Design of Fixed Wing Unmanned Aerial Vehicles
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Lecture - 06
Aerodynamic Center and Center of Pressure, Various Wing Planform

Hello friends. Welcome back. In our previous lecture, we were discussing about centre of pressure aeronautical center, relationship between them. And we also witness how CL varies with angular and how can we model mathematically CL, variation with alpha, right.

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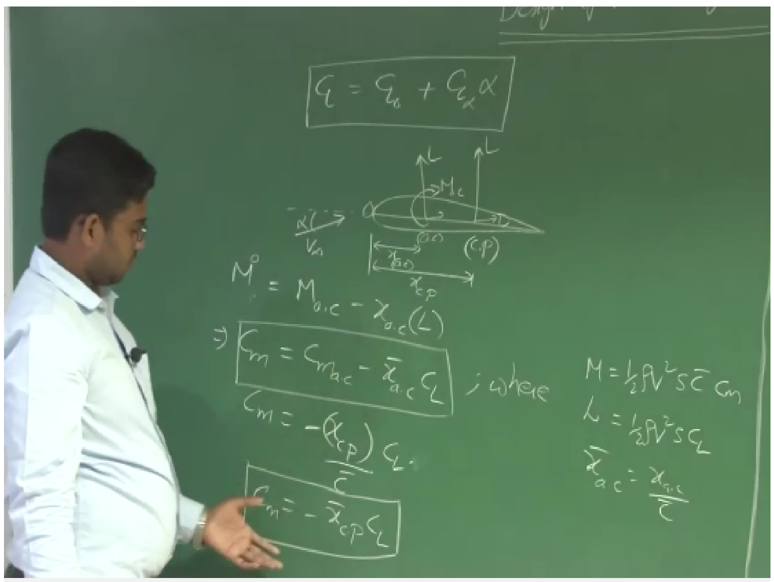

So we had CL= Cl0 + CL alpha * alpha. This corresponds to variation of left coefficient and angle of attack in the linear region of angle of attack. So at the same time we have defined two important parameters. One is Aerodynamic center the other one is center of pressure. So center of pressure is a about which resultant aerodynamic forces act. An aerodynamic center so above center of pressure the pitching moment is 0, right x cp and aerodynamic center is defined as the point about which pitching moment remains constant with angle of attack, right.

So let us now consider an airfoil and say x ac is the distance of aerodynamic center with respect to the leading edge and x cp is the length of this center of pressure, right the location of center operation with respect to leading edge here. Now let us take the moment let o be the leading edge here and we are going to write, we are going to drive the moment expression about this point o for this particular aerofoil. Say, we are testing it at certain alpha.

So let us consider there is a flow with a velocity v infinity or this aerofoil. Now the pitching moment about .abort .o =; so when there is a flow there lift here and drag and lift and drag at moment abort aerodynamic center. Now let us consider the moment abort .o by considering the aerodynamic center here, by considering the forces and moment acting it aerodynamic center.

So moment about aerodynamic center – x aerodynamic center * lift = Cm = Cm ac – x/ac * CL where M= half Rho v square S C bar * Cm and L = half Rho v square S * CL and x bar ac = x ac/C bar, right. Now if you take the moment about the same reference point but by considering the forces acting with the center of pressure. So what we have is the moment due to; since center of pressure is defined as the point about which the resultant aerodynamic forces act, right.

So the moment that; so we are considering only the moment contribution from life because; This is along the same axis the drag contribution is very, very less here so we are neglecting drag here. And so due to lift we have pissed down moment here, so x cp momentum multiplied by; since it is a non-dimensional coefficient you will also have C bar * CL which is equals to –x bar Cp * CL. So these 2 equations represent the moment abort .o due to lift, right.

So this the moment should be equal whether you are considering with respect to aerodynamic center or center of pressure. By equating those 2 what we have?

