UAV Design – Part II

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Lecture-12
Example Problems for Wing alone Configuration

Dear friends, welcome back. In or previous lecture we demonstrated how to make a flat plate stable. So, before that we have derived an equation or the conditions for static stability for a wing alone configuration. And then we have taken a flat plate and then we mounted a weight to bring it Cg ahead of the aerodynamic center and we had a flight for iterate. Now let us solve some more example problems related to this flat plate stability, how to enable the flat plate statically with static stability, right. So, we will solve few example problem just before that let us have a revisit of what we have derived.

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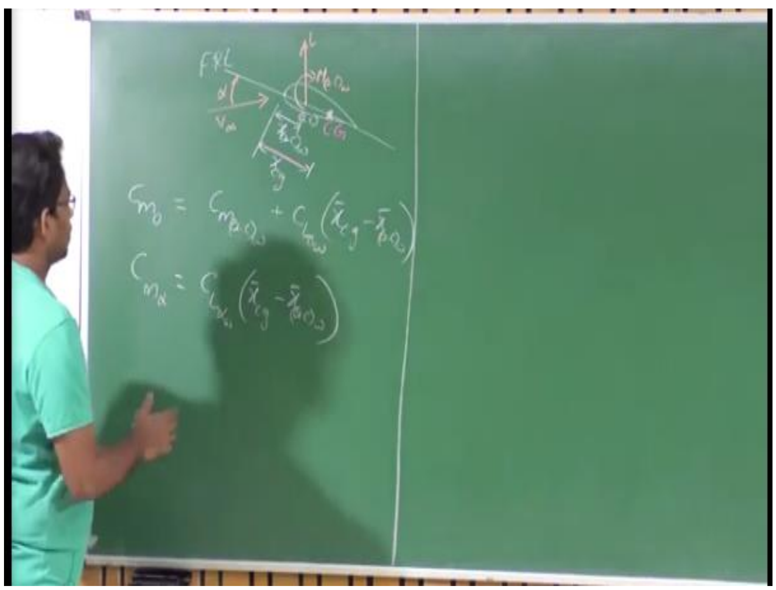

So, assuming this is my fuselage reference line and say my wing error or chord line coincides with the fuselage reference line. And say this is my location of aerodynamic center ac of the wing measured with respect to leading edge of the wing parallel to the fuselage reference line. So, we call this as x ac of wing right and say the Cg of the system is located at a distance x Cg again measure parallel to the fuselage reference line located at x Cg of this entire aircraft.

So, when there is flow the V infinity, so there is lift as we discussed earlier and also. And now we will not consider drag anymore we will not account that and we will also assume a small angle of x. So, that the lift is entirely contributing towards this which in movement about the center of gravity here, so this is my CG. And we have moment about aerodynamic center of wing.

So, what we have derived is C m 0 of this aircraft has to be C m a c of the wing + C L 0 of the wing times x bar C g - x bar a c of wing. And the same time we also looked at the C m alpha the sufficient condition is C L alpha of the wing times x bar Cg - x bar a c of the wing, ok. So, if this C m alpha has to be negative the Cg should lie ahead of the aerodynamic center here. And so if it lies ahead of the aerodynamic center, so this term becomes negative.

So, you need to choose a C m ac of the wing right, if you have dealing with the wing alone configuration. In such a way that now this value should be high enough to overcome this particular negative value right. So, the difference between these 2 terms will talk about it in the coming lectures, what exactly this term, this difference talks about.

So, in order to overcome this difference in the negative contribution towards the C m 0 because of the Cg lying ahead of aerodynamic center and you to choose a reflex in aerofoil with a strong C m ac positive C m ac here, ok. And then yeah, so let us now take up a problem.

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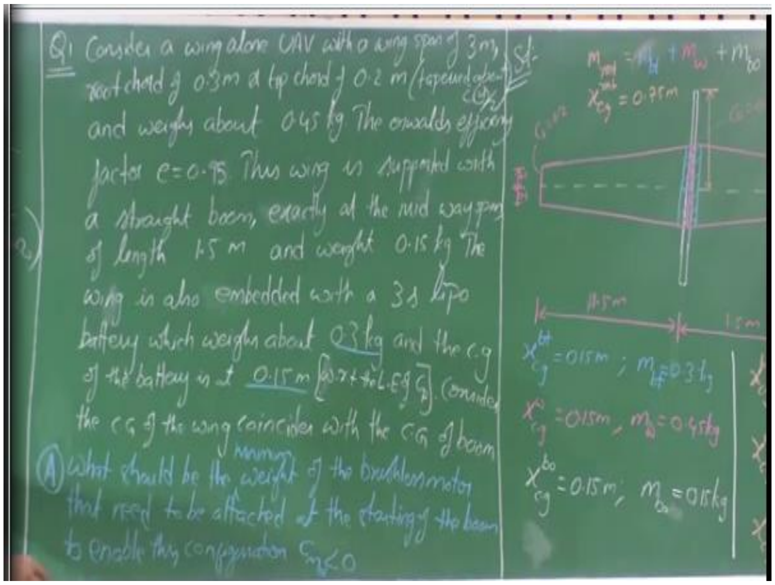

So, the question 1 for this week is consider a wing alone UAV with a wing span of 3 meters root chord of 0.3 meters and tip chord of 0.2 meters tapered about c by 2 at any equations, c of y by 2. So, it is a midpoint you know tapered about c of y if you consider any chord wise location right. So, it the taper access lies at the midpoint of the chord and weighs about 0.45 kg. The Oswald's efficiency of the wing factor e is 0.95.

And say this wing is supported with a boom this straight boom exactly at the mid way of span of length 1.5 meters. And weight 0.15 kg, so the wing is also equipped or embedded with 3 cell 3s lipo battery which weighs about 0.3 kg. And the cg the battery is at 0.15 meters from the or with respect to the leading edge of chord, ok. Question number 1 should be the first question you need to answer here. So, let us say A, so what should be the weight of the battery and consider so here consider the Cg of the wing coincides with the Cg of boom ok, this question.

And the first this is the data given and the first question need to answer is, what should be the weight of the battery sorry, the weight of the brushless motor minimum weight of the brushless motor that need to be attached at the starting off the boom to enable this configuration C m alpha less than 0 ok. So, this is what it is, so let us answer the first question here, so from the given data solution.

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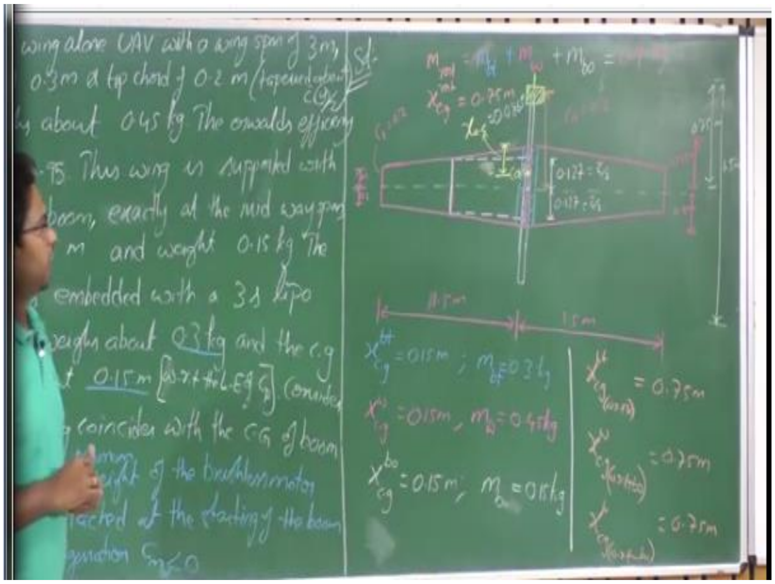

So, what we are asked to do, we have a bingo of 3 meter span with a root chord of 0.3 meters and a tip chord of 0.15 meter. And this taper happened to be the mid chord access at each and every cross section if you consider like at a given chord wise location, the midpoint of that particular chord gives you the taper axis. And with the root code of 0.3 and the tip code of 0.2 meters and this wing weighs about say 0.4 5 kg, that is what it is given here, so 0.45 kg here.

