UAV Design – Part II

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Lecture No -25
Subroutine for Airfoil Selection

Dear friends welcome back, so we in our previous lecture we finished a preliminary approach for wing plan from geometry selection where the driving factors are;

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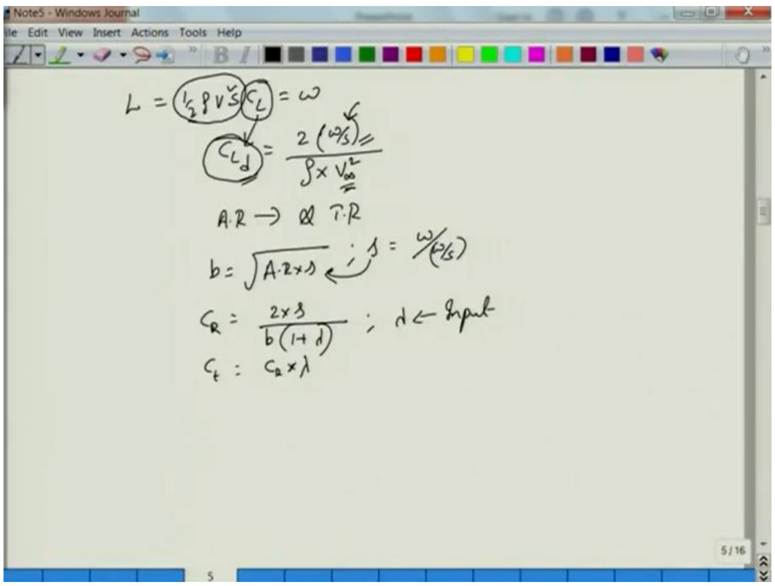

CL design which depends upon the wing loading. So CL design from the level flight conditions it is twice depends on 2 upon 2 times W by S upon density of density at that particular flight attitude times V square, flight velocity square. So from the so we observed for a given flight velocity or the mission requirement V with the variation of W by S there is a variation of CL design right.

So based upon this CL design we have proceeded ahead and this W by S and with some non dimensional parameters as an input such as aspect ratio and taper ratio we figured out how to estimate the wing plan form geometry in terms of span of the UAV, which is aspect ratio times area where area you got S is from W upon wing loading W by S which you have considered as an input.

Variable of the iteration and then using this S here you figured out what is the span for the for a given aspect ratio and then with the input of lambda taper ratio you got what is the root chord what should be the root chord to achieve that area with the span with that particular span which means if this is equals to 2S upon b times 1 + lambda, so lambda is this input here. And then you figure out what is Ct based upon lambda, which is CR times lambda.

So with that we estimated what should be the wing plan form area right so but CL design ideally depends upon so plan form area governs the total force here is not it, but the cross sectional properties governs this particular CL. We need certain CL design for a given wing plan form area and the weight of the UAV. Which more or less we can say it this CL design depends upon this wing loading and this CL design is governed by the cross sectional properties of the wing, is not it.

The force is governed by S here plan form area lifting area and now with that lifting area and like lifting area and then say the dynamic pressure you are now having CL value is not it, so the CL factor varies from what 0 to say typically 1.2, 1.3 near tall. So more or less when you operate at a certain angle of attack where the CL is within less than no 1 so it is actually decreasing the overall lift that it will generate is not it half row square is a lift no or say it is a force multiplied this by this non dimensional term right.

Will just will talk about the total lift generated right so this CL is governed by the cross sectional properties. Now, like in the current lecture we are going to discuss about what should be CL alpha for the wing and;

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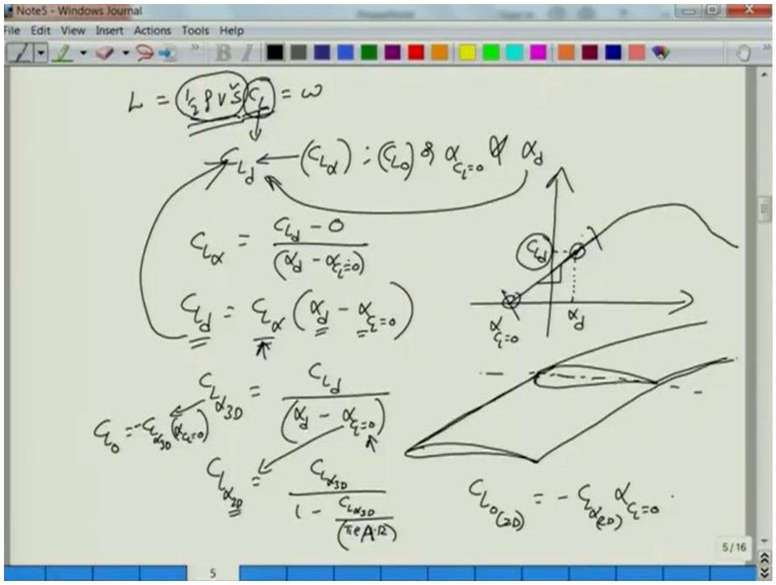

