Flight Dynamics II (Stability)

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Module No. # 10

Longitudinal Dynamic Modes

Lecture No. # 33

Flying and handling Qualities, Cooper Harper Scale

So, as we were discussing, parameters of aircraft are going to play a role in changing the Eigenvalues, location of the Eigenvalues in the complex plane right. So, we were in the last class discussing the effect of changing the CG. We had moving it aft, so that the static margin is going down and we want to see the effect of that on the location of the Eigenvalues.

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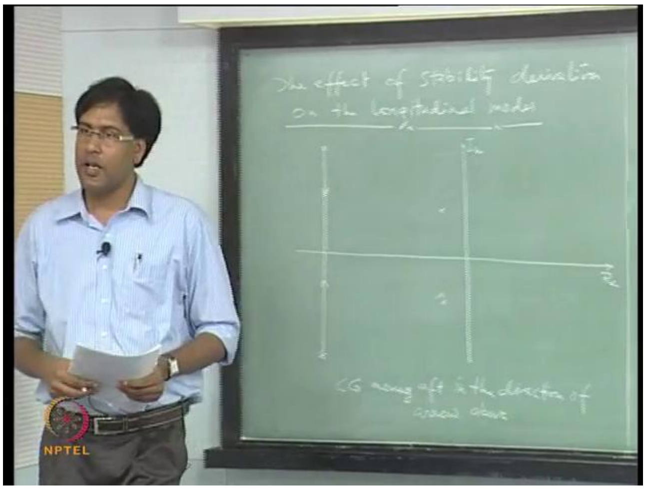

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The effect of that stability derivatives on the longitudinal modes. What we want to look at is how the short period and the phugoid mode Eigenvalues are moving, when we are changing something.

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So, the variation, the direction of the arrow is CG is moving aft.

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To start with, my CG is at some place and then, I start moving the CG backward .. towards the neutral point. So, static margin is going to decrease right. So, let us see what happens to the phugoid mode Eigenvalues and the short period mode Eigenvalues.

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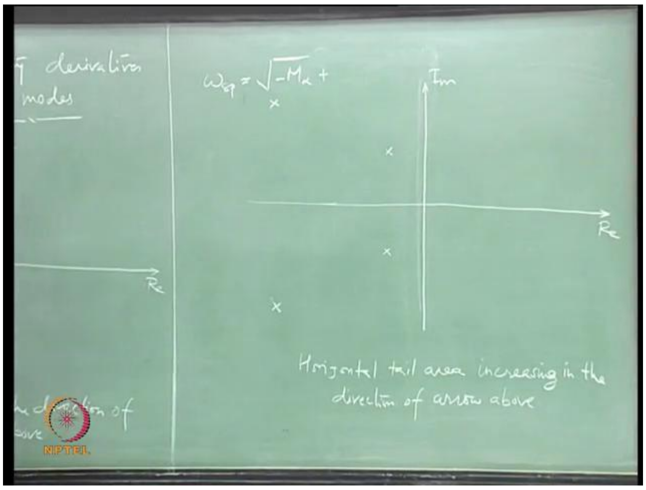

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So, we are changing CM alpha. Is it not? So, when you are changing CM alpha, what is going to change? The short period frequency ... We have got an approximate formula for this as ..... (Audio not available: 3:20-3:26). This was for the case when we are looking only at the constrained pitching motion, and plus something right. That is coming from the Z alpha term. (()) ....

So, effect of changing CM alpha is going to be on the short period frequency right and what is happening here, is exactly the same. So, damping is constant because we are at the same location on the real axis ... and the roots are moving in the direction of the arrow vertically. So, the frequency is decreasing right and once it reaches here, it splits like this.

Just look at what is happening to the phugoid mode. You will not expect the phugoid Eigenvalues to change right, because of CM alpha term. But changing CG is also going to change something else, right or in other words, now as I just said short period motion and the phugoid motion are coupled. So, the short period mode is going to have an effect on the phugoid mode, that is what we discussed yesterday. So, phugoid mode Eigenvalues are also going to move when we change the CG.

