Introduction to Flight
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Lecture 51: Number 10.1
Introduction to Static Stability: Center of Pressure, Center of Gravity and Neutral Point

So for that, I have to thank Vijay Gaikwad, an intern who came this summer from VJTI Mumbai and help me prepare the content for this particular presentation. In which we will discuss longitudinal stability and neutral point. Two important Concepts that you will need.

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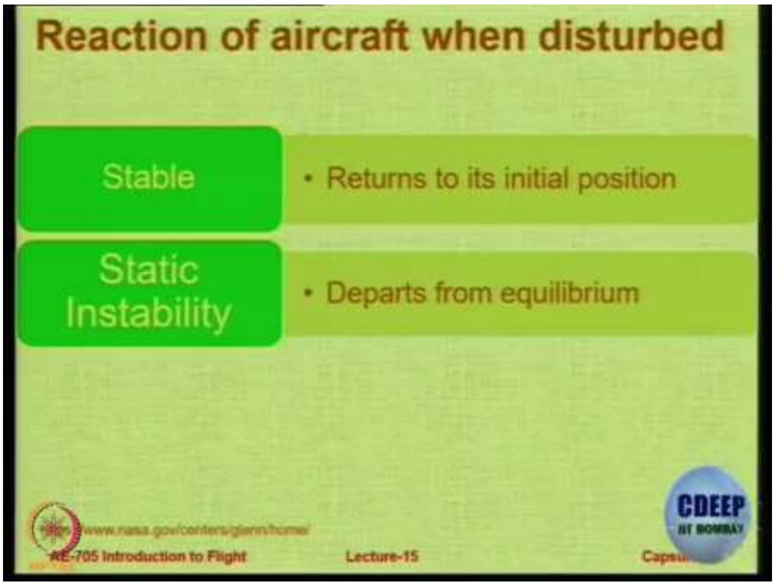

So, basically let us see; what is the reaction of an aircraft when it is disturbed? So, the aircraft in trimmed condition forces are in Balance moments are in balance and now some disturbance acts on that particular aircraft. So, its reaction determines its stability. So, the aircraft is considered to be stable. When after disturbing it, it comes back to its initial position, without any action of the pilot. If the pilot has to bring it to the condition is called as control.

But stability means without pilot input on its own. So, therefore; if it does not return to the initial position, then the aircraft can be considered to be unstable. But there is also one step in between called as neutral. So, stability is of two types; that is static instability, in which the aircraft departs from the equilibrium, you it just departs. And you also have Dynamic instability in which case, not only does it depart; it also becomes more and more unstable. Okay, so the tendency initially is static and the final outcome is dynamic, okay. Let’s have a look. So, in short if you look at static stability the first step, it is only a function of the initial reaction the tendency not the final outcome, but the initial reaction.

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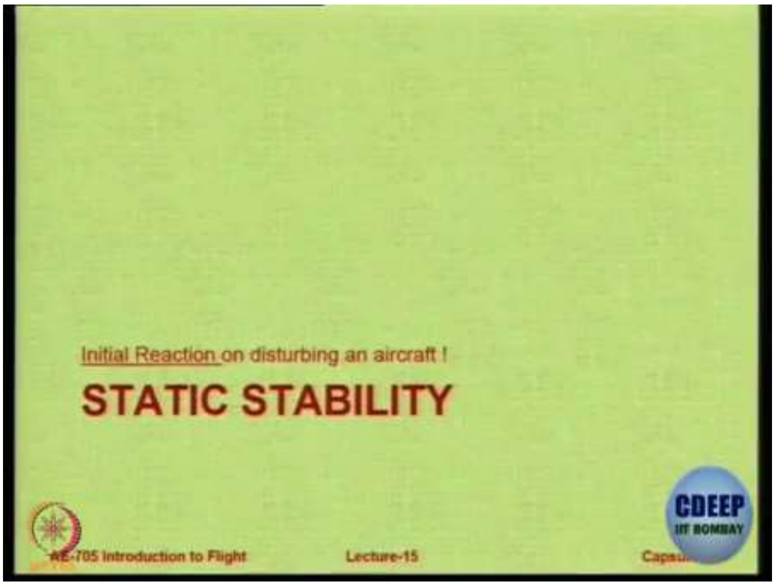

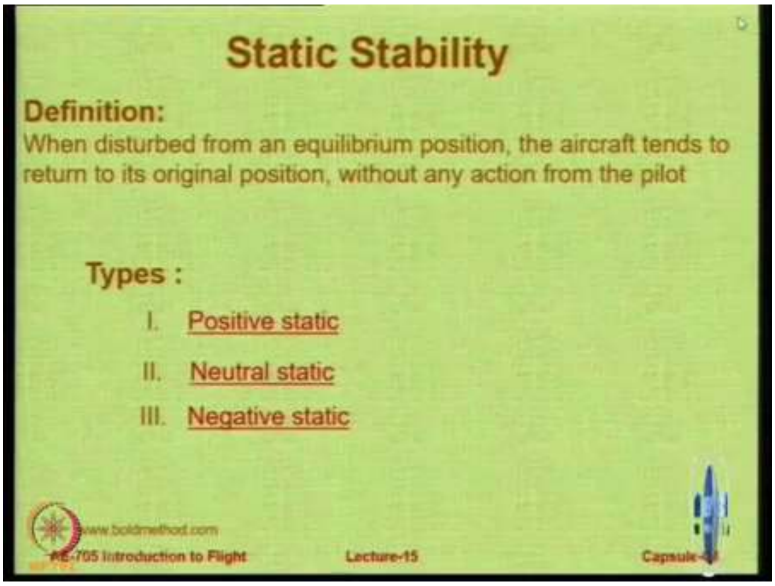

As you disturb the aircraft what is its initial reaction on its own? That determines static stability. So, the definition is when you disturb an aircraft from a trimmed position or equilibrium position. If the aircraft tends to return, tends to return it need not return finally. But at least the tendency is to return then we call it as a statically stable aircraft. Okay, so there are three basic types one can have positive static stability which is illustrated by this kind of a behavior.

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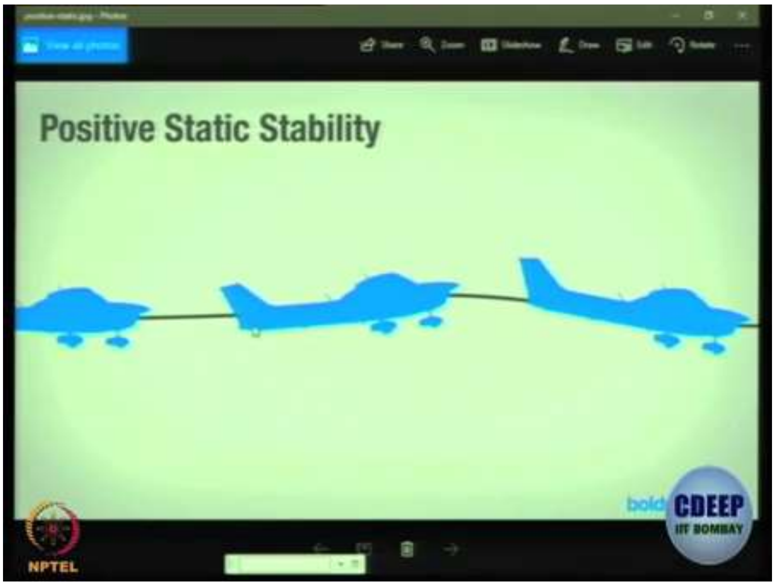

So, you have an aircraft on the extreme left. It is disturbed because of which it is pitching up slightly. So, the tendency is it is coming down. Okay, that is the initial tendency. So, this is the positive static stability.

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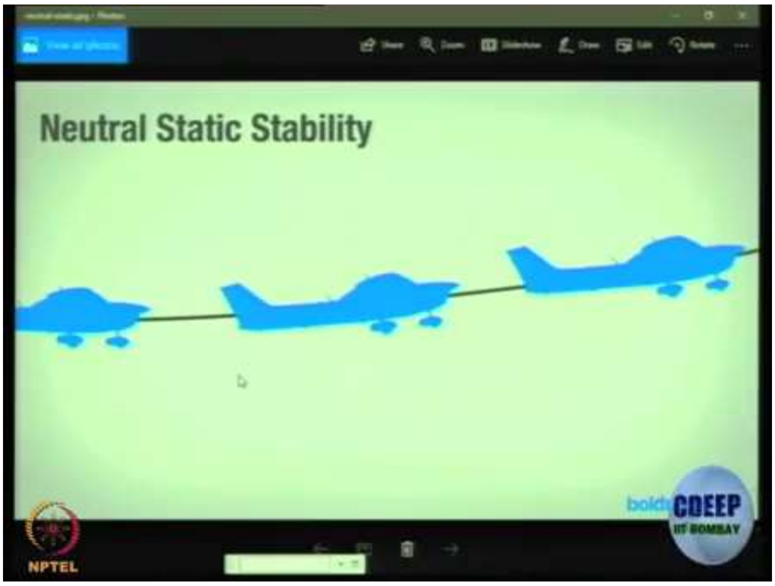

Then you have neutral static stability, in which case there will be no attempt to either become undisturbed. So, neither will it come back to the position nor will it go away. If it is disturbed it remains disturbed and remains disturbed, this is called as a neutral static stability. It is still stable because it is not going away. Okay, but it is neutral.

