UAV Design – Part II
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Lecture No -22
Subroutine for Climb Performance (Powerplant Selection)

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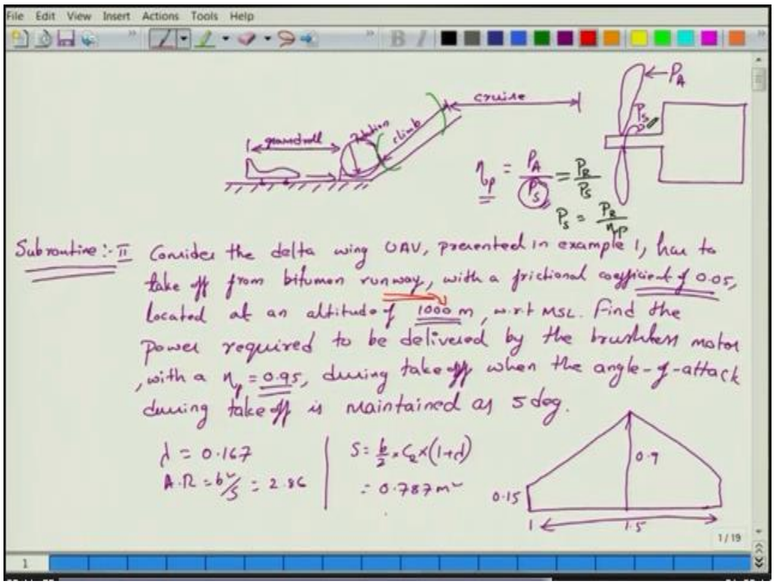

Dear friends, welcome back. So in our previous lecture we have solved the takeoff performance of a delta wing UAV. So we have, what we did is we developed a sub routine that estimates the power requirement by this UAV to take off from a location or a runway which is located at about 1 kilometer with respect to mean sea level. Now we know what is the power requirement during takeoff, right? And we earlier we have also solved the problem for power requirement during cruise.

Now we will try to solve for the power requirement during climb condition so that we will understand what is the typical power requirement for this aircraft to perform a particular mission? Apart from this cruise if you say, if you want to loiter for some time, so what will be the apart from flying at a particular velocity for the given endurance what will be the corresponding power required will see, aspect will solve as we progress.

So for the time being we are going to solve this client performance, what is the power requirement so that the details about this power requirement will help us to understand. So with these details we will be able to understand the corresponding specifications or the kind of power plan that we need to select. So now let us take up a problem, same problem almost.

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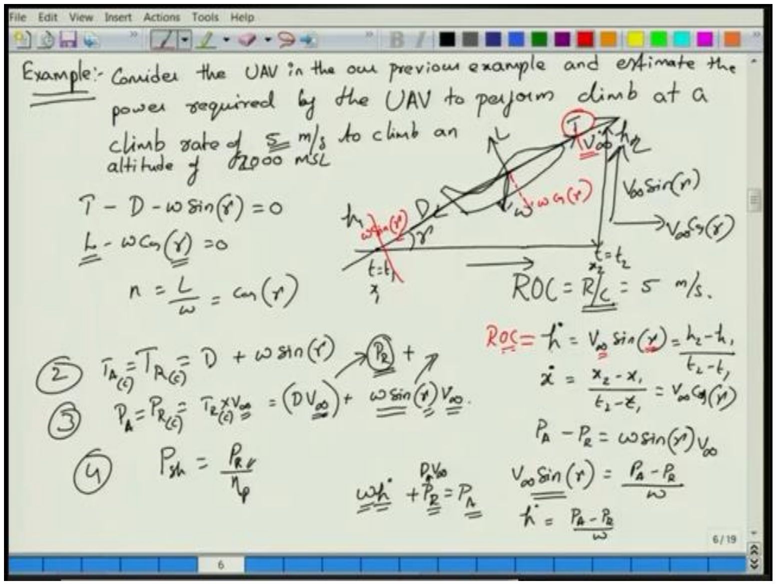

So instead of, so example; consider the UAV in the above example or say in our previous example and estimate the power required by the system. Note by the UAV to perform climb at a climb rate of say 5 meters per second. So for us this data is inadequate, is not it? So just before proceeding this to this particular subroutine development, we will have a quick look at the dynamics that we have discussed earlier for climb performance.

Let us say this aircraft is moving at a forward velocity v infinity, right, is said to be inclined with a climb angle gamma. So let us assume a steady climb in this case. So where the thrust is acting in the direction of flight and drag is acting opposite to the direction of flight and there is lift perpendicular to flight velocity and the weight of the aircraft is acting vertically downward here. So the dynamic conditions here are T - D - W sin gamma is 0.