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So, you can go on actually doing this. Change some parameters and see the effect of that on location of the Eigenvalues. This is called root locus. When you change parameter of the system and look at how the roots are moving, the trajectory of the roots in the complex plane is known as root locus. So, let us look at one more, effect of one more parameter on these two Eigenvalues.

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Remember, there are things which you can change right and there are things which you cannot. So, two of the things that are kind of still in the hand of the designer, you have a tail, now wing sizing will depend upon the performance requirements, ... tail sizing is usually depending upon the stability requirements.

So, here I am showing you the effect of those parameters on these two Eigenvalues, which are still under control right. You can still design your horizontal tail area, you can make it bigger or smaller, and you can change the CG definitely because you can have dead weight inside your aircraft which can be moved to change the CG. You also would want to look at the location of these Eigenvalues, when passengers are moving on the aircraft. So, this plot gives you that information. Just look at the horizontal tail area or effect of changing that on the longitudinal mode Eigenvalues.

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What is tail area going to do? If you increase the tail area, it is going to, it appears somewhere in the expression for CM alpha. Remember, when we added a tail, we increased CM alpha. So, ... this horizontal tail is also known as stabilizer right, so adding to the CM alpha. What else? Remember, we also defined the damping term with respect to the tail coming from the pitch rate. (()) Yeah, what is it? So, we are coming to that. So, it is going to, so frequency is going to become what? Higher and damping? It will also be higher. So, it is going to move in this direction.

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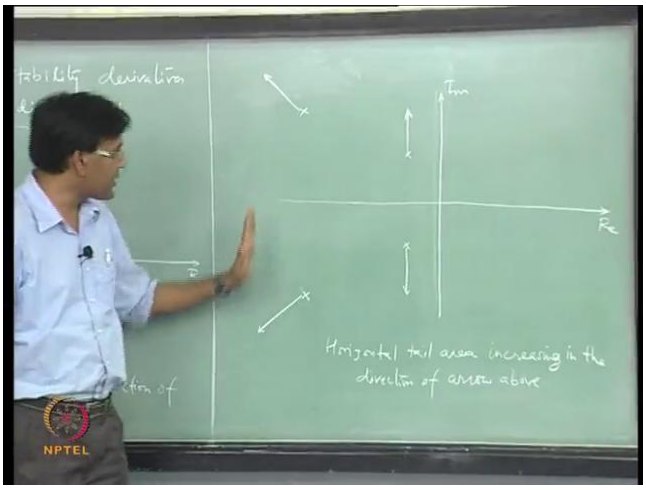

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But phugoid, effect of that is also to change the phugoid frequency right. So, phugoid frequency becomes large and the time period becomes small. You know usually you do not worry about the phugoid if you have a really good pilot sitting inside the aircraft, because he can take care of that. You can apply corrective action to control the aircraft in phugoid because the time period involved is very large ... But if such a thing happens, then you are going to lose that advantage. Frequency is going up, so time period is going to be smaller right. So, the problems associated are these. If the damping is low in short period, then controlling the motion is going to be difficult ... Low damping in any motion is going to be difficult to control right.

... These are related to the pitching motion. Short period mode Eigenvalues are related to the pitching motion of the aircraft. So, if it is not damping fast .. then this pitching motion is going to last longer and I am sure you are not going to like it when you are sitting inside such an aircraft right, which is doing this and is taking longer to settle. Phugoid, it is a long period motion, even though a pilot can control it, it can become really tiring for the pilot right. So, there we actually start talking about pilot comfort with the aircraft ... and that is related to the flying quality of the aircraft, flying or handling (qualities).