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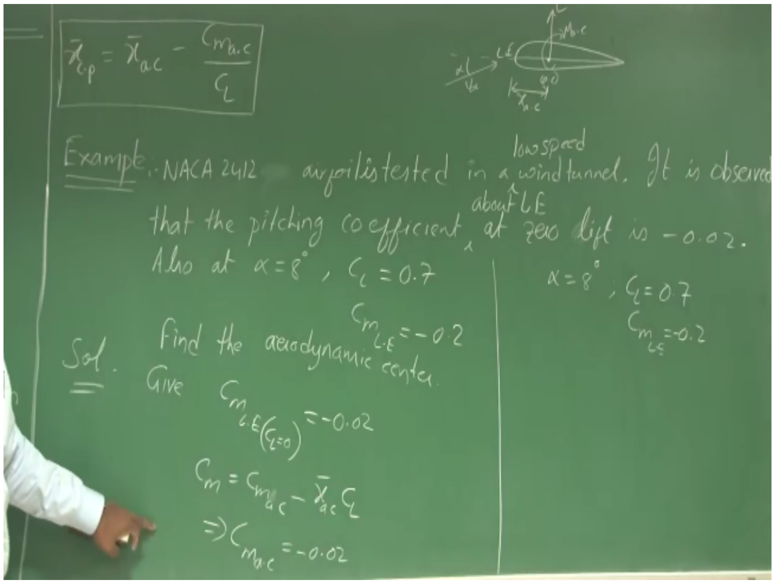

x bar ac or x bar Cp = x bar ac – Cm ac/CL. So this is a relationship between center operation and aerodynamic center. We also address that at higher angle of attack the CL increases due to right which this quantity becomes very low and this x center of pressure will move close towards aerodynamic center. Now let us take a small example. So let us take up an example in NACA 2412 airfoil is tested in a low speed wind tunnel.

It is observed that the pitching moment coefficient about the leading edge at 0 lift is – 0.02. Also at x=8 degrees the CL is measured to be 0.7 and Cm abort leading edge is -0.2 Now we have to find the aerodynamic center for this airfoil, right. Now, given Cm abort leading edge at CL=0 is -0.02, right. So we know from this equation. So moment abort leading edge say here is Cm ac CL is 0, right it is mentioned CL is 0 and the moment measured to be -0.02 which turns out to be the moment abort aerodynamic center.

Let us say this is our leading edge and this is my aerodynamic center. Let this distance be X ac. So v infinity and alpha will have lift and moment abort aerodynamic center. Now, if you write an equation for pitching moment abort aerodynamic center about this leading edge with respect to this aerodynamic center. What we have is Cm = Cm abort leading edge = Cm abort aerodynamic center –x bar ac * CL.

So in mentioned here that X CL is 0 the Cm is measured to be -0.02 that means the Cm ac is -0.02. This implies Cm ac = -0.02. And another information we have here at alpha = 8 degree, right CL=0.7 and Cm – Cm at abort leading edge = 0.2. So from the same equation we have CL and at alpha 8 degrees we have CL and the corresponding Cm, right.

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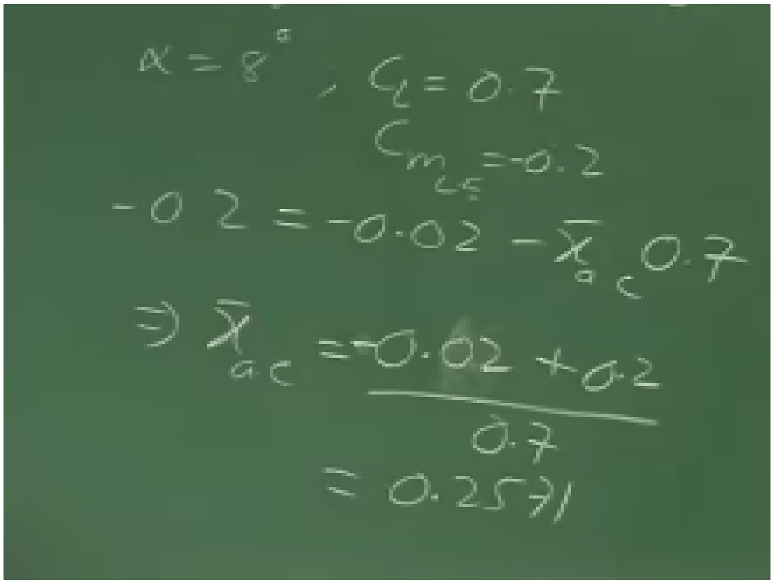

Can we substitute this to -0.2 = Cm ac is -0.02 – x ac x bar ac* what is CL, 0.7. X bar ac = -0.02 + 0.2 / 0.7, right it is 0.2571. So X bar ac is 0.2571. X bar is non-dimensional number right.