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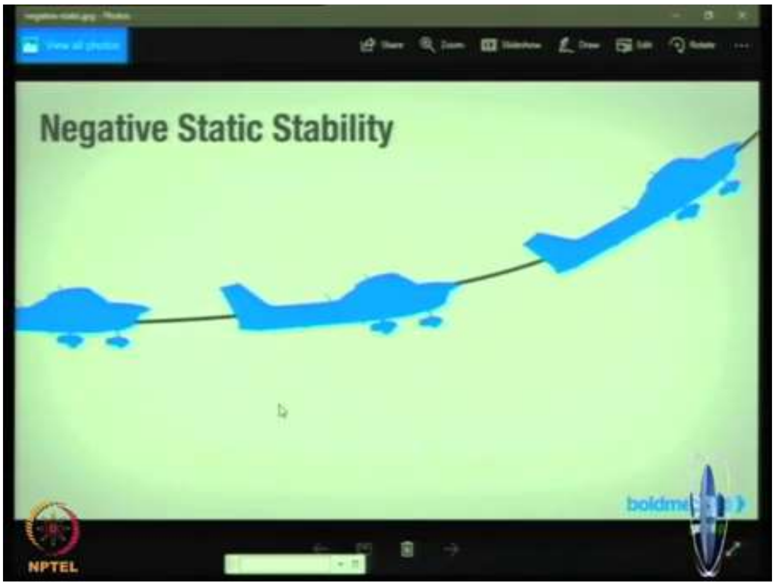

The third one is of course negative static stability. In this case, you will notice that if you disturb it, it goes to a position of disturbance. But then on its own it goes further away. Then we call it as a negatively static stability, but then why the word stability? Because we do not know what is the in the end Okay, right.

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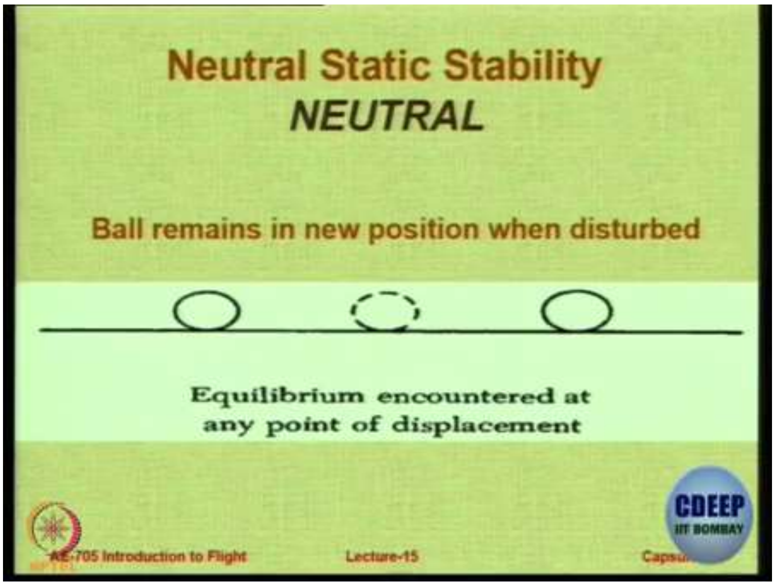

So, let's look at these three steps in some other way. Okay first is neutral stability. So, we have a ball on a flat table. We push it to a position it goes to that position and remains there. You put it towards the left and leave it, it remains there. This is neutral. Okay.

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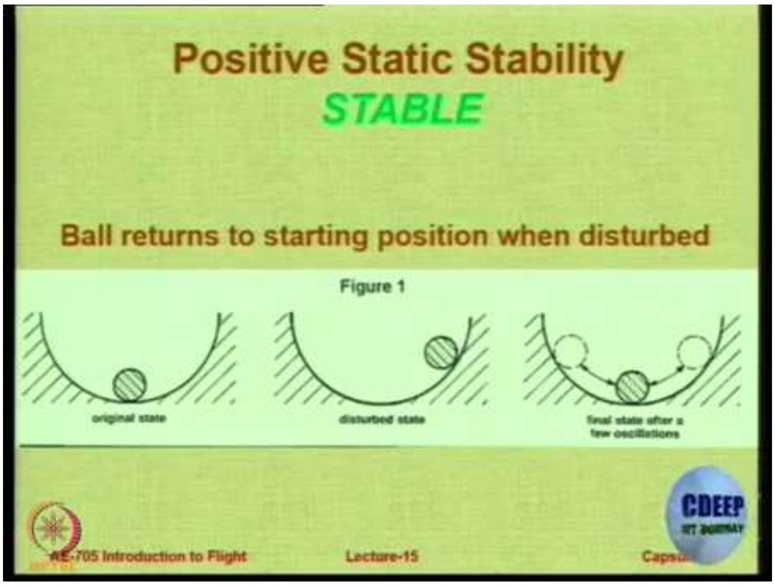

Now let us look at positive. So, this is an example of positive stability. You have original state when the body is at rest at the center to take it to the right and leave it. It does not go further ahead. It comes back, but it may exceed the position when it go to the left and then come back and then go and then come back what eventually happens it is a function of dynamic stability. But the ball is statically stable because it does not go away further away. Okay and this is negative stability.

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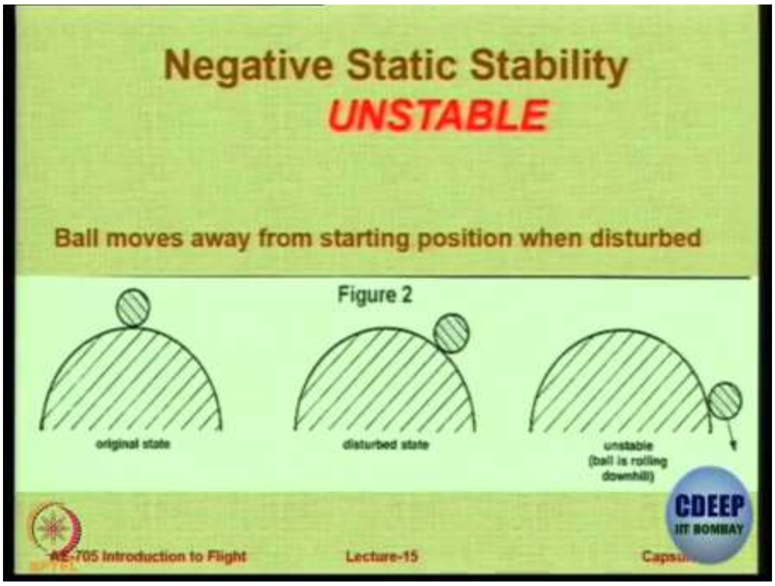

So you place the ball and now you disturb it slightly it will keep on going further and further away either on this side or on the that side. This is unstable.

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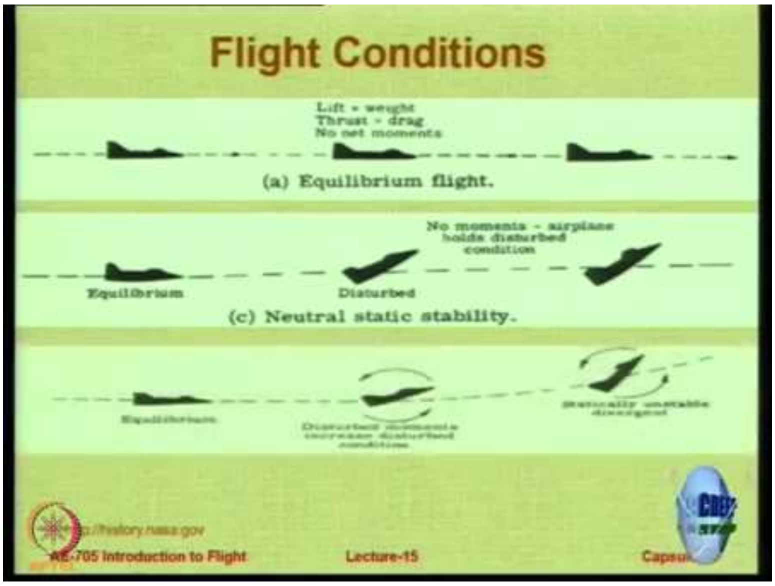

So these are simple examples but we are concerned about flight not about balls on rotating surfaces. So, this is an equilibrium flight the aircraft is at some angle of attack though not shown but it is level. So, thrust is equal to drag lift is equal to weight if it is a level flight.

And no net moment. You could incline it to make it a climbing flight study again it will be in equilibrium, moments are still in balance although lift is not equal to weight lift is in fact less than weight inclined. Now this is neutral, you fly an aircraft you disturb it remains disturb. And this one is unstable, okay.

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Example of an unstable aircraft
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Example of an unstable aircraft
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Example of an unstable aircraft
Introduction to Flight
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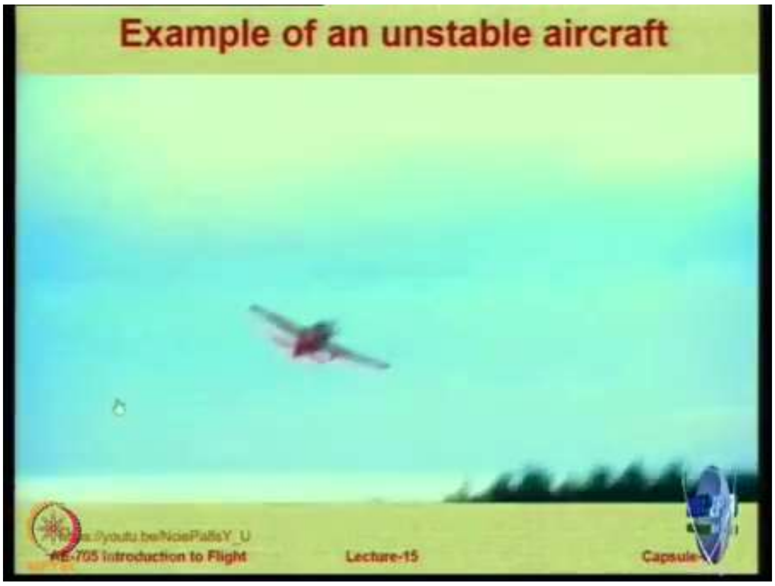
Capsule


