Introduction to Flights

Prof. Rajkumar S. Pant
Department of Aerospace Engineering.
Indian Institute of Technology Bombay.

Lecture No 10.7

Tutorial on Stability Control

Okay, so welcome to the tutorial for capsule number 8. In this tutorial we are going to look at some basic questions on aircraft stability and then we will move on to the quiz.

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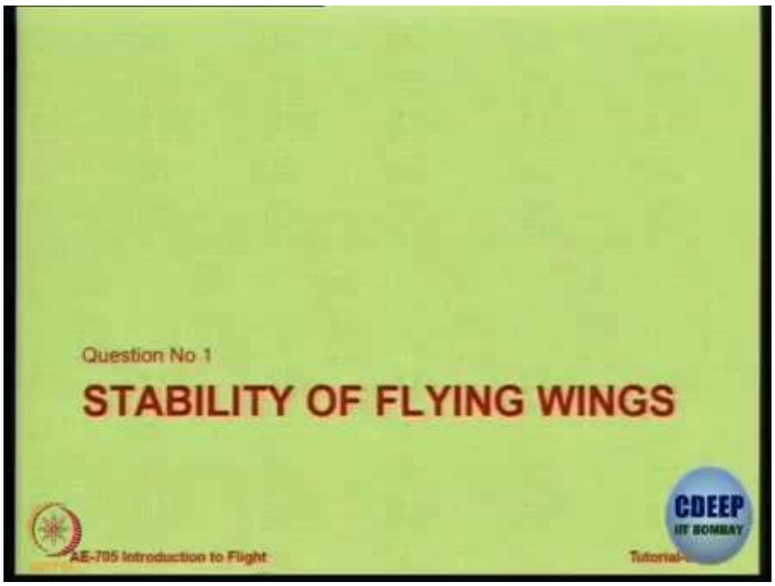

So, first we will look at stability of flying wings. I thought this is a good occasion for me to talk something about flying wings because these are very unique kind of aircraft. So, when you think of flying wings you think of something like this.

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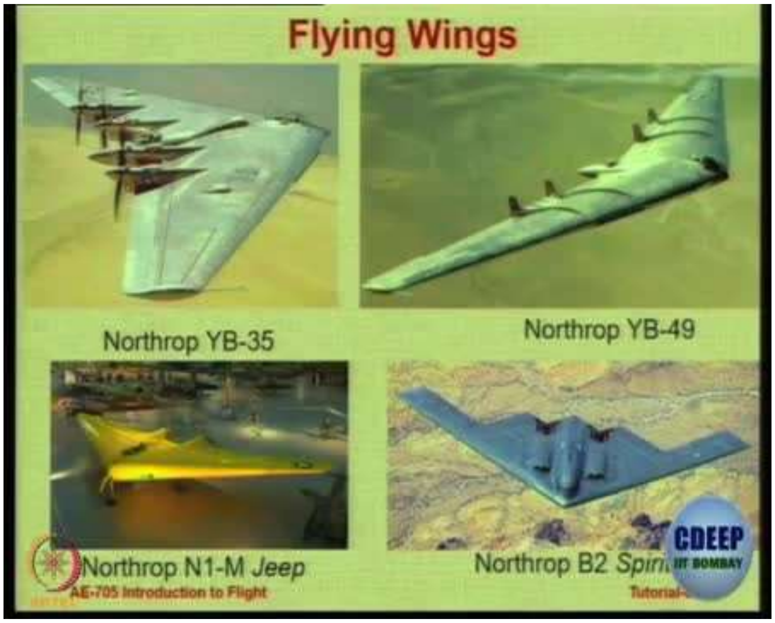

This is the Northrop N1-M also called the jeep which was designed in 1940s. One company Northrop has been a champion in the US of flying wings. So, they have made many, many flying wings. I will show you 4 of them. So, 1940 Northrop NM1 then in 45, 5 years later they came up with this turbo prop version of a 4 engine flying wing called as YB-35. So, this aircraft revolutionized the concept of flying wings because there were some flying wings design also been taken up by the Germans and by people in England also. But this was the first one that actually took part in lot of combat.

In 1947, 2 years later it was converted into a jet version. So, those 4 turbo crafts were removed and then jet engines were inserted and in place of the engines we have these vertical tails and the intake of the engines is from the leading edge. So, these are the varied engines. And then the most famous of them is the B2 bomber which came in 1989. So, this is the circle of just one company from 1940 to 45 to 47 to 89.

