UAV Design – Part II

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Lecture No -24
Subroutine for Planform Geometry Selection

Dear friends, welcome back. So, in our previous lecture we have solved for a weight estimation problem.

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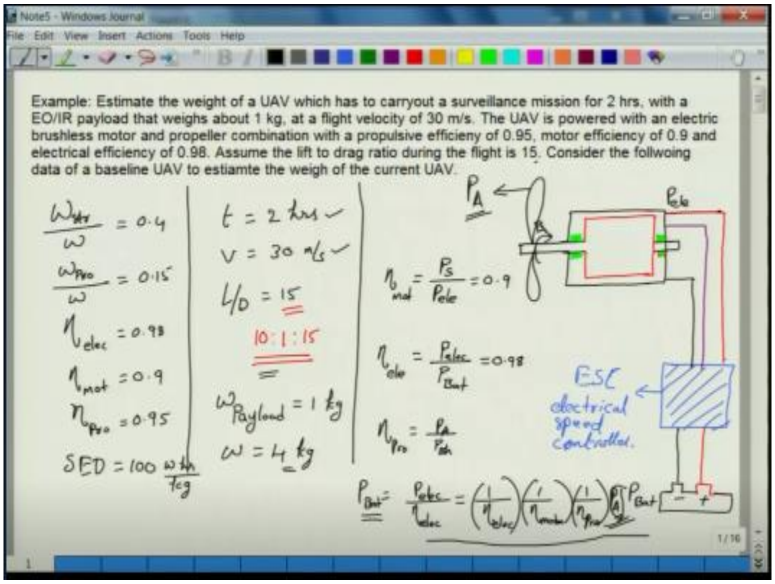

Example: Estimate the weight of a UAV which has to carryout a surveillance mission for 2 hrs, with a EO/IR payload that weighs about 1 kg, at a flight velocity of 30 m/s. The UAV is powered with an electric brushless motor and propeller combination with a propulsive efficieny of 0.95, motor efficiency of 0.9 and electrical efficiency of 0.98. Assume the lift to drag ratio during the flight is 15. Consider the follwoing data of a baseline UAV to estiamte the weigh of the current UAV.

$\frac{W_{Str}}{W} = 0.4$

$\frac{W_{Pro}}{W} = 0.15$

$\eta_{elec} = 0.98$

$\eta_{mot} = 0.9$

$\eta_{Pro} = 0.95$

$SED = 100 \frac{Wh}{kg}$

$t = 2\ hrs$ ✓

$V = 30\ m/s$ ✓

$L/D = 15$

10 : 1 : 15

$W_{Payload} = 1\ kg$

$W = 4\ kg$

$\eta_{mot} = \frac{P_S}{P_{ele}} = 0.9$

$\eta_{ele} = \frac{P_{elec}}{P_{Bat}} = 0.98$

$\eta_{Pro} = \frac{P_A}{P_{sh}}$

$P_{Bat} = \frac{P_{elec}}{\eta_{elec}} = \left(\frac{1}{\eta_{elec}}\right)\left(\frac{1}{\eta_{motor}}\right)\left(\frac{1}{\eta_{Pro}}\right) P_A$

Where the; UAV that we have considered has to perform a surveillance mission for 2 hours with carrying a payload of which is electro optical and IR sensor which weighs about 1 kg with the flight velocity of 30 meter per second. What we are asked to do is, what will be the total takeoff weight of the system if the flight happens at 15 L by D. If the corresponding cruise flight happens at 15L by D and then we were also given the data about efficiency. So, we have solved this by means of this subroutine.