Example of an unstable aircraft
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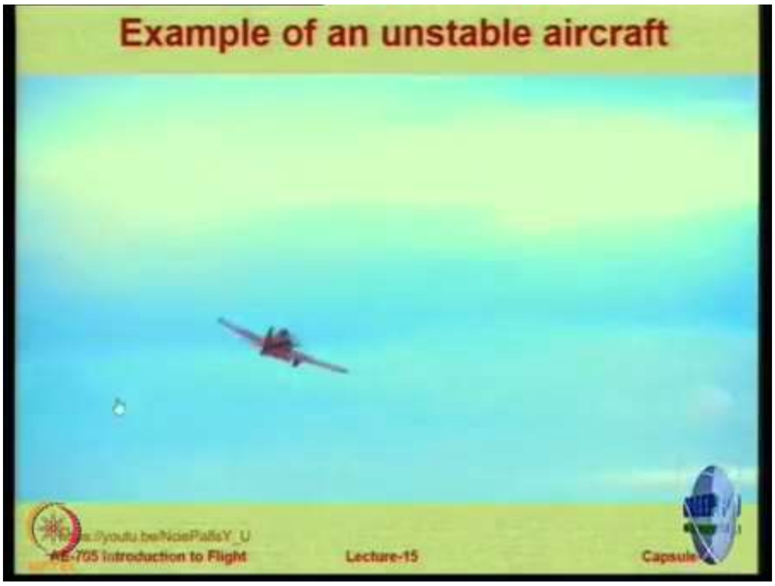
Capsule


Example of an unstable aircraft
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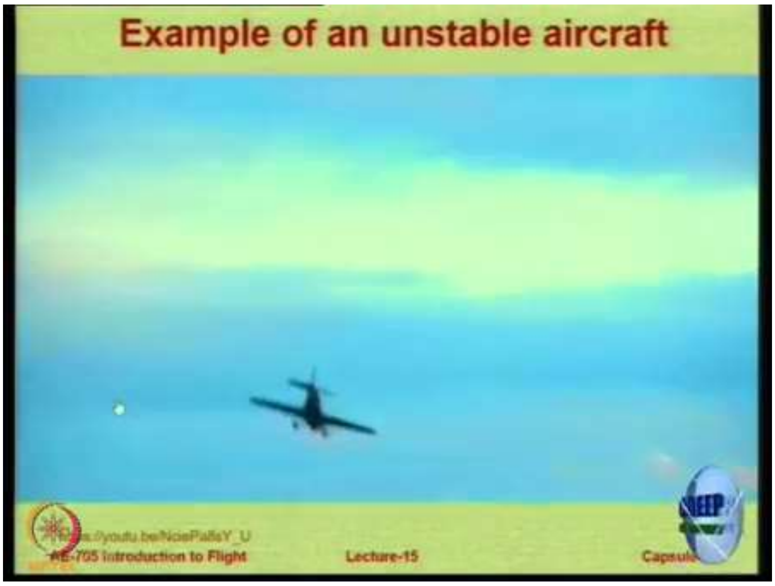
Example of an unstable aircraft
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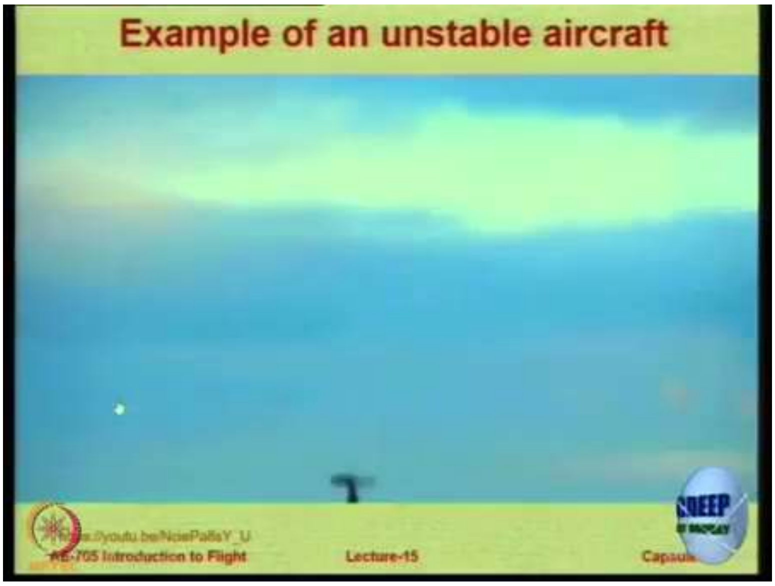

So, I will give you an example a small video clip which shows the behavior of an unstable aircraft. This is a remotely controlled aircraft. It takes off go then to nose up some disturbance comes, gone. If this aircraft was statically stable then when the pitch down moment came because of the disturbance, it would not have just gone down, okay. Let’s see, once again observe the motion of the aircraft. So, take off his fine, it lifts off some disturbance. We cannot see there is some disturbance, but after that no way of recovery on its own. So, if the pilot of this aircraft was highly skilled and very quick in reacting he or she could have avoided a crash. When the aircraft is pitching down he could have quickly put the elevator and made it pitch up so you can control an aircraft which is statically unstable.

This is what the Wright brothers did when they were flying the first aircraft Wright flyer. It was inherently unstable, but they were making it stable or they making it fly by very skillful flight controls. Okay, but you can expect that from every pilot. And therefore, we want to make the aircraft sufficiently stable. If you make it too stable than the pilot has to really work very hard to do any control. That's also not desirable, okay.

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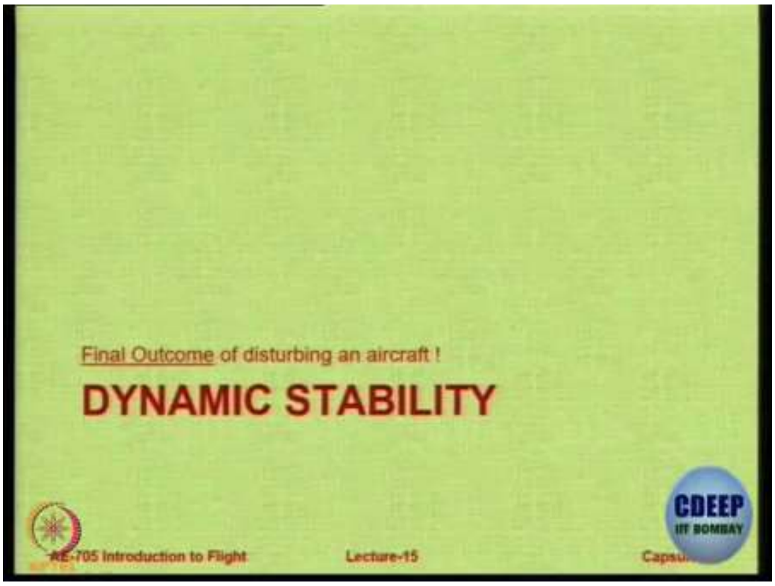

So, we need stability, but we need adequate amount of stability. We do not need the plane to be too stable. And obviously we do not want to plane to be unstable. So, both extremes are bad. So much about static stability. I will just sum of once again static stability is basically only that intention or the initial tendency of the aircraft to respond to disturbance on its own.

If the initial response of the aircraft is such that it tends to come back to the undisturbed position, it is statically stable. If the response is that it does not either come back or go away, it is neutral. If the response is it wants to go further away, it is unstable statically. Now let us come to dynamically. So, where is a static stability, the intention or the initial tendency is the only consideration in Dynamic stability. We want finally the aircraft to come back actually to the original position on its own. So, not just intention, not, just tendency, but actually coming back so the final outcome of disturbing of an aircraft depends on its dynamic stability; the initial response depends on static stability. So, let's see.

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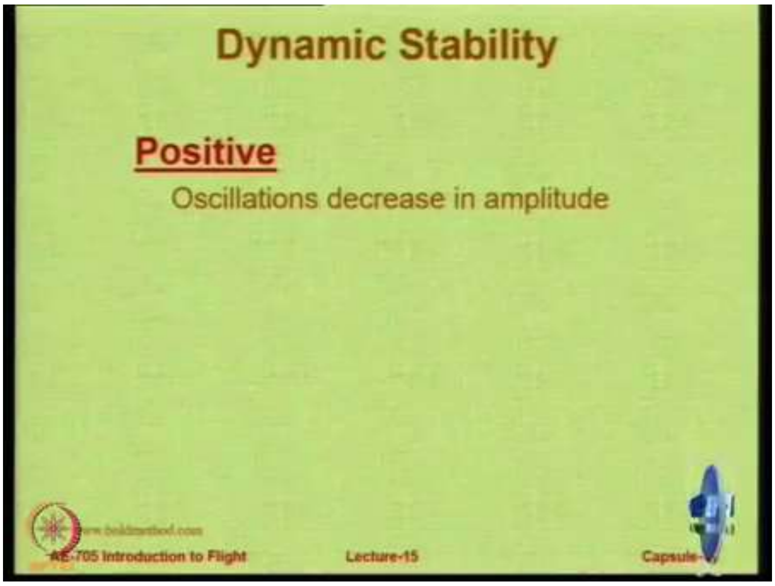

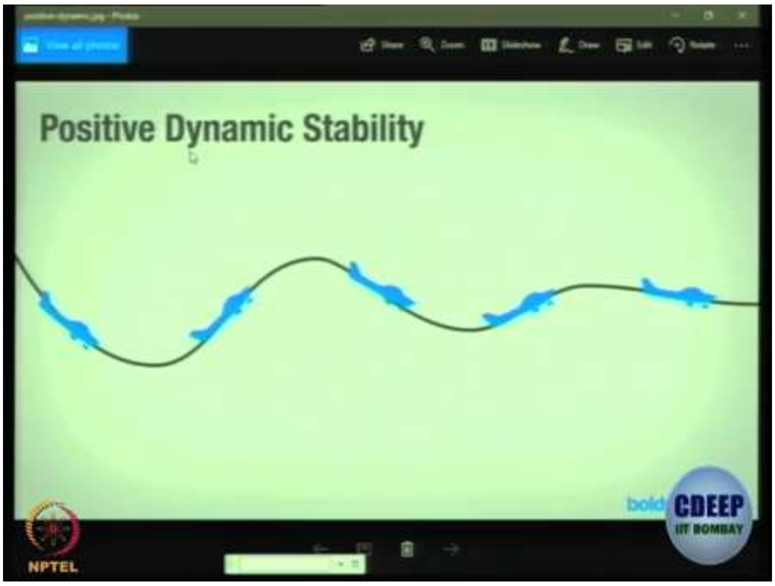

So, an aircraft is going to be positive in dynamic stability, if the oscillations after disturbance reduce in amplitude with time and the extent by which they reduce is the extent of dynamic stability. If the oscillations damp out very fast, it is highly dynamically stable. If the oscillations do not damp out, okay, then it is neutrally stable. If the oscillations increase, it is unstable. If the oscillations damp but slowly, it is less dynamically stable. Okay, so you can see in this case you have an aircraft going level flight there is a nose on pitching moment. So it has to come up that means, it is statically stable but it overshoots again down again up again down finally comes to the original position after a period of time. Hence, it is having positive dynamic stability.