Since we are considering a steady climb here, so L - W cos gamma is 0. So that means the load factor n, which is L upon W is cos gamma. So during climbing flight, I require less lift compared to that of level flight I require to generate a lift which is adequate to overcome a component of weight, which is W cos gamma. So, W cos gamma will be balanced by this lift. So W cos gamma; so W sin gamma is balanced by the engine here.

So we are loading engine more in case of climb. So, W sin gamma will be acting opposite to the direction of flight, so which we need to satisfy. That means the thrust required by the system is drag. Apart from drag you also have a component of weight which is W sin gamma. Higher the value of gamma greater is this particular component W sin gamma. So now if this condition has to be satisfied by the engine here that means we should make this thrust available to the system to overcome the drag as well as to carry the weight, a component of weight in the direction of flight.

So now the power required by this system is thrust required times V infinity. So the thrust required here for climb, I will say the bracket c talks about climb because we also discuss TR for level flight as well. So TR in bracket c talks about climb. So the thrust required during climb should be. So the drag plus W sin gamma, so this is equals to drag times V infinity plus W sin gamma times V infinity.

So I need to know this particular value. If I have to solve this above example, I need to know what is the power required or say this is the power required by the system what should be the power available by the system. This shaft power that need to be generated through this engine, so which we discussed earlier, is not it? The shaft power here that we need to generate, sorry. So this is for electrical efficiency.

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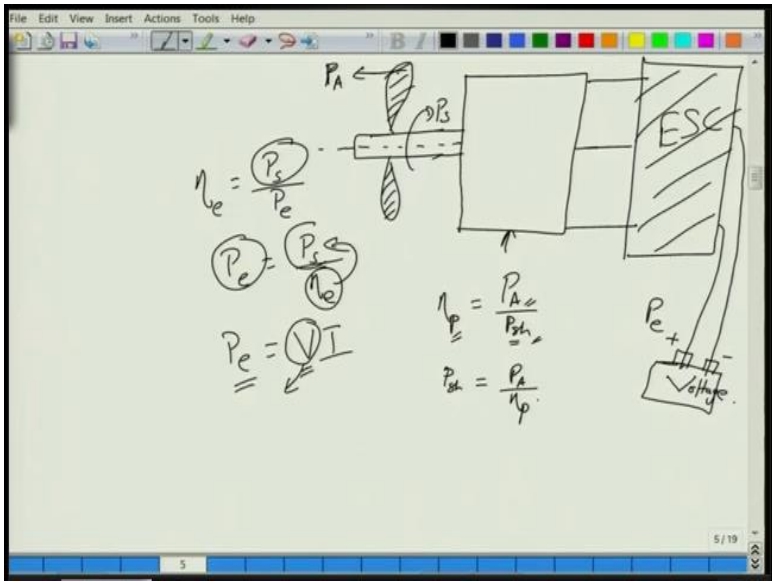

So the shaft, otherwise the efficiency propulsive efficiency, eta p is equals to power available upon shaft power. So with the help of this propeller we are converting the available shaft power from the brushless motor of the engine to the available power that helps the aircraft to move forward. So this is power available, the output from this propeller and brushless motor combination. So the output is power available upon shaft power is the propulsive efficiency.

So if I want to know what should be the shaft power ultimately the engine delivers shaft power. So if I need to know what is this shaft power that the engine has to deliver is equals to power available upon propulsive efficiency. Now this is what we need to ultimately figure it out. So here the shaft power that I need to generate is equals to, so this should be the power available to move at this particular flight velocity as well as at this particular gamma.

So if you can notice here, so this power drag times velocity is nothing but power required in level flight is not it? Power required in level flight, so in level flight we just require our engine to deliver this particular power required to fly at this particular velocity. But in case of climbing flight we apart from this power required what we need is additional power that carries a component of weight at a desired climb velocity or forward velocity that helps you to climb.

So now the shaft power Psh is that the engine has to deliver or make available for the propeller or the aircraft is power available or the power required by the system upon shaft propeller efficiency. So from the above step let us say if you consider so this as, so this is like second step and this is like, so because from step 3, we will be able to find out what is power required or the power available that need to be made available by the propeller power plant for the aircraft to fly at this particular velocity V infinity.

Now in this particular question, we were given the data about rate of climb. The R by C stands for rate of climb or you can also say ROC rate of climb. So I would like to use both the nomenclatures. So both of these as the nomenclature to represent rate of climb which is given as 5 meters per second. That means the vertical component of velocity, h dot is equals to V sin gamma here. This vertical component of velocity is V infinity sin gamma and the horizontal component of velocity is V infinity cos gamma.