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Ho-2 Flying Wing Aircraft (1935)
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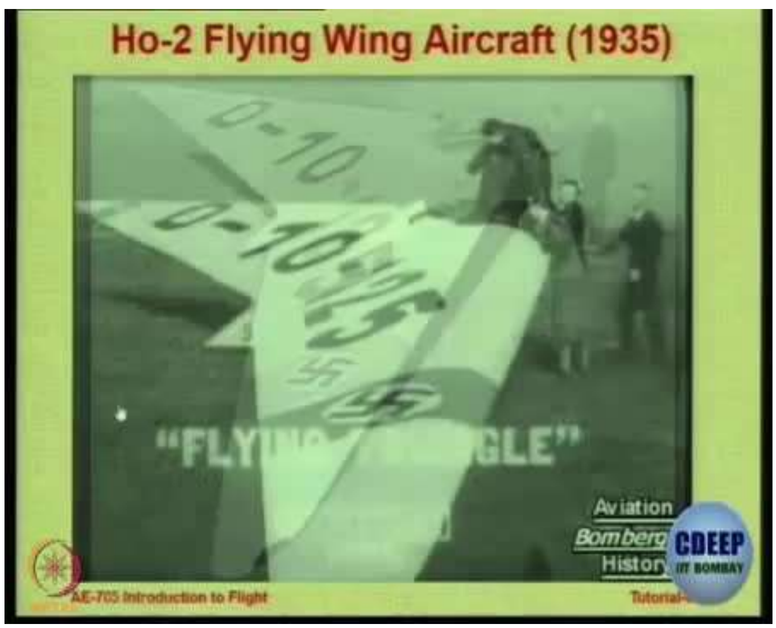
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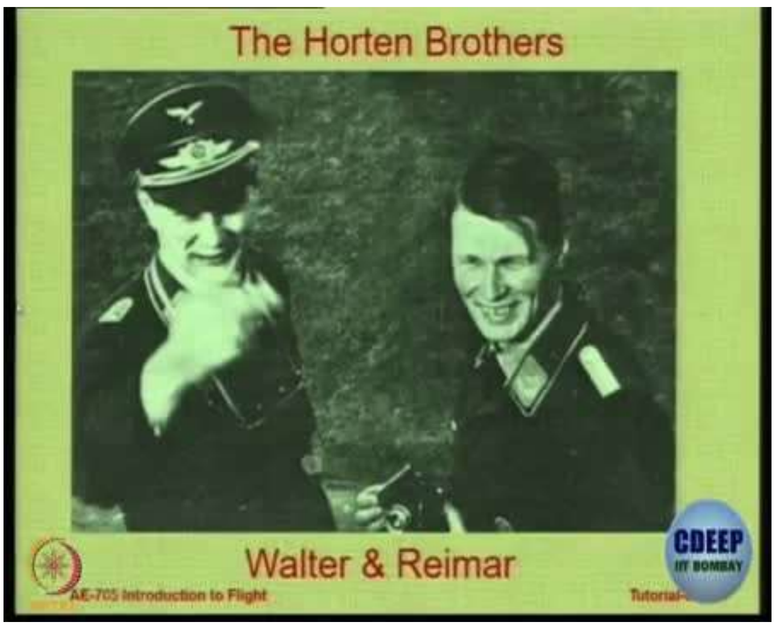

But, I want you to look at this old film that talks about flying wings, okay. And it talks about one particular aircraft the HO-2 flying wing. So, this is called as a flying triangle. So, you can see it is being pulled by a chase aircraft. So, a biplane is pulling a flying wing. Single wheel landing; just see how it turned doing the approach at very high angle. So, this is the historical film and these are the 2 brothers; the famous Horten Brothers from Germany. They were a part of Hitler's secret army and it is said that in the first world war they learnt flying during war. So, they learnt flying on the aircraft which took part in the war. They survived and later on they went to join the Hitler's youth brigade and they ended up designing many delta or flying wing aircraft. One of them I have already shown you.

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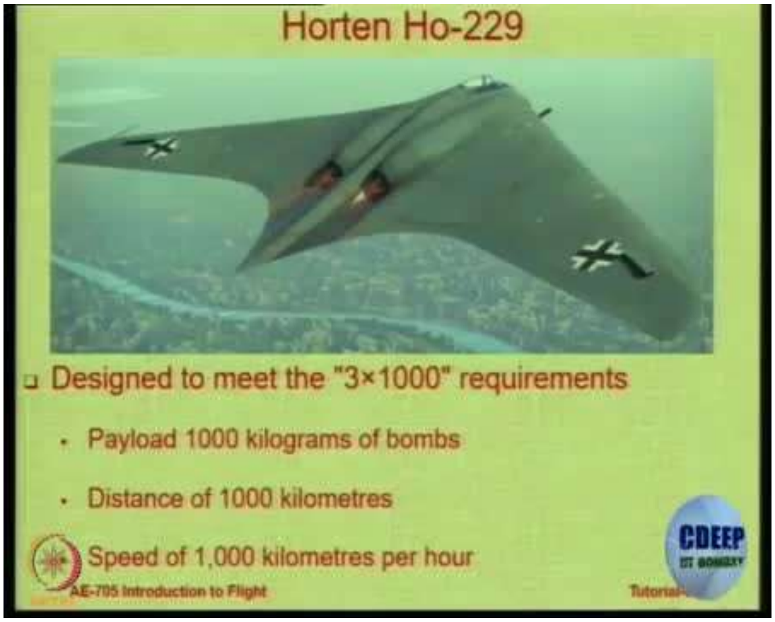

This is the most famous of their flying wings Horten-229 and this aircraft was designed to meet the requirements of 1000 by 1000 by 1000 which was proposed by the German Luftwaffe in almost at the end of Second World War. So, the requirement was to carry 1000 kilograms over 1000 kilometres on 1000 kilometres per hour.

And this was designed in keeping in mind these particular requirements very famous aircraft. Unfortunately, it came into play only at almost at the end of the second world war. So, Germans could not really use this too much effect in combat. So, it was a wonderful aircraft that came too late.

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Alright. And in India also, we are looking at a flying wing configuration. So, information regarding DRDO's unmanned combat aerial vehicle or UCAV is not very easily available. It is being publicized. So, some sources. So, these numbers may be little bit off by here and there it is basically the most complex and taunting mission taken up by DRDO.

As far as aerospace engineering is concerned, DRDO likes to call this aircraft as a self defending, high speed reconnaissance UAV which also has a weapon firing capability. So, that sentence defines AURA. So, we have done some basic calculations, design studies related to aircrafts like aura. One of my M.Tech students have also published a paper on this. So, those of you who are interested in design of aircraft especially in this kind of aircraft you are welcome to look at this particular paper, okay.

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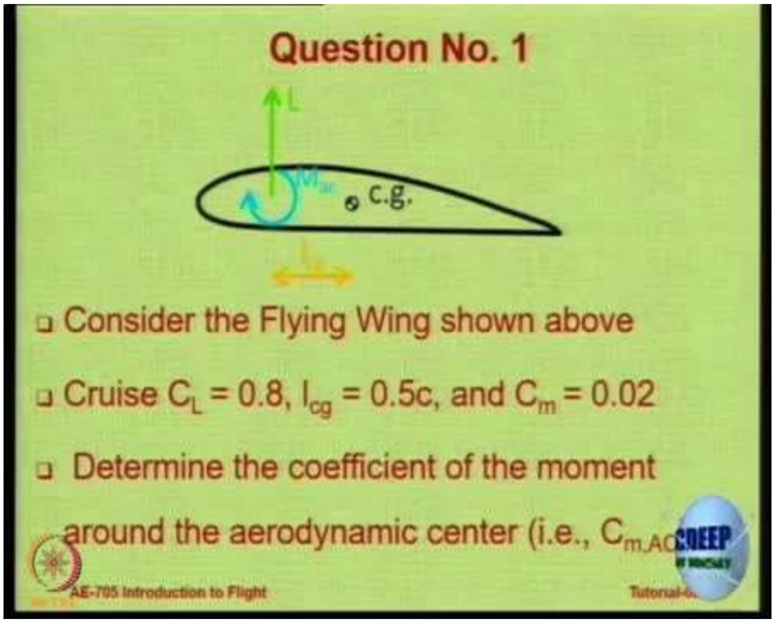