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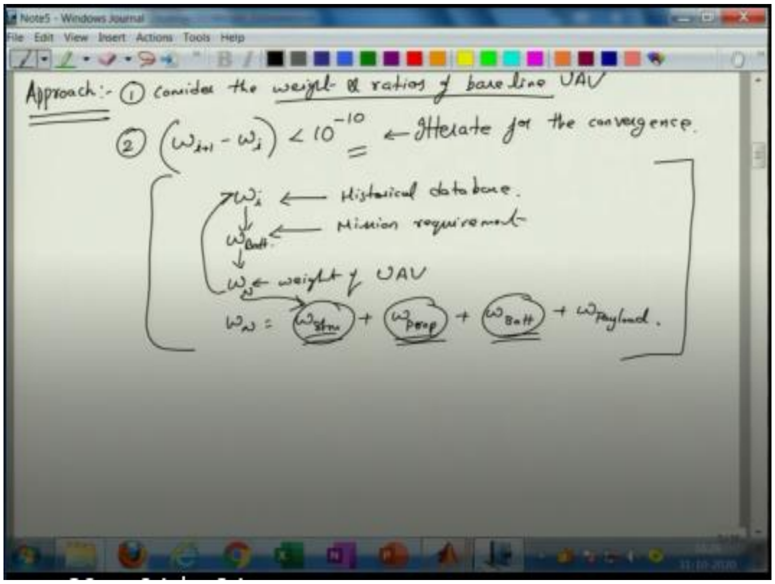

Approach:- ① Consider the weight & ratios of baseline UAV

② $(W_{i+1} - W_i) < 10^{-10}$ ← Iterate for the convergence.

W_i ← Historical database.

W_{Batt} ← Mission requirement

W_N ← weight of UAV

$$W_N = W_{Stru} + W_{Prop} + W_{Batt} + W_{Payload}.$$

Where we have considered the weight and the ratios and the like weight ratios from the baseline UAV.

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Which was given from the data like in the question itself and then what we did is after considering the efficiency of the propeller, various efficiency factors here then we proceeded to figure out what is the battery weight for the initial iterations we consider the baseline weight to start with. And then for this particular mission requirement what will be the weight of the battery required.

Thereby updating the total weight of the aircraft and using it to compare or using and finding out the error with respect to the previous weight which the baseline aircraft for the first iteration. So, the previous weight will be the baseline aircraft weight for the first iteration here. And then we compare the error and we checked if it is less than 10 power -10. Then it will stop, the code will stop.

So, that means so from the first iterations where the, so during this first iterations first while loop here. During this first while loop what we did is like we updated battery weight, and the overall weight. But this weight structural weight and propulsion weight are estimated using weight fractions yes of course we will keep the weight fraction same for throughout this process but based upon the initial baseline aircraft weight.

Now the need is to upgrade them to the current aircraft weight. So, what we did is after this first while loop, so again the structural weight is updated by means of the current weight of the aircraft. Which was obtained from the above loop, where the battery weight has been updated based upon the current mission requirements. So, from there the weight of the propulsion system is also upgraded.

Now this structural weight and the propulsion weight correspond to the current UAV for the current mission requirements. So, this weight that was output from this earlier while loop will now become the input for the second while loop. Which will again because of the change in the weights of the structural and propulsion systems. So the battery weight or the power requirement will also changes the overall weight has to change.

So, the battery weight has to change, so and hence we have iterated it again to figure out what is the updated weight of the aircraft. So, the final weight of the aircraft we obtained after this second while loop for a particular L by D. So, this for loop iterates for different L by D starting from 11 to 16 with the increment of 1. So, for each and every L by D we are trying to find out what is the total take or total weight of the aircraft. We are estimating total weight of the aircraft.

During the process we also figured out what should be the total battery weight for that particular L by D what should be the structural weight as well as propulsion weight. And we have plotted that. So, from the plot we notice that from the question we so in the question we were asked like what will be the total take takeoff weight when we are flying at L by D 15. So, it will be about 8.1 kg.

Now let us consider this as an input and the L by D as an input as well as the flight velocity as an input to figure out what should be the typical planform geometry or planform parameters or what should be the typical being planform geometry that helps us to fly this aircraft at the desired velocities as per the mission requirements,. So that means we are going to get the planform geometry with the method that we are going to use, now or the subroutine that we are going to develop.