For example, so at time t is equals to 0, this say this is like t1 the time at which the climb is initiated and then after a time t2 say t is equal to t2, so it has climbed to an altitude hf, right let us let it be h2 and h1 be the initial altitude at which the climb is initiated. It can be 0. So the total change in the vertical distance is h2 upon h1. This is h2 - h1 upon t2 - t1, that is h dot here that is a vertical component of velocity when you are climbing at particular gamma.

You also cover a horizontal distance, which is x dot say this is like a t is equals to t1 you are at x1 and at t is equal to t2 you are on the ground you are at x2. So this h and x are with respect to a frame that is fixed on the ground, we call it as initial frame here. So this is nothing but x2 - x1 upon t2 - t1. So this is equals to V infinity cos gamma. Now say you are given the information about rate of climb, R by C.

So can we directly use that rate of climb to find out what is the power required? So, one way to do that is, so from this equation from the above equation, so this is power required for climb PRC here. So now this PR stands for power required for level flight. Let us keep the same flavor of this PR that is that we use it for level flight condition. So the power available from this equation, which was present in step 3, power available minus power required will helps you to like the difference between that power available minus power required.

Which is power required is drag into velocity which is a level flight power requirement, is will help you to propel this aircraft forward by taking a component of weight at a velocity V infinity. So this V infinity sin gamma from here is power available minus power required upon w called the difference between PA and PR is the excess power and when divided by W we call it as specific excess power.

So this rate of climb h dot, so given h dot is equals to PA - PR upon W. So the power that need to be made available is depends upon h dot times W plus power required, that is not it? Power required is drag into velocity. Given h dot here and you know the weight of the aircraft. If you know the drag, the PR will be able to find out what is PA. So this PR is nothing but drag into velocity again.

So here D is again a function of CL here, now is not it? So D is again a function of CL and CL depends upon gamma. To find out CL you need to know what is gamma. That means it is not a straight forward approach, you need to consider different values of gamma and see for the same rate of climb how the power requirement is varying. Now say you can also have a iterative approach in terms of, like instead of fixing this rate of climb 5 meters per second.

You can also iterate rate of climb for different at each and every rate of climb you can vary the value of gamma and see what is the corresponding power required by the system. And also what will be the forward velocity that results in. So we will try to figure out all this aspects.

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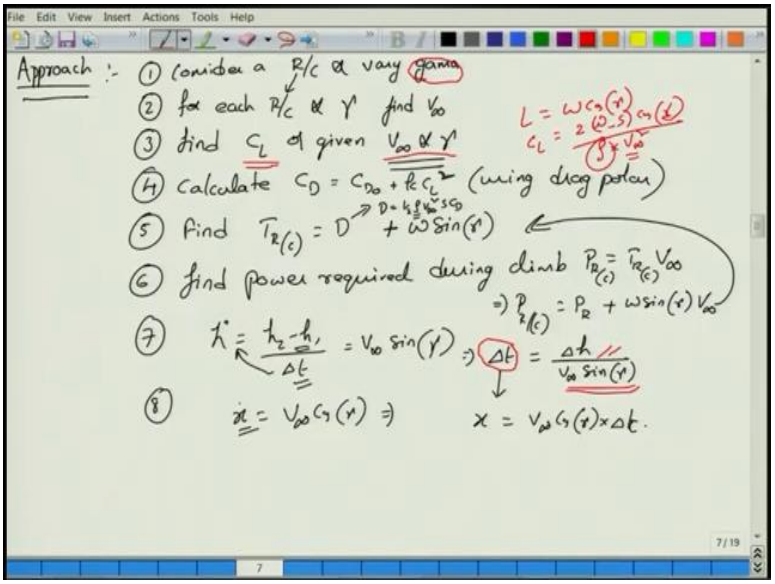

So let us follow the step by step approach. So first consider a rate of climb R by C or ROC. For this rate of climb and vary gamma. So for a particular rate of climb vary gamma. From here for each and every gamma; for each R by C and gamma find V infinity which is forward velocity. That is what we just discussed. So this is the forward velocity that we are talking here. So find this forward velocity with the input of rate of climb ROC, rate of climb and so this h dot is rate of climb, this is ROC or R by C, you can say.

So the input of rate of climb and gamma find out what is V infinity forward flight velocity here, the climb. And then so you know gamma and you know V infinity for this particular case that means so the approach that we are adopting stands for a particular R by C, the single value of R by C and you can iterate the entire procedure. You can repeat the entire exercise for different rate of climb.

So R by C and gamma find V infinity and now find CL for given V infinity and gamma. So this corresponds to again for this particular rate of climb. So once you have this CL you find out what is, so find or say calculate CD, which is CD not plus KCL square using drag polar. Once you know CD so find the thrust required during climb, which is drag times velocity plus W sin gamma, sorry, drag plus W sin gamma here right?