So, let us come to tutorial now. So, this is the first question. There will be 3 questions before we proceed to the quiz. So, here is the flying wing therefore it has no tail. It has a centre of gravity. It has a aerodynamic centre at which we can assume the lift force to be acting and also some moment about the nose okay. So, the question is that during cruise if the lift coefficient is known to be 0.8 and if the lcg that is the distance between the aerodynamic centre and the centre of gravity is 0.5 times the chord. The chord is from the nose to the end and the pitching moment coefficient Cm is 0.02.

If this is known the question is determine the coefficient of moment around the aerodynamic centre or we call it as Cm,ac, okay. So, this is your first question. So, very simple question just like taking the moments about centre of gravity you can solve this question, okay. So, the net moment is 0.02. Net moment coefficient cm is 0.02, Cl is 0.8, lcg is 0.5c. Find the location of Cm,ac .Okay.

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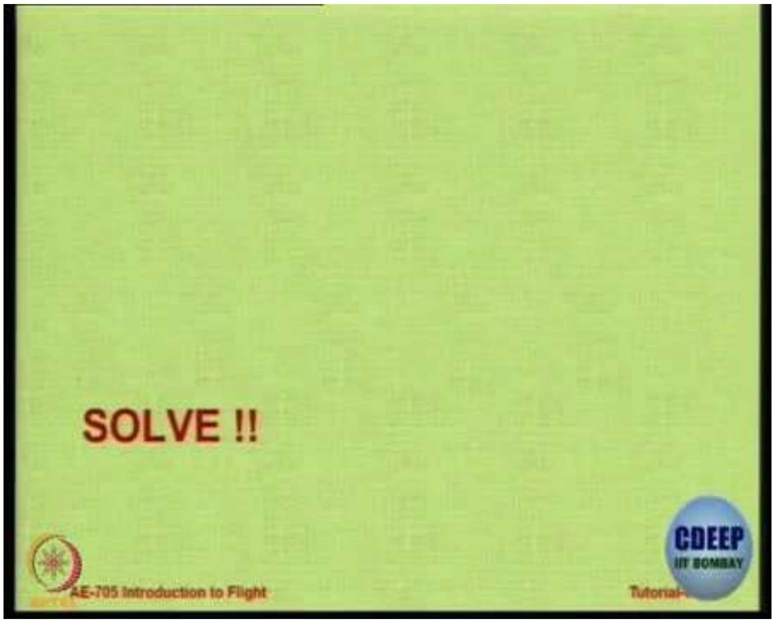

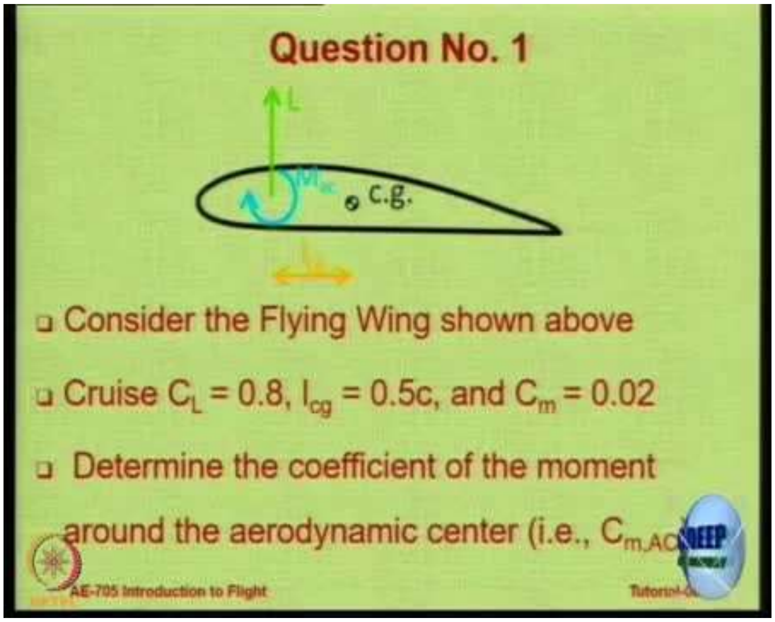

I will give a few minutes to solve this question. So, please solve. Draw this figure. So, Cm is the moment coefficient about the centre of gravity. Which is the net moment coefficient of the aircraft? Since, there is a positive value we must do something to drive it out. Normally, in a flying wing is by giving a reflex at the trailing edge but there is no tail available. So, you give a reflex at the trailing edge to take care of the moment the net moment, okay. So, if you have already drawn this figure then I think you can now proceed with the calculation. So, very simple one line solution taking moments about the centre of gravity. Yes? Minus 0.38, okay. We will confirm if somebody else gets the same answer. Minus 0.38.

Now, what is your answer if value of Cm is minus 0.02 not plus 0.02? Can you just do that calculation also? If the value of Cm is not 0.02 it is minus 0.02. So, it is just an addition basically. Yes, everybody has the answer? Same answer, okay. Let us see how we can solve it. So, basically we have to take the sum of the moments around centre of gravity which will be $M_{ac} + L * l_{cg}$, right?