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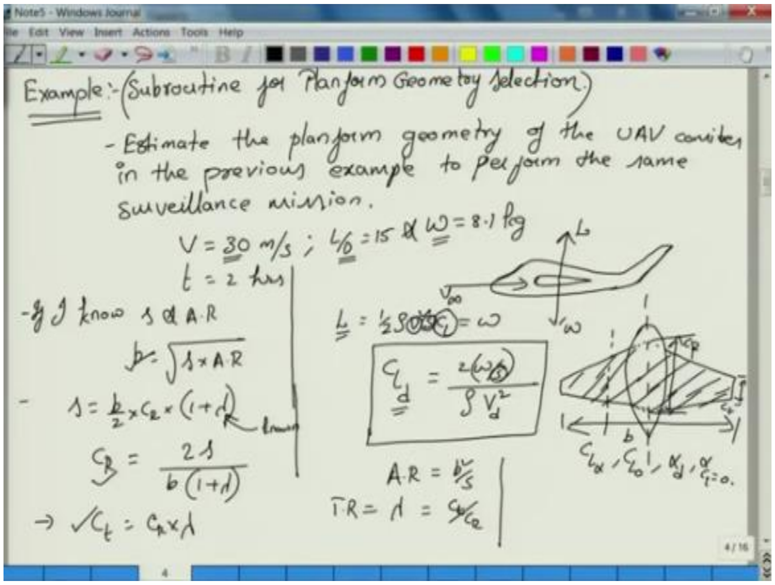

Example:- (Subroutine for Planform Geometry Selection)

- Estimate the planform geometry of the UAV consider in the previous example to perform the same surveillance mission.

$V = \underline{30}\ m/s$; $\underline{L/D} = 15$ & $\underline{W} = 8.1$ kg

$t = 2$ hrs

- If I know S & A.R

$b = \sqrt{S \times A.R}$

- $S = \frac{b}{2} \times C_R \times (1+\lambda)$ ← known

$C_R = \frac{2S}{b(1+\lambda)}$

→ ✓ $C_t = C_R \times \lambda$

$\underline{L} = \frac{1}{2}\rho V^2 S C_L = W$

$$\boxed{C_{L_d} = \frac{2(W/S)}{\rho V_d^2}}$$

$A.R = b^2/S$

$T.R = \lambda = C_t/C_R$

$C_{L_\alpha}, C_{L_0}, \alpha_d, \alpha_{C_L=0}$.

So, what we are going to do here let us write down the example. So, this is another example or subroutine for planform geometry selection. So, estimate with the planform geometry of the UAV considered in the previous example to perform the same surveillance mission. The surveillance mission is for 2 hours,. So, that means so we will consider the same mission requirements here. So, where the velocity has to be 20 meter per second sorry, 30 meter per second it should be. So, the velocity is 30 meters per second and then the flight time is about 2 hours. These are the typical mission requirements that we have considered earlier along with this parameters.

So, but what do we require, now is the following we just need because with all other parameters including structural weight ratio and propulsion weight ratio as well as payload and propulsion weight sorry efficiency factor and then electrical efficiency factor and motor efficiency factor. So, including all this we have figured out that the aircraft when flying at L by D of you 15 it has to weigh about 8.1 kg.

So, this is what is required for us to go ahead with the planform geometry selection. So, what exactly the planform has to do here, let us say so I am trying to erase this part. So, the apart from 30 meter per second what we have is L by D of 15 and the total weight of the aircraft is 8.1 kg.

These are the things that we are going to take it as an input. So, now as we know the UAV and performing this mission.

So, the first and foremost thing that we expect is at this particular flight velocity. What is the corresponding CL that I need to generate? So, that I can like satisfy that lift is equal to weight condition. So, I can lift this total otherwise I can generate a force which can sustain the total weight of the aircraft. So, which is 1 by 2 rho v square SCL = W. So, I am flying at a particular velocity.

Which means the CL which is designed is not it. So, we are going to design the aircraft to fly at that particular flight condition. So, the design CL depends upon twice the wing loading times rho v square. Or v infinity square or v design. So, v design is here almost 30 meter pe second. That is what we have to design it for about. So, CL design is 2 times t double 2 times W by s upon rho V d square.

Now so assuming this particular plan form so the planform here the plan from parameter that comes into this L= w is area of the way is not it area of the plant form. So, that is the only thing that I require to design in the first place. And then we will see how to we using that planform how can I achieve that particular CL design. That we look into like look then we have to look into the cross sectional properties of that, is not it?

So, the wing here for example if you take the top view of this, of this UAV. So, if you consider the top view of this UAV. So, the wing that you are going to design here so the planform here ok. So, this plan form here is responsible for generating the lift,. This particular, when moving at this particular velocity will generate the lift combined with some CL value here non dimensional. So, the CL here talks about the cross sectional property at e.