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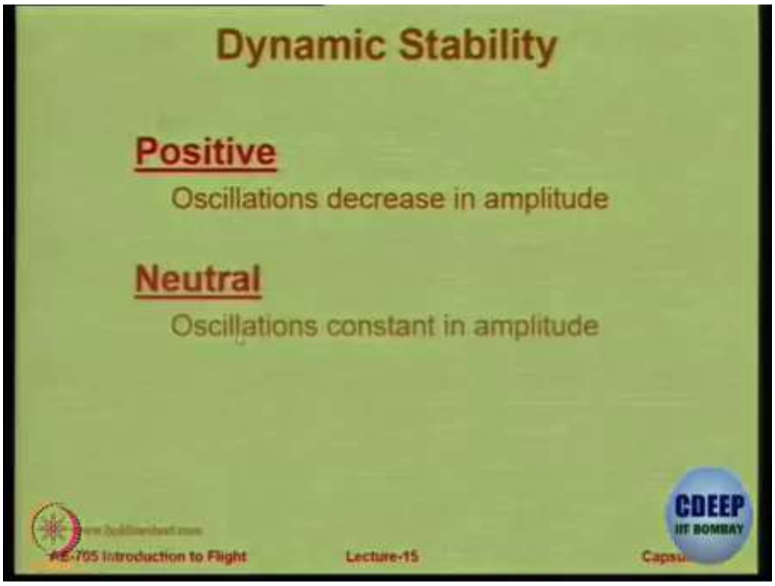

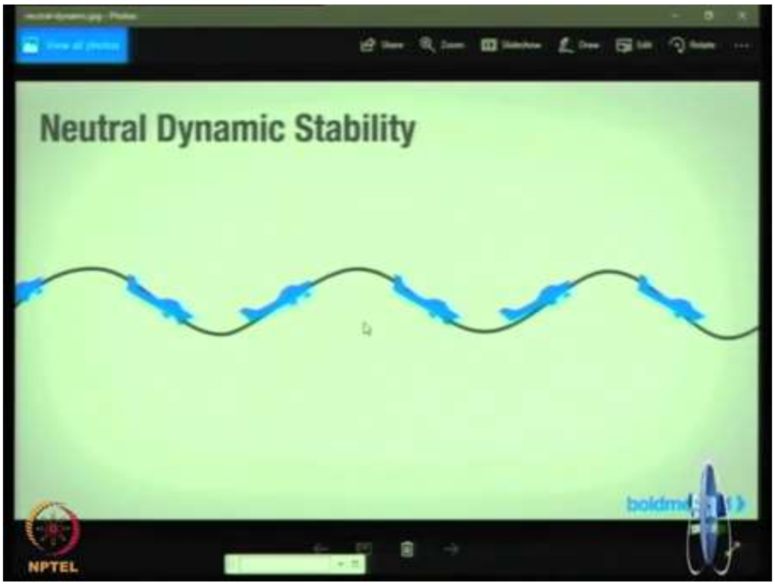

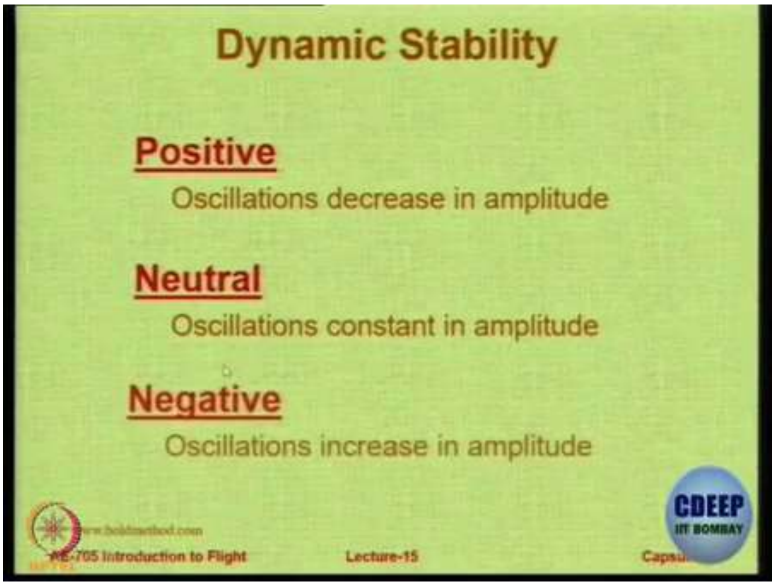

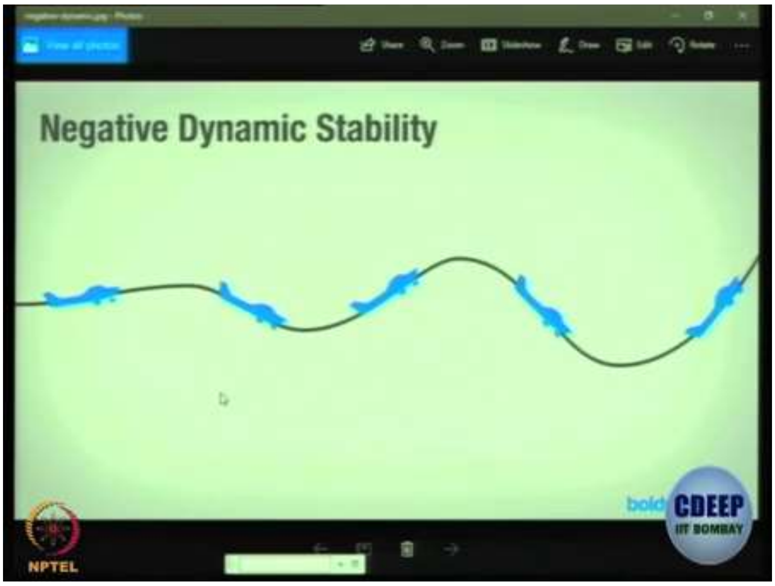

In neutral once again, the oscillations are same in the magnitude in the in the amplitude when you disturb the aircrafts it oscillates, but it does not either come down or go up it remains. This is neutrally stable. It is stable because it is not unstable. That's why we says stable and obviously unstable or negative stability is when, the oscillations are going to worsen increase further with time.

Now how do you control this aircraft? Only by Pilot intervention you can still fly this aircraft but you will need constant and regular pilot intervention. In today's modern aircraft you might be able to control the aircraft by automatic flight control. Which senses the position of the aircraft, senses the moment acting on it and deflects that control surfaces automatically. Okay, so you can do that.

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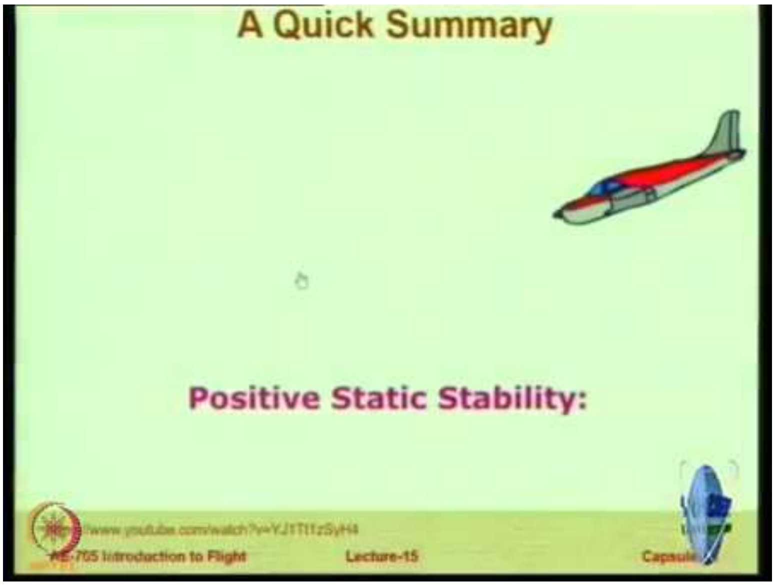