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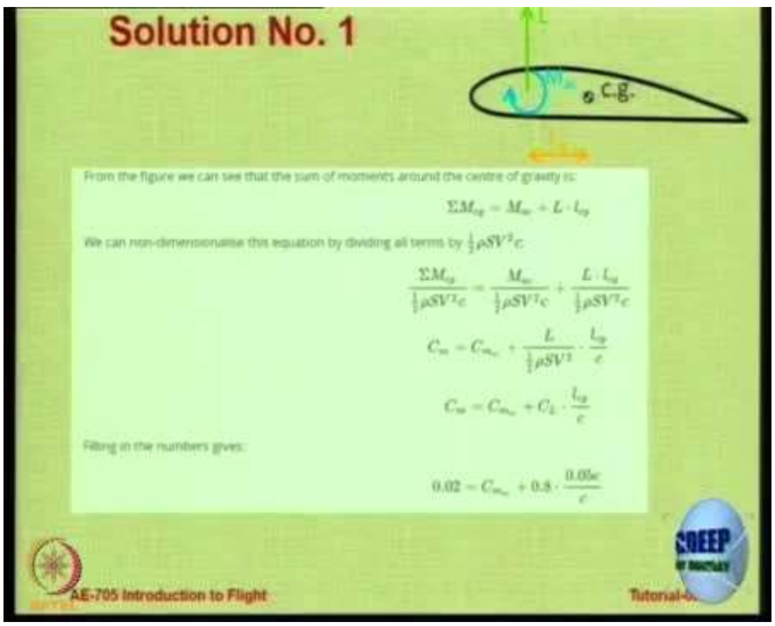

So, if you divide both sides by $\frac{1}{2}\rho V^2 Sc$ to make it non dimensional. Then you get

$$C_m = C_{m,ac} + \frac{L}{\frac{1}{2}\rho V^2 S} * \frac{l_{cg}}{c}$$

Or in coefficient form

$$C_m = C_{m,ac} + C_L * \frac{l_{cg}}{c}$$

And now you put all the values. So Cm,ac is known, Cl is known, lcg upon c is also known because lcg is given in terms of c. So, 0.02 is cm and that is equal to 0.8 times into 0.05c. Therefore, 0.02 is equal to Cm,ac plus 0.8 into 0.05 therefore Cm,ac will be 0.02 minus 0.8 times. So, it is minus

0.02. So, if you have assumed the pitching moment to be positive by looking at the figure you have to keep in mind that figures are drawn for a general case. Yes.

Okay Okay Okay, that is the reason you got a wrong answer sorry. Then I made a mistake there okay. So, if it is 0.05c then you can put the corresponding values. Yeah then it is 5 into 8, 40 minus 0.2. Then you stand corrected. So, I am wrong I gave the wrong number in the tutorial. But I think you get the idea. It is a very simple moment balance, okay. Let us go to the next one.

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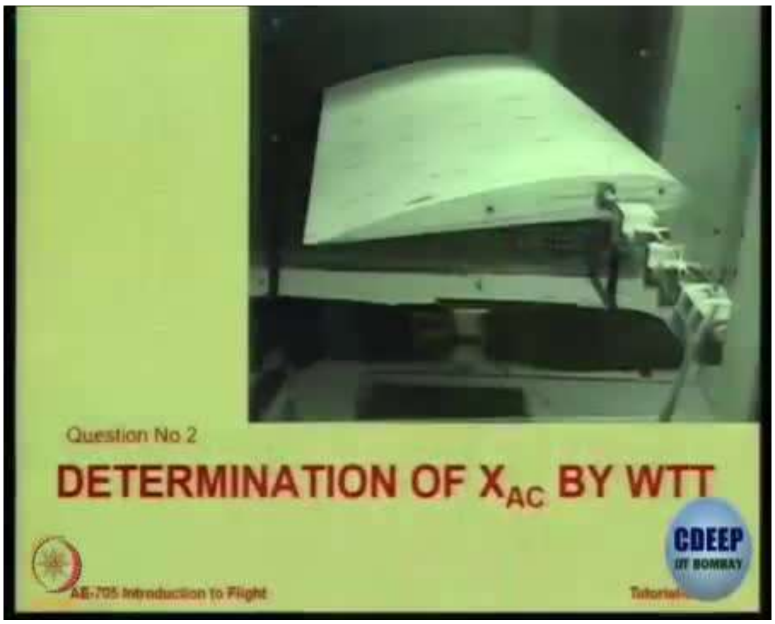

The next question talks about yes what is your question?

Student: The CGs of aircraft?

Professor: Here, there is nothing like aircraft and wing it is a flying wing. So, CG of the aircraft is CG of the wing, okay, right yes.

Student: I have one question. Length of CG location is giving 50 percent at the cord.

Yeah so, that is the main mistake it was mentioned as 0.5c factor 0.05c 5 percent of the chord.

Student: My question is not sir because lift is acting at the aerodynamic centre. Which roughly we can see that at one fourth of the chord. So the distance between the CG and the aerodynamic center where the lift is acting will be the half of 0.05.

Professor: Why will it be half? So, you just take you just take the values about centre of gravity. You do not have to worry about from the nose.

Student: Correct but M into distance so distance between aerodynamic centre and CG.

Yes, it has already been given that the lcg the distance between the aerodynamic centre and cg is 0.05.

Student: Okay so that is not from nose.

No, you see the figure. It is given. It is given.

Student: I thought it is between from nose to CG.

It is given in the figure as a distance from the aerodynamic centre to the centre of gravity. So, a lot of time we used wind tunnel testing WTT is wind tunnel testing to determine all these parameters.

So, in wind tunnel testing basically, we make a model of the aircraft. In this case, it is a wing and we put it in the wind tunnel and there is something called a wind tunnel balance. So, you can see in this case we have mounted the model and at some particular point there is this contraption coming in. So, this particular contraption is called the wind tunnel balance. The wind tunnel balance essentially works on the principle that if there are some forces or moments acting on an model because of the wind.

If you externally apply those forces and moments and balance out the values then the forces are in equilibrium and hence, whatever you have applied is equal to whatever is acting. That is why it is called as a balance. So, you externally outside the wind tunnel you balance the forces and moments coming by adding weights at some distances and use it to calculate the forces and moment, okay. So, in this experiment there is a wing mounted with the wind tunnel balance, okay. Now, we assume that the conditions are ISA conditions in this example.