So, these talks about like you need to talk about the cross section of the wing there. That means you need to talk in terms of CL alpha, CL not alpha design and alpha at which CL is equals to 0. So, this will handle for the time being we assume that CL is provided. This CL design is provided given I have certain W by s. So, how to achieve that. So, that means I need to know what should be the S?

When I say s I need to talk about what? The span of the UAV is not; it span of the wings or say root code of the wing CR here. So, this say, this is my CR and CT. Am I correct or not CR CT b. So, based upon this I can talk about wing planform area. Am I correct? So but it is always better to deal in terms of non-dimensional parameters before actually talking in terms of this dimensional variables like CR CT and b here.

So, the non-dimensional parameters for wing plan form are aspect ratio which is b square upon s, and taper ratio lambda or taper TR dapper ratio is lambda is CT upon CR. Now if I consider so now the question is if I know s. And AR I will be able to find out what is the span of the UAV for that particular s and aspect ratio. Am I correct? So, now once I know what is s. s equal to once I know b.

So, what is b by 2 times CR times 1 + lambda. If I know lambda or say I can make it a variable as well,. If the lambda is known I can find out what is CR is 2 times s upon b times 1 + lambda, for a straight tapered wing. So, when there is sweep and all, then you consider the cause of leading in sweep or in your any of the legion gates view. So, that I am not going to talk about here.

So, I am talking about a straight tapered wing and then CR and what about. So, I know b I know CR, once lambda is known I can also find out CT. CT is equal to CR times lambda. So, that means I know what is CT what is CR what is b. These are good enough parameters to talk about platform area,. So, this is what we are going to find out. So, what we are going to take as an input is the weight of the UAV that we have estimated.

And the L by D which we are flying is not it? So and what is the velocity of flight. So, these 3 are the parameters that we are going to take it in for this particular algorithm. So, what am I doing, right now?

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So, let us write a new script. So, I am not going to write down the detail like steps there it is I do not think that is necessary so and then altitude. So, you need to know what is the altitude of flight as well. Let us assume it is at 3 kilometers surveillance mission at. So, what was the earlier question surveillance mission is at. So, it was not mentioned there so let us consider this this is happening at surveillance at 2 kilometers altitude, 2000 meters.

So that means we have to use the density function that we have developed earlier,. So, what I am going to have here is just enter the altitude is not it? Input; I am taking the inputs in the first place enter the altitude of flight in meters and then v is so cruise input enter the cruise velocity or design velocity. Enter the design velocity or desired velocity of flight from the mission requirements, velocity of flight see we may not be able to generalize the design process.

So, this based upon the measure requirements you have to figure out which kind of subroutine you have to develop, with the respective variables. Since we have velocity as an input here so I am considering it as a desired velocity here. So, the surveillance has to happen at a particular velocity. So, w from the weight estimation algorithm. So, let us say this w; I am considering it has an input.

Enter the weight of the estimated weight of the aircraft, estimated weight of the UAV otherwise in kg. So, this is multiplied by g will give me 9.81 will help me to find out weight in newton's. Otherwise W is like w times 9.81 minute per second square. So, I have z v w and W,. Now so what is design CL so for me to find out so L by D is also an input. But it is rarely used here other than finding CD not in k.

We will use them we will use those parameters anyways so I need to find out what is CL design, CL underscore design CL underscore d is 2 times of w upon s is not it? Otherwise w underscore s upon den, So, I need to find out the den equals density of z. So, this will help me to find out what is the density at that particular altitude. So, z is the altitude that we are considering altitude of flight that we are considering so DENSITY is the function name so I am calling that function.

So, this is like 2 star w underscore s is wing loading let us say so wing loading upon density times v square. So that means we understood that ok for a given flight velocity at an given altitude so if the wing load is very varies the CL design varies,. That means so wing loading we considered it as a variable of this iteration,. So, it varies d of i, j that means so i stands for the current iteration.

Which means wing loading w underscore s for w underscore s varying from say wing loading is varying from 4 to 10, let us say ok with an interval of 1. So, before this; what I would like to do is i = 0. So, inside this loop i is a variable of this iteration which is increasing by 1 for every iteration. So, this is 2 w by s upon rho v square CL design. So, we what is j here we have so there is also a variable j will try to get back to that soon.