So now you can find out once you have that find power required during climb. So the power required is equals to during climb should be equal to thrust required during climb times V infinity corresponding forward velocity of flight during the climb. So this you have estimated from step 5, so which is nothing but power required for climb is power required during cruise which is drag times velocity plus W sin gamma times V infinity.

So this anyway you will get it from this step 5. So now you can also find out what is the time. You know what is the climb angle and you know what is this you can find out what is the say how much time to take time taken to climb a particular altitude. Otherwise within a specified time what is the distance it can travel because it is a steady climb we are talking about. You know, h1 and h2 and you know what is a h dot, you know rate of climb and you know what is h2 minus h1 upon delta t.

So this constant velocity of climb; so which is nothing but V infinity sine gamma. You know what is V infinity and gamma. So from here you will be able to find out with a, so within a particular time interval, you will be able to find out what is the height this aircraft achieved. How much within say or say to climb a particular altitude what should be the corresponding height what you call time required.

So that means h2 - h1 is given, you will be able to find out what is the corresponding time. Let us consider, let us add some more to this question time of rate of climb to climb an altitude of say. So this is pretty much right forward now. There is not much exciting thing involved with this. So 1000 meters. So which is like; how much time it takes to climb this particular altitude. That is V infinity sin gamma, so we, so the time taken delta t is equals to so delta h, let us say if you are climbing from sea level to 1000 kilometers.

So 1000 meters or the problem is already delta h to be 1000 say. It is already starting from thousand MSL, so let us make it 2000 MSL here. 2000 MSL, so another important aspect that we need to consider is the drag here, is not it? So the drag you are calculating it from half rho V square S times CD. So as the altitude changes here, your density also changing, is not it? So assuming you are flying at a constant velocity throughout, you have to consider the change in density as well.

So earlier we have come up with a sub routine where with the input of altitude you will be able to find out what is the corresponding density. So we will use that subroutine in this to find out drag at each and every altitude when you are flying at a particular velocity and at forward velocity and at particular climb angle. So this is delta h upon V infinity or rate of climb, V infinity sin gamma. Similarly you can find out, so what will be the horizontal distance that you can travel which is x dot V infinity cos gamma.

So since, see ideally it has to be a numerical integration but we are considering a constant velocity of flight, so we can like use a direct, you can use delta t directly to figure out what is the corresponding distance travelled. So corresponding distance travel, horizontal distance travel in this time is V infinity cos gamma times t. So delta x of the horizontal distance covered is V infinity cos gamma times delta t.

So delta t you get it from previous step, step number 7 and with step 8 you will be able to find out what is the corresponding horizontal distance travelled. So these are the parameters that we are going to plot right for various climb angles. So we have to make a subroutine.

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So this was our previous question, performance, takeoff performance subroutine. So I would like to take a new code here. I am clearing the memory of this matlab compiler and then I am closing say if there are any figures or some windows which were open because of the previous code, they all will be closed and then clc stands for clearing the screen of the command window. For example if I write something here then say clc will actually clean this command window.

Clear screen right? So now since we are talking about the same UAV earlier, so I would like to input the geometric as well as aerodynamic data from my previous code here, right? So I have just copied the input geometric data where the mass of the UAV is 3.5 kg. So the weight is now obtained by multiplying the mass with g which is considered as 10 meter per second square and the span must give as 1.5 meters with root chord of 0.9 meters and tip chord of 0.15 meters.

So we end up having a taper ratio of about say 0.167 and the area of this plan form as per the geometry based upon this root chord, span and the tip chord with the taper ratio. We will be able to figure out what is the area which is which turned out to be 0.787 meter square and the aspect ratio here is b square upon s. So which is about 2.86 and Oswald's efficiency is given as an input 0.89 and w, wing loading is estimated here.

So apart from the just explaining what are all involved here. So now apart from that we also considered the aerodynamic data which with CL not as 0.06 and CL alpha of this delta we use to 0.9 to close to 3 per radian here again. Better to mention its radian. So CD not is 0.03 and induced drag correction factor can be calculated using this expression and we also have propeller efficiency which is 0.95. We require a propeller efficiency, is not it?

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So in order to find out what is shaft power the need to deliver, so we need to talk we need this popular efficiency as an input here.

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So now what we need to do is to consider the climb parameters. So what we want to vary here? So rate of climb I would like to vary. Let us say rate of climb R underscore C here I would like to vary initially the rate of climb. So that is our first step, rate of climb is equals to so varying from say I would like to vary it from 1 meter per second to with an interval of 1 meter per second again to say what to 7 meters per second, let us say rate of climb.