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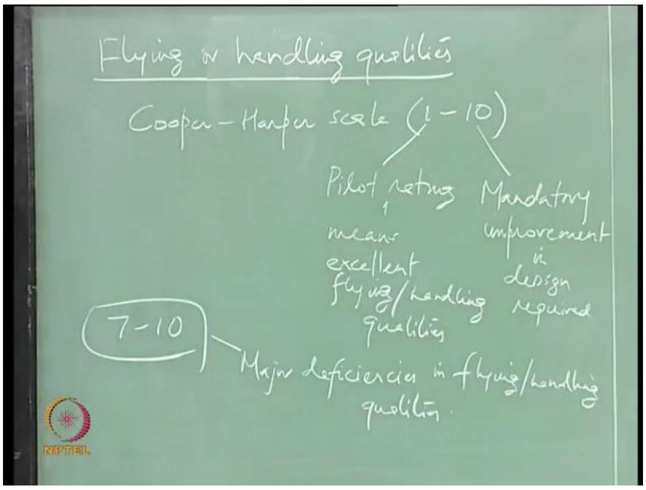

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So, there is a scale, you know the scale, ... Cooper-Harper scale. On a scale of 1 to 10, it tells you what kind of quality your aircraft is having. On 1 to 10 scale, if the rating is 1, then your aircraft is excellent in terms of satisfying the pilot, in terms of all other requirements. If it is 10, then you better go back and change something in your design or maybe you will design control system, which can add to the flying and handling qualities.

So, this rating 1 means excellent flying and 10 is really bad and you recommend mandatory improvement.

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Actually, 7 to 10 is objectionable and it relates to major deficiencies.

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This rating is based on three different criteria. So, these criteria are depending upon pilots input, how much pilot work load goes up or how comfortable pilot feels operating the airplane.

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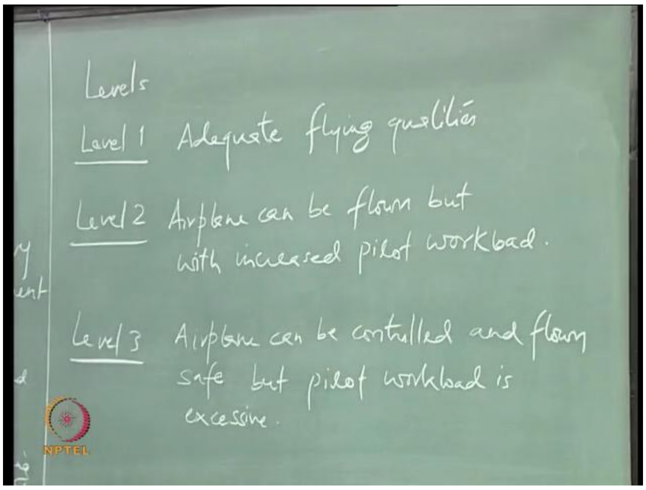

So, there are three levels which relate to the pilot work load.

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So, level 1 is ...... If your aircraft falls in this category, level 1, or just level, because category is another thing here, when you have adequate flying qualities, pilot feels really good about flying this aircraft.

(No audio from 16:50 to 17:19)

So, in level 2 ...., this airplane can be flown comfortably by the pilot, but only at the cost of increased pilot work load.

(No audio from 17:32 to18:16)

Level 3 is ..... In level 3, an airplane can be controlled and flown safe but pilot work load is excessive. It also depends upon what category of aircraft you are talking about.

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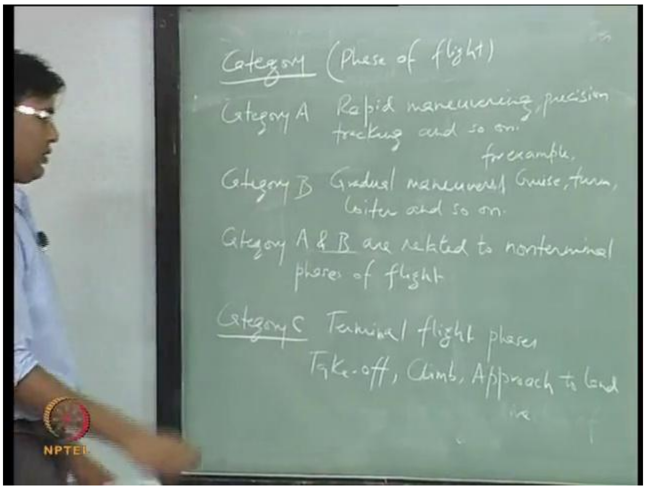

So, category is based upon the phase of flight, maneuvering phase of flight right.