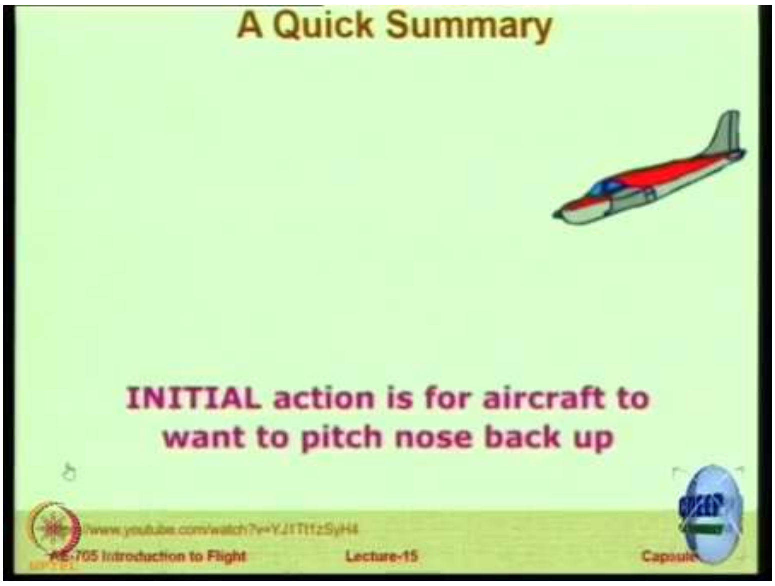
A Quick Summary
INITIAL action is for aircraft to want to pitch nose back up
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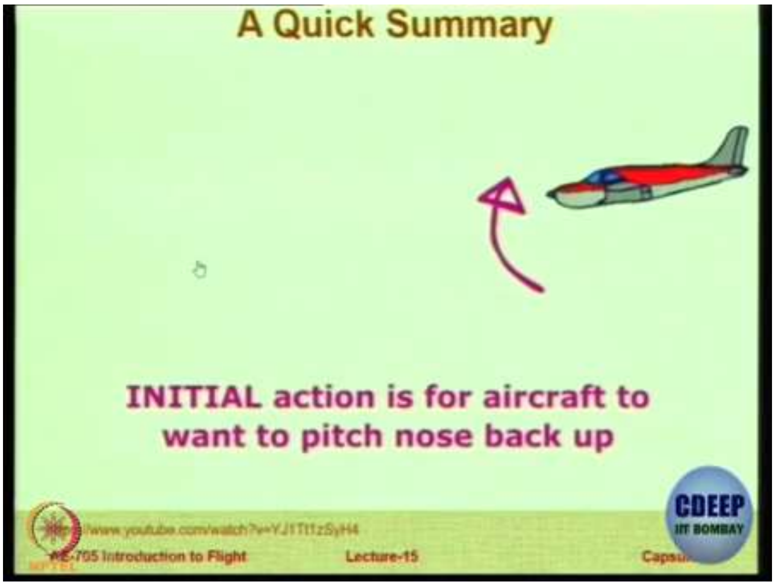
A Quick Summary
INITIAL action is for aircraft to want to pitch nose back up
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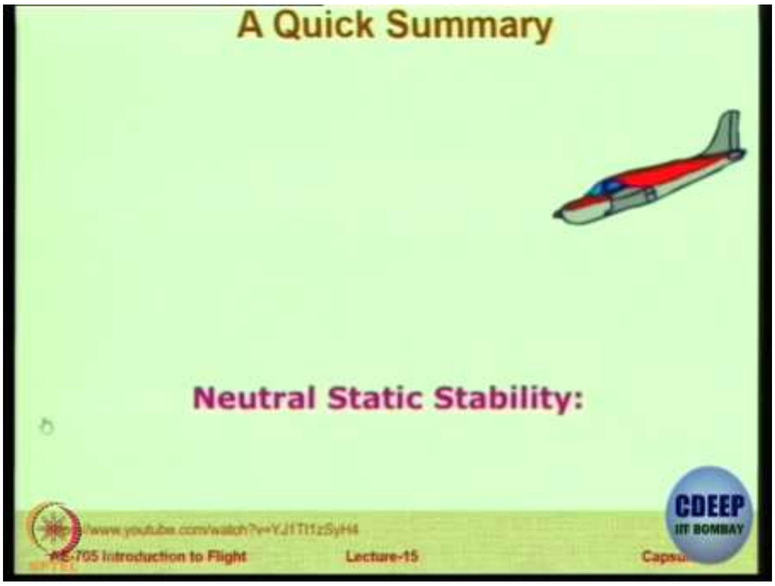
A Quick Summary
Neutral Static Stability:
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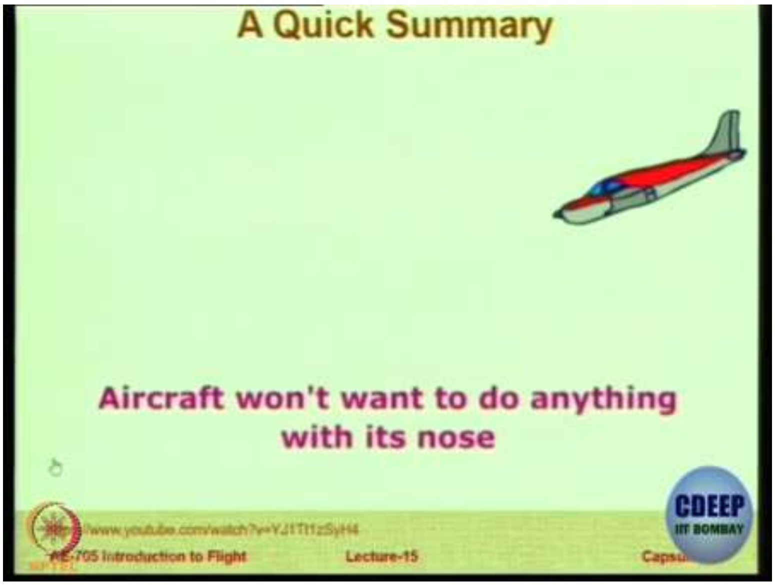
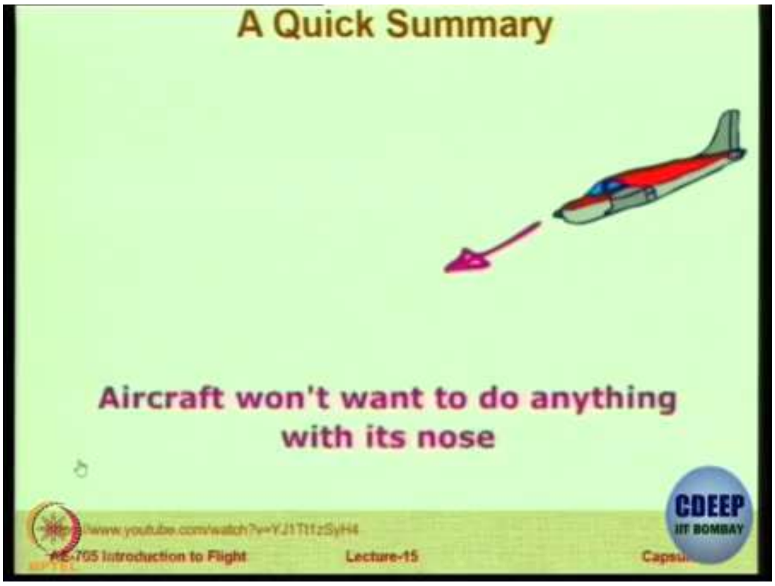

A Quick Summary
Aircraft won't want to do anything with its nose
CDEEP
IIT BOMBAY
AE-705 Introduction to Flight
Lecture-15


A Quick Summary
Aircraft won't want to do anything with its nose
CDEEP
IIT BOMBAY
AE-705 Introduction to Flight
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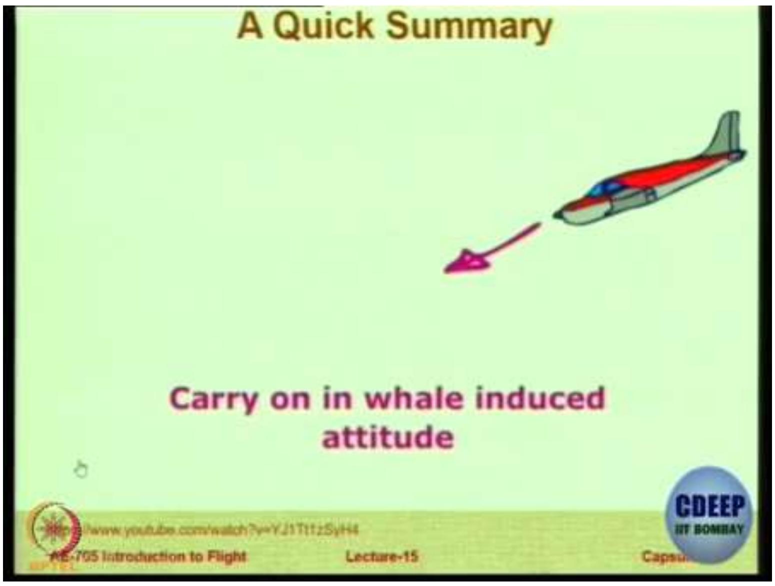
A Quick Summary
Carry on in whale induced attitude
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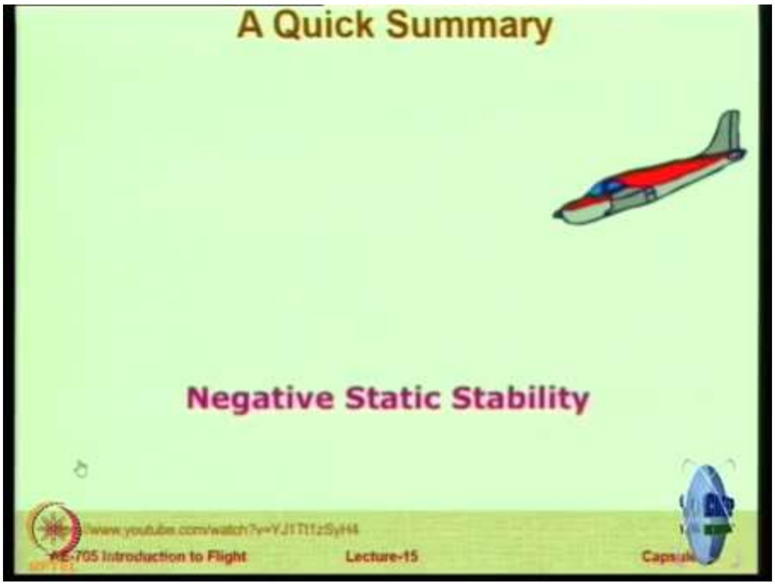
IIT BOMBAY
AE-705 Introduction to Flight
Lecture-15


