, 0.35. Again 0.35. This is 1.0 and this is 0.4. This 0.4 star we have put this may change based on the customer's requirement.

These are finer details. So you please try to understand. For the level I handling qualities, they have been specified. Now by minimum Dutch roll damping ratio, also the product, Zeta D Omega D and also minimum Dutch roll frequency in radians per seconds for B it is all, 0.08, 0.15 and again 0.4 star.

For C, for flight phase C, again you will see that for I, II and IV, it will be 0.08, 0.15 and 1.0. And for II as well as III, there are different variations of category, class II. So I am mentioning both. You will find again, it is 0.08 and 0.15 and 0.4 star. Similarly we will find for level II, level III.

So I do not want to really make your life miserable by going on writing all this. What I wanted to communicate to you was when we are talking about handling qualities, you have seen for Phugoid, for spiral or for Dutch roll, these are primarily decided by the damping ratio and natural frequency or their combinations. Those who are interested to know exactly numbers, I will suggest them read latest air worthiness requirements. You can google search, go for textbook.

These numbers go on changing depending upon the technology, depending upon the control system you have got. These are some guidelines, numbers. What is the important message is we need to know how to find Zeta D and Omega N. We also need to know how can I change Zeta D and Omega N because I know this Zeta or damping ratio changes with speed, changes with our attitude.

You cannot design an aircraft by laying out its components where Zeta will not change. Because Zeta depends upon density, speed. So wherever you require different values of Zeta and Omega or different handling qualities, the SAS is very handy. That is why we are designing SAS. Okay.