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So we were asked to find out at, the question was to figure out rate of climb, no not rate of climb. What is the power required when you are climbing it 5 meters per second, like with a vertical velocity of 5 meters per second. But here we are not just limiting our approach for 5 meters per second, vertical velocity of 5 meters per second.

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Instead we are now iterating from 1 meter per second of vertical velocity to 7 meters per second. You can increase this. I just thought like this will be useful for you when you are, when you want to change this parameters. So that is the reason why I am including it here. So let us say j is the variable of this particular iteration for rate of climb. And I would like to consider another variable i for this as a variable in this integration.

So not integration, I am sorry, variable for this iterations here. So j is now increasing whenever there is an increment in the rate of climb. So initially it takes value of 1. So I would like to store this ROC, rate of climb as j comma 1. So it is a vector column, vector here. So rate of climb is equal to R underscore C. Now so let us say for the first iteration it takes a single value of ROC that is 1 here. Now once I consider rate of climb.

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So according to our approach we need to vary gamma, is not it? That is what it is here, so we have to vary gamma here. So this value has to be varied here.

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So now to do that what I am considering is another for loop because I need to vary it, I need a loop here to vary that parameter. So gamma is now varied from say 1 degree. So otherwise FP, I will say, I will write it as flight path, FP is varied from 1 degree to, so it is in degrees, I will convert into radians. So, 1 degree with an increment of otherwise say 2 degree flight path angle with an increment of 2 degrees.

Every time it takes an increment of 2, say if starts with 2 degrees of gamma, then it will in the next iteration it will take 4 and 6 and so on till say 20 degrees of gamma. So we will have almost 9 data points here, including 2 it is like 20 I guess, including 2 it is 10 data points will have. So this flight path is varying. So, again as I mentioned, i is the variable of this iterative approach for gamma where j is a variable for ROC, rate of climb, i is for gamma here.

And then I would like to convert gamma which was there to radians because matlab understands radians. So the flight path angle which is in degrees is converted to radians by multiplying it by pi by 180. And now I would like to store these values of gamma as well during the iterative process. So it is like i, j. So, it anyways going to be constant. So but still I would like to store this for every k.

So this will be like what is the size of FP? Size of FP cross size of RC. So that will be that will have the matrix of gamma will be, size of FP cross size of RC. So i, j so; each and every column corresponds to a particular rate of climb here. So that is what it is, j talks about rate of climb. So j here, x, y in the sense here i, j. j stands for each and each value of, particular value of rate of climb you can say.

So this is equals to gamma. So ideally all the columns has to be same. Of course, it is nothing but know we have fixed our steps of increment from 2 to 20 with the interval of 2. So ideally all the columns of this gamma, capital Gamma; so it has to be same identical. It will be anyways.

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So once you have gamma, find with for each R by C and gamma find V infinity.

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What will be the forward velocity of flight? We have vertical velocity of flight which is rate of climb. Now what will be the forward velocity of flight for this particular rate of climb? So this equals to i, j. So i stands for different gamma what at for a particular, so V of i, j stands for different gamma that means i is varying inside this loop, the second for loop. It is varying for the second for loop. So let me close this.

So this will end the second for loop and we have the second for loop inside the first for loop. So now it makes sense. So this particular sub loop which is inside this main for loop. So we will iterate for gamma. So select, once we select particular rate of climb, so this second loop iterates for gamma here. So that is what it is. For a particular j value, j value will not vary until you break this loop, until you break this for loop here.

The gamma, until the gamma varies from 2 to 20 with the step of 2, this j value remains constant. Once it is done for the first time, it will break this particular loop, it will come out of this inner loop and it will like again check for the condition for the outer loop here. Once the reason increment in the rate of climb here the j value increases and hence the new again the gamma is again varied from 0 to, 2 to 20 with an interval of 2.

Now that those values will be stored in second column there. So I guess you might have already got used to this environment and then started using matlab as well. So with that what you call assumption I am proceeding to solve this. So V of i, j is equals to, we have rate of climb upon sin gamma. So R underscore C upon sin of gamma which is gamma here. So gamma is already in radian.

So rate of climb is constant for a particular but gamma is continuously changing inside the loop and this is constant for this inner loop to be frank. So for when it comes to the outer loop R by C again changes when it, once it, once the inner loop starts from here, it will remain a, it will remain constant for that particular loop whereas gamma will be the variable of this loop here. So we have velocity of climb and then thrust required if I am not wrong.

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So calculate what is the CL for the given V and gamma, V infinity gamma. How can I do that? We have lift is equals to W cos gamma, this is what I need to produce. So, CL is equals to 2 times W upon S. So that is including times cos gamma upon rho times V infinity square. So we have V infinity and gamma and these details are given, geometric details and density I need to find out at each and every altitude.