CL and alpha trim so in order to achieve the CL, what we call it as CL design? We need to talk in terms of what should be CL alpha of the planform say CL naught of the plan form or say alpha at which CL =0 or alpha or say definitely and instead of or we should use and here any CL naught or alpha at with CL=0 anything is sufficient right either this, this or this. CL naught or alpha to CL = 0 and alpha design which corresponds to CL design here.

Is not it or not, do you remember this formulation? So we assumed a linear variation of CL with alpha till certain domain right after that there will be non-linear variation near stall there is a loss in lift. So within a linear regime, so what you have is alpha at which CL is 0 this we discussed many times. So say if I am so let us say this is my CL design corresponds to CL d and this corresponding alpha at which I can achieve this CL design is alpha d.

So using the definition of slope CL alpha of this wing entire being should be or say CL design - CL at which alpha it which CL is 0 is the CL at alpha at which 0 is 0 is not it upon alpha design - alpha at which CL = 0. So CL design = CL alpha times alpha d - alpha at which CL is 0. Is not it am I correct or not? So, that means if I have to talk about this L design, I need to talk about CL alpha which is again the cross sectional property of the wing.

Say let us say there is a wing here that is giving you the lift, desired lift. So this is the wing that you have designed it is giving you the desired lift. So but cross section is what is going to the wing area is going to help you with this half of the square S right where the cross section is what is going to help you with the corresponding CL design. So when you talk about cross section that means you need to talk about CL alpha.

CL alpha of the entire wing and then finally the entire wing is made out of cross section into each and every location right that means you need to know what should be the profile that you need to generate select for the particular wing. To be frank it what should be the aerofoil that you need to select right? How can you select that aerofoil by knowing what should be the corresponding aerodynamic characteristics of a particular aerofoil.

Now say if you get what should be so in order to generate this CL design what should be the 3 dimensional CL alpha right and alpha design as well as alpha at which CL is 0. If you know those parameters then you can convert them to 2 dimensional profile what should be CL alpha 2d based upon 3d data right and the wing plan form geometry in terms of aspect ratio and e you can use those values to find out what should be the corresponding CL 2d here right is not it.

So for example see this from aerofoil to aerofoil this particular the same CL design can be achieved at different alpha d. Am I correct or not alpha design? If you select a particular aerofoil, it has a particular alpha at which CL = 0 which we thought more or less constant for wing as well as aerofoil and alpha design for wing will be different as well as aerofoil is different. So but for the time being we assume both are more or less same.

Otherwise alpha design we will say it is possible at a particular angle of attack 3 dimensional angle of attack from there you find out what is alpha at which CL = 0 vary alpha at which CL = 0 for those for a given alpha design. By doing so what happens is the CL alpha varies. Because you know CL design you have fixed alpha design right you make these two as variables of the iteration so you can find out the corresponding CL alpha is not it. Once you know, CL alpha 3d you can find out what is CL alpha 2D because you know.

What is aspect ratio and you know, what is it e based upon the previous what you call discussion right we have developed this previous sub routine in based upon for the plan form selection, so there from there you figure out what is the aspect ratio and what is the e. Then using those two values as an input here, you can find out CL alpha 2D so to be frank it is like CL alpha 3D = CL design upon alpha d - alpha at which CL = 0.

So this is same for aerofoil as well as wing is not it so depending upon this we can find out what is CL alpha 2D, what is CL alpha 2D CL alpha 3D upon 1 - CL alpha 3D upon pi e A R, so we know what is e what is AR, you can find out what is CL alpha 2D from there. Once you know, like CL alpha 2D you know, you can find out based upon this alpha at with CL = 0 you can find out CL naught 2D. CL naught 2D = - of CL alpha 2D times alpha at which CL = 0 the CL alpha 2D = - CL alpha CL naught 2D is - CL alpha 2D times alpha at which CL = 0.

