Introduction to Flight
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Lecture 51: Number 10.2
Aerodynamic Center and Effect of Center of Gravity

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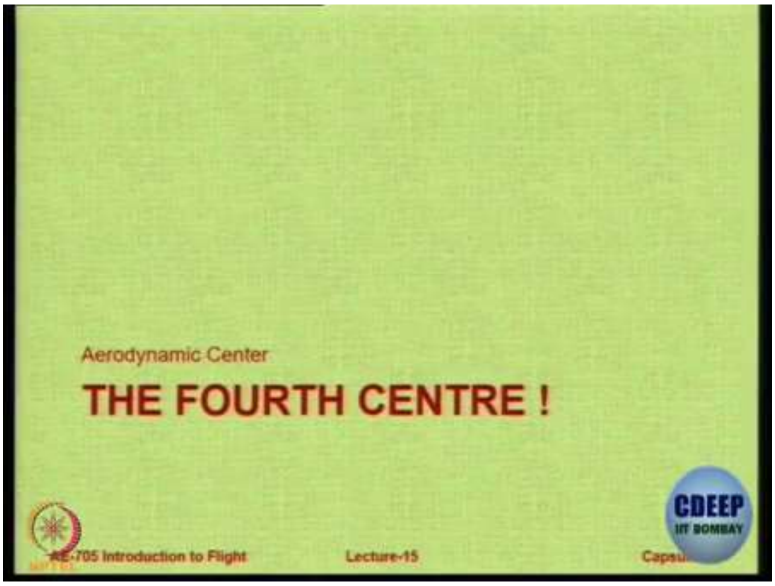

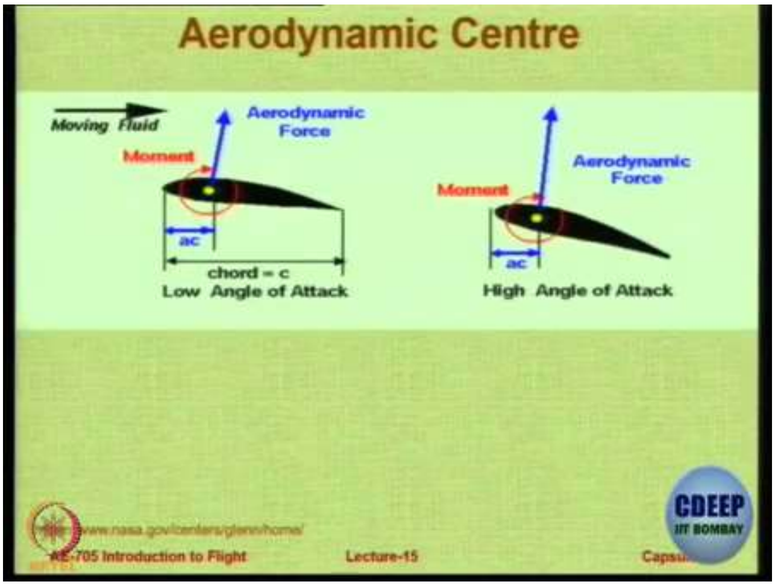

But we have now a fourth centre also and that is the Aerodynamic Centre or the AC as we call it. So what is this AC? AC is basically a theoretical point. It is not a practical point it is a theoretical point. Such that the effect of angle of attack or the effect of the aerodynamic moment on the angle of attack is removed. So the aerodynamic movement remains same at all angle of attack about the aerodynamic centre. Centre of pressure moves then it moves back. If you have a flight which is supersonic it may even move forward, because it is a function of pressure distribution; but now we are not bothered.

Whatever be the pressure distribution there is some lift, there is some drag, there is some moment. So the moment does not change about the aerodynamic centre. So at all angle of attack you have the same moment. So that is a beauty of this theoretical centre called as the aerodynamic centre. Interestingly, if you take a flat plate or a very thin aerofoil the approximate location of this particular place theoretical place is one fourth of the chord. So if you want to do a very quick and simple design and if you want the aircraft to fly, you should try to adjust your centre of gravity near the quarter chord of the wing, because that is where the aerodynamic centre is.