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Categories A and B are related to non-terminal phase of flight.

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So, these two categories are related to ...... (No audio from 19:17 to 20:00). What does this mean? So, we are not talking about flights which are related to ending the flight or you know beginning of the flight, so non-terminal phases of flight. So, it is about maneuvering right. So, category 1 is related to rapid .... maneuvering (No audio from 20:30-20:45) ....., high performance aircraft .. in maneuvers. Category B is related to gradual maneuvers and these maneuvers can be cruise, turn, loiter and so on.

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Category C is related to the terminal .... flight phases and in this .... you have phases take-off, climb, approach to land.....

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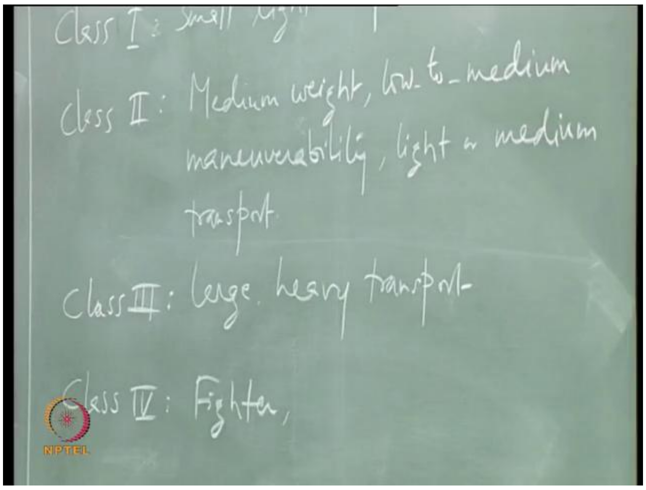

Now, what kind of aircraft we are talking about that is not clear. Is not it? So far, we did not talk about the type of aircraft.

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So, you have four classes of airplanes. So, in Class I .... small light .... The Class I belongs to these small light airplanes. Class II is .... medium weight.

(No audio from 23:45 to 24:17)

Remember, you are going to see all kind of airplanes, all variants. For example, if you are flying cross Atlantic, you are flying in a Boeing in a 747 ... capacity 400 plus right. In India within the country you are flying, you are flying in a 100-120 seater. If you are flying, from let us say Delhi to Kanpur, so short distance, you are going to see some airplane with only 20 passengers seating capacity right. So, you have different class of airplanes, .. other than combat and non-combat aircraft, you have these classes also.

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So, class IV is the class belonging to the combat fighter airplanes.

Now, how do I .. define this rating in terms of level, category, and class of airplanes? You know that is what we should talk about and the only thing that I worry about is the Eigenvalues right, because that is what is going to tell me about the aircraft behavior about, perturbed behavior about an equilibrium state .. So, let us look at the flying and handling qualities keeping these three types in mind.

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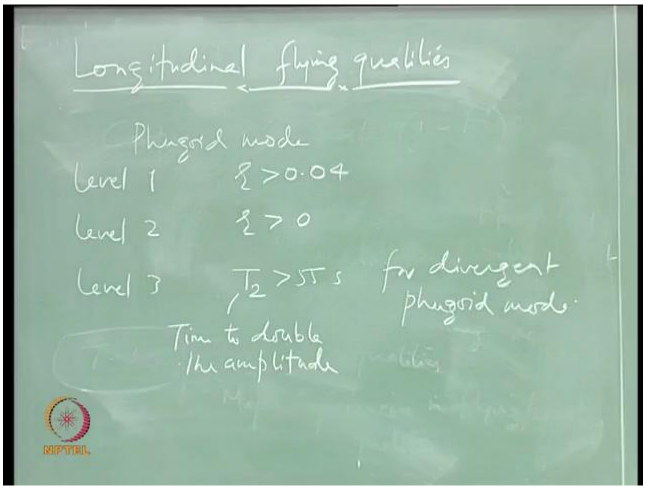

Let us talk about longitudinal .....