So, and then this wing is supported by means of a boom like fuselage for it right. So, this boom length is about 1.5 meters with yeah which weighs about 150 grams right. So, and moreover say for example, this wing is also let us say. **(Video Starts: 11:18)** So, we have a wing here and it is equipped with a boom right and then this wing is also equipped with a battery. Let us say this is this is a battery and it is embedded with the battery means the battery is inside this wing altogether.

And say the wing or the weight of the battery is about 300 grams and the Cg of the battery is say 15 centimeters from the leading edge of the roof chord. So, this say this is my leading edge of the root chord, so 15 centimeters behind the Cg of this battery is 15 centimeters behind the root chord leading edge of the root chord, right. And also the Cg of this wing which is at the yeah it is coincides with the Cg of the boom ok.

And let us assume that the Cg the weight distribution is or say the Cg of the wing is at the mid chord itself, ok. **(Video Ends: 12:10)** So, this is the another assumption we will consider, so, what you can say is the wing CG is at the mid chord. So, about the taper accesses itself the Cg of the wing is also present longitudinal Cg location. So, from the given data we will be able to draw the UAV schematic of the UAV.

Let us say this is the boom right which is about 1.5 meters, so say this is 1.5 meters, let me reduce the size. Otherwise I may not able to draw in to this draw it to the scale ok. So, say this is yeah 1.5 meters ok and then I have a wing of 3 meters and the Cg will be at c by 2 is not it with root chord of say 0.3 meters and the tip chord of 0.2 meters ok. So, first let us figure out the taper axis and we were told the CG is at the midpoint of the wing itself.

So, let us assume this is the midpoint of this particular tube, right or the boom. Because it is a cylindrical boom and then we can assume a huge homogeneous distribution here. So, the Cg can be at the L by 2, right, so that is a decent assumption. So, the Cg is a 1.5 meters, so the Cg is 0.75 meters right. So, with respect to the starting of this boom, the Cg of this boom is at 0.75 meters and the taper axis of the wing will also be a 0.75 meters with respect to this starting of the boom is not it, why.

Because the Cg of the wing coincides with the Cg of the boom and it presents at the midpoint of the chord which is the taper axis itself right. So, this will be say my taper axis which is the midpoints of the chord. Say, this is my root chord, root chord is given us 0.3 meters, right. So, say this is my root chord, let us say the root chord is 0.15 meters ahead and for 0.15 meters behind the taper axis, right, so which is total 0.3 meters, ok.

So, this is my root chord c r and say the tip chord again is tapered about the same axis. So, what I have is 0.2 is the total chord, so I have 0.1 meters above the taper axis and then 0.1 meters below the taper axis here, ok, so 0.1 meters below the taper axis. So, this will be my wing, so I will join the leading edge and the trailing edge of all the chords here, so this is my wing, right. So, similarly here I can assume, ok, this is my wing of this UAV and the span of the wing is given us, so 3 meters right ok, make sense. Now I have a root chord here c r this entire part is my root chord, so the entire part is C r which is 0.3 and C t from the given data.

And the Cg of this lies at the midpoint of the root chord right is not it, so and it coincides with the mid Cg of this boom which is at 0.7 5 meters with respect to the starting of this boom with respect to the mouth of the boom, we can say here. Now we need to attach a motor to this boom such that the Cg of this entire configuration and again yeah so just to add this point as well there is a battery, right.

So, this battery weighs about let us say whatever the weight must be distributed. So, the Cg of this battery is also coincide in with the Cg of the entire system. Because it was given the Cg of the battery is at 0.15 meters with respect to the leading edge of the root chord. So, this is my leading edge of the root chord 0.15 meters from the leading edge of the root chord falls on the taper axis which is in fact the Cg of V Cg of the boom as well as Cg of the battery.

Let us assume this is the distribution of my battery along the span which weighs about 0.3 kg, right. So, and the Cg of this battery is also at this particular location, right. So, now what I can do is x Cg of battery, so superscript here b stands for battery, ok. So, x Cg of the battery is at 0.15 meters with respect to the leading edge of the root chord and the mass of the battery is 0.3 kg, so that is what it is given 0.3 kg, 0.15 meters.

And then the wing x Cg of the wing is at 0.15 meters again with respect to loading edge of the root chord. And the mass of the wing is about 0.45 kg, right. And we have the boom, so x Cg of the boom is equals to 0.15 meters with respect to leading edge of the root chord is not it. So, with respect to, so let us say 0.15 meters, so if I do not write anything beneath the cg right as a subscript to Cg.

So, that means it is we are measuring with respect to the leading edge of the root chord ok. So, and the mass of those boom is, so let me add bt for battery and bo woofer boom ok, so bo for boom here, bt for battery ok. So, the moon mass is about 150 grams, right 0.15 kg. So, the boom cg can also be like we can also take the cg reference with respect to the starting point of this boom.

So, the cg with respect to or say so, the cg in all these cases with respect to the starting of this boom with respect to this point, so X Cg of battery with respect to boom right. Let us say w r t with respect to boom bo with respect to bo is equals to 0.75 meters. In all the case it is 0.75 meters, right it is a 0.75 meters. So, similarly x Cg of wing with respect to bo with respect to boom is also 0.75 meters.

And x Cg of battery with respect to boom is also 0.75 meters, ok, we will see why we require this. So, for this particular configuration the cg is more or less same is not it m 1 x 1 + m 2 x 2 + m 3 x 3 upon m 1 + m 2 + m 3 sigma m is not it. So, in all the cases x Cg is same with respect to the boom with respect to starting of boom. We can say the cg of this entire system which includes battery, wing and the boom is at 0.75 meters from the starting of the boom, right.

So, let us say this is for the rest what we can call it as so m of mass of the rest apart from the motor that we have to add mass of the rest is equals to mass of battery, ok. So, is equals to mass of battery + mass of wing + mass of bo boom ok which is equals to 0.9 kg, ok. We can add it 0.3 + 0.45 is 0.75 + 0.15 is 900 grams, ok, so that is a and the cg of all this cg of rest I should say X cg of rest is equals to 0.75 meters.

So, with all these components together the cg’s also at 0.75 meters, ok. Now, what do we need to find, so what should be the weight of the. So, first of all if you have to talk about C m alpha, we need to know what is the aerodynamic center. So, C m alpha we can talk only when we know what is x Cg and x ac, C L alpha is positive let us we do not go into those details of C L alpha right now, right.

But if you have want C m alpha positive or negative that is governed by this distance between x Cg and x ac. So, I need to know what is the location of x Cg and x ac of this particular configuration, right. First of all let us figure out what is the current x Cg of this location, right and we know it is 0.75 meters, right, we want to know what is the aerodynamic center for this.

So, that means, so with the given data we should be able to find out mean aerodynamic chord and project the mean aerodynamic chord onto the root chord and figure out the corresponding aerodynamic center with respect to leading edge of the root chord or with respect to the boom here, correct. So, if you are talking about this particular equation, then let us talk in terms of leading edge of the root chord itself, ok.