So you can find out 2D as well as here from here you can also find out what is 3D CL naught required CL naught required is like CL alpha 3D times alpha at which CL = 0 is not it minus of. So once you know, CL naught what should be the 2D CL naught what should be the 2D CL alpha and what should be alpha at which CL = 0 2D again, right 2D and 3D are the same. So then you will be more or less getting that you will be able to find out.

What should be the corresponding aerofoil from the aerofoil database. So that is how you can select the aerofoil here. So let us now write an algorithm to do this.

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So it is a new script again. So what we have is CL underscore design, so CL underscore design from our previous performance look wing plan form geometry, we will try to take data from there. So at 2,000 meters when flying at 30 meters per second with a weight of the UAV is 8.1 kg so 0.4 taper ratio. So what we have is e so let us now assume the aspect ratio as 10 for this particular case, let us assume aspect ratio is 10.

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So now I will try to take a new sheet here.

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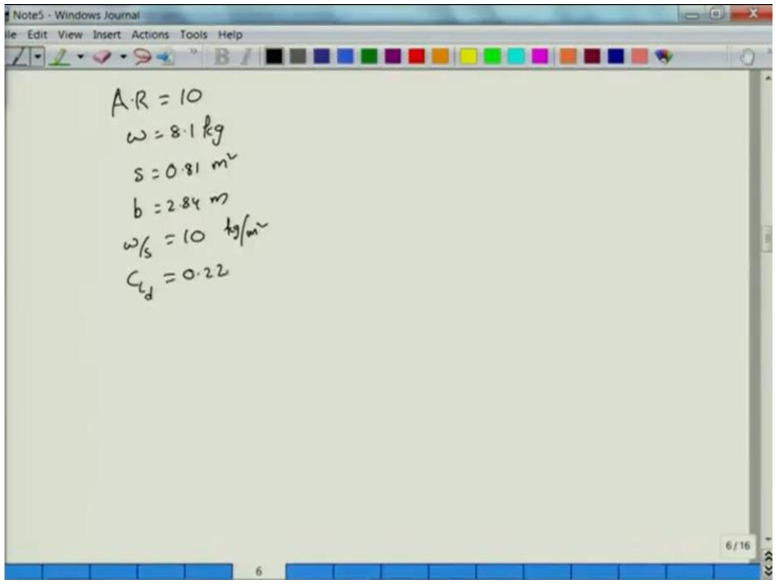

Let us take aspect ratio 10 let take a let us take the data corresponding data, so the wing loading is otherwise the weight of the UAV is 8.1 kg S of the UAV is what? For aspect ratio 10 S is approximately 0.81 meter square. So S is 0.81 because meter square now this is for sorry wing loading of 10 not aspect ratio of 10. I am sorry this is wing loading of 10 so the wing loading so it is simply W upon W by S its 0.81 meter square.

So with this area and wing loading by considering an aspect ratio now the aspect ratio here varies from 4 to 10 so for data 7, which is which corresponds to aspect ratio 10 and at wing loading 10 kg per meter square the wingspan is about 2.8 right 2.84 meters and the aspect ratio show that we have considered here is 10 and the wing loading is also 10 from the data. 10 kg per meter square or 100 newton per meter square approximately.

So and then what do I require essentially is this particular parameter CL design. So CL design here you have is approximately CL design is 2.2, so let us consider this as an input here for me to calculate sorry 0.22 not 2.2.

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So the CL design from here is 0.216, which is 0.22, so this is 0.22. We have considered so CL design is 0.22, so the value of k for this particular aspect ratio and aspect ratio, so for aspect ratio 10 the value of k is so the 7th value 0.0421 so the value of k is 0.0427 and where e otherwise you can say since aspect ratio is 10 you can also do this way aspect ratio is 10 and also sufficiency factor for this aspect ratio is 0.7566 0.76 considering that is 0.76, so k can be 1 by pi r. 1 upon pi e AR.