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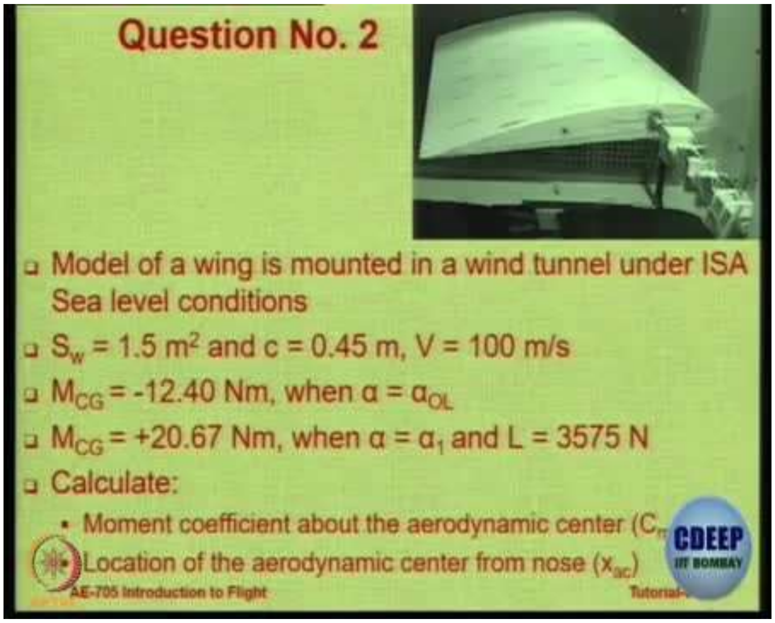

And we assume that, note down these numbers because you will need them. Area of the wing reference area of the wing, in this case it is a single wing. So, if it is a single wing the area of a single wing geometrical area in the top view. So, Sw will be 1.5 square metres and chord of the model is 0.45 metres. And assume that in this wind tunnel now that is a very high speed but assume that you are able to generate 100 metres per second in this wind tunnel. Normally, wind tunnels produce only 30 to 40 maybe 50 metres per second.

But this is a numerical example. We assume that the wind is 100 metres per second, okay. Now, we mounted the aircraft at some angle and we kept on changing the angle till we reach an angle at which there is no net lift acting. Notice that that angle could be negative. It may probably be minus 2 or minus 3 degrees for such a wing, okay. So, is it possible that you have a wing and the lift is 0. It is possible it depends on how you orient it. So, there is some alpha 0 lift; alpha o L. The numerical value is not important.

The point is at that condition the aircraft was producing no net lift. So, in the wind tunnel balance the place where you experience the lift force you have 0. But under that condition under that condition obviously the moment may not be 0 because the moment is basically dependent upon the angle and it is a summation of all the forces acting ahead and behind the centre of gravity. So, the moment about CG was not 0 it was recorded as minus 12.4 newton metre. Now, how is it recorded?

You create a moment of 12.4 N-m to match it and you find that total lift acting is 0. So, now you move it to some other angle alpha1. The numerical value is not important. Some angle alpha1. At that angle now the moment changes direction and you have 20.67 newton metre; positive moment and you also have lift 3575 Newtons. So, actually these the numbers are applicable to an actual aircraft. We are just showing a simulated wind tunnel, okay. So, you have to calculate the 2 parameters; the moment coefficient about aerodynamic centre and location of the aerodynamic centre from the nose.

So, go ahead copy down this information and start calculating. Get the value of Cm,ac and after that get the value of Xac. So, to make it easy for you I am going to show you I want to show you this figure here for some time. So, draw the same figure you had drew last time because once again this is a flying wing, kind of flying wing. There is nothing like tail here. So, draw the same figure. Draw one moment about about aerodynamic centre. Mark the location of CG. CG is at some point. So, try to calculate and give me the answer. So, the same equation I will show you once again if you.

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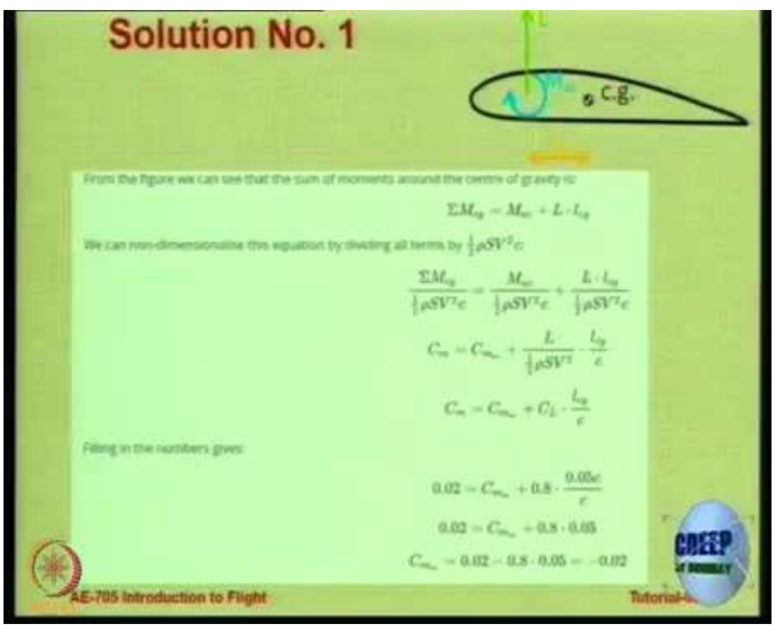

The same equation will be applicable here also. Moments about CG will be $M_{ac} + L * l_{cg}$,