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So when I have to find the density, that means I need to know what is the corresponding altitude of flight here? So I need to give, for the time being let us say we get it from here. We will try to arrange that. So density is also given as an input. For the time being let us assumes that. So otherwise we need to solve this entire procedure in time domain. So let us not do that for the time being. We will consider density as an input that is the density of the density from which the climb is initiated.

So from the density of the altitude from the climb is initiated. So we have that function. So we have density function which was used earlier here, no. Takeoff was not, input density we have already used this function. So we consider the initial altitude of cruise. So density, so we are confining this to the initial altitude which can be solved in the time domain. I wish you should take it as an assignment, but just modifying the variables of the integration.

So z, let us take z as an input here which is enter the altitude of flight, initial altitude of flight or altitude enter the altitude at which cruises initiated. At which, sorry, climb is initiated, climb is in meters. So this I am talking about performance, not takeoff. So I will type climb and of course all these are meant for power plan selection. This entire exercise helps you to figure out what should be the power plant here.

So you have V, rate of climbs and gamma and then you can find out what is the CL value here. CL of this flight is i, j should be 2W upon, W underscore S is already like considered here, which is wing loading, which is W by S. So here we cannot give W upon S. We cannot use any mathematical operations to define a variable. So W by S stands for W upon S, wing loading here. So W underscore S times cos gamma upon density times V square V of i, j square.

So from here I will be able to find out what is CL. The corresponding CD of this flight, CD which is CD not given, CD not is given here using drag polar we can find out what is, CD not is given, k we have calculated. So CD not plus k these are constant times. CL is a variable again here depends upon flight velocity and gamma. And gamma is a variable and hence the flight velocity as well here because rate of climb is again a variable in this.

CD is done. Now, I will find out what is the drag. That is good to find out what is the lift as well, that is nothing but W cos gamma, that is okay. So instead of drag, I will say directly the power required instead of drags or say thrust required kCL, kCL square, so the thrust required here is equals to, so thrust required for cruise, say so climb CL, Tr underscore CL stands for climb. Thrust required for climb is drag which is of rho V square, half rho V square times S times.

S is given, half rho V square S CD of i, j corresponds to the particular velocity and CL that CL of course which depends upon V and gamma there. Half rho V square S times CD plus W sin gamma. This is a thrust required W sin gamma. So the power required or should be made available for this climb performance from a j should be equal to thrust required for this climb performance multiplied by the corresponding velocity of the flight, for odd velocity of flight.

So this is done. So if it has to reach an altitude of say or say wherever it is going to take off it has to reach an altitude of or say the cruise altitude and the takeoff altitude the difference between them should be 1 kilometer, let us assume that. Then the time taken to reach that altitude t of i, j which depends upon again gamma and flight path angle here, so is equals to so let us say that difference should be 1000, we are fixing it here 1000 meters, multiplied upon velocity, so V of i, j. So, here the time of flight.

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Here rate of climb is fixed, is not it? And we have that vertical distance, this vertical distance is fixed and rate of climb is fixed. That means this will not be a variable inside the second loop. There should be the variable in the first loop itself.

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So that means so here the time to climb for a particular rate of climb, with a particular rate of climb what will be the time that is required to the depends upon delta h, delta h is the difference in the altitudes or say the final climb altitude and the altitude initial climb altitude, the altitude at which the climb is initiated, the delta h upon rate of climb here R underscore C. So this, so it returns time here time for this delta t to climb to that particular altitude.

So this delta t, within this delta t what is the corresponding horizontal distance travel? So that depends upon gamma. So that is x here, which we have discussed. So x is equals to, again this is a variable because it depends upon gamma x, i, j is equals to V infinity cos gamma, that is V i, j times also gamma times delta t times or t of j, 1. So when you fix the difference in the altitude the time required to climb that altitude and the rate of climb.

So that means for each and every iteration rate of climb is fixed for the outer loop. So and then del_h is already fixed we want it to be the altitude. It has to climb should be about 1000 meters. So let me put it down here. So del underscore h is 1000 meters, h2 - h1 should be 1000 meters. So for each and every because del_h is fixed that is from the machine requirements and then with different rate of climb you will have different time taken to climb that to climb to that particular altitude.

So within this time the horizontal distance covered is V cos gamma times t, the respective t within that and say if you want to find out the distance travelled along the flight path.

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So say if you want if you want to find out the distance travelled along the flight path within that so along this direction, within that delta t you, have V infinity times. So that is the velocity of flight and we assume steady flight condition. So it is pretty straight forward.

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So V infinity times the corresponding time. So I think there is not much here. So we can end this. Almost completed all the required. So we have computed all the required variables here. So now let us plot here. So what are we going to plot in the first figure? So let me subplot first major focuses on what should be the power required here. So power required and as well as thrust required and of velocity also let us see in the horizontal distance.