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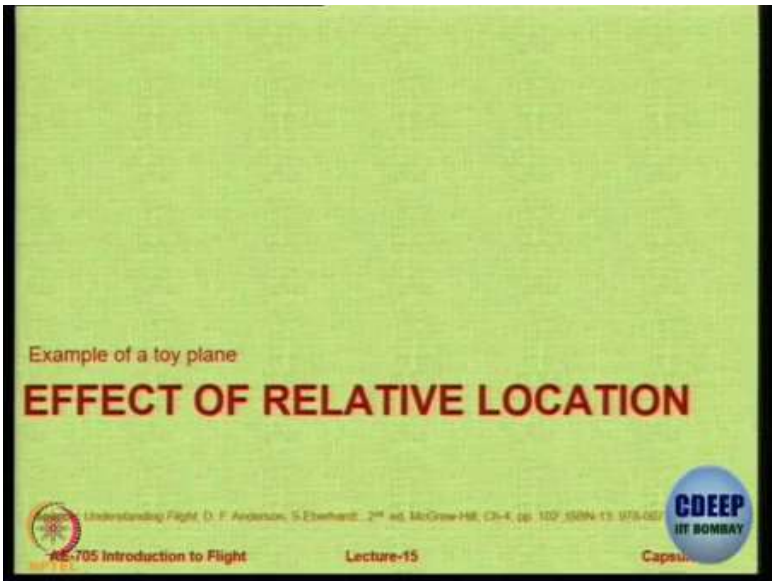

Now I will show you how to decide the exact location. So we will take a toy plane. I will be I will be doing I will be doing two experiments in the class. One is not an experiment, but demonstration using only sketches. A toy plane. So these are basically figures, taken from a textbook and this textbook by the way, a very interesting textbook by professor Eberhardt and Anderson. Professor Eberhardt was a visiting professor in our department for one semester in 2011. He worked the Boeing company for many years, then he joined Washington University and then he now travels all over the world taking up assignments as a visiting professor. So he has he was in Spain, he was in Australia. Now he has gone to some other location. Ok!

He has written a very nice book along with D.F.Anderson. This not the same Anderson that you know. This is some other Anderson. So Anderson and Eberhardt, one of the best books to understand the basics of flight. In my opinion even far better than Anderson. Available online, just by a simple Google search. Copies are available. In fact I have a autograph copy also by professor Eberhardt, but we have in our departmental library as well as in the main library. I recommend all of you to go through this book. And I borrowed this particular example from his textbook using a toy plane.

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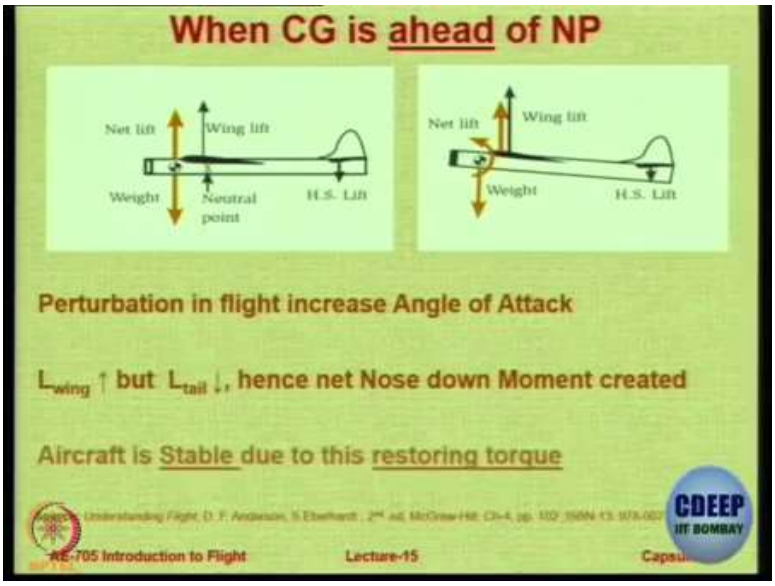