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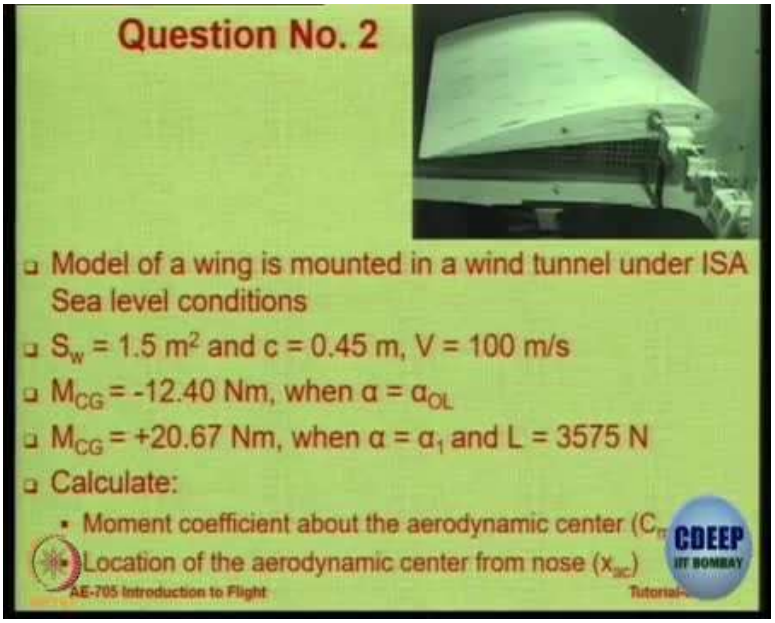

Okay. So, let us let us solve this question as we go, okay. I can give a couple of minutes more.

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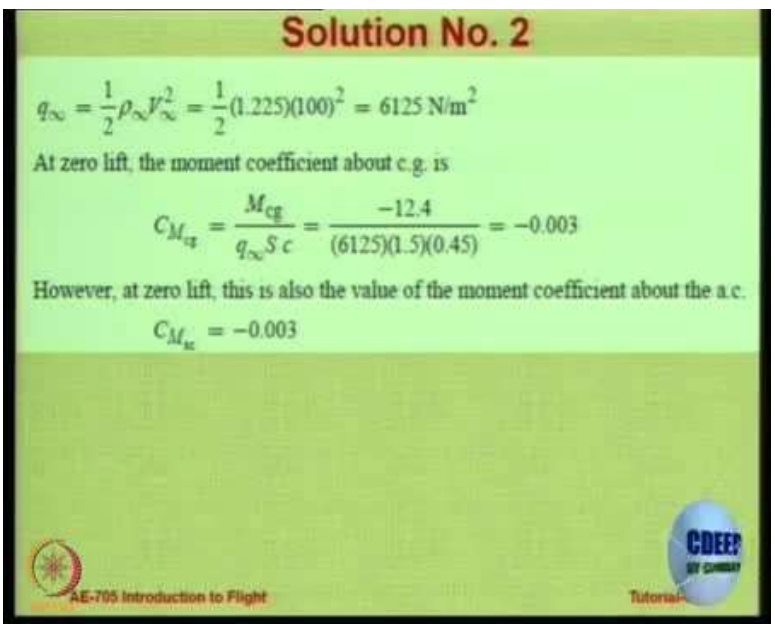

Okay. So, the first thing you can do is to calculate dynamic pressure which is half into rho infinity into v infinity square. Since, the conditions are sea level density is 1.2256 or 1.225 kg per metre cube and the velocity given is 100. So, this is the dynamic pressure.

So, do not look at me please. You have to do this calculation yourself. Now, when you have 0 lift; at that time Cm,cg will be equal to L which is 0 into Xac plus mcg. So, Mcg upon q infinity sc. So, q infinity is known, s is known, c is known so you can get the moment coefficient about centre of gravity at 0 lift which is minus 0.003. Okay interestingly because this is the condition for 0 lift. This also is Cm,ac and this is the expression you will find out it is the same. So, with this you can calculate Cm,ac.

The next is at any other condition we have the lift available so we calculate Cl at that condition and then Cm,cg will be Mcg upon q infinity s into c. The moment is given as 20.67, fine. So, with this expression you can get the moment at the centre of gravity under that condition when lift is 3675. After that it is very straight forward. Cm,cg is known, Cm,ac is to be calculated, Cl is known.

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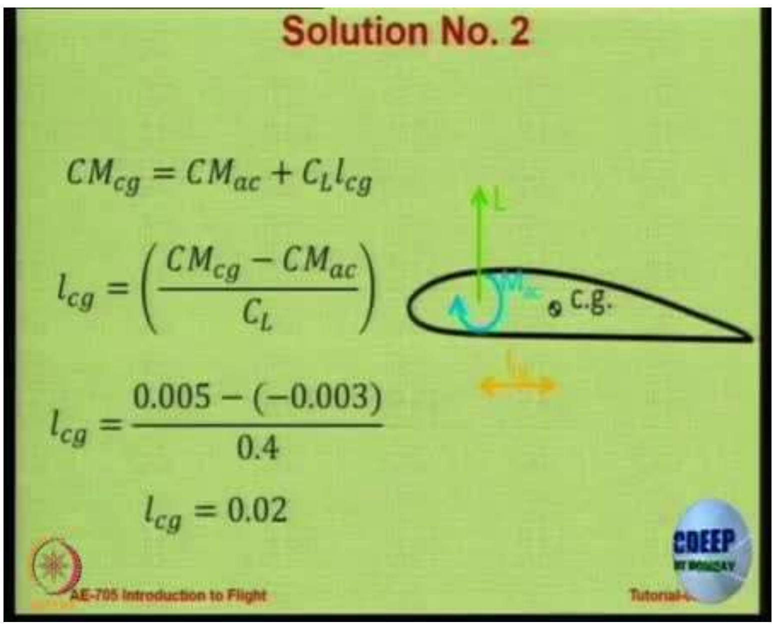

So, lcg will be nothing but the difference in the moments upon Cl which will be 0.02, yes. It is actually how to find the? Yeah, so how do you find that? You cannot find it because it could be any number, okay.

It could be any number. So, what you can look at is only lcg location from between the CG and aerodynamic centre. That is all you can calculate. I do not think we can calculate anything more than this, okay right. So, again I will have to ammend that question.