Fine, we will plot all this 4 variables here. So let me take it 4 by 1 by 1 which talks about it say. So in the figure you will have 4 columns 4 rows that is 4 horizontal plots and 1 vertical plot.

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There is only 1 column. The if you have 4 by 2 that means you will have 8 different plots. Now 4 by 1 you have only 4 plots. So when you say 4 by 2, so in the first row you will have 4 rows like, sorry, in the first column you have 4 rows, in the second column you have 4 rows. So sub plot 4 1, 1.

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This 1 talks about the first plot. You are trying, now you are trying to plot it in the first plot. 4, 1, 2 talks about like, 4, 1, 2 talks about even your plotting in the second plot, second sub plot of the figure. What I need to plot is the following. So I need to plot variation of gamma, is not it? So gamma, so is a any at each and every rate of climb it is 1 in the same because the variation is to 2 to 20.

So I can plot any one of the column that should be good enough, all the column variables. So if I say 1, it stands for a particular rate of climb. So first column, when R by, when j is 1 here, j is 1 column here represents all the rows here, all the rows and first column that means gamma matrix. For example I will show that there is only let me just. So let I will just commented this. I will run this program and show you how the gamma matrix is. So climb, enter the altitude at which climb is initiated in meters.

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So I need to, so let us say from the data as soon as the aircraft takes off it has to climb, that is what we have started this program, is not it? So in the question it is given located. The runway is located at an altitude of 1 kilometer with respect to mean sea level.

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So I need to consider density at that particular altitude for this particular problem or in general when you talk about solving this in time domain, you can also have density variation with altitude as well. So this particular function returns you that particular value of density at altitude, which is considered here as the altitude at which the runway is located, that is nothing but the altitude at which climb is also initiated, let us say 1000 meters.

W should be small later I guess, is not it? So here W is in small case. So now, so when it has executed till this point that means there are only 2 more lines that are to execute. So can I assume the code is fine till that point? So it is done. So if I take this out here aspect ratio 2.8571 that we have talked earlier 2.86 close to. So and then CD again know, it is varying inside the loop it is like 70 cross 7, is not it?

Because there are gamma, span values of gamma. First let me show you what this gamma here. So the gamma here, so gamma here is. See, there is some issue. Every time i is not getting 0 here, i is increasing every time. Let me just correct that. So I will just try to correct it. So here after i + 1 again once it comes here, so after 10 it will start 11. So instead of initializing this i is equals to 0 here, so let me initialize here.

So for inner loop, for outer loop it has no effect whenever the program completes this inner loop once it starts for the next variable in the outer loop, once it assigns the next rate of climb, so this will also make the variable of that inner loop to 0. That way it will help us to find out know, have the same columns of like the same size. So this is 1000 meters. So for example, now you can see so the first column corresponds to when rate of climb is 1.

The second column is 2, when third column corresponds to rate of climb 3, fourth column corresponds to rate of climb 4 and the rate of climb is 4 meter per second. So first let us look at gamma here. So gamma see here. As I told you it will be same for all the columns because we are varying effectively fixing this variation, is not it, through that for loop command or this syntax that we have assigned in for loop.

So we are actually, we have already fixed the initial and the final value as well as step size. So this is in radians, no, if you can just multiply this with 180 by pi you will get to know the degrees respect to degrees or say. So I can, what I can do is gamma times 180 by pi, 180 upon pi. So this will help me see - 2 degrees, 4 degrees, 6 degrees, 8 till 20 with a step size of 2 degrees. So this is constant and it is same.

So for each and every rate of climb it starts again with 2 degrees, 4 degrees to 20 degrees. So this, so the gamma here, I can plot, I can now plot so the so now you will be more comfortable to appreciate this. So considering any one of the gamma, any one of the column in the gamma is good enough for me to like plot the variation of any other variable with respect to gamma. So now, so each and every column corresponds to a particular rate of climb and if you can see, you see here rate of climb is just varying from 1 to 7.

So if I just either I can look it from the workspace or I can just write it down here. Rate of climb is varying from 1 to 7. So I wish I may not, I will plot for only 1 figure. So you try to plot it for the rest. So let me take sup plot 4, 1, 1, gamma and then what is what am I plotting it for you can use either for loop, I am making it explicit here. So gamma and then rate of, so gamma I need to plot for power required for climb here.

PR for climb, power required for climb, which is colon comma 1, the first column. Power required and then I have colon k star. k stands for black color, star stands for the corresponding marker at the particular gamma i, j, power required i, j. So that particular point is now represented by this marker star k stands for color code, which is black I am using and this column stands for the line type, know line type what which you can mention explicitly for each and every variable. I would like to use the shortcut here.