Otherwise I will use it when we define that, so this is i so i, 1 will return me a column vector so I prefer to use column vectors here. And then CL design is now varying with w by s. So for each and every w by s there is CL design. So, how can I find s from here or so that means for each and every w by s there is an s. Am I correct or not? Where w by s is a variable here. So, w underscore s is wing loading in Newton per meter square.

So, CL design. So, wing area based upon input weight and wing loading. So, w upon w by s will return me s in meter square here. Ok, so once I have s I will be able to find out b am I correct b of i, 1 equal to square root of aspect ratio times s of i, 1. So, now it is a tricky part is not it. We do not know what is aspect ratio here? So, let us now iterate aspect ratio also for different aspect ratio sqrt yes.

So, let us now make it a variable aspect ratio so let AR is varying from say 4 to 10. Again the same let us assume so with the increment of 1. So, w e so let me call this as w s which is in kg per meter square. So, I am converting this kg per meter square multiplied by 9.81. So, that it becomes in Newton’s per meter square. So, this W s let us say W is itself, so is in kg per meter square when multiplied by 9.81 what I am going to get is Newton’s per meter.

So, Newton's per meter square. So, w here is in Newton's so w by s is in kg. So, either I use w here. So, that it is in kg. So, it returns in kilometer per minute square. So b, for b I need to have aspect ratio as an input so aspect ratio is varying here. So, I will use this; another variable of this outer loop, what is j so here j is increasing for every aspect ratio increment in aspect ratio. So, particular so a value of j corresponds to a particular aspect ratio here.

So, I would like to store this so ar let us say of aspect ratio or A underscore R otherwise aspect ratio I am storing it just for storing purpose. So is j,1 = AR. So, now aspect ratio is an input s is an input to find out what is b based upon wing loading and the initial weight. So, we figured out what is s here. So, if you want me to change this a w underscore that will make more sense w is in kg, kg multiplied by 9.81 will be Newton's.

So, once we have span of the UAV we can find out root code, span and area and aspect ratio say so the root code we for not to find root code what we require is lambda as an input tapper ratio. So, this is 2 times of s of i, 1 upon. So, here if you see the span neither span or the area is affected by this taper ratio here. Is not it. So, that is why it majorly placed between root chord and tip chord that is how I prefer using it.

So, the CR here is 2s upon b times b of i again it is a variable here inside b of i, j. So, now whatever i here should be replaced by j for a particular aspect ratio, so all these calculations are for particular aspect ratio. The inner lobe runs for a particular AR that is runs for a particular j value here. So, the i progression here happens with j input if i want to save this wing what I can do is W underscore S.

This is just for storage purpose. So, of i, j wing loading. So, wing loading will be again will be same for, is not it similar to that of what we witnessed in our previous subroutines. So, for each for every j the column vector of w, s will remain same, because we are varying it, we are forcing it to vary with this like from 4 to 10 with an increment of 1. So, this is equals to W underscore S. So, I am using this wing loading for a particular j.

And this keeps increasing from 4 to10, so to calculate CL design and then s span root code. So, root code requires an input. Here, lambda is an input here 1 + lambda 2 s upon b times 1+ lambda. So, lambda is taper ratio let us say lambda is 1 + TR tapper ratio. So, I am not considering taking in another iteration like another loop here for tapper ratio instead you can do that. But instead I would like to do it here for a particular tapper ratio let it be 0.4.

So, either you can consider this as an input you can make it as a input here instead of w because w is already done earlier. So, velocity of flight is also more or less known yes let me make this also an input here. So, tapper ratio TR is enter the tapper ratio of UAV. So, we made this also as an input so I get tapper ratio from there and it remains constant for this entire iteration. So, you can plot multiple like for various aspect ratio you get for different w by s.

You will get to know what is the corresponding like root code tip code and the span and the wing area to generate the desired CL. So, based upon this data you find out what is like now you change the tapper ratio. You change the input and find out the same plot. So, that you have you can also cross plot them to compare or to figure out which tapper ratio is more feasible for you to manufacture.