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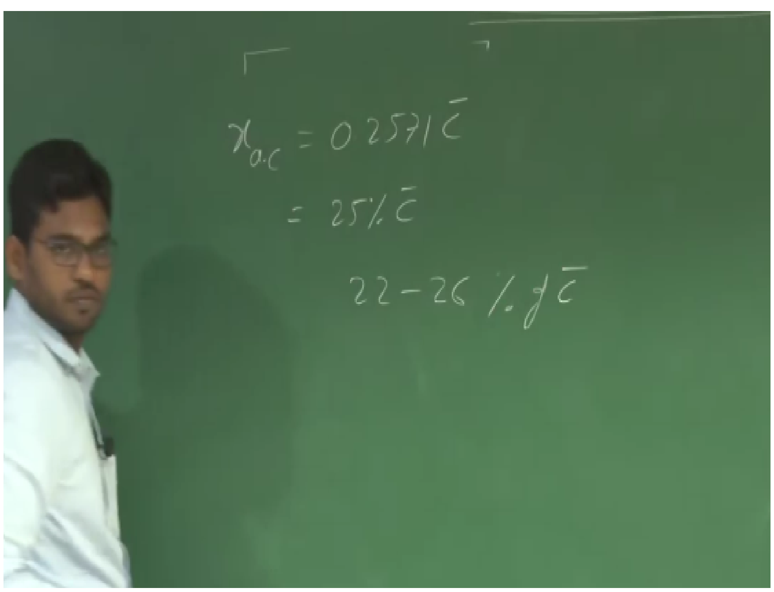

So what we have is X ac = 0.2571 of C bar. This equal to 25% of C bar almost quarter chord of this C bar, right so the aerodynamic center in general lies for a low speed for low speed light vehicles the aerodynamic center in general lies about 22 to 26% of mean aerodynamic C bar, right. And also it is worth noting that the center of pressure, keep varying with angle of attack. Why? You have CL keep changing here from this equation.

At the same time, you know as an angle of attack changes the pressure distribution changes, right and once you have different pressure distribution you have different centroid for the distribution. So x cp keep varying whereas X ac is remains constant over a range of velocity. And of course angle of attack it always remains constant.

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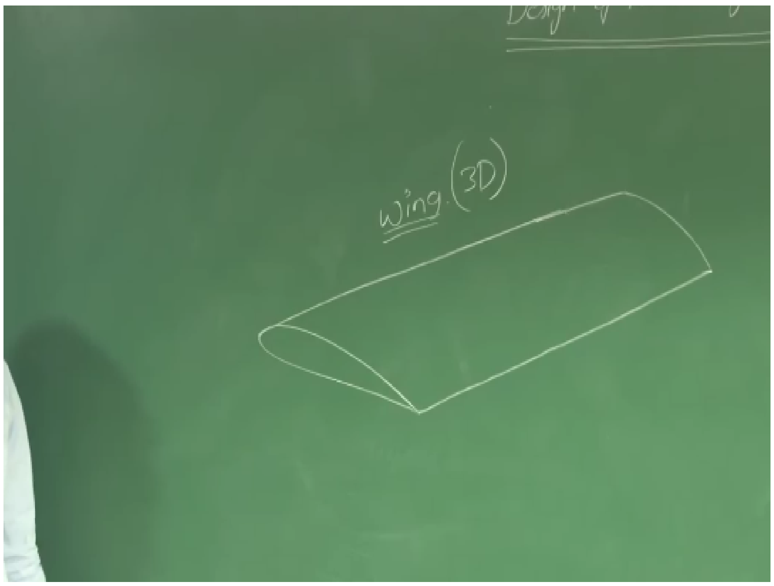

So till now we are talking about airfoils. Let us say if I extrude this airfoil what you have is wing. So airfoil is also known as infinite wing or two-dimensional wing, right. So this is a 3D object whereas airfoil is 2D or also termed as infinite wing, okay. Now since it is a 3D object it is worth talking about planform geometry.