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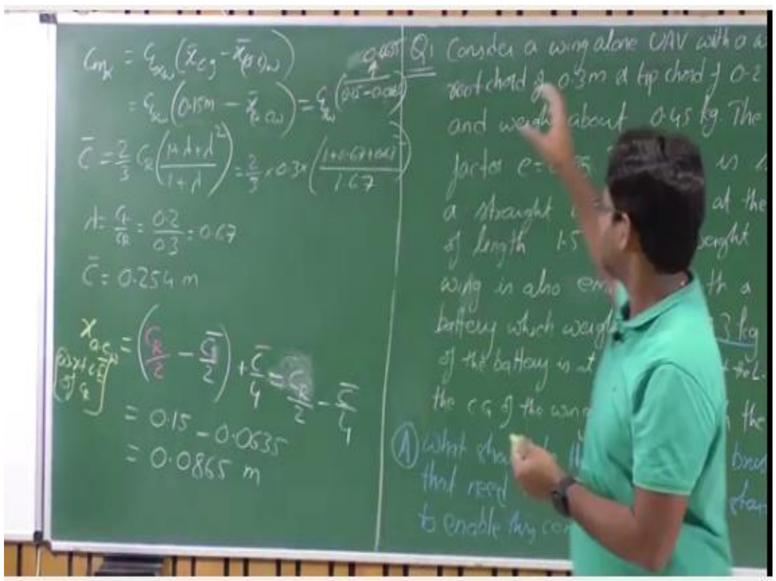

So, C m alpha is equals to C L alpha wing times x bar cg - X bar ac of wing, correct. So, we know what is x Cg here, so C L alpha of wing is equals to with respect to the leading edge of the root chord. It is about 0.15 meters, am I correct. So, this is 0.15 meters - x bar ac of wing, so I need to find out what is x bar ac of wing. So, how can I find, so first I will find out what is C bar, C bar is 2 third C R times 1 + lambda + lambda squared upon 1 + lambda, it is a straight tapered wing, right.

So, 2 third times C R is 0.3 meters times what is lambda here, so lambda is equals to C t upon C R. So, C t is 0.2 upon C R is 0.3 which is 0.67, ok, so multiplied by 1 + 0.67 square upon 1.67. So, it turns out to be, so C bar is equals to 0.254 meters, ok, so C bar is 0.254 meters. So, now project this on to the root chord, how can we do that, see we know this point that is C bar by 2 and C R by 2 they lie on the same axis because it is the taper axis.

So, we know these 2 points lie on the same axis you can simply, so if you want to know the difference between the leading edge of the mean aerodynamic chord and the leading edge of the root chord, it simply C bar C R by 2 - C bar by 2. Because this is a midpoint of each and every court if you project it onto the root chord that is a midpoint here ok. So, this is 0.254 is a total C bar, let us say this is my total C bar which is 0.254, if I project it onto the root chord.

So, what I have is, so let us say this is my mean aerodynamic chord, right, I projected it onto the root chord. So, what I have is, so 0.254 is the total half of that will be 0.127 is called 0.7 centimeters. So, above the tapper axis it is 12.7, below the tapper axis is 12.7 centimeters right which is 0.127 meters ok. So, this is my C bar by 2, so this is like C bar by 2, this is also C bar by 2, ok.

So, I know the aerodynamic center here x ac, let us say is at certain point, so with respect to leading edge of the root chord it is at a distance of, so say this is my aerodynamic center x ac, this is my this point a low point is my ac. So, ac we know C bar by 4, am I correct, this is C bar by 4 x ac is C bar by 4 with respect to the leading edge of the C bar. Now, in order to find this location of aerodynamic center with respect to the leading edge of the root chord, what I need to do.

I have C R by 2, I know C bar by 2 because this is tapered about mid axis and subtract C bar by 2 from C R by 2. So, what I have reached with respect to leading edge of the root chord is leading edge of the mean aerodynamic chord. So, from there one fourth from there is my aerodynamic center. So, what I mean here is x bar or x ac aerodynamic center, so this is with respect to leading edge of C R, ok is equals to.

So, say this is by default we are doing this we always considered with respect to leading edge. But here there is a need for us to talk with respect to the leading edge of the boom as well. So, that is a reason why in order to avoid confusion here we are talking about x aerodynamic center with respect to the leading edge of the root chord right. So, I have a C R by 2, so C R by 2 - C bar by 2.

So, with this I have now reached from leading edge of the root chord, I have reached to the leading edge of the mean aerodynamic chord plus C bar by 4, ok. So, from leading edge of the root chord, so this takes me from the leading edge of the root chord to leading edge of the mean aerodynamic chord from leading edge of the mean aerodynamic chord I am reaching aerodynamic center here C bar by 4, right.

So, this equals to C R by 2 - C bar by 4, ok. So, what is C R by 2 is 15 centimeters right - C bar by 4 is like. So, C bar is 28, right, so 25 centimeters upon 4 is approximately yeah 0.0635 64 is 24, right approximately 6 centimeters, is not it. So, if you subtract this what I have is 0.0865 meters. So, with respect to the leading edge of the root chord this particular value the location is at 0.0865 meters which is 8.6 centimeters approximately.

So, if we move down to 8.6 with respect to the leading edge of the root chord you will find your aerodynamic center here, right. So, we got to know 0.15 is the cg with respect to leading edge of the root chord and now you know the aerodynamic center of the wing with respect to the leading edge of the root chord. So, can I substitute that value here, so what I have is C L alpha being times 0.15 - 0.0865 this is equals to 0.6 or 0635, so this value transfer to be that.

So, which is close to 6 centimeters, that means this is positive, so C m alpha is becoming positive here, so with the current cg location it is positive without adding any motor. Now what we are asked is what should be the minimum weight of the brushless motor that need to be attached to the straight at the starting of the boom right. So, we need to add some mass here, let us assume that as this particular block, now that motor as this particular block here.

So, say this is my brushless motor, I am attaching to the boom here, ok, this is my brushless motor. So, it is attached exactly this let us assume the cg of this motor coincides with the starting point of the boom ok, that is one assumption that we will consider. And now with this attachment, so the cg now has to shift forward, we know that, right. So, what should be that minimum weight of this motor that makes this configuration C m alpha negative, ok, is it clear.

That means a mass of the motor which is say mass of the motor m, m is the mass of the motor that I need to attach to make this configuration stable, right. So, at least in case of C m alpha has to be less than 0. So, now I need to talk everything with respect to the leading edge of the boom because this is attached at the boom, right. So, now I will try to talk about the cg location with respect to the leading edge of the boom, ok.

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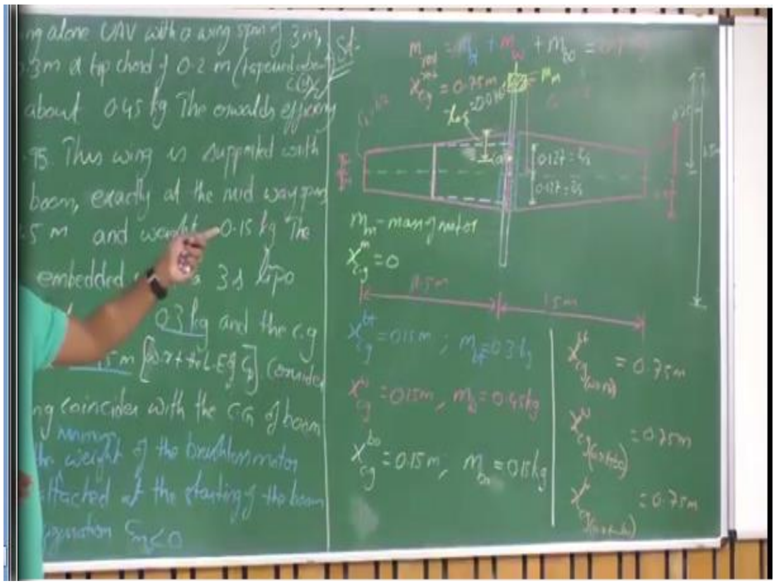

So, for that what I need to do, so what should be the minimum location in the first place or what is the boundary condition when C m alpha is, am I correct. So, right now it is positive if it has to go to negative and there should be a point where C m alpha is also 0, there should be cg location where C m alpha is 0. So, what should we that location C m alpha can be 0 when cg is equals to aerodynamic center.

So, now let us find out if the, so what is that weight you know that we are adding ahead of this being that brings the cg to the aerodynamic center. See, right now the cg is at this tapper axis, aerodynamic centre is here, right. So, I need to bring the cg of this entire configuration without motor, right, to this aerodynamic center by adding a particular motor. Now I need to choose what should be the minimum weight of that motor, right.