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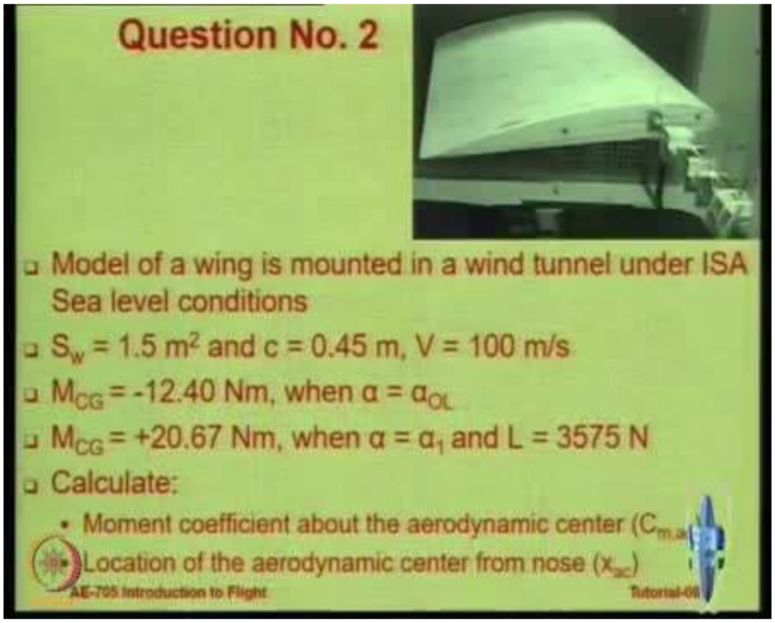

Yes. What is aerodynamic centre? Correct, okay. So, do not we assume, so at the centre of pressure there will be some lift and some moment. At aerodynamic centre, we have the same lift and fixed moment. That is what we do. That is how we define aerodynamic centre so that we do not have to worry about changing location of centre of pressure with angle of attack. So, the definition of aerodynamic centre is such that we do not have to worry about so that is why it is a theoretical point which takes care of this problem.

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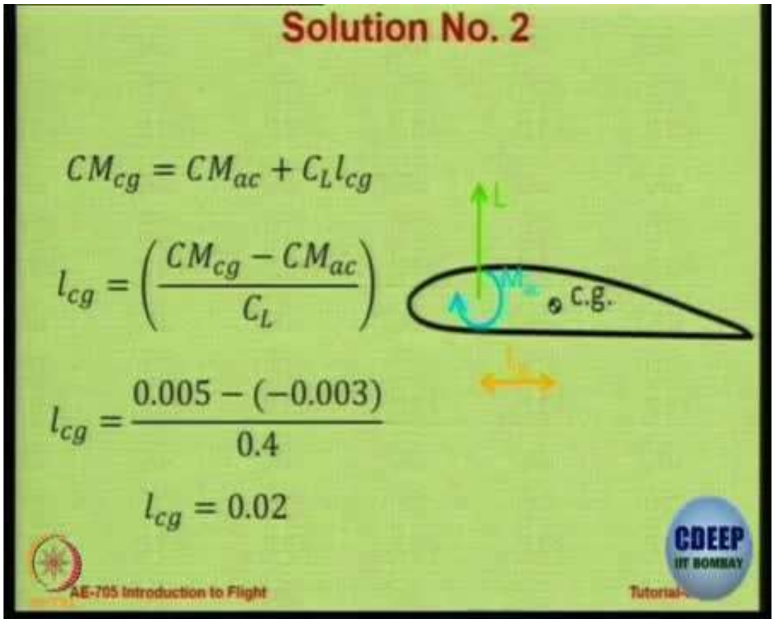

Yeah yeah, so how much is the chord? So, that should be there. You are right again you are right. It should be 0.005 into c but you are calculating moments. So, the whole of it should be multiplied by c. So, I mean I am giving this in terms of c. I am giving the whole thing in terms of c only. So, I will just write c there. I will put c there and c here, okay.

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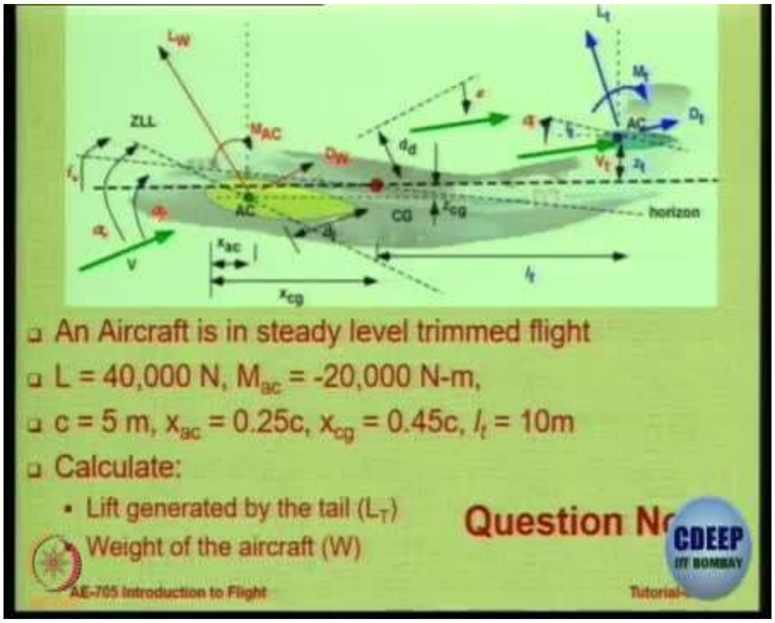

Right. Now this a nasty picture but this is what happens in general, okay. But we will simplify this picture and bring it to level flight. I wanted to put this picture but I wanted you to understand what kind of complicated figures we have to deal with when we have to study flight mechanics. So, this is a general picture. Now, the aircraft is this case may not be in steady horizontal flight. There comes in the picture in between a general condition. So, what is the condition? The condition is that there is something called as the angle of a attack, there is a flight path angle.