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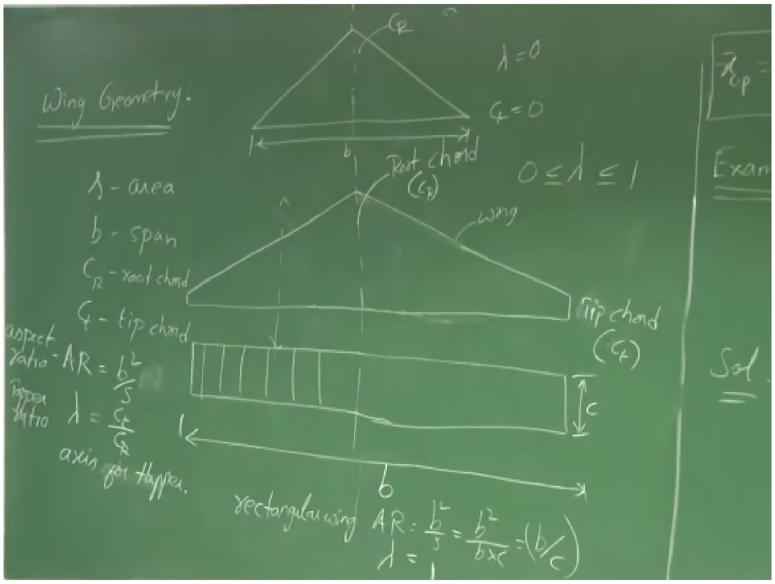

So let us talk about Wing Geometry. Assume that this is an aircraft okay. So we have wing here and we have a horizontal stabilizer. Now what in general we assume is this wing extends till the center line of this; let us say this is my center line or fuse loss reference line, right; so wing extend till the center line right. Now when you are measuring the Planform for geometry, planform is a top view of this, right.

When you are measuring the planform geometry that means if you want to check the length of this wing which we call here as span. Span is a lateral length of this wing. This is a lateral direction. This is span which is a length measured from Tip to Tip. You call this as tip of the wing; you call this as root. Now let me just erase the fuse loss, okay. So this is what you have here is a root. And the longitudinal length of this airfoil will be;

Say, what is longitudinal length in this direction right. So what will be the longitudinal length? This is nothing but the cross-sectional length at that particular point. So what do you have at this cross-section is an airfoil. So you measure airfoil in terms of chord the longitudinal length of this airfoil is chord so the longitudinal chord, also at that particular location is a chord. So the one that is present is the root is known as root chord and at the Tip chord.

So let us consider a Ct be the Tip chord and CR be the Root chord right. And you have here span which is a length between length measured between Tip to Tip of this wing, right. At the same time, you have area here, area of the wing. Let S be the area of the wing. B be the span. CR is the Root Chord. Ct be the Tip chord. Now let us talk about some of the non-dimensional parameters here of the wing. We define something called Aspect Ratio which is b square/S.

There is no dimension for this. And for a delta wing configurations, so this aspect ratio will be usually will be < 3 or 4 or 5 let us say. We call them as Low Aspect Ratio wings. And same plain from 8 to 16 and for gladder it will be beyond 16, right. The Aspect Ratio is b square/S here and Tapper Ratio lambda. Let us denote Tapper ratio as lambda. This is Aspect Ratio; lambda is Tapper Ratio. See what are we tapering?

We are tapering the chord. When you are reducing the chord we witness that the maximum thickness and everything will reduce, right you are scaling down in fact. You will be reducing the here, chord length here when you say tapper you are trying to reduce the chord length as we move along the span of this wing. So Tapper ratio lambda is Ct/CR, right. When we mention Tapper ratio, are we missing anything? Do we need some other information?

Do we require any additional information? Or when we talk about Tapper is this lambda sufficient enough or do we require any other information? So as far as I am concerned, see let us consider this pointer right, so you see the radius is it is conical in shape right and the diameter here is large compare to that of tip, yeah definitely because you have a; for a chord you have a bigger base and a smaller tip, right.

Now you see it has been I mean the diameter has been reduced but the reduction has happened above the particular axis, right. It is for this particular tip for this particular pointer it happened about the longitudinal axis, right longitudinal axis of this pointer. But for a wing what are the possibilities? So if you look at here what you can see is it is stepped about trailing edge, right. That means your trailing edge of each and every airfoil are in the same location are in the same straight line here I mean; so the wing is tapered above trailing edge. Okay.