So, first of all the minimum weight to make it C m alpha negative, we need to know the weight of the motor that we are going to add right, that makes this aerodynamics cg coincides with aerodynamic center, am I correct, right. So, first if you find out that any mass more than that will try to shift the cg ahead of the aerodynamic center that makes that particular C m alpha negative for this configuration, ok. So, I need to add first of all I will find out that boundary condition that makes Cg coincide with the aerodynamic center with the motor, right.

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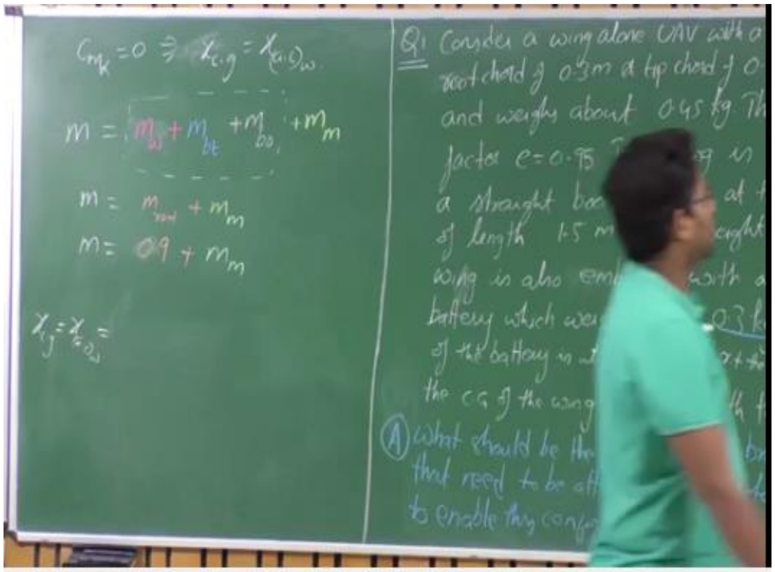

So, C m alpha for me to become 0 right which implies x x's Cg should be x ac for this of wing, am I correct. So, by just by substituting that C m alpha 0 in the previous equation, so what we have is this x Cg must be equals to x a c of the wing, right. Now, if this has to be the final x c g what should be the mass of the motor. Now, what is the total mass of the aircraft, let us assume m represents the total mass of the aircraft, right.

That is equals to earlier it was like mass of wing m of wing + mass of battery bt and we have mass of the boom as well, right. So, m of boom bo and now, so we call this particular expression like this m of rest, right, so that is the reason why we use rest. And now what we have is in addition to it, we are adding yeah motor mass of motor ok which we need to find out in fact, right.

So, what I have here as an expression m is equals to total mass of the aircraft is mass of rest + mass of motor. So, I know mass of rest is 0.9 kg, right, so mass of rest is about 0.9 kg + mass of motor ok. And now with the addition of this mass at x, so what is the location of this mass, what is the c g location of this mass with respect to boom. So, x m m is a mass of motor in the corresponding x Cg of motor is 0, it is exactly with respect to the boom, right.

I am talking with respect to the boom, right, it is exactly at the leading edge of the boom or you can say at the starting of the boom ok. So, with that assumption, so the new c g I need is as aerodynamic center here, right. So, the new c g what I need is nothing but the aerodynamic center of the wing is at the aerodynamic center of the wing which is about 0.75 meters no I am sorry.

So, what is the aerodynamic center of this wing with respect to the boom leading edge of the boom, alright. So, I know what is this with, so I know C R by 2 I know boom length up to here is 0.75 meters, I can subtract seer from here C R by 2 + what is the corresponding x ac, am I correct or not.

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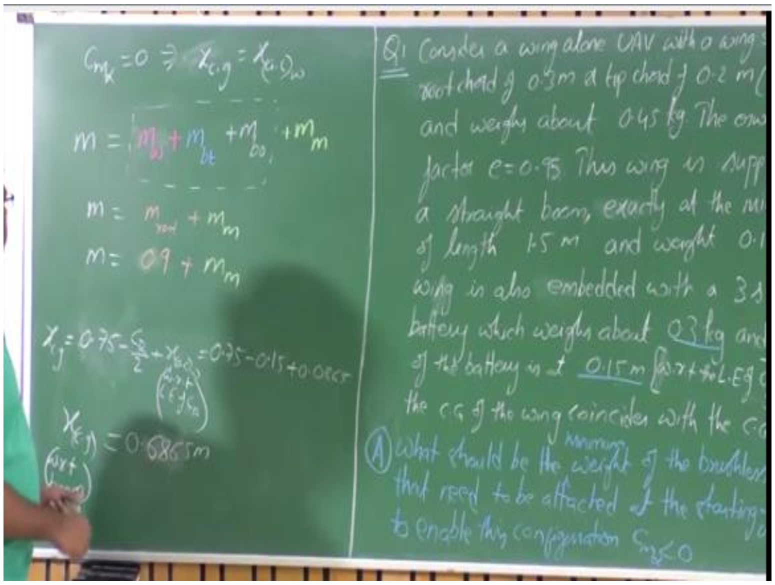

So, now we are talking with respect to the boom, so X c g is equals to so 0.75 is half of the length of the boom minus C R by 2 + x a c of wing with respect to leading edge of C R, ok. So, this particular value is with respect to leading edge of the C R here root chord, so 0.75 is length by 2 that is where current c g is, am I correct, - C R by 2 is the root chord. I am subtracting this root chord from that this entire length, so that I reach this particular leading edge of the root chord.

From there again I am adding X ac which is the aerodynamic center with respect to the leading edge of the root chord. So, this is equals to 0.75 - 0.15 - + 0.0865, so this equals to, so the new cg with respect to the boom, so cg with respect to the boom new cg, this is the new cg ok. So, new has to be at 0.065 which is nothing but the aerodynamic center, location of the aerodynamic center of the wing with respect to the leading edge of the boom or say a starting point of the boom, 0.6865 meters.

So, it is about 68 centimeters from the starting of the boom, alright, so x Cg, this is the new x Cg. Now in order to achieve this new x Cg what should be the mass that I need to add, right, ok. So, how can I find it out, so I am again erasing this part.

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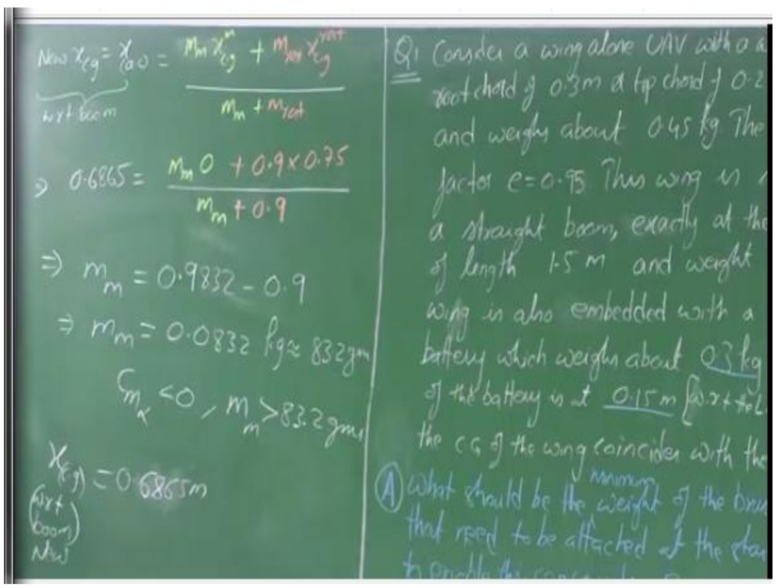

So, x Cg or the new x Cg or it has to be the x aerodynamic center both with respect to leading edge or with respect to boom starting of boom is equals to m 1 or m m motor mass times is the additional weight rate. So, with this additional weight we are trying to shift to the new cg from the current Cg which is nothing but the aerodynamics center of the. So m m times x cg of motor plus the rest young m rest times x Cg of the rest upon total weight here is not it, + m m + m rest is 0.9 kg, ok.