So these are the now what we need to do is I need to we have to vary this we need to find out what is CL alpha 3D, CL alpha this capital letter CL here talks about 3 dimensional case. CL alpha = CL design upon aoa underscore design right - aoa underscore 0 CL. And let me define this variables used so this is lift curve slope it is 3D. For so we need to vary this values angular of attack as well as design angle of attack and then angle of attack at 0 lift.

So first of all let I would like to vary these two parameters. aoa underscore design angle of attack. If it varies from say 2 degrees or say 1 degree, 1 star Pi by 180 so it varies from 1 degree with an increment of 0.5 degree by 180 up to 5 degrees, let us say. So you have data for about 10 points here. So pi by 180 instead of 0.5, let me take it make it 5 sorry 1 degree. You can choose the like interval just to minimize the plotting time I would like to use it as 1 step of 1.

You can choose it to be 0.5 or point less than that even less than that. So this is how typical design angle of attack now within this range because even L by D maximum for typical aerofoils will also fall within this range may be up to 7 degrees, you can say, maybe up to 7 degrees. And CL alpha from here is like depends upon aoa and then alpha at which CL = 0. So if this varies let us say.

For aoa underscore 0 lift coefficients right or sorry angle of attack at which lift is 0 is from say -0.5 degrees to with an increment of 0.5 degree with an increment of -0.5 degree. So it should be -0.5 or 0.5, it should be from varying some say 0.4 degree. So - 4 degree say pi by 180 with an increment of 1 degree. So I am trying to convert this degree to radian here, so this is pi by 180 so up to, say up to 0 degrees let us do that.

Upto symmetrical aerofoil let us say this times pi by 180. This is in general from 2 degrees right 2 degrees or 3 degrees at least design angle of attack, otherwise there is no use right we cannot use the effectively use the CL maybe from 3 degrees to be frank from 3 degrees so that makes sense so let me introduce the variables of this iteration so from j = j+ 1 sorry j = 0 so it becomes what? j = j+1 here inside this loop.

So I would like to store angle of attack design of j, 1 = aoa underscore d multiplied by pi by 180 by pi I am storing it in terms of degree second pi by 180 by pi. So it is done aoa design and then; so we have CL alpha 3D is not it so let us have another variable for the inner loop. So CL alpha here depends upon both alpha design as aoa d as well as aoa with CL is 0, so I would like to store the second variable as well aoa at which 0 CL 0 lift coefficient, so which is again where I can simply store it as a single column vector.

Or say I can repeat storing for each and every iteration outer loop iteration as well, so this = aoa underscore 0 CL times 180 pi 180 by pi, so converting it to radians again. So 0 lift angle of attack in radians. So similarly design angle of attacking radians, CL design is what we need to produce is not it when moving at 30 meters per second we need to produce the CL design so with the wing of aspect ratio 10, so S we are not using it anyway here so weight of the UAV.

Capital W is 8.1 times 9.81. S of UAV is 0.81 because as we considered for wing loading 10 here and then what do we need so CL alpha is known so CL alpha 2D, CL so let us make it small letters l underscore alpha so talks about 2D case. So this is like CL alpha 3D for that particular iteration upon 1 - CL alpha 3D upon pi e AR. So airfoil lift curve slope which is 2D and then we need to know what should be CL naught capital.

So capital CL naught, CL naught = CL alpha. 3D - of CL alpha 3D times alpha at which CL is 0, so lift coefficient at 0 alpha 3D for wing right. So we need to now talk about lift coefficient at 0 alpha for airfoil. So the second depends upon CL alpha 2D times the same angle of attack because we considered that is a decent that as a decent assumption. It is 0 lift there is no induced angle of attack that is what we assume.

So it will be more or less same so what we have is lift coefficient or 0 lift coefficient airfoil 0 lift go efficient. So airfoil let us make this as airfoil underscore airfoil selection. So now another important aspect is like once you select this you should also look at that design cl are you able to achieve that particular l by d that you have considered right that is another aspect that you need to take care of.

I am not going to do include that particular aspect here right so figure one what I am trying to plot right now is so for different design angle of as a angle of attack design which is nothing but trim angle of attack for that particular design CL. So for different values of this or say for different values of 0 lift angle of attack how this CL alpha is varying and CL alpha 3D 2D as well as CL naught 3D 2D right for wing and aerofoil.