A Quick Summary
Negative Static Stability
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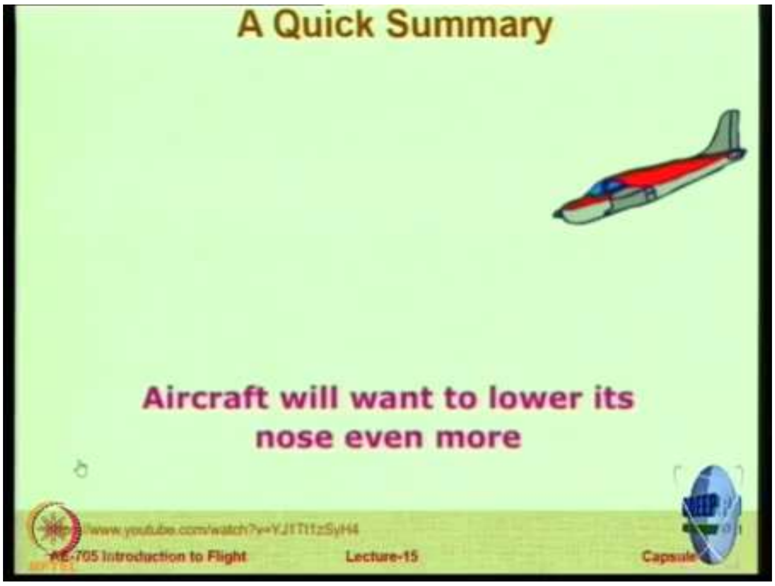
A Quick Summary
Aircraft will want to lower its nose even more
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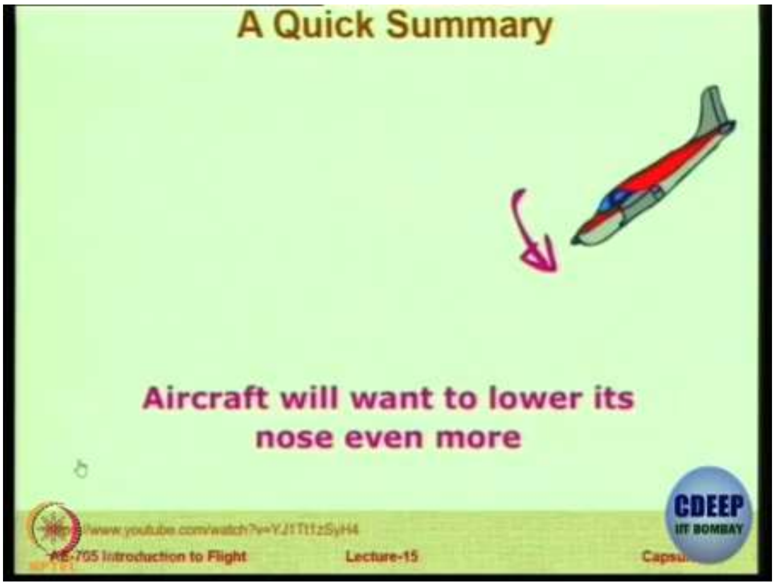
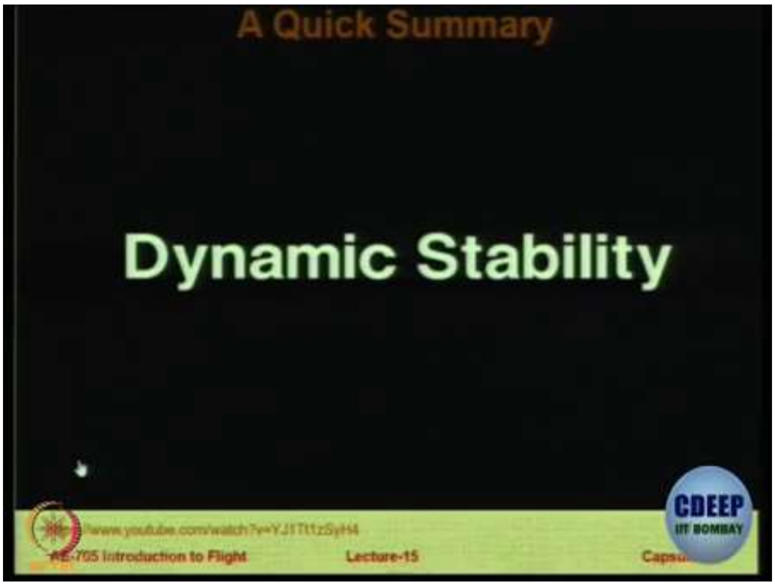

A Quick Summary
Aircraft will want to lower its nose even more
CDEEP
IIT BOMBAY
AE-705 Introduction to Flight
Lecture-15


A Quick Summary
Dynamic Stability
CDEEP
IIT BOMBAY
AE-705 Introduction to Flight
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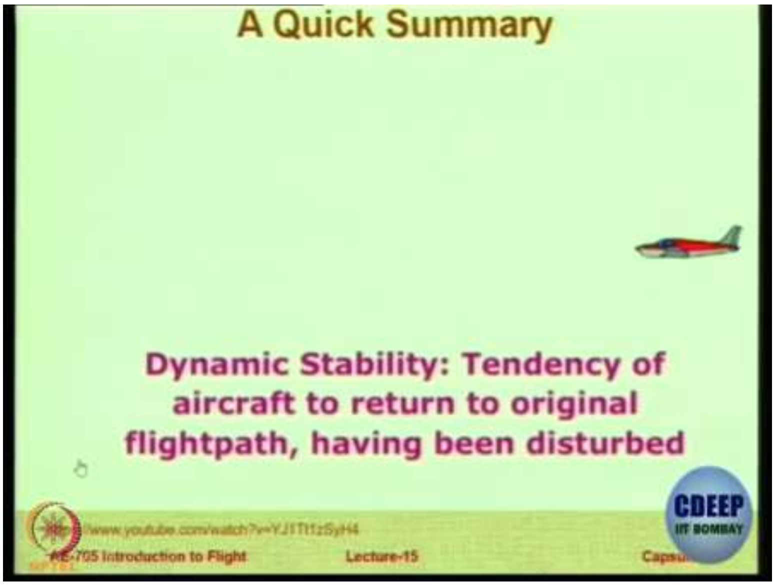
A Quick Summary
Dynamic Stability: Tendency of aircraft to return to original flightpath, having been disturbed
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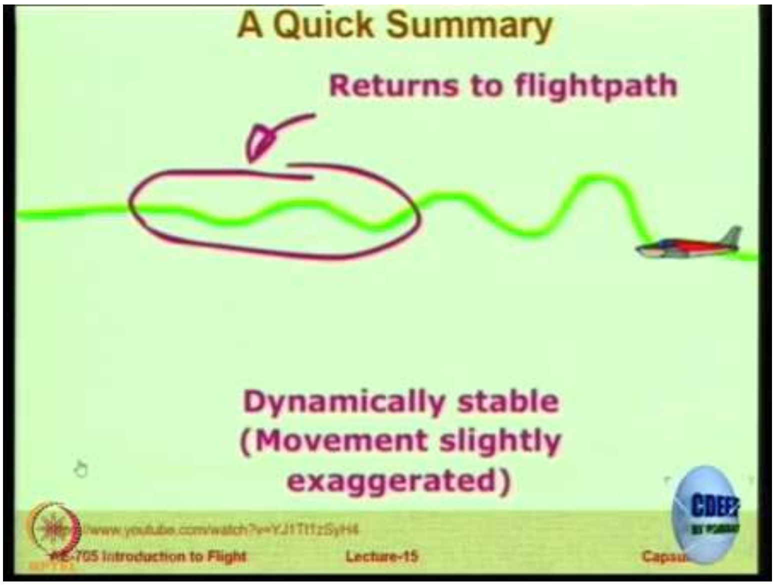
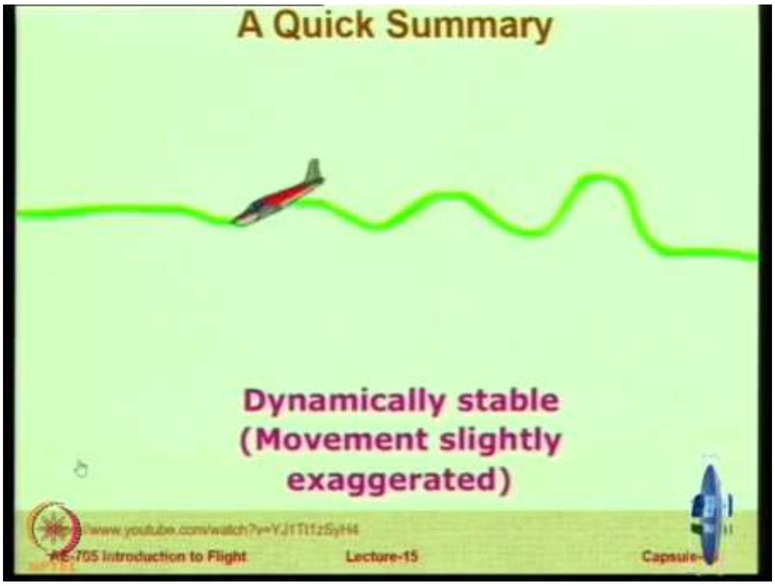
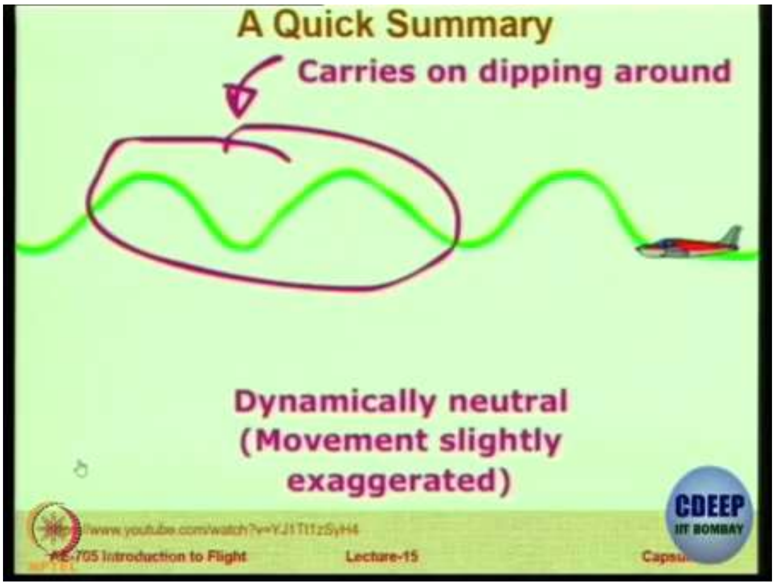
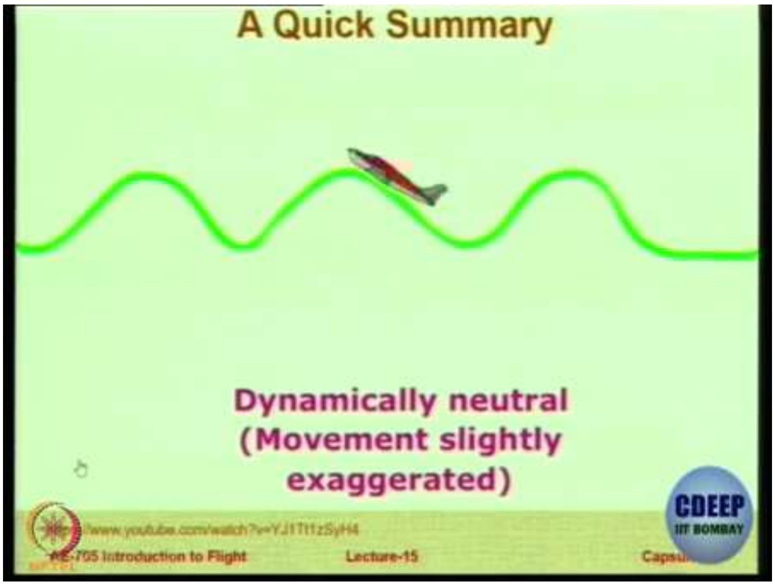
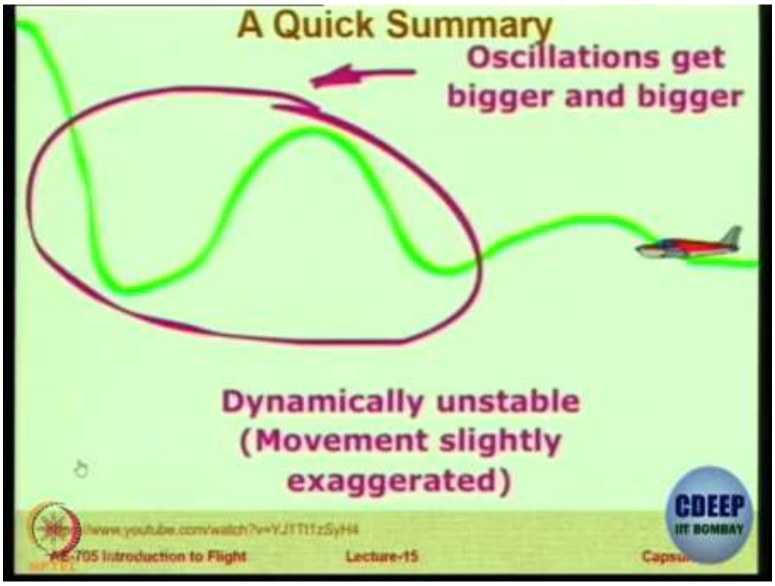
AE-705 Introduction to Flight
Lecture-15