So, I need to find out what is m m from here, right. So, the new cg which I want is 0.6865 meters is equals to, so m m times 0 x Cg of motor is 0, that is what we have. And plus 0.9 times 0.75 is the cg of the rest you can see that, you know cg of the rest is 0.75 upon what you have is m m + 0.9, right m m + 0.9. So, if you solve this m m is equals to 0.9832 - 0.9, right.

So, this mass of the battery is equals to 0.0832 sorry kg which is approximately 83.2 grams. So, you need to at least choose a motor right which weighs about 83 grams in order to make C m alpha 0. And you need to choose anything more than this 83.2 grams to make it negative, right, C m alpha negative. So, in order to make C m alpha less than 0, so I need a motor of mass which is greater than 83.2 grams, ok, is it clear.

So, if you find this 83.2 if you take any weight more than this 83.2 grams and you find the new cg location then if you substitute that cg location and the corresponding aerodynamic center location in the equation, you will be able to find C m alpha is negative, right. That is how you are shifting cg ahead of the aerodynamic center here, so this is the motor that we require, ok. We can solve the second problem now.

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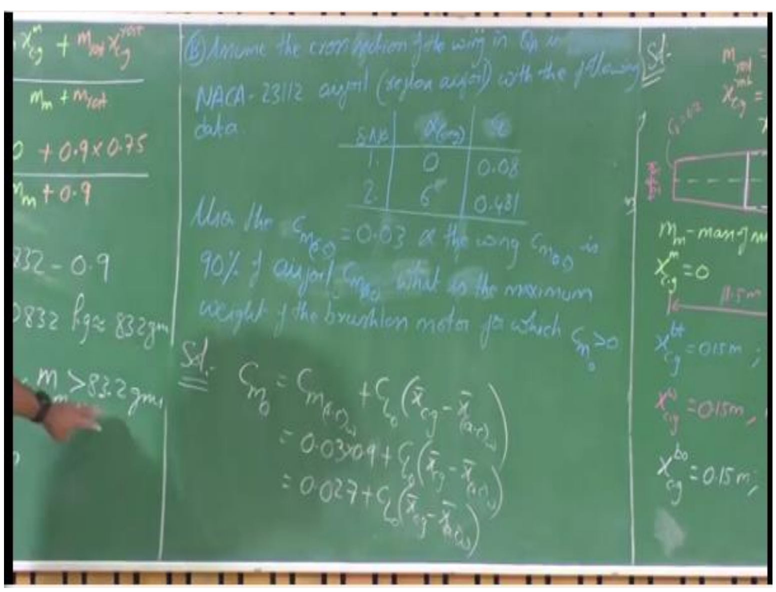

So, the second question B for this is assume the cross section of the wing in question 1 or question A is, so NACA 23112 airfoil which is a, right reflex airfoil with the following data, it is alpha and C L, alpha is in degree, ok. So, first is at 0 degrees angle of attack this is approximately 0.08 right, this is 0.08 and then at 6 degrees angle of attack it is 0.481, ok. So, this is the data given for the airfoil, right.

And also the C m about aerodynamic center or C m C by 4, so more or less same you know unless there is a huge deviation C m by 4 is close to 0.03, right 0.03, so that is a reflex airfoil that we can talk we can immediately get to know that you know C m ac is positive it is a reflex airfoil. And the wing C m ac and consider the wing C m ac is 0.9% of or 90% of C m a c of airfoil, ok or 90% of airfoil C m ac, ok.

So, what do we require to find, first thing is what should be the maximum weight what is the maximum weight of the motor for which C m 0 is greater than 0, ok. So, let us first look at the given data. So, what do we need to do you know in the first place, we rast C m 0 has to be greater than 0, C m 0 of this is equals to C m ac of the wing + C L times x bar Cg - x bar ac of the wing, am I correct, ok.

So, for C m 0 has to be positive, alright, so this has to be this is given a 0.03 times 90% is 0.9%, right which is multiplied by 0.9 which is 0.027 kind of ok, right, what is a value, 0.027, right, ok plus C L times x bar Cg - x bar ac of wing ok. So, this is 0.027 + C L 0 times x bar Cg upon x bar ac of wing. So, without adding the motor we know what is the x Cg, right, is not it, so it is at 0.75 meters and the aerodynamics center is behind ahead of the cg.

And we know this is positive, right and this is positive C m 0 is positive, by adding the motor we brought cg ahead of the aerodynamic center, right, is not it. If you add motor which is anything greater than say 84 grams, that means this quantity will be lesser than this quantity, ok. This makes it negative and so now you are subtracting it from this positive C m ac the reflux aerofoil which you have considered to trim at a posture angle of a type.

Now you are trying to compromise at that, right by bringing the cg more forward, ok. Now say if we consider a motor which is heavy enough to make this particular quantity more negative than this C m ac of the wing. If you do so then C m 0 becomes negative, right which is undesirable in our case, am I correct. That means first we have to find out that limiting condition what we rast, so what should be the weight of the motor that shift the Cg so much that it make C m 0 negative.

Or say or what is a maximum weight that you can afford if you have to afford then C m 0 has to be positive, right, is not it. So, in order to trim at positive angle of attack C m 0 has to be positive. So, that means this particular quantity the maximum weight say the minimum weight is about 84 grams. Now say if you consider whether it should be 200 grams or 300 grams that makes this still positive.

So, in order to get that answer first we need to find out what is the limiting condition when can when can C m 0 become 0, what should be the weight of the battery I need to add such that this quantity becomes negative, right or exactly equal to this particular quantity, am I correct or not. So, what will be the corresponding cg location for that, aerodynamic center is not going to change, right, so only cg will change with the addition of motor.

Now we know aerodynamic center of the wing with respect to boom there, is not it. So, now we can write with respect to the boom there, ok, that distances we shift the reference to the boom right now. And then substitute them here and see and equate the C m 0 to 0 and find out what is the corresponding cg location. Once you know the cg location, you know that should be the cg that you need to achieve by adding a motor of mass m.

So, figure out what should be the maximum motor weight of the motor, ok, got it. So, if I have to shift this let us say we will find out the cg location with respect to the root chord itself, then we will try to shift it, right. First of all this is with respect to the root chord of the leading edge, this equation is with respect to the root chord of the leading edge right.

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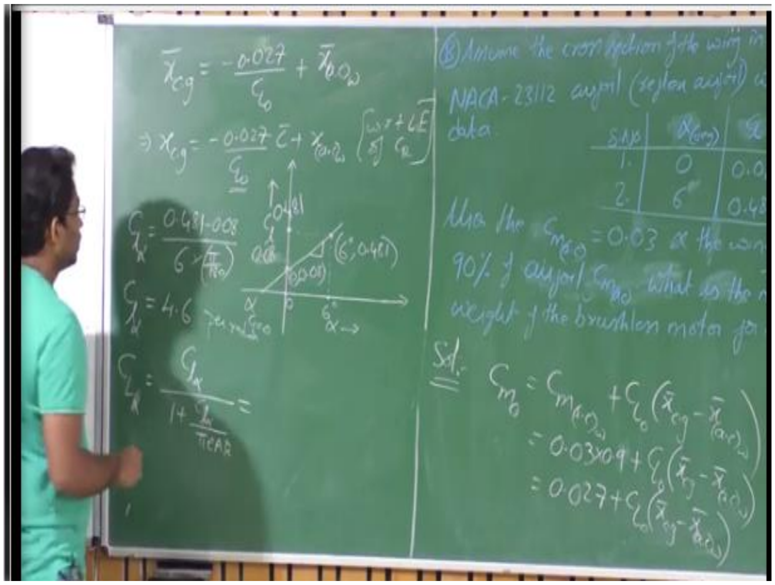

So, now x bar Cg or x Cg should be equal to -0.027 upon C L 0, right, C L 0 of the wing + x bar or x ac of the wing let for that x bar ac of the wing, ok. This equals to x Cg equals to -0.027 upon C L 0 times C bar + x ac of the wing, so this entire thing is with respect to leading edge of C R, ok. We know what is C bar, C bar is 0.285 approximately, right.