So here is a toy plane. Now this toy plane assume that through some magic. I am throwing it in the air and it is in equilibrium at some condition. And now some disturbance acts on it, because of atmospheric disturbances whatever. And there is a nose up pitching moment. Before we go ahead let us first look at the forces acting on this aircraft. So as we see the point marked by cross is the neutral point. How do you find it? You cannot find it. It is not easy to find it, but it is there. In this example as is typically the case, the lift of the wings acts slightly ahead of the neutral point. The centre of gravity is far ahead. So centre of gravity is far ahead of the neutral point.

Now what will happen tell me? So tell me why do we have the tail loads and the in the way it is shown. So take moments about centre of gravity. Lift alone, is going to give you a nose down pitching moment, but I said the aircraft is in equilibrium. Therefore the tail has to carry a down load. Now why is the load on the tail much smaller? Because it is far away from CG. It is the moment that is important not the force. Because we are trying to take moments about CG. So this aircraft will fly in a trim condition only when the moments about CG are zero. So in this condition the lift force into that distance is equal to and opposite to the tail force and the tail distance of the tail aerodynamic centre from the centre of gravity. So something like LW into

XW equal to LT into XT and there is no net moment. So therefore about centre of gravity you have some net lift which is the brown vertical line which is the lift of the wing minus tail. And the total weight of the aircraft W. They are both equal, balanced, opposite and hence the aircraft is in trimmed horizontal flight.

Now for some reason there is a perturbation in the flight because of which the angle of attack increases. What will happen? As the alpha increases and if the alpha is below alpha stall, then the lift will increase. So as the angle of attack increases the lift is going to increase. So the nose down pitching moment is going to be created because of the delta L. But what will happen to the angle of attack of the tail? If the aircraft was at some angle in trimmed condition and the tail had negative load that means tail was deflected little bit down. And now the alpha is increased, what is going to be the angle of attack of the tail? It is going to decreased little bit. So if it decreases, its lift will not remain the same.

Therefore the tail down moment created by the tail will be lower than the nose down moment created by the wing. So we distort the aircraft. We created a angle of attack which means the nose went up. But the nose will come down, because the nose down moment is more than the tail down moment. So what can you say about this aircraft? This is positively stable or stable. But we can only comment on the static stability. We do not know what will happen in the end? But at least the tendency is to come down. In other words, when the centre of gravity is ahead of the neutral point then we have a situation when the aircraft is stable.

Now one more question I want to ask you. Suppose I move the centre of gravity further, by adding a weight in the nose. Now what will happen to the aircraft? Will it become more stable or less stable? Who will answer this question? More stable, less stable, none of the above unstable I do not care. You can. I do not want to hear I do not care. Tell me will it become more stable or less stable. More stable. Why will it become more stable? Because the nose down will be further, but remember even the tail also will have a longer tail arm. But the numerical value of the lift is far more than the tail. So if you give more moment arm larger force with that delta X will give you more moment than a smaller force with that delta X. Agree, Manikandan not happy. Ok!