So what you require is axis for tapper, axis about which this tapper you are tapering a wing; axis for tapper. And now let us consider a classical or a rectangular wing. So what do you mean by rectangular wing? At each and every point you have equal chord. So let this be C right. So what will be the Aspect ratio of a rectangular wing? For a rectangular wing Aspect ratio = b squared/S = b squared/b*c = b/c, b/c is the aspect ratio.

So what will be the tapper ratio? Lambda here is; Ct and CR are same, so Ct/CR = 1. So let us consider another case. It is a triangular wing or a delta wing. So what is a tip chord in this case? This is CR what is Ct? Is 0. For a delta wing or a triangle wing we have lambda = 0, right. So the lambda varies from 0 to 1. Okay. Now we have this rectangular wing. Let us assume above some points we are trying to rotate this wing. Understand rotate this two half's, above this point we are trying to rotate give a rotation.

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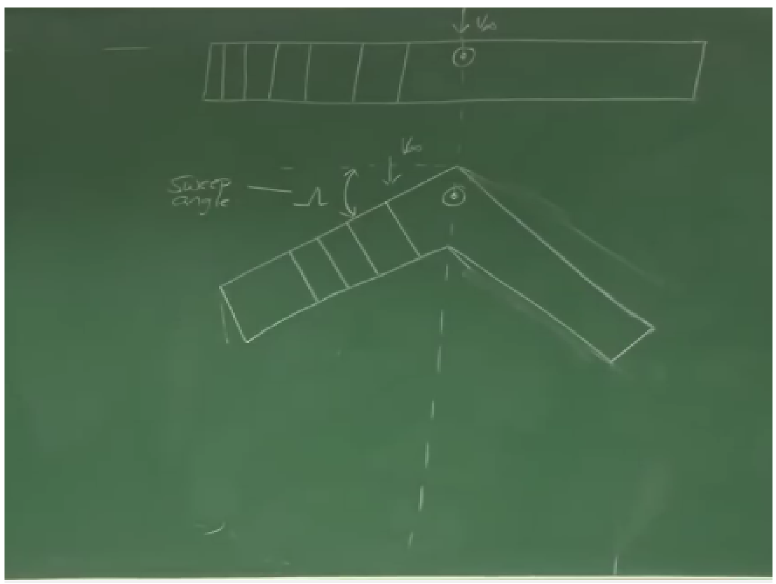

So initially we have rectangular wing, so above the point you are trying to rotate this wing. What happens? Am I correct? To almost look like this, right. What you have done is you have rotated by an angle about above some reference points, okay. If you take this rotation above leading edge or in general this angle is known as sweep back angle, or swept. So if you sweep it forward and if you push if you rotate the wings backward then it is sweep back angle, capital omega.

So this is a leading edge you have leading edge sweep and if you sweep above trailing edge you will have trailing edge sweep above quarter point quarter chord you will have quarter chord sweep. Similarly, tapper you will have it about quarter chord tapper or mid-chord tapper or trailing edge tapper. Like the airfoils here will be say if this is if this my v infinite the airfoil will be the chord of this airfoil will be aligned with the flow.

But right now what happens is a component, so if this is v infinite then whatever the airfoil will face is a face that generate lift is v infinite cos omega. So usually swept is essential when you are travelling a high speed, right to delay the mac number. Mac number on the airfoil, right. Although with respect to ground you will be travelling at a mac number but the airfoil is a lower mac number, right. That we will discuss as we progress. And this is a sweep, right.

At the same time when there is sweep there will also be a tapper. It does not mean that only sweep I mean only rectangular wings are swept you can also sweep the tapered wings.

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You also have something called dihedral, right. So let us say this is your actual wings level attitude; this is a front view okay. You have propeller here mounted on the nose, right; this is a front view, right. Now let us say this is my wings level attitude, so the angle made via the wings with this level attitude is known as dihedral. So we will see why we need sweep and what is dihedral why we require, right.

What are the conditions during which you have to use the dihedral for wing? Now coming back to this planform geometry.