So, first of all we need to find out what is C L 0 in order to solve this question we need to find what is C L 0. So, from the given data, so I am plotting the given data here, so the information that I am having is at 0 angle of a tag say this is my alpha and this is my C L 2D C L ok. So, airfoil C L, so this at 0 angle of a tag I have C l 0 of the aerofoil, this becomes C L 0 of the aerofoil, this is aerofoil data 0.08.

So, this point corresponds to 0.08 here, ok and there is another point, so this corresponds to 0, so there is another point at 6 degrees angle of tag, so what I have is C L has how much 0.481. So, this particular point corresponds to 0.481, so this coordinate corresponds to 6 degrees, 0.481 and this coordinate corresponds to 0, 0.08. So, say this is a linear regime ok, is the linear regime that I am considering.

So, first of all I can find out what is the slope of this curve. So, this point corresponds to alpha at which C L is equals to 0, right. So, first of all I need to find out what is the slope, so 2 dimensional slope C L alpha is equals to 0.481 upon - 0.08, right upon 6 degrees multiplied by pi by 180. So, what is the value, so C l alpha is equals to 2D is equals to 4.6 per radian, right, this is per radian, so that is a reason why multiple by radian, ok.

Now I have 2D C L alpha, I will be able to find out 3D C L alpha am I correct or not. So, how can I do that, so 3D C L alpha is equals to C l alpha 2D upon 1 + C L alpha 2D over pi eAR. So, Oswald's efficiency was given earlier, so what is the aspect ratio here, you need to know what is the aspect ratio.

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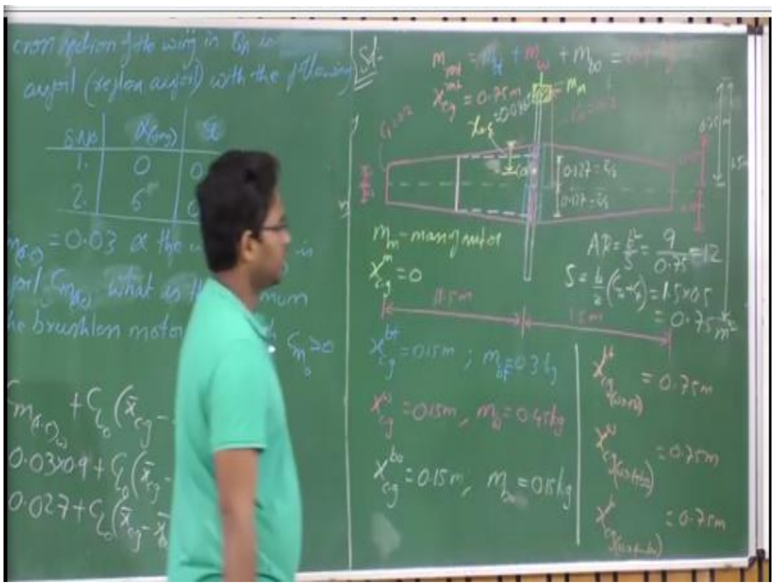

So, from the given geometry it is aspect ratio is equals to b square by S which is 3 square which is 9 upon what is S, what is the area of this, sir C l alpha 0 getting 4.0 yeah please make a correction, small correction here.

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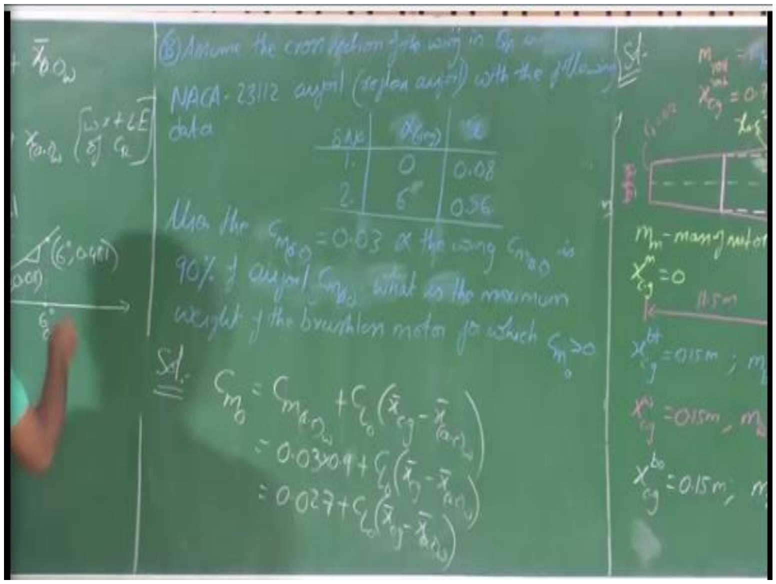

This is not 0.4 this is 0.56, right. So, consider this as 0.5614 here, so if I have at 6 degrees it is 0.56.

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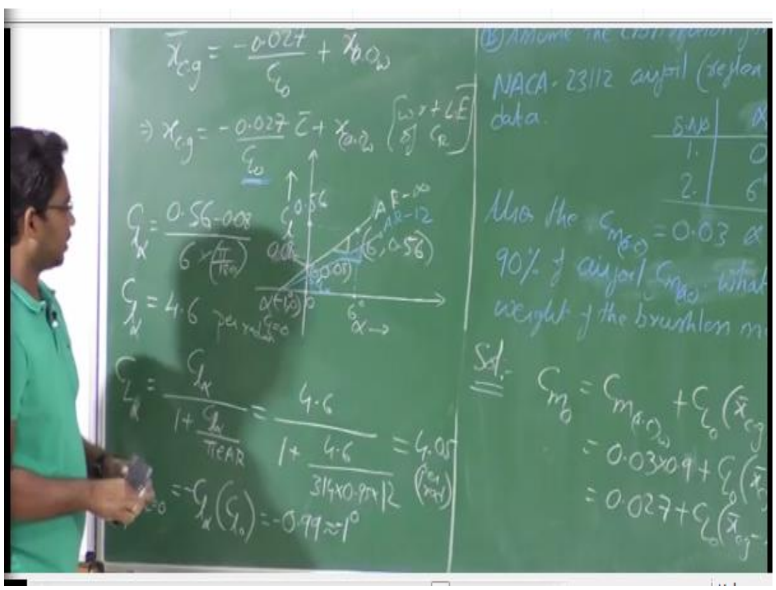

It is 0.56, ok, 0.56 this one so if you substitute that 0.56, so what you have is 4.6 per radian here, right. Once you substitute this 4.6, so we need to find out what is the aspect ratio, so b 2 by S, S you can find out b by 2 upon C R + C t, right what is the value here b by 2 is 3 meters upon 2 is 1.5 times C R + C t is 0.75, is not it, S is 0.75 meter square**,** so this is aspect ratio is 12, ok. So, 900 upon 75 is 12 there, so 1 + C L alpha is 4.6 upon 3.14 times 0.95 is the aspect ratio that we considered earlier, sorry 0.95 is the Oswald's efficiency factor.

And from the given data you refer to the previous question and the aspect ratio here is 12. So, the value is approximately 4.05 per radian, ok, so C l alpha 3D for this particular configuration is 4.05 per radian, ok. Now once we have C l alpha 3D you need to find out C l 0 3D, right. So, that maybe for example, so say this is my so that is for infinite wing, this is for finite wing, right. So, this is for A R infinity, so this is for A R 12 that is for A R infinite, right.