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These qualities I want to define in terms of the damping and frequency characteristics of the longitudinal modes.

(No audio from 27:22 to 27:53)

So you have good flying quality in phugoid mode under these levels and the damping ratio is: level 1, if it is greater than 0.04, then you have good phugoid characteristics right. Level 2, the damping should be positive. In level 3, it is defined in terms of the time period and this should be greater than 55 seconds right. So, even if you have a divergent phugoid mode, that is the unstable phugoid mode .... then you should have the time period of doubling the amplitude .... It should be more than 55 seconds.

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This is true for all categories of flight phases in all class of airplanes ...

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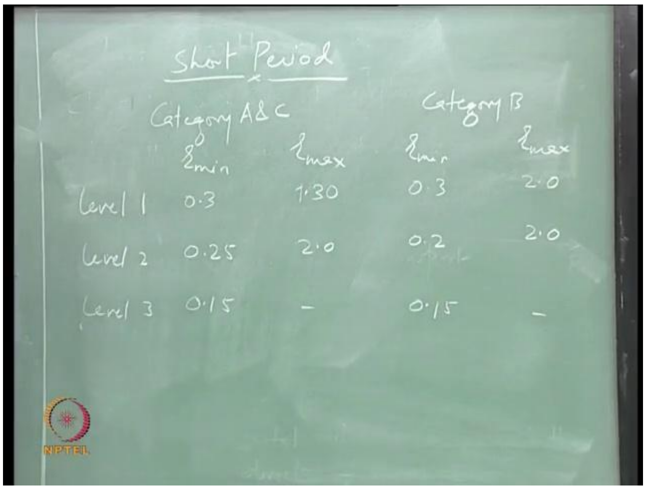

Here, the quality is depending upon both level and the category of airplanes, or category of flight phases.

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These numbers are standardized. So, you will find these numbers same in all the text books. They are not going to be different. .... What this means is, it is not given, for this level.

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So, with this we conclude our longitudinal perturbed dynamics.

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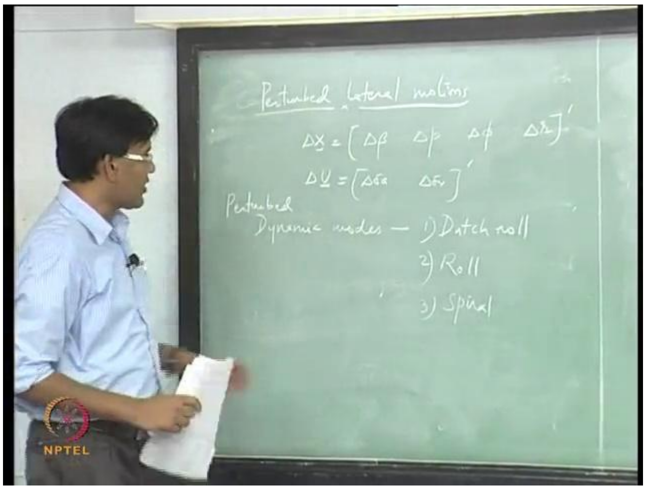

Let us look at perturbed lateral motions now. So, what is happening is, we are again considering the same equilibrium flying conditions and now we are not bothered about what is happening in the longitudinal plane right. Now, we want to look at dynamics in the non-longitudinal planes...

So, aircraft is flying this cruise condition, and gust will hit the aircraft as usual and you want to look at the perturbed motion. So, motion is going to be in roll ... and yaw, sideslip ... and the bank is associated with the roll. So, the variable of interest here are delta beta, delta p, delta phi and delta r right. So, my ... state variable vector, perturbed state variable vector is now consisting of these four variables, and the control vector is consisting of perturbation in aileron and perturbation in rudder right.