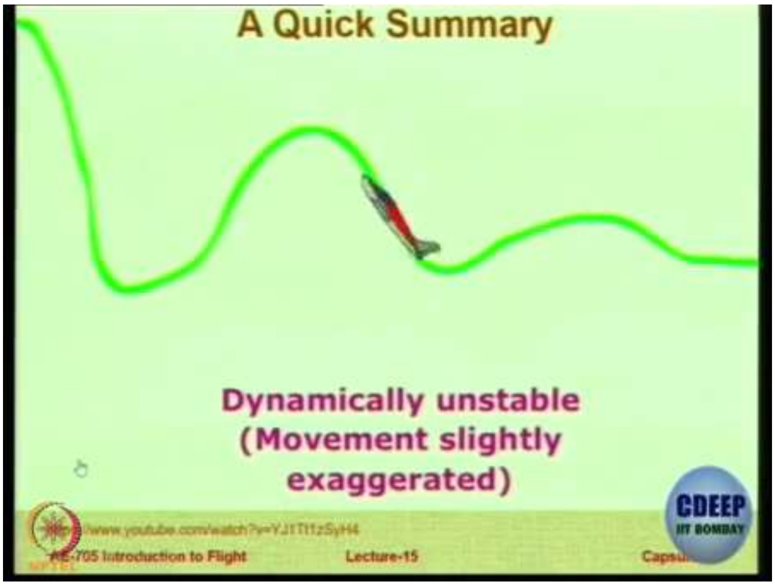

A Quick Summary
Returns to flightpath
Dynamically stable
(Movement slightly exaggerated)
AE-705 Introduction to Flight
Lecture-15


A Quick Summary
Dynamically stable
(Movement slightly exaggerated)
Lecture-15


A Quick Summary
Carries on dipping around
Dynamically neutral
(Movement slightly exaggerated)
Lecture-15
CDEEP
IIT BOMBAY


A Quick Summary
Dynamically neutral
(Movement slightly exaggerated)
Lecture-15
CDEEP
IIT BOMBAY





So, a quick summary is basically given by this small video. You can actually make out by looking

Video: Actually nose down even further, so that is static stability. Dynamic stability is the overall tendency for the aircraft to get back to its initial flightpath. A dynamically stable aircraft will eventually return to the flight path after a few oscillations. A dynamically neutral aircraft will carry on oscillating like some horrendous roller coaster. A dynamically unstable aircraft will carry on oscillating but with increasingly large oscillations, which look probably.

Professor: Okay, so, this is a quick summary. Remember this video on YouTube is actually seven minutes long. So, what you have seen is only a small clip. It's a very detailed video which talks about stability static, dynamic, longitudinal, lateral all stabilities and it gives it is a very very detailed video. I will request you to watch it as a self-study. But our concern right now is only this.

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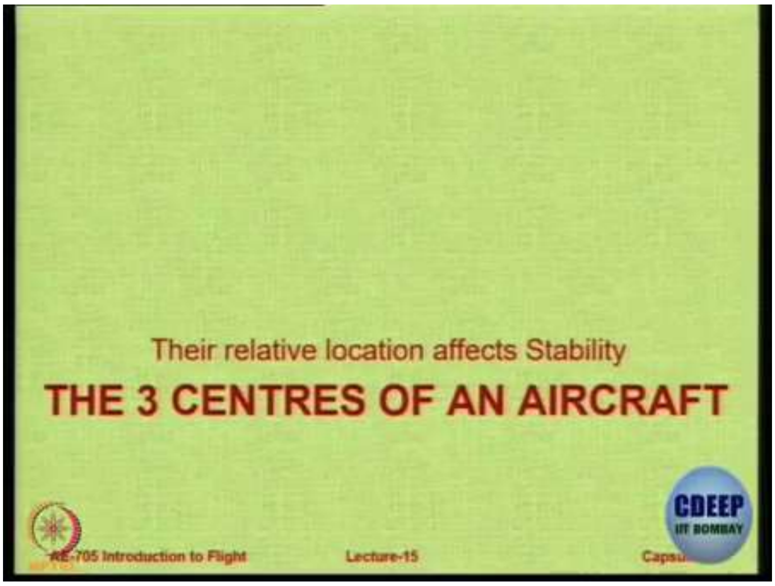

Now obviously when you are going to take part in the competition you would like to have a stable aircraft because you do not have any control on it. It is a glider and you are not remotely flying it nor you are sitting in the aircraft to fly it. Once you throw it, okay whether you use a rubber band to throw or whether you use hand to throw that is up to you. I have not mentioned, but I am allowing you to do anything. But when you launch it, it is gone. After that its behavior will depend only on its stability characteristics. So therefore, you cannot and some people might have got an idea. Let us make the aircraft neutrally stable dynamically. So, that when we throw it will go up and down up and down up and down.

It will spend more time in the air. We might win the endurance flight. Okay, some people have tried this. But try it out at your own risk because, if that does not happen the plane will simply crash. And you will get neither long-distance not long endurance. Okay, so it will be safer for you and a good idea for you to make the aircraft adequately stable. Not too much stable. Now if you want to have a flight of maximum range, actually the aircraft has three kinds of stability; stability in Pitch, stability in roll, stability in yaw. So obviously, you want an aircraft stable in all of them. But our syllabus does not cover the other side of other two types of stability.

I just give you a very brief idea. If you perfectly balanced the aircraft, if both the wings are equal weight or when you hold the aircraft. It does not have a tendency of imbalance. It may not roll. Okay. It may not do this. Remember if the aircraft rolls it will not fly straight because we have seen in the last lecture rolling and yawing are coupled. So, if your plane starts rolling and you do not have any control it will definitely yaw if your plane starts yawing. It is also roll slightly.

So, you have to design your plane so that it does not roll, it does not yaw only then you can throw on a straight line and hit the pillar because any deviation is going to be subtracted. So, what you have to do is from the point of view of your yaw stability? The only thing you can do is when you throw you ensure that it flies straight; it does not have any inbuilt imbalance. So, the vertical tail should be perfectly centered to the if you use one vertical tail.

If you use two of them, then they should be equidistant and they should be perfectly aligned. That’s all you can do and of course a lateral balance, but if you want the aircraft not to roll you have to bring in some roll stability and that I leave it to you how to figure out how to make it stable and roll. But I will teach you today how to make your aircraft stable in longitudinal motion so that when you throw it does not go up and then down, or it does not go down.

It flies fairly straight. Okay, obviously tell me one thing. How will you get maximum range? For a given for a given amount of throwing capacity. What is the condition that you will try to implement? Right, you have to throw it at an angle or you have to make the aircraft at with the wings fixed at an angle so that when you throw horizontally the angle of attack of the aircraft is corresponding to maximum L by D. How do you know that you might get the angle for maximum CL by CD for an aerofoil from the data, but how about the aircraft, so it is not easy? Okay, but at least you should be sure that your aircraft flies fairly straight. So, let’s see how you make to do it. The whole game is basically about these three centers. Okay.