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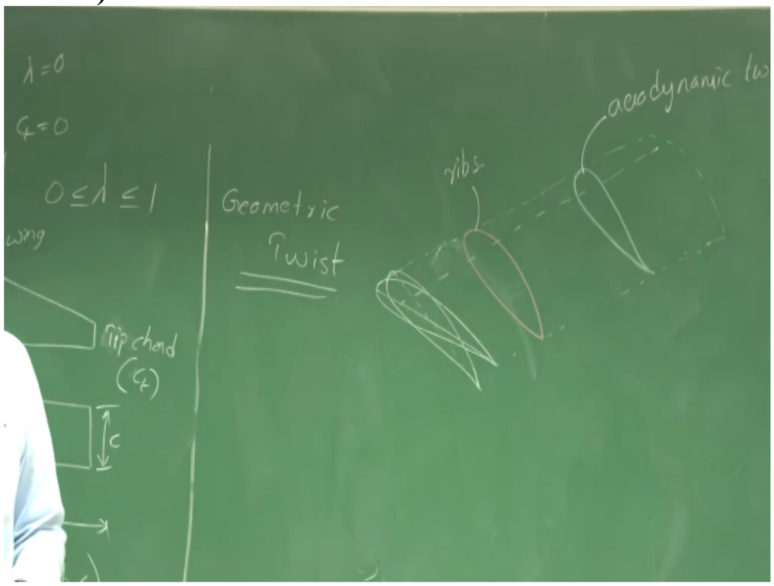

So say this is Root chord okay. Now, so this is your wing. Say if the airfoil here so the airfoil here say the same airfoil we are using; if it is rotated with respect to this root chord okay. So the airfoil which is present at this particular section is rotated with respect to this is the wing has airfoils which are with different orientation, you can have the constant twist or a variable twist wing.

So as you progress along the span of this wing you can actually orient airfoil at different angles, right. What we call that has, twist. So you call this as Twist which is by geometry. You are not changing the airfoil you are using the same airfoil and you are rotating it. You call it has geometric twist. So let us say I am not giving any physical twist but say if I change airfoil at the root chord I will be using one airfoil.

And as I progress along the span I will be changing the airfoil itself. Although, I am not giving any twist but the shape that once you look at the shape because the when you change the airfoil the upper surface and lower surface quadrant changes right with respect to root chord it will be of different thickness and all. So that gives you an aerodynamic twist, you are changing aerodynamic characteristic of the wing as you progress along the span.

This is geometric twist. So aerodynamic twist is like you use; here I may use a symmetric aerofoil, right. And here I may use symmetric airfoil or another type of airfoil with different thickness. So ultimately you are changing the aerodynamic; by changing this airfoil you are actually changing the aerodynamics along the span. So this particular twist, although it is not a physical twist but from the geometry it looks as if the wing is twisted.

So this particular twist is known as aerodynamic twist, right. So as far as the wing is concerned if you slice it at different location what you have is an airfoil. The structural name for this particular airfoil is a rib, right. So you will have ribs and you will have sparse that connect this ribs. And to cover this skeleton deforms the skeleton of the wing. And to cover this skeleton we will have skin.

So instead of making a solid wing we will be trying the whole idea is to design a wing which can have equal strength or sufficient strength, right by making it as hollow as possible. So let us look at one of the wings of UAV that we are going to develop.

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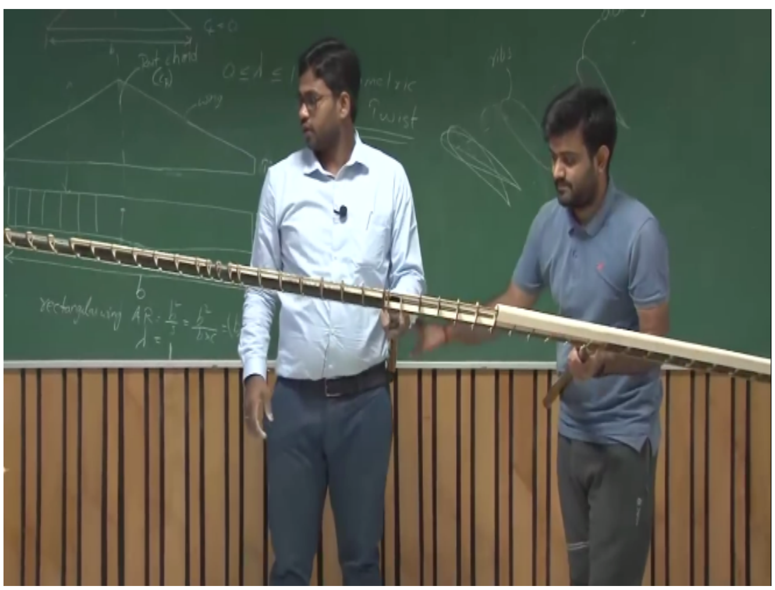