So, I know what is the lift curve slope 3D right now. So, in order to find out C L 0 here this is the C L 0 that is required so this is from here, right C L 0 point. But I do not know how to find out because I have only C L alpha 3D right for this blue curve. So, we know that it is a descent assumption to consider that the lift coefficient or the angle of a tag at which the lift coefficient is 0 is same for finite wing as well as infinite wing that is a descent assumption that we considered earlier.

So, if we can find out this alpha at which C L is 0 then I will be able to find out C L 0 there because I will have one point anther curve point under the slope there, right. So, how can I find out that from the aerofoil data, so I know what is C L alpha 4.6 and I know C L 0 from the given data is 0.56 sorry 0.08. So, this is 0.8 from the given data, I have the slope as well, so I will be able to find out that.

So, alpha at which C l is equals to 0 is equals to C L alpha 2D - C L at alpha 0 or C L 0 right, what is the value - 0.99 degrees which is approximately 0.1 degree, ok, so this value corresponds to 0.1 degree. So, this particular value corresponds to 0.1 degree here, right. So, once I know what is alpha at which CLE 0 which is - 1 degree, I will be able to find out this is - 1 degree, 0 this particular coordinates. So, I will be able to find out what is C l 0, so how can I do that.

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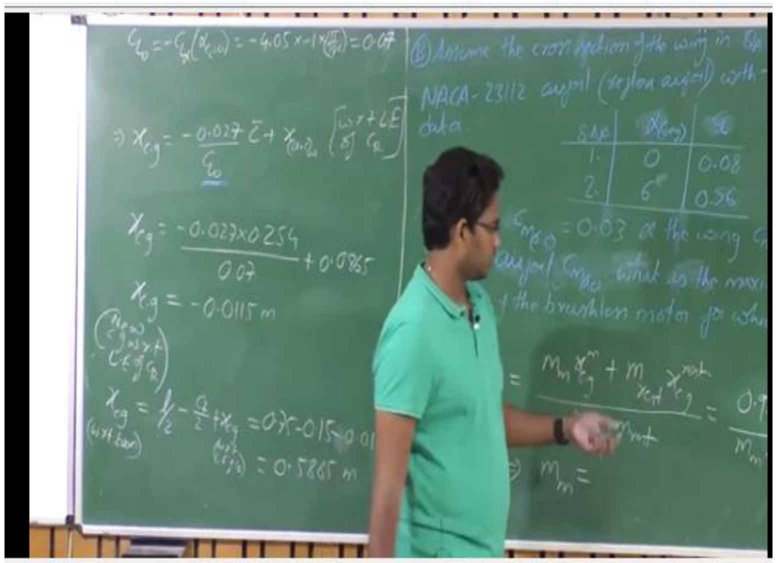

C L 0 is equal to C L alpha - C L alpha times alpha at which C L is 0 this is equals to - 4.05 times - 1 multiplied pi by 180 because C L alpha is in for radian, so what I have is approximately 0.07. So, I have C L 0 right now, and I know C bar and I know with respect to the leading edge of the wing, I get to know I can find out what is the corresponding cg location with respect to the leading edge of the wing, right.

So, if I substitute that C L 0 in this particular equation, so now the x Cg is equals - 0.027 times 0.254 upon C l 0 is 0.07 + x ac of the wing is 0.0865, ok. So, if you do that the new X cg the new cg with respect to leading edge of C R ok, so the same thing is equals to - 0.0115 meters. So, approximately it should be 1.1 or 11 mm ahead of the, so this new cg, so has to be 0.0115 yeah meters which is approximately 11 mm ahead of the leading edge, so this is the new Cg.

So, initially the cg is here, now adding a motor to make C m 0 0, so a mass of motor that makes C m 0 0, so for the yeah cut this part. So, this is the new cg location which is 0.015 meters ahead of the leading edge of the root chord, right. So, I need to bring the cg which is from 0.75 meters to this particular location, the new cg location, so by adding a mass of motor by adding a motor of mass m m, right, ok.

So, I have this x Cg here, so this must be the new location, now the minus here indicates that the cg is ahead of the leading edge here, right. So, now with respect to the boom, this location will be like length of the boom by 2 - C R by 2 minus this particular length, right. So, that is when I know what is this length, if I subtract this length I am here and if I subtract this distance further from the leading edge which is the new cg location, I will be at the cg location with respect to the starting of this boom, right.

So, x boom x Cg with respect to boom is equals to L by 2 which is length of boom by 2 - C R by 2 + x Cg. If you do a vectorism it is this otherwise you take the absolute value of it otherwise + x cg with respect to the leading edge of C R. So, this is how much 0.75 - 0.15, right plus or this is - 0.0115, what is the value 0.5885 ok. So, the maximum weight of the motor has to be, so say if this is the cg then, so this is X cg with respect to the boom is equals to 0.5885 this one is.

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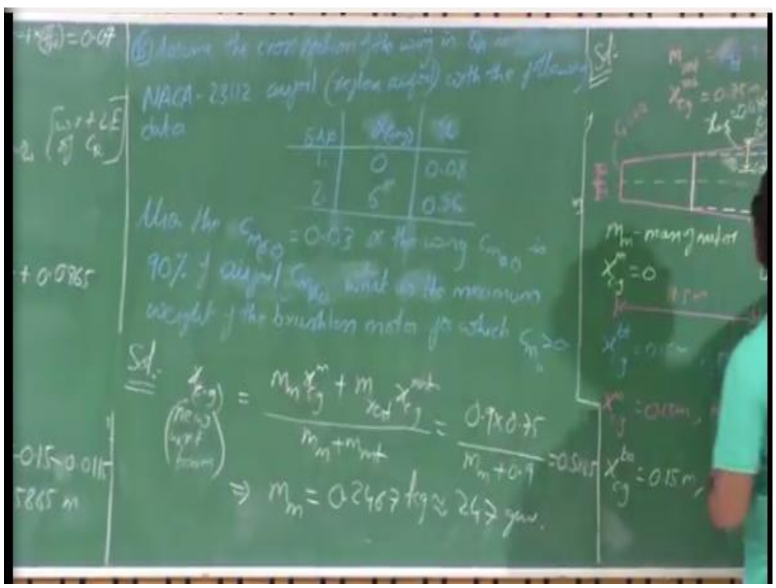

So, this has to be this particular value, we substitute this value there and you will be able to find out the mass of the motor. The maximum mass of the motor that still allow C m 0 to be you know 0 or non negative is equals to so 0.2467 kg, so which is approximately 247 grams, right. So, you can add 247 grams here, if you add 247 grams, this makes C m 0 0, right, that is how we calculate it.

So, anything less than maybe 247 can be the maximum weight, right that makes C m 0 0 or 240 6.9 grams maybe you know or anything gram less than this will make C m 0 some positive value, ok. So this is the maximum minimum weight and how the cg shifts and how you can play with C m 0 and C m alpha of the configuration, right. So we will continue with this with one more small example problem, what we will try to do is. So, assuming a motor mass of some grams, we will find out what the C m alpha and C m 0 of the configuration, right, so that will be the final exercise for today.

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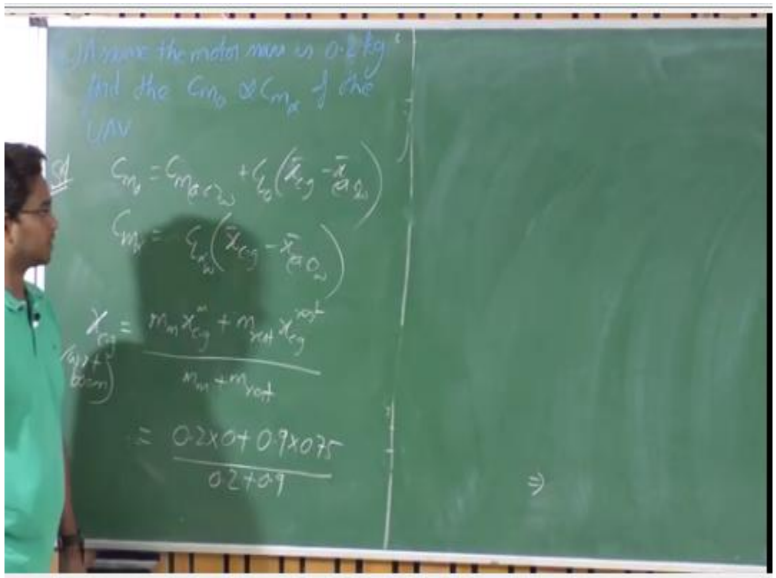

So, this is question 3, you know, so R c, so assume the motor mass is 0.3kg sorry 0.2 kg find the C m 0 and C m alpha of the UAV, right. So, simple question, the same data you are given here the mass of the motor is 0.2 kg.