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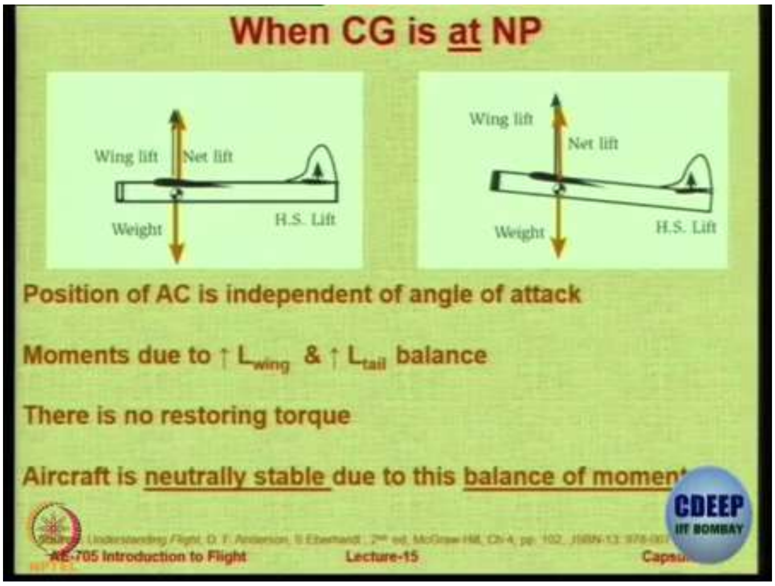

So if you move CG forward it will be more stable and more stable and more stable correct. Let see now when CG is moved behind and it is at neutral point. It is at a neutral point now. So when the CG is at neutral point, the wing is still such that it is lift will acting slightly ahead of the CG. Now it is ahead of the CG because the location of the lift on the wing is a function of the wing geometry and the wing location and we are not change the wing location. I did not move the wing behind I just move the CG behind. So the wing lift will now give you a nose up moment and the tail has to have up load to cancel that because I am saying thta the aircraft is flying in a steady level flight in this condition. So when the CG is at NP and the aircraft is still in stable flight now the position of aerodynamic centre does not depend angle of attack ok so it remains the same place. So as the angle of attack increases lift on the wing will go up but the tail lift will also increase and because it is neutrally… because the two moment are going to balance your CG is at neutral point therefore there will be no restoring torque. So therefore this aircraft is neutrally stable, because the moments are balanced. As alpha increases it increases both for tail and for the wing.

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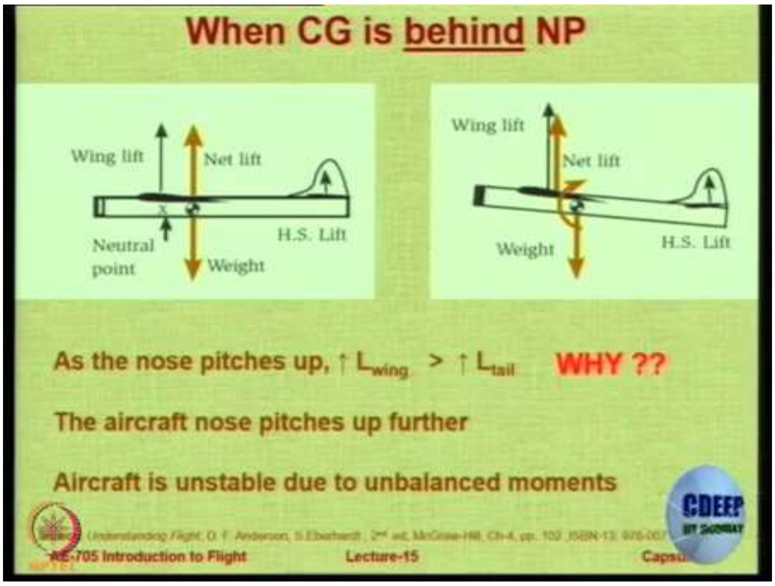

Now let us look at the situation when the CG is behind neutral point. So now when the nose pitch is up the increase in the lift on the wing will be more than that on the tail. You have to tell me why? Why will the delta L wing be more than delta L tail both will increase because alpha has increase but why is it so that change in the lift of the wing is more than the change in the lift of the tail. Let me give you a hint, suppose we assume the same aerofoil for both, because the aerofoils can be different. So just to remove that confusion both have the same aerofoil. Therefore the dCL by d alpha is same. Change in the CL with change in the angle of attack is same. So it is not because of any change in the lift coefficient.