So, we are looking at longitudinal and non-longitudinal dynamics as completely decoupled and that will happen only in this particular flying condition. If you are talking about let us say level turn, then it may not be decoupled right. The dynamic modes, ... perturbed ... dynamic modes are related to the perturbed motion of aircraft from the equilibrium state. So, dynamic modes here are: dutch roll, second is roll. Dutch roll is different from roll. It appears to be rolling but it is not actually rolling. That is why this name, and Spiral.

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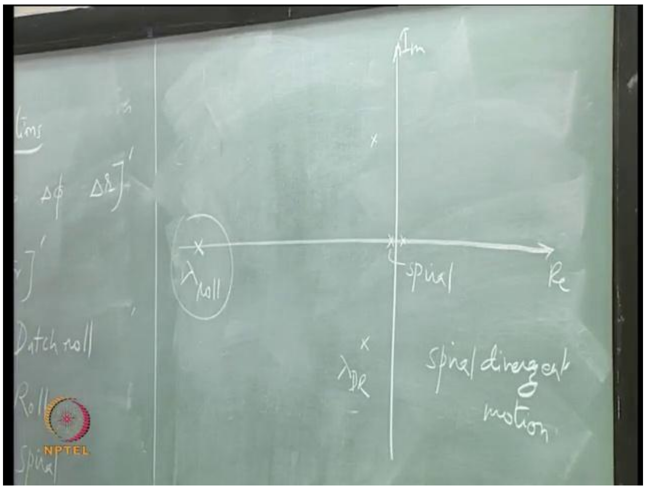

If you look at the location of the Eigenvalues corresponding to these modes in the complex plane,..... (No audio from 36:07 to 36:21) typically they are located like ... this. So, pair of complex conjugate Eigenvalues and two real Eigenvalues right. Many times this mode, which is called Spiral mode Eigenvalue can be lying also on the other side right. So, other side if it is lying, it is like a divergent mode... So, if it is lying on this side, then you have a motion called Spiral divergent motion. This pair of complex conjugate Eigenvalues is related to the Dutch roll motion and this Eigenvalue is related to the roll mode. So,.. you see here that this Eigenvalue is actually lying quite far from these 3 right.

So, we can .. kind of assume that this particular motion is decoupled from the rest ... and based on that, we can now make some approximations. So, before we go into doing that, let us try to understand what designer would be worrying about. When he is talking about lateral motions, what is exactly in his mind?

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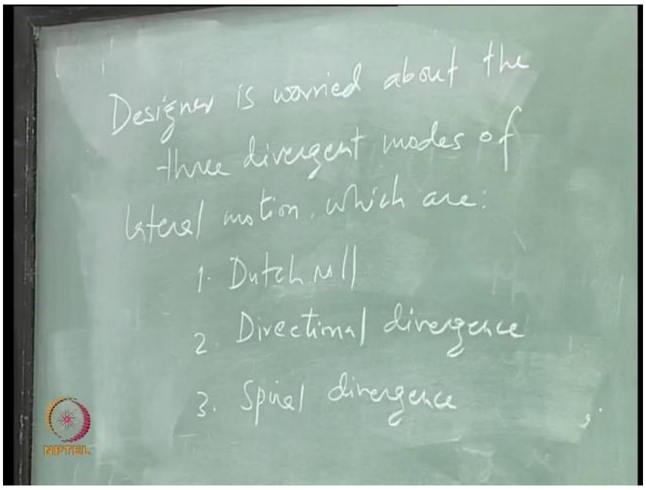

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A designer will be worried about the divergent of motion.., unstable motions of aircraft. He has to ensure that aircraft is stable ... to start with. If it is unstable, how unstable it is ..? So, these are three modes of motion in lateral directional dynamics which the designer has to keep in mind.