So in the same plot I want to, I want to plot for the rest of rate of climb as well. So say plot for gamma 1 comma because whether you take first column or second column in gamma it is 1 and the same. So I am not varying it. So, I have taken the second variable and instead of green k, I have taken red here, red. So the second talks about rate of climb 2, is not it? The second value here or say the second column it talks about rate of climb when the rate of climb is 2 meters per second.

So I will hold on, hold on this plot so that I can superimpose this. So the third column when rate of climb is 3, so say instead of I say green so, hold on. So I will say instead of now I am plotting it for rate of climb 4 which corresponds to column 4 here, the data here. So instead of blue, I will take blue and star and then control v. So instead of now I am plotting it for when rate of climb is 5 meters per second and m stand for magenta here, you can so rate of climb 6.

So this will, so and all the like plots, I am no more holding it on this particular. I will say or say after y label and x label just copying it, just to save few seconds. So power required that is what we are talking about, power required Cl climb. So this is the power required directly by the system is not it? So can we also divide this by or say this is power required by the system, so what should be the shaft power available?

PS for client performance. PS underscore Cl let us say for climb should be what? i, j should be power required for climb upon efficiency, efficiency of propeller which is given here eff underscore p. So instead of writing Pr Cl, I like to use Ps Cl here. So now this is like in watts, yes, of course in watts power required during climb, C l i m b, power required during climb. So instead of this, you can repeat this for, so I will just plot any of the 2 variables.

So I will just plot what is the forward velocity as well as, sorry. So I will just plot 2 sub plots. You can repeat this exercise. So in the second one instead of Ps, what I like to plot is the velocity, what will be the corresponding forward velocity of flight. So, that sounds help me to identify that it has completed the replacement of that variables from the point where I have selected till the end of the code.

It will again go to the top of the code and start searching for the variables. So this is in velocity, which is in forward flight velocity V underscore back slash in t infty, infty or inf? What is that, infinity? It is experiment V infinity. Let us see meters per second. I am just plotting for these 2 and let us see the result. So here it is not i, 1, it is i, j. So let us run this code again that. So the altitude at which we are initiating this climb is 1 kilometer with respect to mean sea level and we want this to climb to an altitude of 1 kilometer from there.

So I can notice so infty, a backslash infty stands for V infty here. So x label here. Gamma in degrees, so I am plotting here in radians. So let me just correct this multiply this by say, if I multiply this by pi by 180, sorry 180 by pi, I will convert this in degrees. So replace 2, 3, 4, 5, 6. So done I will run this again and see let us hope proper output. So this, there is something here. The symbol did not appear.

I will just check it. So the power required during, shaft power required during climb is in watts here. So when it is 2 degrees, so to have the same what you call rate of climb, so we have we need to have the label here. So legend we can insert legend. Legend has come. So, the black one corresponds to rate of climb 1. So red plot corresponds to rate of climb 2, red and then this is seventh one corresponds to rate of climb 7 at 7 meters per second.

So here you can notice know, as the rate of climb increases with a lesser climb angle you need to because the distance is fixed and the rate of climb is fixed, you need to fly at a very high speed. That is why the overall power requirement during this is about say, 1000. No it is 10000 watts which is like 10 kilowatts kind of. So similarly what will the corresponding flight velocity is 200 meters per second.

If you want to achieve the rate of climb as seven with the 2 degrees of climb angle and it drastically decreases you can see, when rate of climb is 7 so it has to be just 20 meters per second. The forward velocity and the power required, so maybe the scale is quite big. Here it is 10 power 4 it is approximately. So you require about 392 watts. That means if you take a 12 cell or a 6 cell battery, 6 cell battery what is the power 6 times 3.2, let us say approximately 18 6 3.7 approximately.

Each lipo battery can is of approximately 3.7 Volts into 6 is like 22 volts. So when you want to supply this much power of say about 392 or 393 is the power upon 22 volts, let us say you need to supply an amperes of about, it takes about 18 amperes. So the motor draws 18 amperes. Again you have to divide it by efficiency factor so that you will get to know what should be the battery capacity. From there how much time you require, you know, what is delta t.

So multiplying that with delta t you know, what is the battery weight required for the particular flight envelope. So hope you will extend this program with the other variables as well like how the drag is varying and the CL is varying with gamma and for different climb rates here.

(Video End Time: 59:47)

So okay, thank you and in the next lecture we will be talking about, in the next lecture we will be talking about weight estimation subroutine. So once we are done with the weight estimation subroutine we will proceed to find out how to like plan form geometry selection as well as profile selection, wing selection ideally, so wing job wing design subroutine. Thank you.