Professor: What is a reason?

Student: Sir

Professor: Because the.

Student: Surface area of the aerofoil shape….

Professor: I would like to hear not surface area but reference area. Yeah yes that is one reason wing is larger in size. Reference area is larger. Any other. Any other reason. Take a theoretical case when both have the same reference surface area. Still I will say wing has going to have more. The reason is actually the aspect ratio of the tail is normally kept lower than that of the wing and because of that also you will get higher value. Fine.

So when you have larger lift from the wing then the nose will pitch up further. So now you will not have restoring moment you will actually have imbalance moment. The nose of the Aircraft has gone up it will tend to go up and tend to go up and tend to go up. Therefore the aircraft is unstable.

So it is very straight forward. The relative location of the centre of gravity and the neutral point is what decides the stability in longitudinal direction. If CG is ahead of neutral point, aircraft is stable. At neutral point neutrally stable. Behind neutral point unstable. The further behind, more unstable. The further ahead more stable. But we forgot there is another position the third centre is there.

Yes you have a question.

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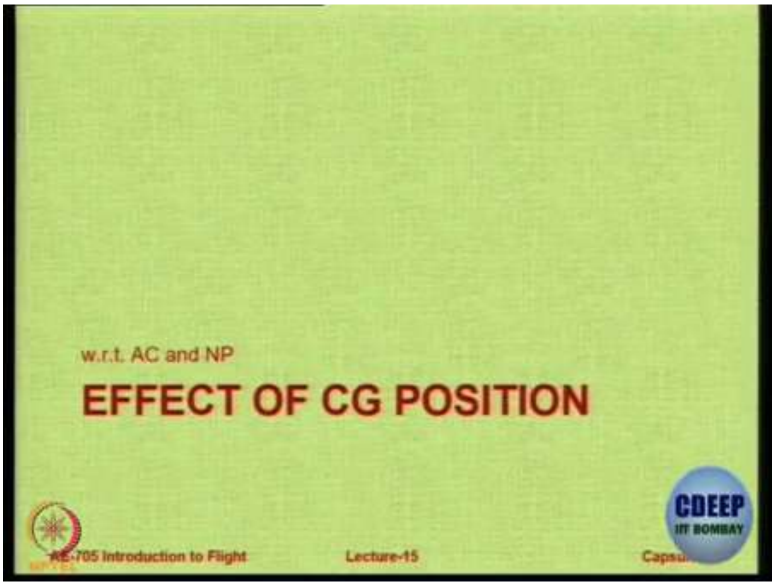

Neutral point is a theoretical point. It is difficult to explain it as a physical quantity like centre of gravity we will say Oh! where the net weight acts. So it has a physical significance. Centre of pressure there is a physical significance that is the centre of the pressure which acts but aerodynamic centre and neutral point do not have any physical significance. These are some theoretical points. So you you can just assume that there is a point called as neutral point. Its location depends on the geometry of aircraft. Such that if the CG has is at ahead of that point the aircraft is laterally dynamically sorry longitudinally stable. If the CG is behind it is unstable. If the CG is exactly there it is neutrally stable. This is how you define neutral point. There is no other significance.

Similarly aerodynamic centre is a theoretical point, at which the moments are going to be the same at any angle of attack. Lift and Drag forces will change. Yes it is location on the aircraft but you cannot say you can calculate it in this manner. CG you can calculate. You can say take any point, take moments ahead, take moments behind. This is more move move move move move still moments are equal. But aerodynamic centre and neutral point are not such quantities. They are derived quantities. Is it answer of your question?

No that is not the reason. The reason is the third one which we are going to come now. The aircraft is stable depending on the relative position of the CG and neutral point. CG ahead stable CG behind unstable. But it assumes that the aerodynamic centre is between the CG and Neutral point. If the aerodynamic centre is ahead of CG or behind neutral point the things go where so that is why we need to now look at the location of the aerodynamic centre also.