At the same time, we will cross plot like or superimpose not cross plot, superimpose when there is a change in design angle of attack what will be the like variation of this parameters with again aoa at CL is 0. So, plot mainly with the four parameters. So let us talk about only four rest if you are interested you can consider them plotting so what I am interested right now is in plotting for angle of attack for 0 CL.

So that is that remain constant colon, 1. So that I am plotting for various design trim angle of attacks. So what I have is; so I am plotting the variation of CL colon, 1. So this corresponds to when alpha is 3 degree design alpha is 3 degree or alpha trim is 3 degree for design CL right? So I can say I can connect them with the same k colon k star. So, and then so I have to hold it on because this varies.

This varies for various design angle of attacks right that we have considered. So, this can be b black. So for 3 degrees, 4 degrees, 5 degrees this one right 5 degrees. This is for 6 degrees of alpha design, right? And then we varied it from so 3 to 7 degrees so k b g m r let us say and then m control c control v so this is for 5. So 3, 4, 5, 6, 7 degrees. So, and the y label is CL underscore backslash lh alpha right in degrees.

Sorry per radian cl alpha per radian, that is what we can you want to get. So, this is 3 dimensional CL alpha underscore 3D. So I would like to plot for second one which is instead of CL naught 3D right? There is a CL naught so what I can do is this is CL naught so this will be CL underscore naught 3D. The third plot will be cl alpha small cl, is not it? So what we have is small cl right.

So this is capital CL otherwise capital C underscore small l or say cl alpha 2D anyways, we are giving it a name here 2D is so I do not think it will trouble us much. So and then the final plot is about CL naught red. CL not 2D instead of and next label is alpha at which CL is 0 right backslash alpha underscore C underscore L. So, let see just before doing this I will try to give this input so that I will understand the code is initiated right.

So, this is what CL alpha 3D how it is varying for different so if I insert legion here. So say this is I take it here. So this first data corresponds to backslash alpha underscore d = 3 degree. So alpha d is 3 degrees. So, the second one corresponds to 4 degrees. The third one corresponds to 5 degrees otherwise backslash deg backslash it works anyways. Fourth one corresponds to 6 degrees.

If alpha design is at 6 degrees and alpha design is it at 7. So there are few optimization algorithms in order to achieve this number so I we are not discussing about those algorithms here, so this is what no so at alpha say design alpha is at 5 degrees where you are able to achieve the same l by d, so at 5 degrees say so this is like this green color here so that 5 degrees say if you were aerofoil CL naught or say alpha at which CL = 0 is - 2 degrees let us say right.

So this will be the corresponding CL naught of 2D so CL naught of the aerofoil should be 0.067 approximately for that particular case and then CL alpha 2D should be so this is per radian, let us say the design CL is from say 2 degrees angle of attack is from 2 degrees to 5 degrees, so that means 1 2 3 4 5, right? So I am just modifying this I am just removing 7 degrees trim angle of attack is too high to ask so just to make it more realistic I am trying to remove that particular value so.

You can notice so for example, in this particular case when you use a symmetric aerofoil even it demands now when you just trim it at 2 degrees alpha so this is for I can insert the legend here. So the black is meant for initial alpha trim which is say if you are trimming it 2 degrees alpha the CL alpha 3d itself is close to 6.6 radians 6.2 radians, which is quite high right, is not it? So you can say for symmetric aerofoil say for the same this things trim alpha for the same trim alpha.

Which means the data one that corresponds to data one here right, so if I have a cambered airfoil which has say no alpha at with CL is negative right at - 0.5 degree, so then it drops down to say about 5.3 you can see this so this particular value may be 5 close to 5 here. So that is 5 per radian for wing. We are talking about three dimensional wing in case of today it is further more high here it is more than 8 or 7 which is not realistic, is not it?

So you need to choose a particular value of this alpha at what CL = 0 and then CL alpha 2D CL naught 2d right? So using those values so from the database aerofoil database, you will be able to select a particular aerofoil. So once you select that CL naught and CL alpha 2D and CL alpha 3D sorry CL naught 2D you can now go back to this aerofoil database see here we have presented database of all the naca aerofoils.

So from theory of wing sections so this is based upon that data. So you can find out what is the CL naught values here. For this particular aerofoils right and then the CL alpha per radian for this particular aerofoils and you can also see what is alpha at which CL is 0. So you can see these values. So you can select based upon this look considering the corresponding L by D at that particular alpha right. Hope you learned something from this exercise, thank you.