There is a incidence angle. The drag force Dw is not acting along the aircraft; it is acting at some direction. Perpendicular to that is the lift force, okay and even the tail is at some angle but things become easy when we look at level flight. In level flight, this lift vector L will not have any angle and hence the drag will also act along the flight path. So, the question is that the aircraft is in steady level flight and it is in trimmed flight. So, what is the meaning of trimmed flight? When do you say that the aircraft is in a trimmed condition? Somebody here?

Yes, so what do you mean by trimmed condition? Okay, from the pilot point of view the trimmed flight is when the pilot feels no net force on the control stick. But when will it happen from the aircraft designers point of view. When will that happen? Okay, take a mic when will that happen?

Student: When there is no net moment about the centre of gravity.

So, can you still have moment about centre aerodynamic centre when the aircraft is trimmed?

Student: Yes.

You can. So, about centre of gravity, there is no net moment. So, if there is an imbalance in the aircraft and the moment about centre of gravity is not 0, what does the pilot do to make it 0? So, one way is the pilot can deflect the control surfaces intentionally up or down left or right to create a moment that cancels the imbalance but then the pilot has to continue flying like that. So, imagine a situation where the left wing or the port wing is heavier than the star board wing by 1 kg can happen? How can it happen? No, there could be some issue because of which there would be more fuel in the left wing than in the right wing. Even this 1 kg imbalance will create some kind of a moment. So, the aircraft will tend to fly with left wing down.

What does the pilot do? The pilot moves the control to the right create differential ailerons so that the moment by the ailerons is equal to the moment by the imbalance. And now for the remaining flight the pilot has to fly like this, uneasy not acceptable. So, what do they do? What can you do? One way would be that I create a bias in the control system so that so much deflection of aileron is always there. So, I create a bias then I lock it and now throughout the flight whenever I give a control stick it will be that plus bias.

That plus bias will take care of the imbalance, okay. So, what is the problem with this?

Student: I think in that way you have eating away there are some controllability.

That is a very good point that you are already eating away some amount of controllability. Correct. That is true. That is one problem. One problem is that that the aileron is now not useful for that many degrees because it is consumed in balancing. Any other problem? They will be more drag because now throughout the flight level flight is not going to have aileron so many degrees up and down. So, how do you cancel it? By waving a hand like this?

You were saying. So, what is your solution apart from waving hands? So, there is something called a trim tab, okay. So, trim tab is a very small device or a very small aerodynamic surface which the pilot can deflect to create and counter moment to the imbalance and then lock at that position. So, you can fly hands free. That is why as he said that pilot does not feel any net moment during the flight, okay. So, in this case we are saying that the aircraft is in steady level trimmed flight. So, steady means what? You are just murmuring.

Student: Constant velocity and altitude.

No, steady is only constant velocity. Level level will be constant altitude. Trimmed is no net moment on centre of gravity, okay. So, this is the ideal condition for passengers like you and me. The aircraft is in still level flight. So, in this particular aircraft under this condition remember all these 3 words are going to be used in the calculation, okay. So, in this condition the aircraft is having a lift of 40000 Newtons and the moment about aerodynamic centre. I do not know how they measured it? It is minus 20000 newton metre.

The wing has a cord of 5 metres, Xac is quarter chord, Xcg is 0.45c. These are some typical values and lt is the distance between aerodynamic centre and aerodynamic centre distance between the CG of the aircraft and the aerodynamic centre of the tail. That is lt. You can see it is shown here in this figure. This is lt from the centre of gravity of quarter cord and aerodynamic centre of the horizontal tail that is 10 metres. So, if this is the case first of all you must calculate the lift at the tail and then calculate the weight of the aircraft or mass of the aircraft in newtons.

So, go ahead. So, what you can do is you can draw this figure but not all those lines and angles. You just draw lift vertical at AC. You draw the centre of gravity. You draw a tail put the length as lt mark Xac, mark Xcg and mark the chord as c. So, simplify this figure 2000 newton and 42000 newton correct that is perfect, okay. But is the tail load acting up or down? If it is acting up then why is its weight is 42000? It will be because lift is 40 and 2000 is the tail load. So, it is up, normally that is not the case. Normally we have the downward load on the horizontal tail, okay.

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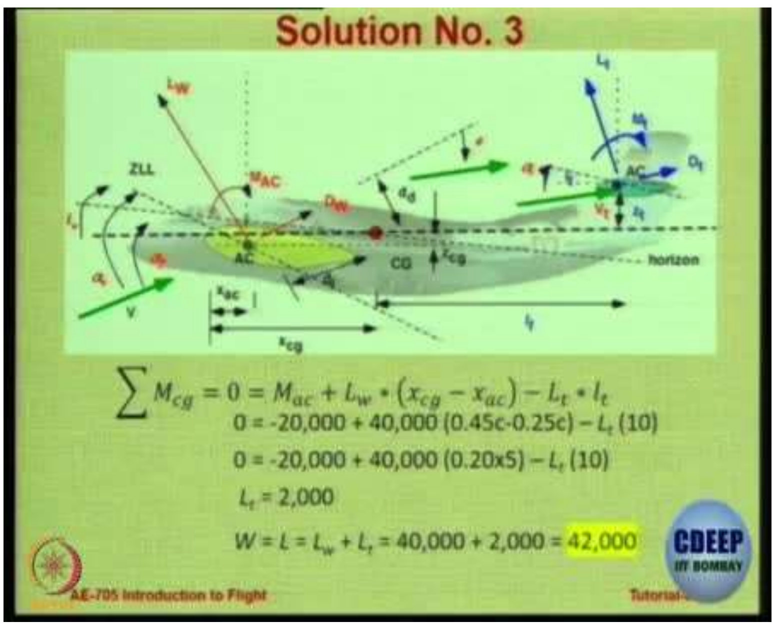

Some people have solved it very nicely and very quickly. So, take moments about CG that will be equal to 0 because it is trimmed so that will be moment about AC plus lift into Xcg minus Xac minus lt into the tail force keeping in mind the directions. So, this is minus 20000 plus 40000 into 0.45c minus 0.25c minus 10 into lt and c is 5. So, lt is 2000 and w is 42000, okay. So, with this now we come to the end of the tutorial.