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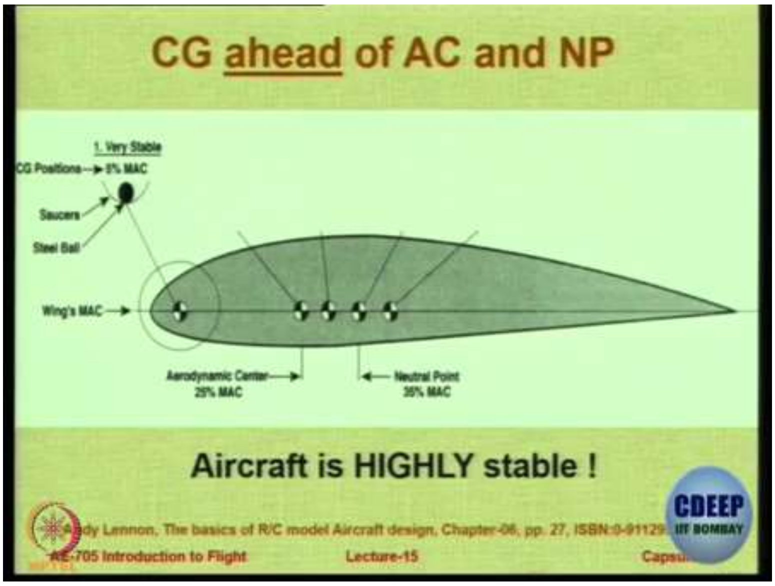

So the first one is CG ahead a neutral point and ahead of aerodynamic centre that is the point which has circled. Now location of centre of gravity of the aircraft by the way this not about wing centre of gravity. This is the aircraft centre of gravity. Interesting point, so typically the centre of gravity of the aircraft lies somewhere on the wing. It will be rarely a situation when the centre of gravity of the aircraft is behind the wing and ahead of wing. It's on the wing somewhere. So what we do is the centre of gravity location when I says when is say CG location I am talking only about longitudinal. All our discussion is only about longitudinal. No lateral and no roll right now.

So the longitudinal CG location of the aircraft is somewhere on the wing. So normally we expressed it in terms of the percentage of a term called as the mean aerodynamic chord. What is a chord u know, chord is the distance between the nose radius and the tail radius. Correct. Or the tail junction but the wing is not always of the same chord. The chord can reduce. It may even increase. There are aircraft in which the chord at the centre of the wing is less than that the tips. Have you seen such an aircraft? There are. So why do not you locate and put on moodle. Picture of an aircraft in which the root chord is less than the tip chord and not just search explain why?

Is there an advantage of doing that because nobody will build an aircraft with the configuration unless in some advantage. So this is a interesting assignment find out aircraft where the tip chord is more than the root chord and explain the reason. And why do not we see it very often? Why do we typically see that the tip chord is equal to root chord and less than the root chord? So therefore in general the chord changes along the span. So therefore we define one particular chord called as a mean aerodynamic chord. It is not a geometric mean but it's aerodynamic mean. There is a formula now that goes into aerodynamics will not get into that assumed that there is some way to calculate mean aerodynamic chord

So the centre of gravity of the aircraft you are going to locate along the mean aerodynamic chord at some location. So we normally called it as percentage of MAC. Five percent ten percent fifteen percent twenty percent. Please understand the mean aerodynamic chord may be larger than the chord and the root or smaller we do not know. So this is just an illustration. So to avoid confusion assume that the aircraft has got the same chord throughout. A rectangular wing no confusion. Now the MAC is equal to C at the root. So the CG will be located at some position we measure it in terms of the percentage of the MAC.