Let us try to understand what these motions are. So, you are flying, you are still flying a cruise condition, and now you have a gust from side. So, there is a change in side slip and that will change, that will result into the perturbed motion of the aircraft. So, you are flying in this, actually on this line. You know at some altitude you are flying along this line with velocity vector in this direction ... and flying level. So, altitude is fixed, wings are level right. So, let us see what happens with respect to some of the parameters that we have already seen earlier.

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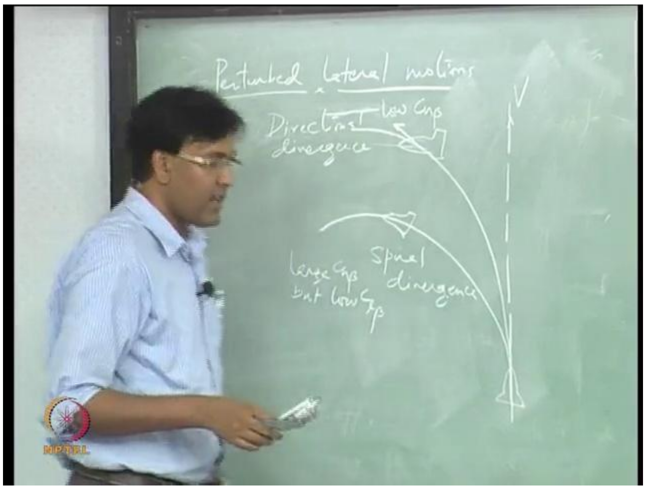

If the aircraft is having low Cn beta (yaw stiffness term), so small Cn beta, what it will ? What effect that will have on the aircraft motion? So, a perturbation is introduced. This Cn beta will not be enough to kill that delta beta right. So, aircraft will start going on a curved path which is like this, and the beta will keep on increasing. That delta beta will keep on growing and finally, your aircraft will be flying like this right.

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So, the beta has grown, ideally it should have killed the beta. If it had enough Cn beta, it should have killed the beta, but the velocity vector is in this direction now and aircraft is looking somewhere else. So, that means there is a beta introduced right. So, there is a non zero side slip, which can be large if you keep on going, if you do not correct it in time and this is related to ... this motion is called directional divergence.

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So, there is another situation when you have enough Cn beta, but you have low Cl beta (roll stiffness or dihedral effect).

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In that case, what happens is, aircraft still follows a curved path, but it is able to kill that beta because it has large stiffness in yaw... So, now it will follow the velocity vector ... So, beta is zero all the time, but because of this Cl beta which is low, it is going to give rise to a rolling motion ... So, slowly the aircraft is actually, it is killing the beta, so, it is moving like this, but it ... is also turning... And because the bank is introduced now, you will have a lift component which will be lower than the weight, so, it will also start going down ... So, steeper bank and it is going down. So, it is going into a spiraling motion about a vertical axis. This is called Spiral divergence. This Dutch roll motion is predominant in beta and r; actually, there is not much roll involved. It looks like, it appears that the aircraft is rolling, but it is actually not rolling. So, what is happening here is, let us look at this.

.. You are yawing right, so you have a yaw rate r which is non zero. You are yawing and you are also side slipping. You know these two are two different things. Yawing is, a pure yawing is rotation about the Z axis. Beta is the angle that it is making with the velocity vector, the nose of the aircraft, and the angle that it makes with the velocity vector is the side-slip angle.

So, it will do this but go like this ... So, it is doing this, in one direction, and in the other direction, it is this, and going like this. So, it is like something like this.... So, it appears that, you know, because of that motion, it appears that it is rolling. Look at this, if I can put it correctly. It is, maybe, it needs a little practice, something like this. So, it look like it is rolling, but it is not really rolling. But there is some amount ... very little amount of roll involved.

(()) This is what actually we observe in flight. So, it looks like, it is the wing, wing tip of the aircraft is making some curve, closed curve, which we observed this time. So, that is where, when you now make assumption that it only involves, it only involves beta and r and then arrived at the approximate formula, you will find that, that formula is not really correct. So, there is some amount of roll involved and that will discuss in the next class. So, we can stop.