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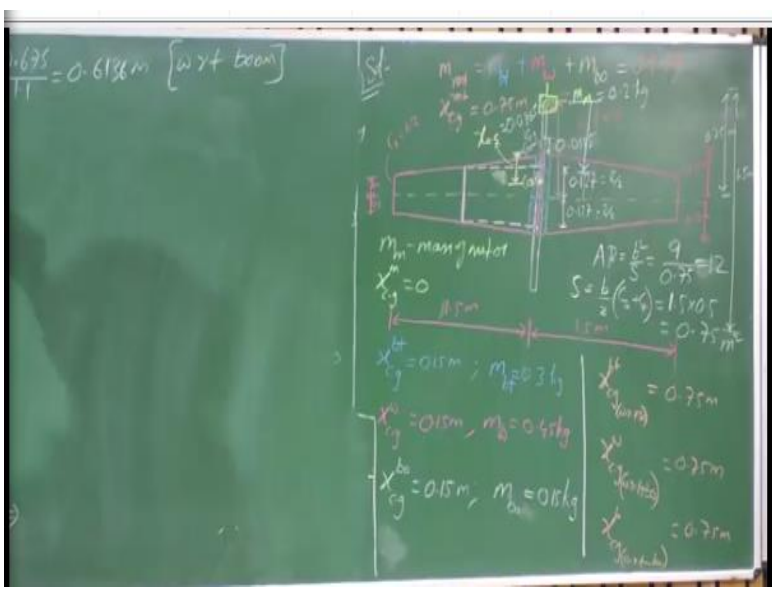

So, the x Cg, so solution we know C m 0 has to be C m ac of the wing this is C L 0 of the wing times x bar Cg - x bar ac, so this is with respect to leading edge of the root chord. And similarly C m alpha is minus, so C l alpha times of the wing times x bar Cg - x bar ac of wing, ok. So, now first of all we need to find x Cg with this motor configuration. We know what is x ac of the wing, we need to find out what is x Cg with this current motor configure.

So, without motor the x Cg is about with the rest of the mass the x Cg is about 0.75 meters ok. So, the new cg with respect to boom is equals to mass of the motor times x Cg of motor + mass of rest times x Cg of rest upon mass of motor + mass of rest ok. So, this equals to mass of motor is 0.2 times 0 because we are mounting exactly at the starting of this and assume that the cg of this motor coincides with the leading or the starting point of that boom ok.

So, is equals to, so + m mass of the rest is 0.9 kg times 0.75 upon 0.2 + 0.9, so what will be the Cg location respect to the boom 0.675 upon 1.1 it is 61 centimeters behind, right.

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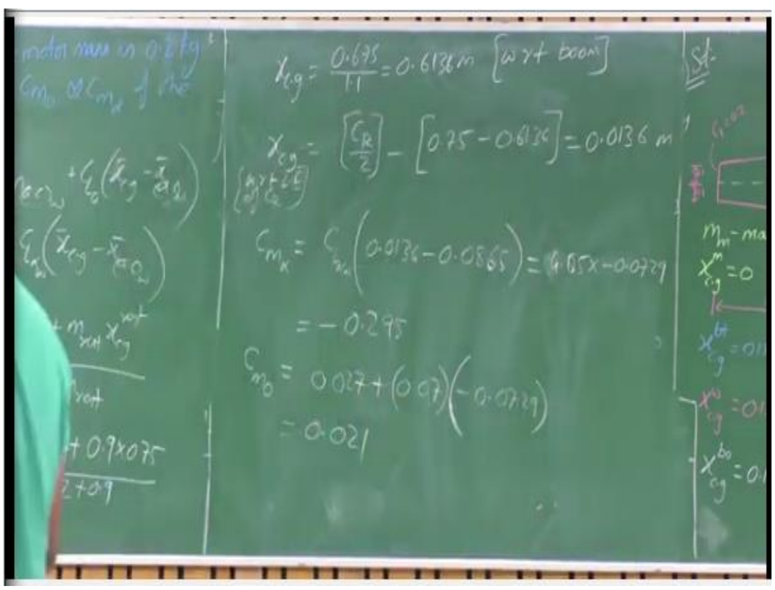

X cg is 0.675 upon 1.1 which is 0.6136 meters, so which is approximately 61.4 centimeters behind the boom, right. The current cg location is behind the starting of the boom, right and at located at a distance of 0.61 meters from that point. So, now you need to find out what is C m 0 and C m alpha it is straightforward. So, the C m 0 of the configuration at this cg location, so now I have to shift this cg location to with.

So, this equation either I need to take this distance with respect to aerodynamic center with respect to the boom, right, or with respect to the leading edge. So, now I prefer shifting the cg from boom with respect to boom do with respect to leading edge of the root chord ok, so this is with respect to boom.

Now if I have to shift this to x Cg, so with respect to leading edge of C R, so what I need to do. So, I know C R by 2, right which is this distance I know this reference point because with respect to this I know the leading edge ok. Now I need to find out with respect to leading is I have to consider anyone of the references. So, I would like to prefer to consider this midpoint as the reference here.

So, with respect to this, this, I know this distance and from this point otherwise vice versa like from this point I know this distance and from this point I know the cg location, right. So, if I subtract that those two from this and what I end up is this particular the distance between the cg and the midpoint of here, am I correct cg and midpoint. Let us say the cg is somewhere here this particular point ok, so on this axis I just projected this at this particular point.

So, what I am trying to do is, I am subtracting this distance from this entire distance, right, what I am end up with this particular distance ok. Now I have C R by 2, if I subtract this I have that particular location with respect to the leading edge of the root chord ok, got it. So, what I have is first I am trying to subtract these two the cg location with respect to the boom which is 0.6136, right.

So, this will help me to figure out what is this distance, right. So now from C R by 2 which is like with respect to from the midpoint I am subtracting this difference, right, that will help me to find out what is the location of this point with respect to the leading edge of the root chord. So this - C R, so from this I am subtracting that, so what I end up with is about 0.0136 meters, so 1.3 centimeters like 13 mm behind the leading edge of the root chord.

So, and my aerodynamic center is at with respect to that is about 1.0865 meters which is 8.6 mm, right, this is like 8.6 centimeters. This is 1.3 centimeters ahead behind the leading edge and that one is 8.6 centimeters behind the leading edge. So, the aerodynamic center is behind the cg here, correct. So, in that case we have C m alpha negative and we will see whether C m 0 is positive or not, ok.

So, with a motor of 200 grams what will be the corresponding C m 0 and C m alpha of this that is where we have calculating right now. So, C m alpha is C L alpha of wing times x bar Cg which is with respect to leading edge of the root chord - x bar ac right 0.0856 meters 865 meters. So, this is approximately 4.05 multiplied by -0.0729. So, this equals to, so - of 0.295 yeah closely - 0.3, right C m alpha is - 0.3.

And then C m 0 for this motor is C m ac which is 0.027 + C l 0 of the configuration is 0.07 multiplied by this particular difference just - 0.0729, right, this equals to 0.021, ok. So, C m 0 is positive in this case and C m alpha is negative that satisfies the static stability conditions, yeah, thank you.