So there are some examples here five percent twenty five percent thirty five percent forty percent forty five percent. And we want to see what happen. So the first one is if the aerodynamic centre which is typically at quarter chord not always but typically at quarter chord. And if the CG is at five percent of MAC, then the aircraft is very very stable because the CG is far ahead of the aerodynamic centre. Neutral point is behind we do not know where it is right now. But the aerodynamic centre also it is far ahead. So this condition is a condition where you have soccer and a steel ball exactly at a centre highly stable. Undesirable not desirable.

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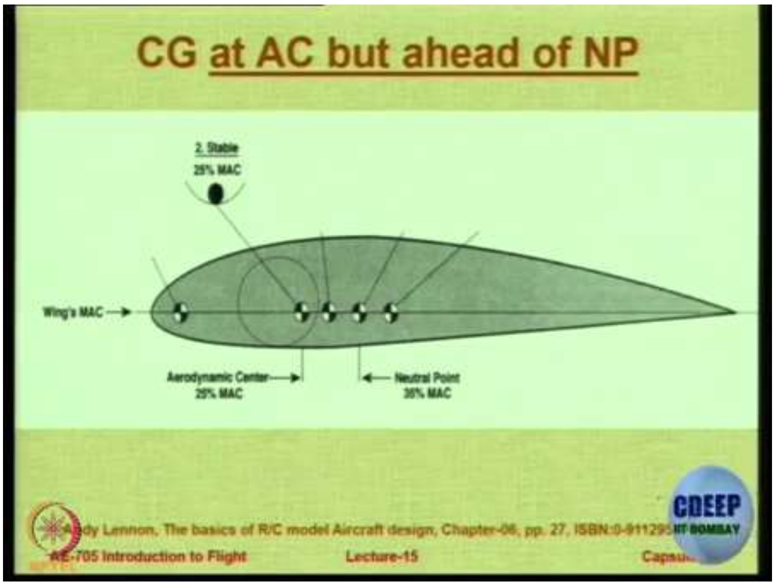

Then we have CG at aerodynamic centre. So progressively we will move the CG behind. First for five percent now CG is at twenty five percent. It is above aerodynamic centre or at aerodynamic centre neutral point is behind. In this example neutral point is at thirty five percent of MAC. Just happens to be you do not know how to calculate it it happens to be. So what will happen now will the aircraft be stable unstable neutrally stable, stable. Sure it is stable. Why it is stable? Because ahead of the neutral point that is it. It is stable and this my friends is a very desirable location for the CG of your aircraft approximately quarter chord. Ok!

Let’s move it behind the aircraft moves behind aerodynamic centre but still ahead of aerodynamic still ahead of neutral point.

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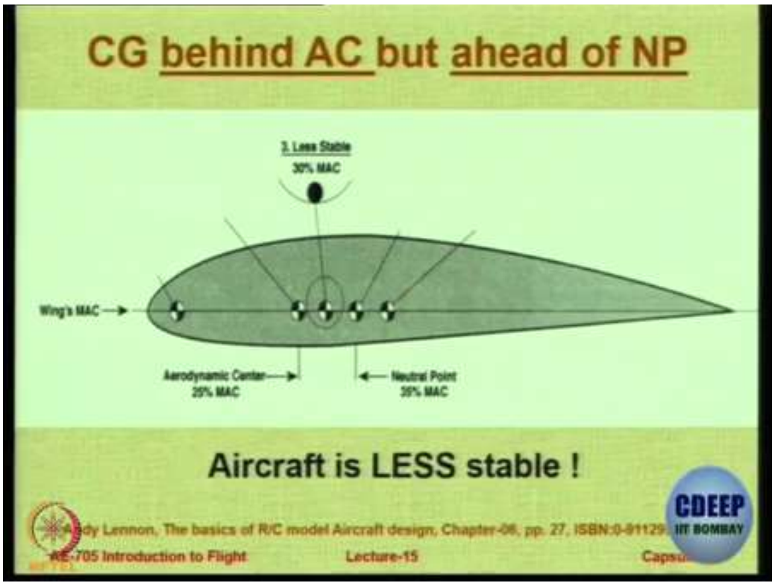

The aircraft is stable because NP is still behind but the level of stability is now reducing because you are moving toward neutral point. The moment you go behind aerodynamic centre your CG is going to be your stability is going to be less. For you and your glider it is undesirable condition. Your glider will still fly but not fly well. It is less stable but still stable but less stable.