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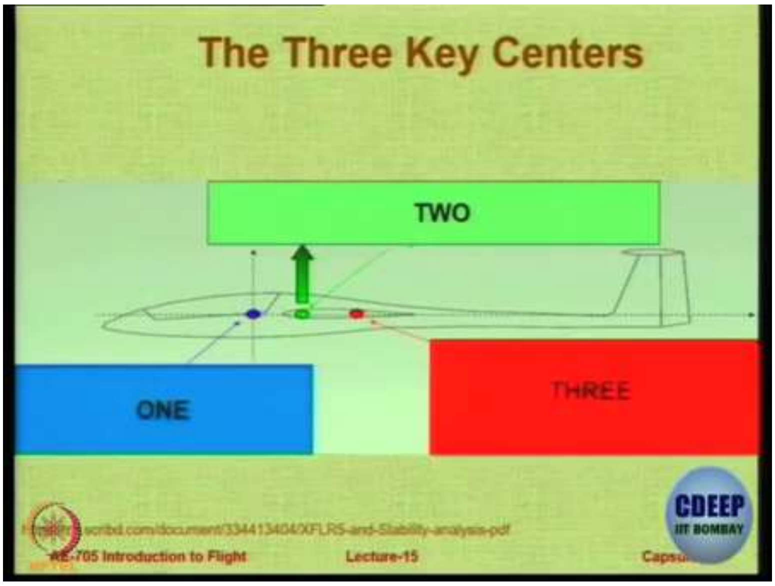

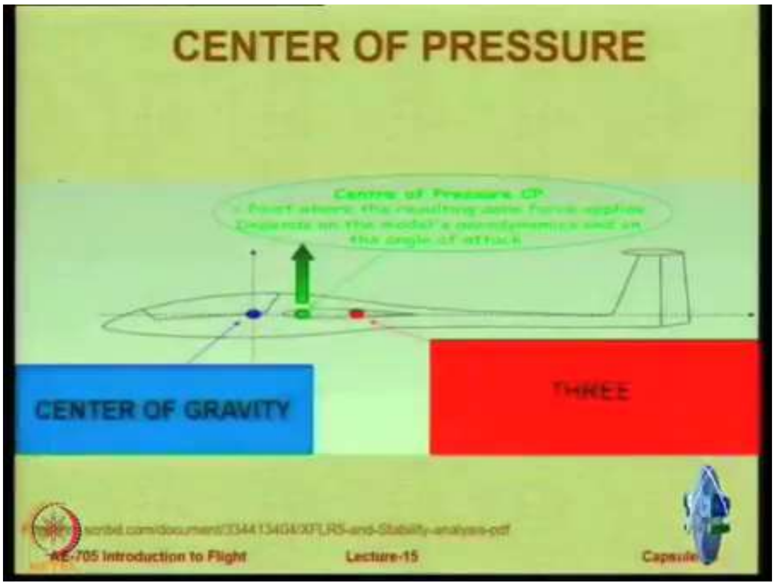

There are three centers in aircraft design and these three centers have to be located with respect to each other in a specific relative position. Okay, so the first one is centre of gravity. The Centre of gravity obviously, you know is the place where the moments on the aircraft are acting because, it's weight act on it. So, normally we take the moments about centre of gravity. One reason is that the heaviest item of the aircraft is the aircraft weight. So, if you balance, you can do about any point, actually, it is not a problem, but normally as a convention, we always balanced moment about center of gravity. So, there is one point now these three locations you do not worry right now. We will very soon see the relative location.

So, this depends only on mass distribution. So, this can be controlled by you. By adding mass, deleting mass, you can control the CG position it does not depend upon the aerodynamics.

Although the shape of the wing will affect its CG, slightly. Similarly, how long is your fuselage? How large is the tail? All that will affect the centre of gravity, what materials do you use but fairly controllable with you. The next one is the center of pressure. The center of pressure is a point where the resulting aerodynamic forces are applied. These forces are the forces of lift and drag and it depends on the models aerodynamics and on the angle of attack. So, now this is interesting.

The location of the center of pressure or the place where the net lift is acting or the net the reaction of the wing is acting that particular point will depend upon two things at what angle you are flying and what are the forces acting on it. Now, controlling the angle of attack at which you fly is very difficult. And even if you throw it my some kind of a launcher, you know one degree, two degree, three degree makes a big difference. So, it will be necessary and interesting for us if we can somehow remove the dependency on the angle of attack. Would it not be nice if the aerodynamic forces and moments could become independent of the angle of attack. So, one variable gone. Okay. So, let's see what it is.

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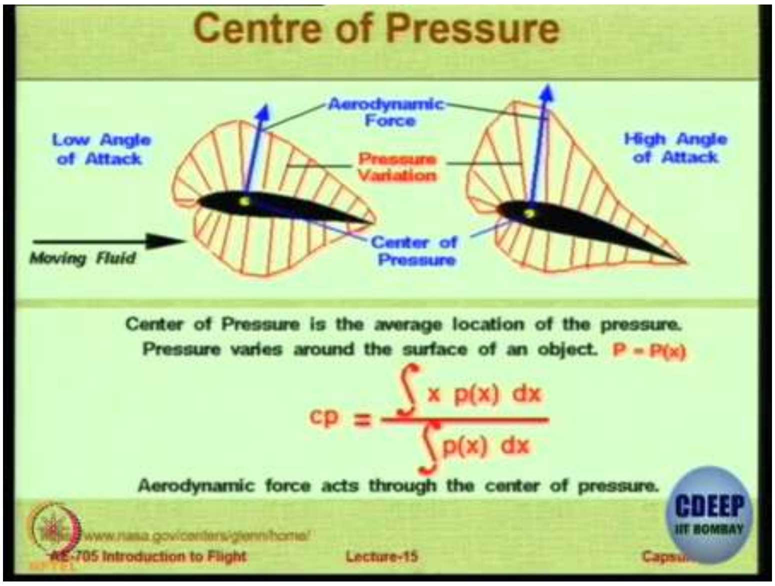

The third important point is called as, so let's see now the center of pressure. Centre of pressure, you know, it's going to change so it depends as I said on the aerodynamic force; it changes the angle of attack. So centre of pressure is the average location of the pressure it varies around the object and numerically, if you want you to take the integral of the elemental force acting on some elemental pressure acting on the specific on small areas into the distance from the nose or a relative Point upon the sigma of the pressure. Okay but this is not of much use to us because it changes in the angle of attack.

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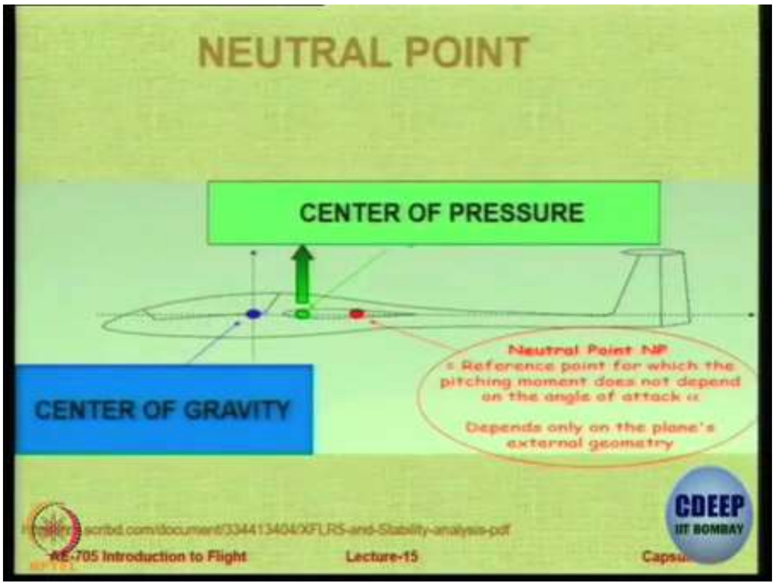

Okay, then we have a neutral point, the third point. This is a reference point for which the pitching moment does not depend on the angle of attack. Right, and this depends only on the aircraft geometry. Not only on aerodynamics, not on the center of gravity, but only on the external geometry.

Again, this is the point which is very difficult to determine is difficult to do calculations and say I calculate and hence and P is here, Okay. So, the location of center of pressure or aerodynamic forces is not in your control. It depends upon angle of attack, depends on what speed you throw and the aerodynamic coefficient of your aircraft. So, you might copy an aerofoil very accurately. But how do you do the calculations for the fuselage, for the tail etc is not easy. Interestingly, individual values are not important. The relative location is important, okay.

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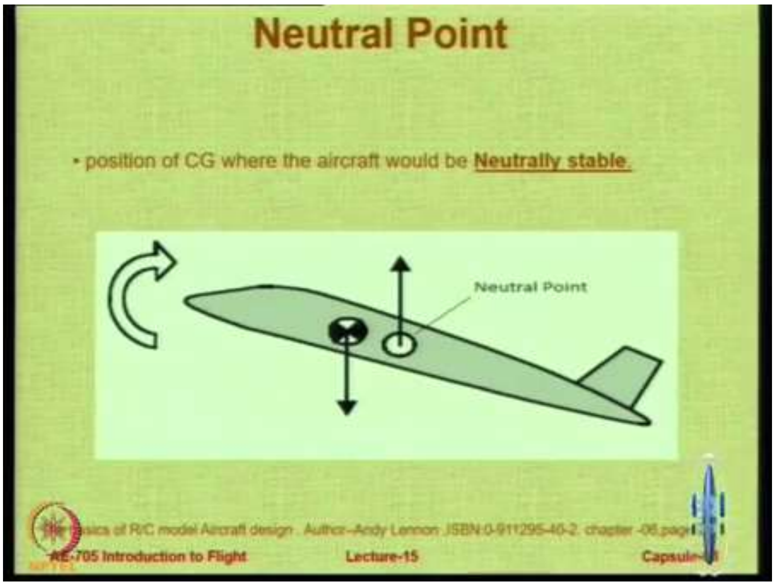

So, the neutral point is another good definition of that would be, it is that place if the CG comes a neutral point the aircraft becomes neutrally stable. So obviously, if it goes behind it will be unstable, which you do not want.

But are you okay with a neutrally stable plane? Are you okay? No. No, because a slight discomfort or a slight miscalculation will make it unstable. So, it’s better to be in the stable domain, but do not make it too stable because then it will not be recovering. Okay, so there is a very good book by an author call Andy Lennon on the basics of remotely control model aircraft design. We have a copy of this book in our departmental library. It is also available in The Institute library and soft copies are available online. So, I recommend for those of you who are serious about designing your plane. It is a very good book to give you basic ideas. It also contains some sample designs which are good. Well flying glider design so you can actually borrow from there. You can copy from there.