So, s upon and also we have discussed in length about what is the significance of tapper ratio and how it will help for the aerodynamic loading as well. So, we have discussed in our previous course so you can refer to those lectures 2 s upon b times 1 plus lambda. So, this makes sense so I will just write it down wing span wing span based on AR and aspect ratio and a wing area. And then root chord wing c r root chord based on aspect ratio or say b span and tapper ratio.

So, what is Ct straight forward? Ct is Cr times lambda is not it. Cr i, j times separation tapper ratio is an input against. So, say can we find out so L by D in the earlier case is what CL underscore CD is 15 here. That is an input. So, we can also find out what is CD for this L by D, CD underscore. Let us assume d, design of i, j = CL underscore D of i, j which is varying with wing loading.

So, upon CL by CD, CL underscore CD. So, which is a constant and then we can find out what is k efficiency factor k. So, first e first let us we have to find out e to figure out what is k. So, e of e again can be find figured out from this empirical relationship value of e can be estimated using this empirical relationship based upon the aspect ratio of the wing 1.78 times 1 - 0.045 aspect ratio raise to the power of 0.68 this is for a straight tapered wing - 0.64.

Using this expression we will be able to identify what is e, also efficiency factor for a straight tapered wing. And again it based upon this empirical relationship. So, it is like 1.78 star so 1-0.045 times aspect ratio raise power of -0.64. So aspect ratio is a variable here so every time it will try to find out what is the new e. So, for a given aspect ratio that means for a for a given j this e value remains constant,. That means so it only varies so what we can do is instead of doing this here we can calculate it outside.

Since it just depends upon the aspect ratio what we can do is this e equal to. So this is just j, 1. So, what we can say is Oswald's efficiency factor. So, once we know e it is straight forward to calculate what is induced drag correction vector. So, which varies with e and aspect ratio again this can be out of this inner loop, it does not depend upon wing loading. So, e k of i, j sorry j,1 should be 1 upon pi e AR.

This is induced drag correction factor or factor. So, CL by CD so CD0 I can estimate for this particular this thing CD 0 or say directly CD0 of i, j = CD underscore design of i, j - k times k of j,1 times k CL underscore d square d of i, j square. This is a profile drag and this is wing tip chord. So, drag coefficient at CL design so based upon. So, this is 0 lift independent drag coefficient or 0 lift drag coefficient.

Based on these parameters that; CL CD drag coefficient CL design and CL by d. So, L by D is an input so CD0 is figured out. So, now I think it is end of the iteration, 1st iteration. And you can end the 2nd iteration as well here. So, the outer loop is closed as well as the inner sorry not the second iteration I am sorry so end of this inner loop and end of the outer loop. So, we can now plot how are these parameters varying with wing loading.

So, let us say this is figure 1 so subplot let it be what CL design CD corresponding CD and then say s b CTCR are these are the planform parameters, for a given lambda. Here, this is for a given lambda we have iterated for different aspect ratio as well as wing loading here. So, that is what we have done here. So, let it be 5, 1, 1. So, plot what I am going to plot is wing loading. So, this is W underscore s again this is in kg.

So, I am sorry so this W S so wing loading and how CL design is varying,. So, wing loading will be more or less same for every; you know colon, 1. For every j the wing loading variation will be same because we are varying it from 4 to 10 as I told you. So, the CD design so will varies with aspect ratio so let us say colon, 1 this is for initial aspect ratio here. Aspect ratio 4 we have 6 such plots here.

So, try I will try to star k and then we will hold on. I will just open our previous program to weight estimation program where we have similar figure that we have plotted just, not in this. What was that it was in climb performance I guess. We have used hold on, for different lord you do not think even this is going to help us ok. So, let us first save this. What are we doing, now wing planform geometry.

So we have this control c control v. So, this we are varying it to let us say this is like + we can still have color code, is not it? So 3 and 4 so this is with red this is with green. So, how many 1, 2, 3, 4are done 7 in total,. From 7 to 10 it is like 7 is not it. Sorry 4 to10. So, this is like 5, 6, 7. I am done with the first plot. So, magenta and then black, blue, red, green, magenta, yellow. So, there is no need to hold it on further this particular subplot.

So, but by label what we can mention is design CL C underscore L underscore d. The 2nd plot we want to vary we want to see how the area is varying, is not it? But CL design it varies with wing loading not with aspect ratio is not it? I am I correct or not? So, it is like same w by s it will not have the variation with aspect ratio there is no point in doing this. I am sorry because this is not going to vary with aspect ratio.