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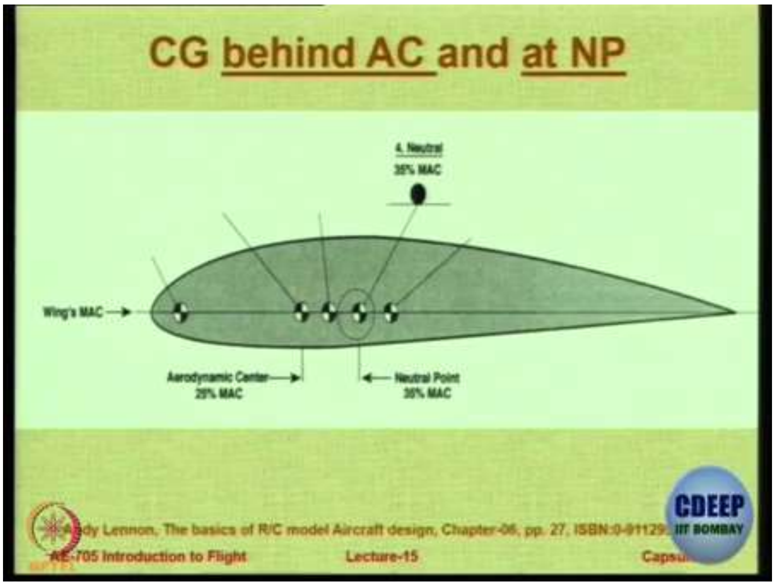

Now let’s say take the CG behind AC behind AC at neutral point, it will be neutrally stable. Now this is the most rear position of CG which is acceptable for flight. I would say we do not want to go so back. In a practical aircraft we never fly at neutral point even near it. We are sufficiently ahead of it but behind this is disaster. Ahead of this is better. Best will be at aerodynamic centre. But here it is neutrally stable. Once you go behind then you are unstable.

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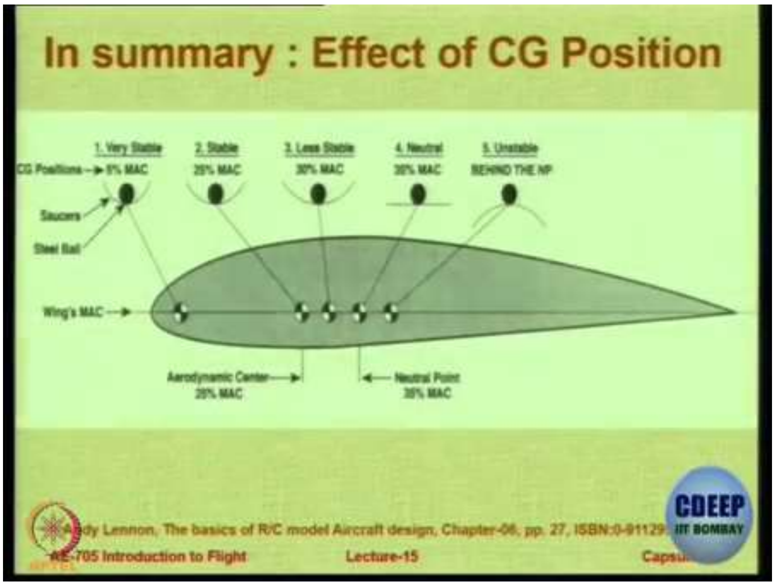

Alright now this was a theoretical exercise. So this is in summary the position.