Yes, friends, what you are looking at is 4-meter span wing that we are going to develop for a UAV. It is a scale down wing. So the actual scale turns out to be 16 meters the span of the actual scale, right. So you can see at different locations we have ribs here, right. I will request one of my researcher to come here to help me out. Mr. Himanshu, can you please help me. If you can hold I can explain better, I guess.

So it is a twin boom UAV where the tail horizontal tail will ultimately end up landing like resting on this two booms which are extending from the wing. And what you have here is ribs right and most of at most of the places we have removed the material to optimize the weight and you have sparse here, so these are the carbon fiber tubes that you can see here. And at some places we have also covered with the scale, right. So this is a covered part of it you can see.

So and yeah it is tapered right, you can see that the wing is tapered. See the tapped. So you can see the thickness also reduces along the span. I thought this will be bit interesting for you so I got it in between the fabrication, I stopped them. So you can give it back to them, right. So coming back to the planform geometry.

Now as we can see from the root to tip the chord is varying. But in all the moments and while considering the moments we are considering some reference length, right. In case of pitching moment, we are considering it has the chord right for an airfoil. But what happens; which length we need to consider for a wing when it is getting tapered, when a mean tapered the chord is varying; the length of the chord is varying along the span.

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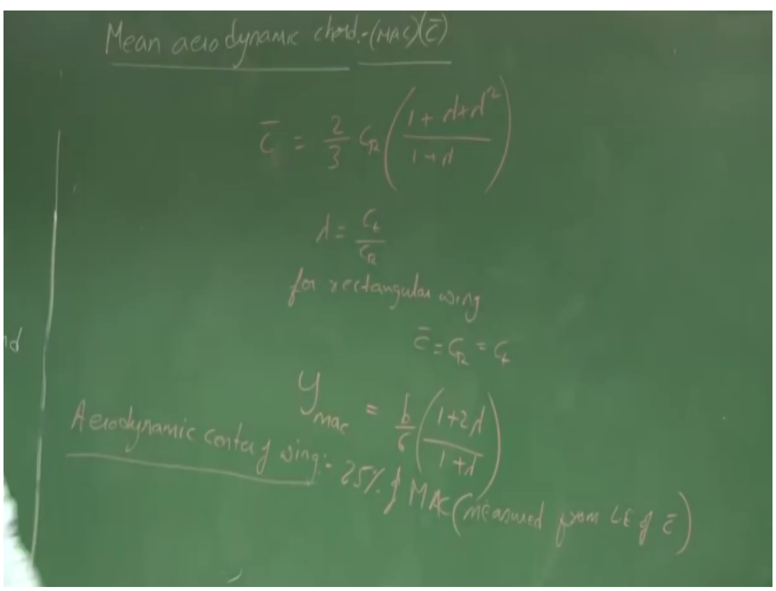

Now there is something called Mean Aerodynamic Chord, MAC C bar, right. So what is this Mean aerodynamic chord? Instead of this entire wing I can represent this wing by means of a straight line for the purpose of analysis, right. So let us say if I want to replace this entire wing, right all I can represent this by means of a straight line which is C bar of the wing, okay. And why because to represent;

What ultimately we have to represent the wing in terms of lift, drag and moment right. So this; and we represent it lift, drag and pitching moment about the aerodynamic center. Similarly, if I know the chord and the corresponding aerodynamic center, right that is good enough for me to represent the entire wing, okay. Now let us see how to find the Mean Aerodynamic chord as well as the Aerodynamic center of his wing.

So the units or meters here, right general units or meters. So you have root chord and you have tip chord. So let us say CR or C bar of the mean aerodynamic chord is given by 2/3rd CR * 1+lambda+lambda squared/1+lambda where lambda = Ct/CR, right. So this is like once you do that then you will end up getting a mean aerodynamic chord on either side which is symmetric. In case of a fixed string aircraft, right.