So, there is no need of holding it on and the simple y label as. So, the second subplot let us do it for say variation of s. In fact s will also not vary with aspect ratio it just depends upon wing loading. So, wing loading is independent of aspect ratio here is another variable of this iterations. So, CL design and s are independent of aspect ratio geometric parameters here. So, what I have is simple no if you plot any one of this it will remain constant here.

So, plot w s there is no need for this entire story. Otherwise I will just copy this so that I can use it for the other plots the third one. So, what I am going to do is delete this and then simple s here, s in meter square done. So, the third one will vary how the span is varying with b. So, b is varying with aspect ratio b in meters. And with the input of lambda we are able to find out what is root called like CR and its variation with aspect ratio CR here.

So we are plotting CR variation with aspect ratio for like CR variation for w by s and cross plotting for and we are holding on the same plot and we are superimposing for various aspect ratios here. See our variation with various aspect ratios. And similarly we can do it for CT here C underscore R in meters there is RCR root chord and C underscore t. So, it is done. So, the x label here is if you just want to see how the drag coefficient is varying.

Then we can have another plot here and just immediately after this we can have another plot let us label it as 2,3, 4 and CD is again of course it depends on L by D and yeah it depends upon C design and design L by D for that particular design. So, it is independent of aspect ratio here. So, we are not considering that here. Anyway, so and k is independent of this wing loading so Cd not again is like it can be outside but CL design, yes is independent of aspect ratio here.

But k depends upon aspect ratio it will not depend upon wing loading but CL design depends upon wing loading but not on aspect ratio here. So, we have added another plot in this in the subplot this is more or less done variation with CT, CR span and then CL design CD design and then the wing area how it is varying. So, with respect to wing loading in kg per meter square. So, I am just using kg /m square here.

So, wing loading variation in kg upon meter square. Let us try to see if we can run this code. So, what is the altitude of flight it is in meters it is say 2000 meters 30 meter per second and weight of the e is 8.1 kilogram tapper ratio is 0.4. So, you can now see if you insert legend here. So, black stands for aspect ratio 4 and it increases 4, 5, 6, 7, 8,9,10. So, this color C and this greenish blue, I call it that way. So, it corresponds to aspect ratio 10.

So, if you look at this the wing area when you are flying at so this particular for these 3 parameters just depends upon wing loading here. So, it is so the wing area turns out to be so at wing loading 10 it requires about 0.8 meter square. So, when you are flying at a lesser wing loading for this mission requirements you end up close to 2 meter square here. it is close to 2 meter square.

And the CL design is say it is far less when you are flying at lesser wing loading is not it? It is about 08 it is not even 1.1 so and then when you are flying at higher w by s, is not it? So, higher wing loading because the velocity is quite high here that is the reason why. So, this is about 0.25 0.22. So, the CL design no this is Cd design I am sorry you we need to correct it in the plot. So, the second one is Cd design red Cd for that CL design.

So, I am not running it again here. So, this is about 0.15 when you are flying at w by s of 10 kg per meter square. So, you can see this tip chord here is with the 0.4 aspect ratio see how the variation of Ct with respect to you know wing loading. So, the tip chord turns out to be about 16 centimeters, and the root chord turns out to be about for 40 centimeters. So, 40 centimeters will be the root chord and tip chord is 16 centimeters and the corresponding span of the UAV is about 2.8 meters.

So, I am talking about wing loading of 10 here, 2.8 meters approximately. So, when you are planning to have a hand launch UAV it should be at least w by s should be at least you know within 6. You know you should not go for higher w by s because you need higher launch velocity then. So, say 6 the Ct is about 20 centimeters or 21 centimeters is close to and then the CR is about say half a meter.

You know half a meter of root cord and the span is about 3.6ms, 3.7ms span for this particular UAV which is weighing about 8.1 kilogram. So, the area here is about 1.35 meter square and the drag that you may encounter is so this is quite less here 0.01 close to, and. So, the design CL is about 13. So, this is how we can like complete the plan form geometry selection. So, in the next lecture we will try to look at what is the cross sectional properties for this particular planform what should be the cross sectional properties. Thank you.