Now what you have to do is project this mean aerodynamic chord onto the root chord or the fuse loss reference line or the center line here, right. And we witness that like this the aerodynamic center lies at the 25% of the C bar, mean aerodynamic chord, right. So now for a rectangular wing let us say what is C bar = C or C root. So what is lambda? So 1. 1=2/3 * CR 3/2 this becomes for rectangular wing C bar = CR = Ct, right. You can verify this from this equation.

And where; so what is the distance for this; what is the distance at which this C bar is located, right a span wise distance. So y of mac. So if I want to know what is the y location or the span wise location of this C bar we have y mac is a span wise location in aerodynamic chord is b/6 * 1+2 lambda/1+lambda. So with the help of this equation you will be able to find the C bar of a given wing and 25% of this C bar is an aerodynamic center.

So how to find aerodynamic center of wing. It is like 25% of MAC, Mean Aerodynamic Chord measured from leading edge of C bar.

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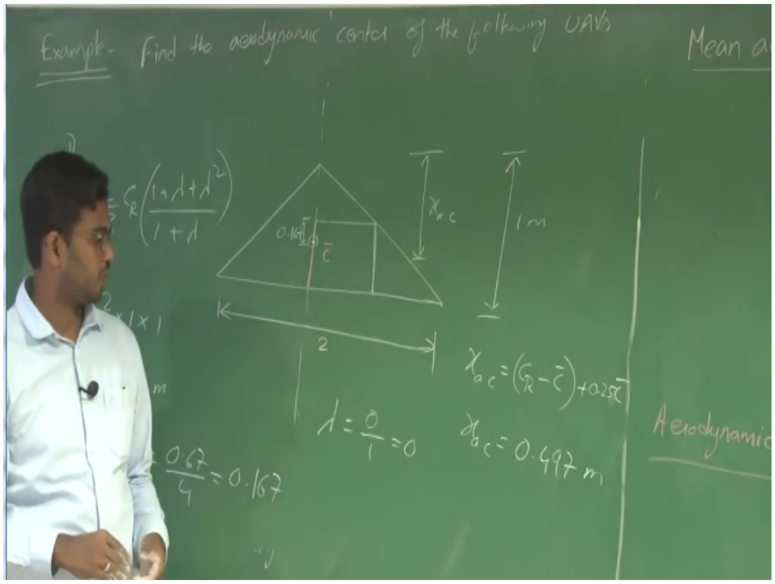

Find the aerodynamic center of the following UAVs. So in the first, in the first place let us consider a here delta. Let this be span be 2 meters and root chord be 1 meter, right. So how to find the mean aerodynamic chord, this is let us say this is my mean aerodynamic chord. So C bar is given by 2/3rd CR 1 + lambda + lambda square/1+ lambda. What happens? What is here? 1 meter * what is lambda, lambda for this, delta wing is 0/1, right Ct/CR that is 1, right.

So 2/3 is how much? 0.67 meters. So 0.67 meters is your mean aerodynamic chord, right. So what exactly a delta wing is here for a low speed, assuming that there is no actual sweep here, so it is actually a tapered above trailing edge, the wing tapered above trailing edge. So generally to construct this what happens, usually if there is a sweep you will take a component of this you will project that airfoil along the flow and you will take that airfoil as a rib to construct your wing, okay.

But in this case the low speed flows that we are talking we are not going to give any sweep, right. Consider, so you can consider in this course this delta wing whenever we discussed it can be a wing tapered above the trailing edge, right in most of the cases, otherwise mentioned it is like it is tapered above trailing edge. Now since it is tapered above trailing edge what I can do? I can project directly because the trailing is remains the same so this becomes my C bar.

So 25% of this C bar is, so MAC like aerodynamic center = 1/4 of C bar = 0.67/4, 0.16, so this aerodynamic center that we got is with respect to the leading edge here which is located at distance of 0.167 meters, right. And what is this distance? CR – C bar, right. So let us say if this is my X ac aerodynamic center, right. So X ac = CR – C bar; CR- C bar will give you this length and plus 25% of C bar that is 0.25 C bar.

So what you get here is; 67 and from one meter it is like 33.33; 33 centimeter + 16 centimeter for 49.7; 49.7 centimeter for approximately 0.5 meters. So the aerodynamic center lies at a distance of 0.5 meters from the nose of this delta wing.